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Monitoring and handling of over-saturated gas downstream of power plants: Case studies from the Columbia River

Prepared by Daniel Deng

Pacific Northwest National Laboratory

Presented by Dana N. McCoskey

US DOE – Water Power Technologies Office

U.S. DEPARTMENT OF ENERGY BATTELLE

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Background: Columbia River Dams

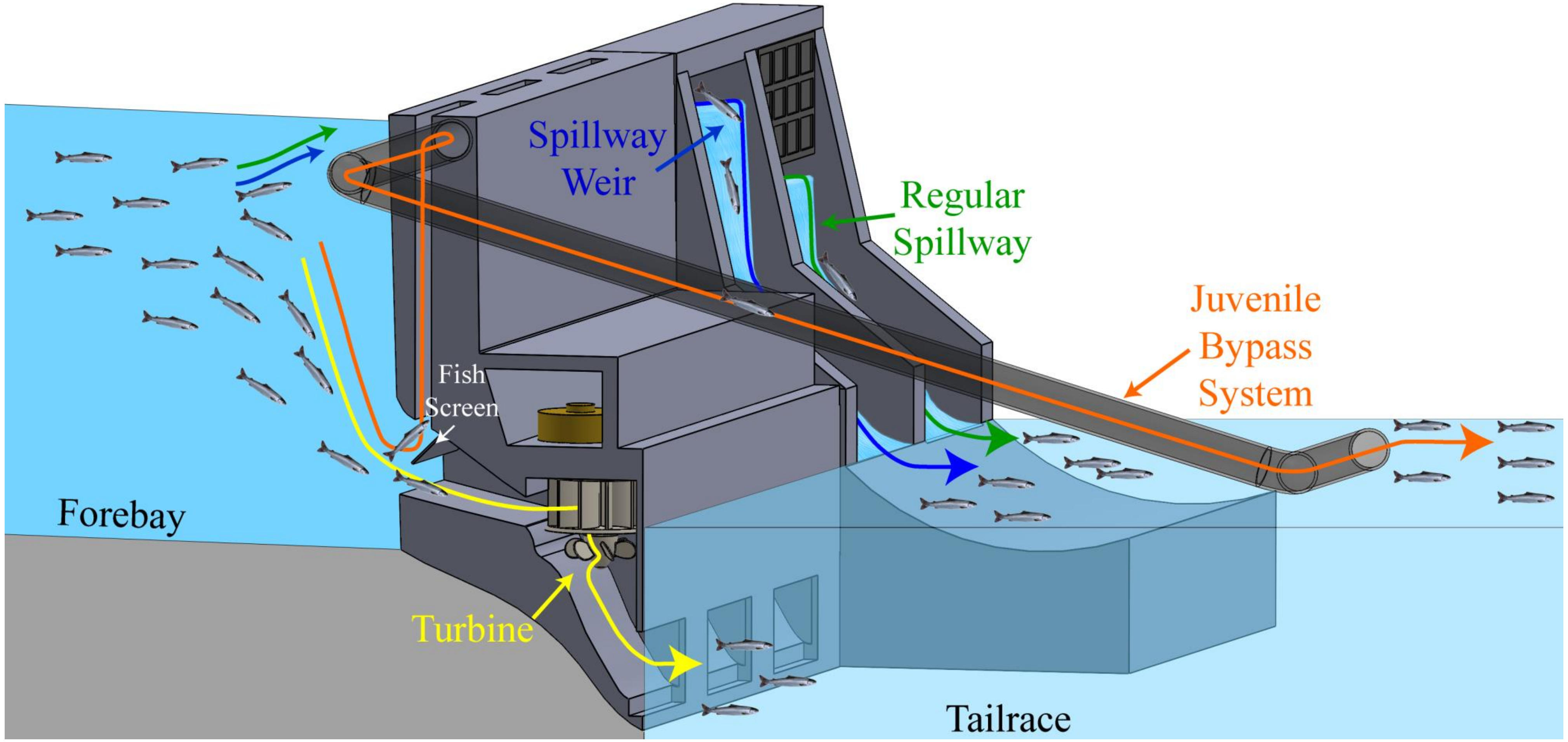
Outline

- Background
- Regulations
- Monitoring network
- Case studies:
  - Lab and field observation on understanding total dissolved gas (TDG) Exposure and fish Response
  - Water Quality Modeling for the Mid-Columbia River System
  - New project
- Summary

Background: Fish Passage Routes

Juvenile salmonids pass dams on the Columbia River using one of three routes:

- Turbines
- Fish by-pass structures
- Spillways



Background: Spill

- Two types of spills
  - Voluntary spill: used to reduce juvenile mortality, assist out-migrating juvenile salmonids, and increase return rates of adult salmon
  - Involuntary spill: used to manage flood risk, navigation and other functions of the system
- The U.S. National Marine Fisheries Service considers voluntary spill as the safest, most effective tool available for improving downstream smolt survivorship.
- Spilling water over dams increases TDG level in the river

TDG Regulations

- During the late 1960s TDG exceeded 140% and several studies documented impacts to both juvenile and adult salmonids
- US Environmental Protection Agency’s TDG standard of 110% of saturation has been generally adopted since 1972
- The U.S. National Marine Fisheries Service publishes Columbia River System biological opinion, which includes TDG and spill regulations
- Recently some short-term modifications were made to accommodate more spills, for example:
  - 120% TDG in project tailrace on 12-hr average to several dams in 2018
  - Federal and state agencies are in the process of making a short-term standards change to allow 125% TDG in the tailrace

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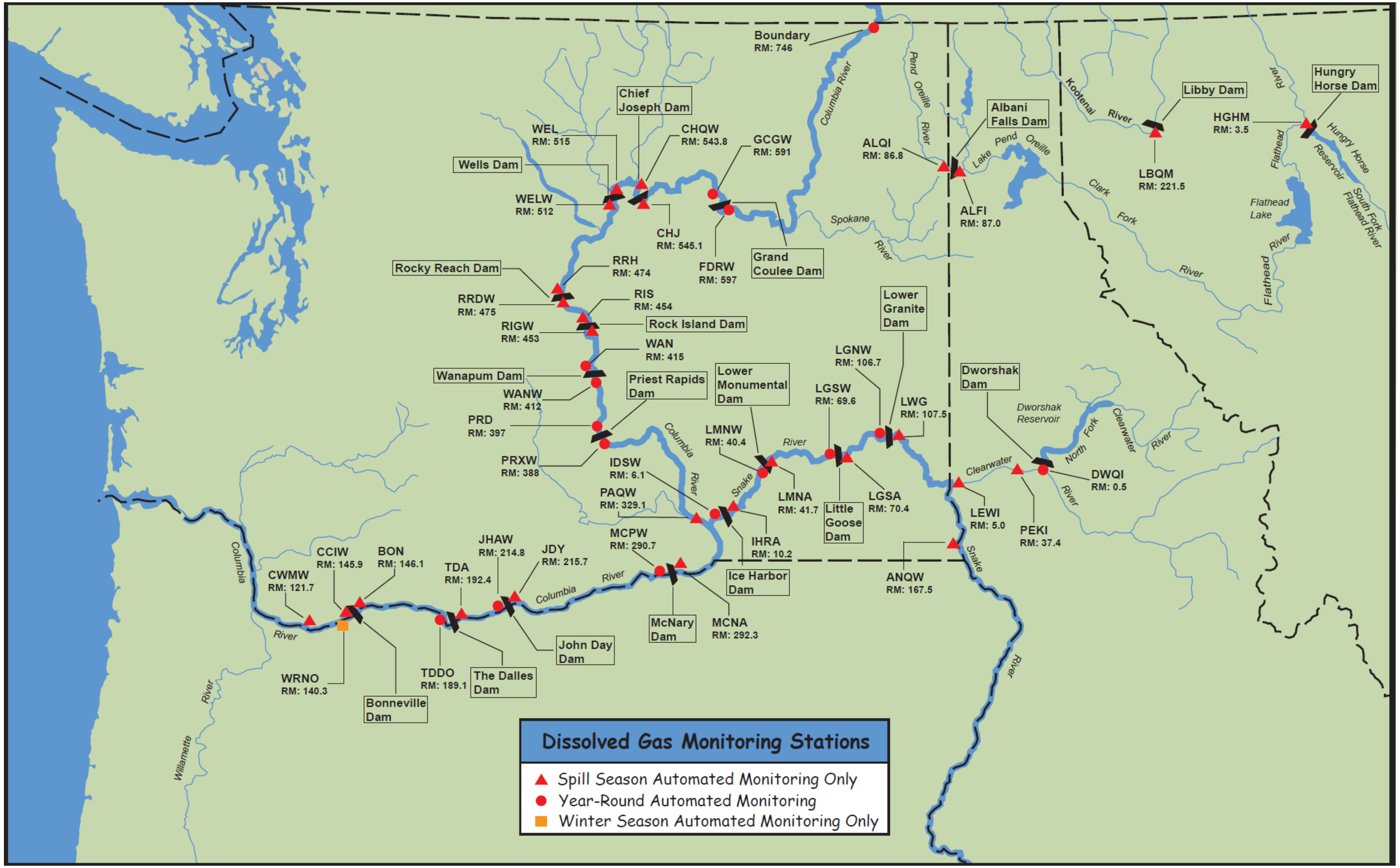
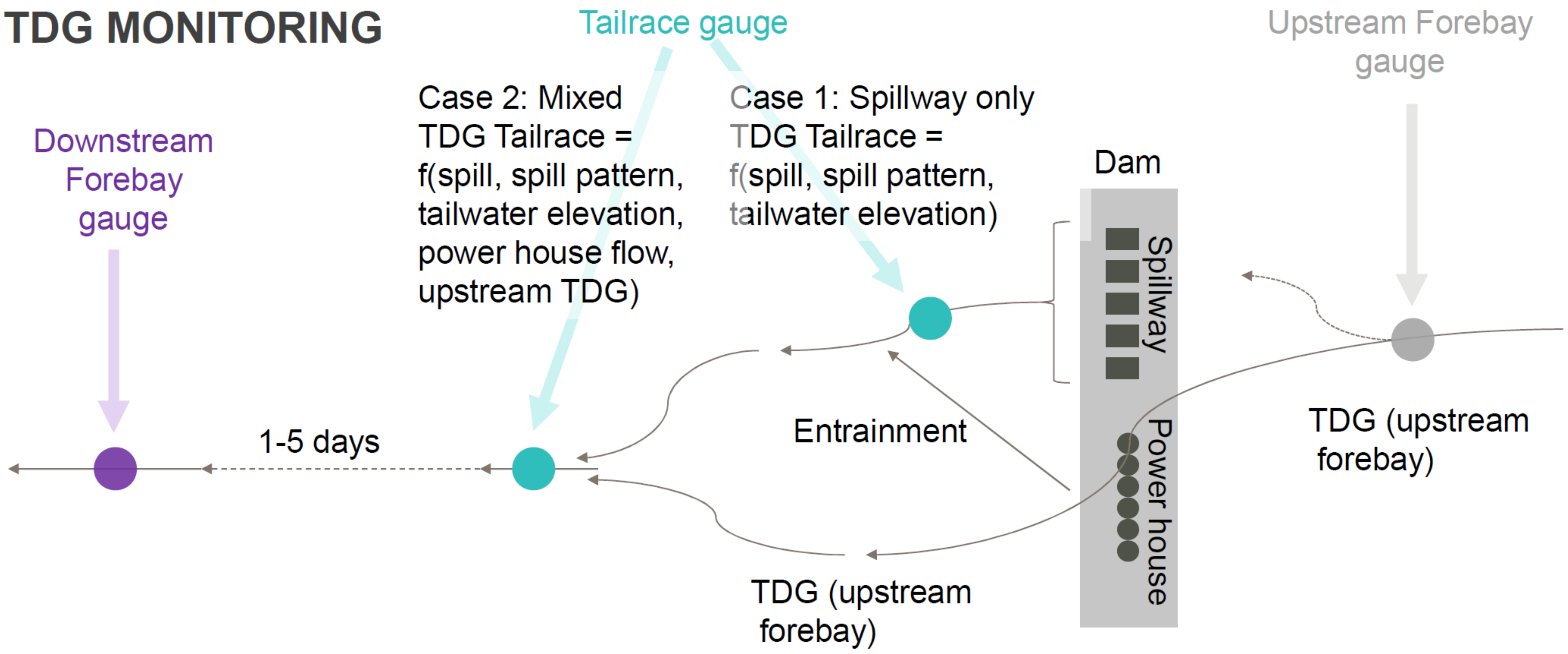
TDG Monitoring Network



TDG Monitoring by USACE



TDG downstream forebay =
f(TDG Tailrace, TDG upstream forebay, spill flow, powerhouse flow, travel time, wind speed, water temperature, barometric pressure, dispersion)

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*Turner, 2018 spring spill report.

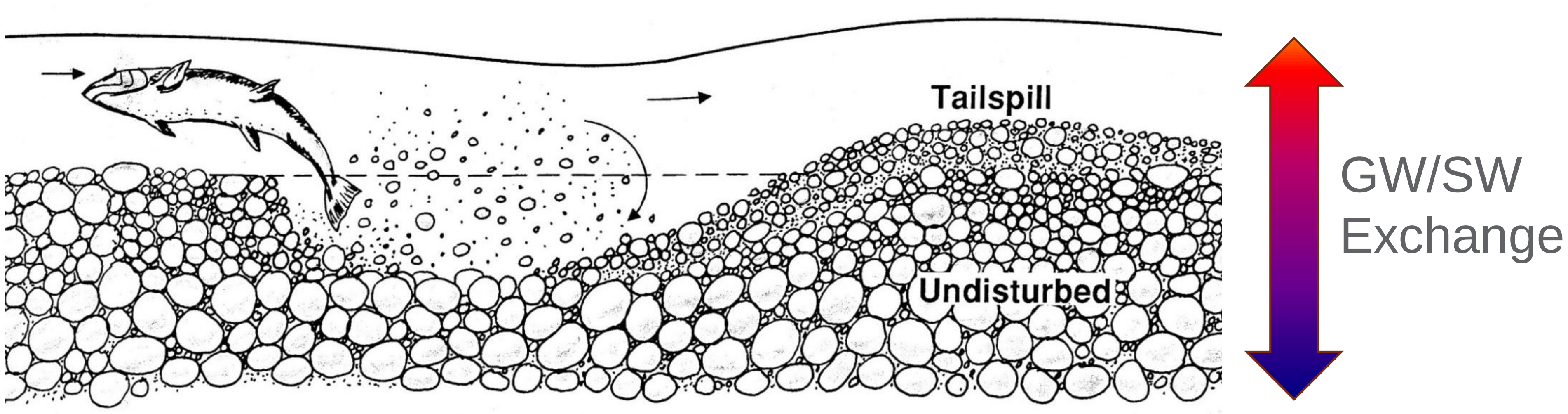
PNNL Studies*: Understanding TDG Exposure and Response

- Potential impacts to fish can be evaluated:
  - Assess exposure
    - ✓ Research to understand life history
    - ✓ Water quality monitoring
  - Observe response
    - ✓ Lab toxicity studies (chum salmon below dam for chronic and lethal impacts)
    - ✓ Field sampling to observe symptoms in fish
    - ✓ Spill-survival relationships

- Arntzen et al. 2009. Influence of the hyporheic zone on supersaturated gas exposure to incubating chum salmon. North American Journal of Fisheries Management, 29(6), pp.1714-1727.
- Geist et al. The effects of total dissolved gas on chum salmon fry survival, growth, gas bubble disease, and seawater tolerance. *North American Journal of Fisheries Management*, *33*(1), pp.200-215.

PNNL Study: TDG Exposure in the Tailrace Downstream of Foster Dam and Bonneville Dam

- TDG exceeded 120% in the surface water during spill operations at these locations (Depth compensated TDG ≤105% is OR DEQ limit in shallow areas <2 ft. deep; 110% in other locations)
- Dam operators needed to know if these levels were harmful to Endangered Species Act-listed species, including eggs and sac-fry in nearby redds
- Alevins cannot adjust their behavior to avoid high TDG

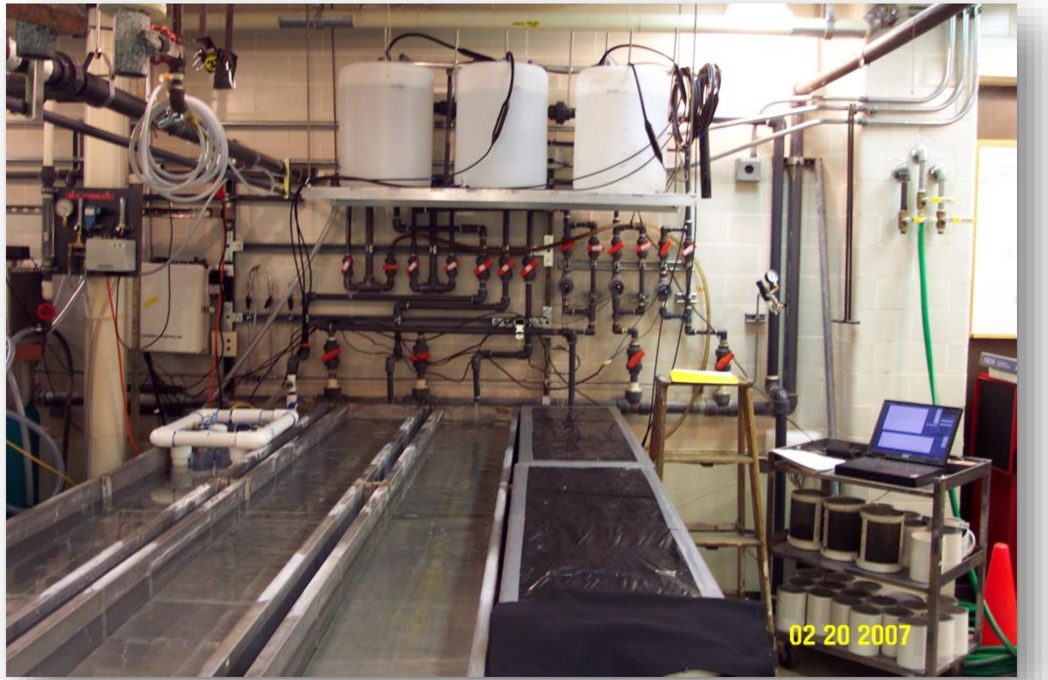


Arntzen et al. 2009. Total Dissolved Gas Effects on Incubating Chum Salmon Below Bonneville Dam. PNNL-18081. Pacific Northwest National Laboratory, Richland, Washington

PNNL Lab Studies to Determine Susceptibility to TDG

A chronic exposure study was conducted (control, 103%, 108%, and **113**% TDG). Samples were tested for survival, developmental timing, and histology (n=4,800). Another group of fish were tested for behavioral observations (sub-sampled from a group of 9,600 fish).

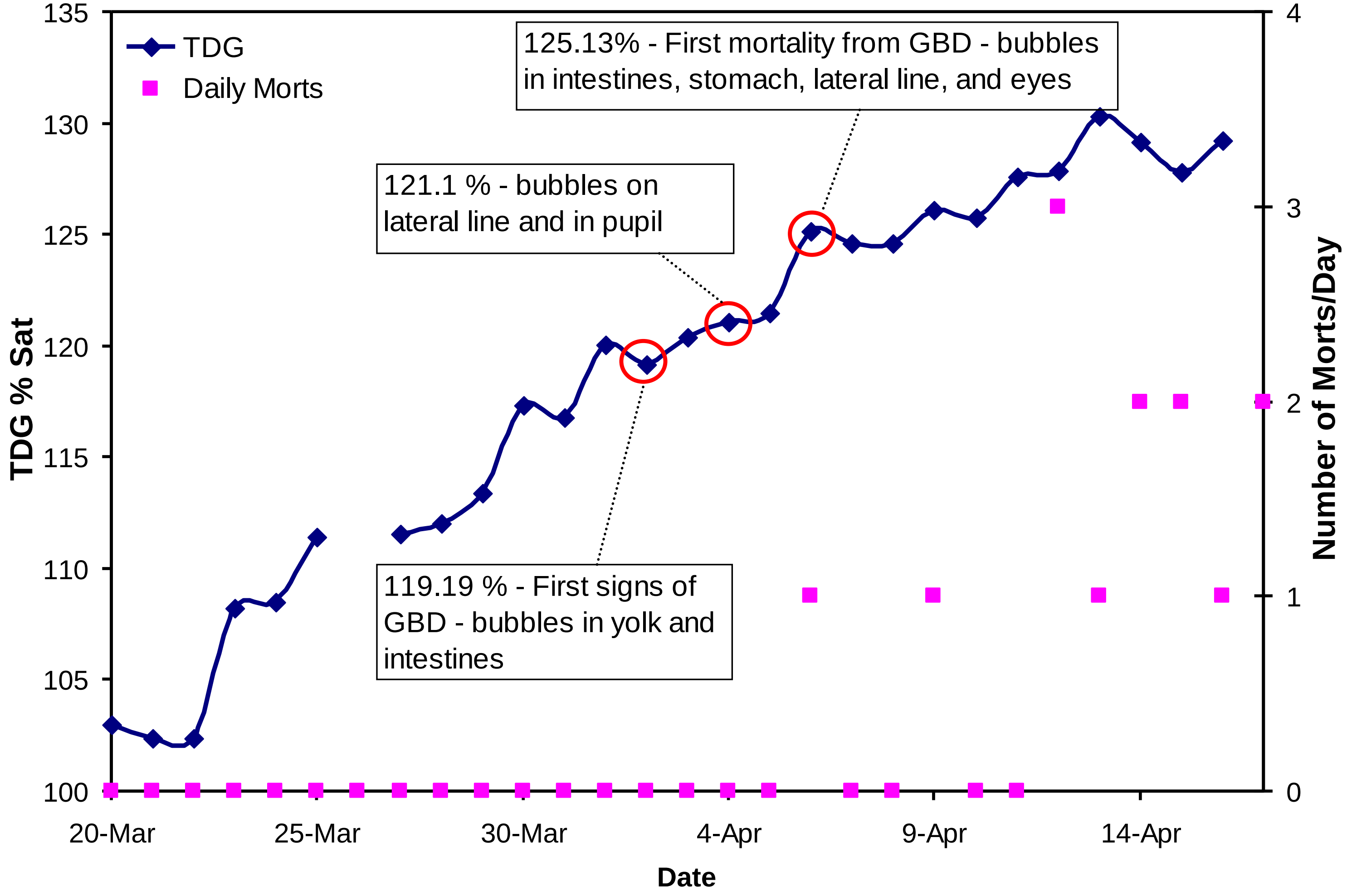
- > 95% survival to emergence, similar time to 50% emergence
- No obvious behavioral differences were noted between treatments through emergence and during the post-exposure period



Incremental Exposure to 130%

TDG was increased from 100% to 130% during a one month time period.

- Gas bubble disease (GBD) is the development of gases in a fish's bloodstream.
- GBD signs were first noted at 119-121% with mortalities at 125%. Thirteen fish (n=52) died during the study due to gas bubble disease .
- Alevins developed lethal gas bubbles between the perivitelline membrane and the yolk sac and on/within the mouth, head, and eyes. Bubbles were also seen on the lateral line, intestines and stomach.



PNNL Study: Exposure Using an Artificial Redd

- One artificial redd was constructed at Ives Island. Eight tubes within the redd, 100 eggs per tube. Tubes were recovered approximately every 2 weeks from early March through mid April
- Sampling occurred approximately 1-2 days after the redd had been dewatered for approximately 12 hours
- Prior to dewatering, depth compensated TDG remained greater than 110% for over 11 hours in river sensors and over 103% for approximately 6 hours at egg pocket depth
- GBD signs were observed in many samples including bubbles in the pupils and the lateral line. Hemorrhaging was observed in the eye, caudal peduncle, and pectoral peduncle. Some fish had inflated swim bladders, unknown whether this is related to TDG

Oak Ridge National Lab Study: Water Quality Modeling for the Mid-Columbia River System

Water Quality Modeling Improvements at Columbia River Basin:

- The complexity of water quality dynamics are not currently represented in real-time hydropower dispatch systems.
- This project, completed in 2016, achieved a Total Dissolved Gas (TDG) implementation in real-time scheduling and the development of a model reduction technique to allow for real-time river system scheduling and optimization
- Improvements were successfully included in RiverWare software

Partners:

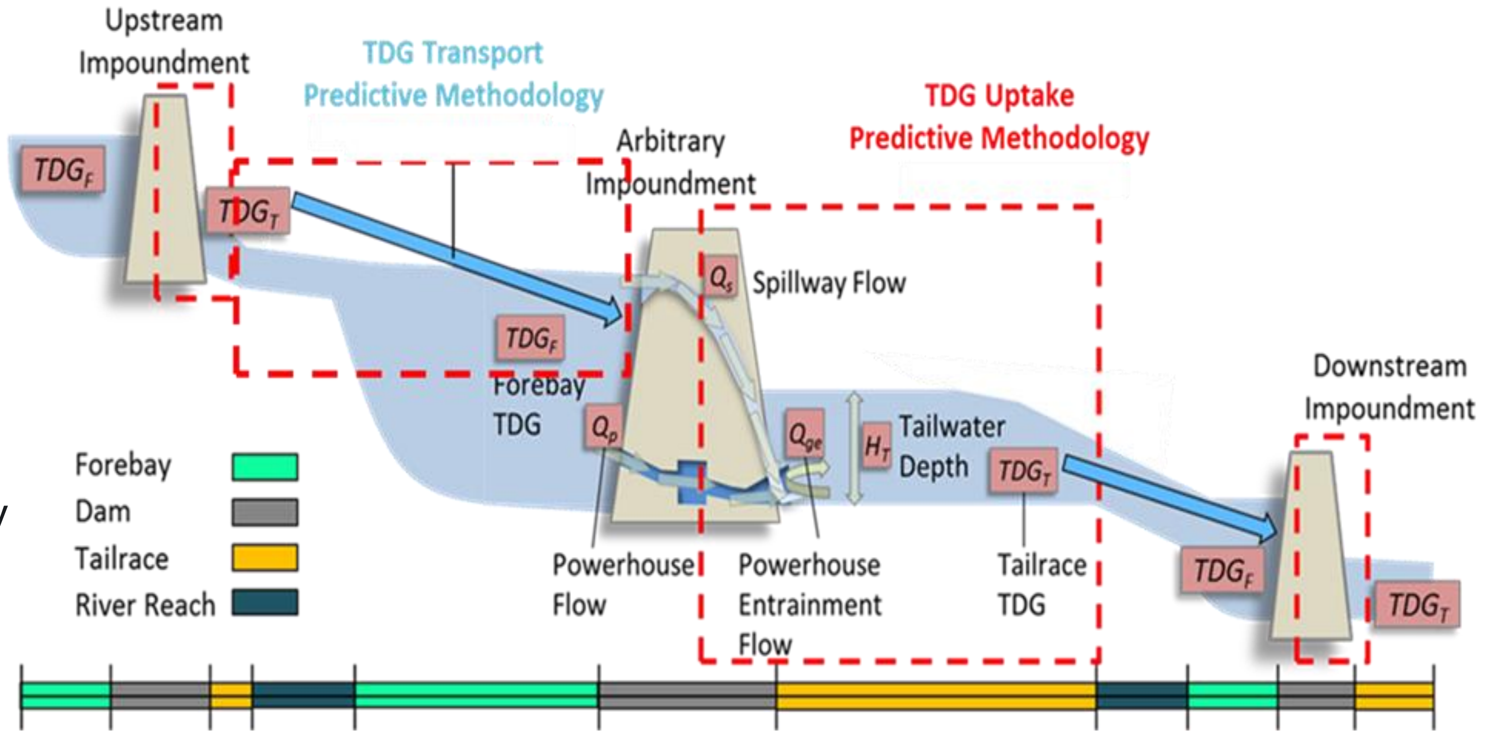
Columbia: University of Iowa, Bureau of Reclamation, USACE Portland District, and CADSWES, University of Colorado.

Funding: US Department of Energy Water Power Technologies Office

*Hadjerious et al. 2014. Predicting Total Dissolved Gas (TDG) for the Mid-Columbia River System.

Oak Ridge National Lab Study: Water Quality Modeling for the Mid-Columbia River System

Technical Approach: develop a simplified physics-based mass-transfer model for total dissolved gas uptake and transport, to be implemented in Decision Support Systems (DSSs) and forecasting applications.

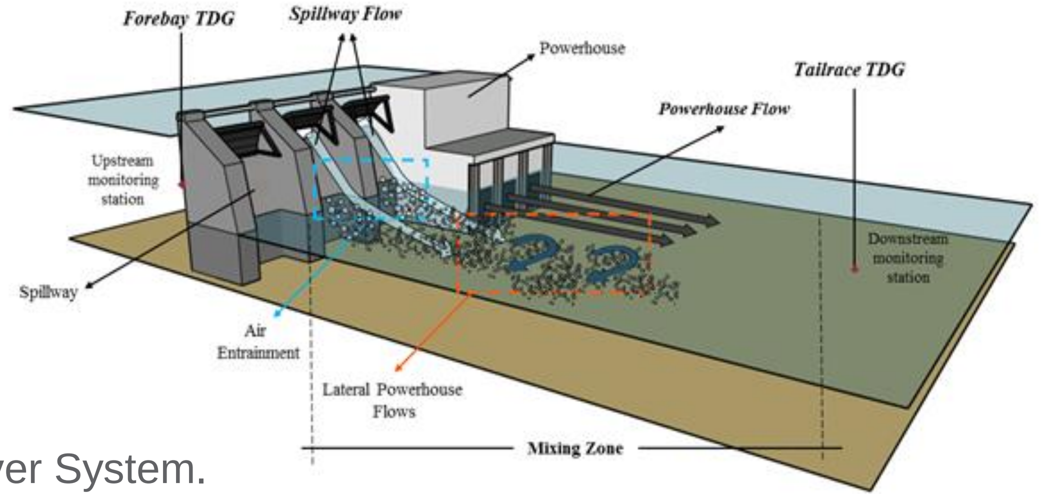


Methods:

- Partitioned river system into uptake and transport regimes (see figure on top right)
- For uptake region, develop TDG representative equations based on physical processes of TDG production and mixing:
    - Air entrainment during spill in the tailrace
    - Air entrainment of powerhouse water into the spillway (see figure on bottom right)
- For TDG transport from upstream to downstream, analyze time lag of TDG plume between reservoirs

Approach Uniqueness:

- A simplified mathematical approach for complex river systems enables straight forward implementation in DSSs to reduce computation without a decrease in predictive accuracy
- Unlike conventional TDG management techniques, this approach allows hydropower schedulers to quickly and accurately simulate multiple operational scenarios to minimize real-time and future TDG levels and meet hydropower reservoir multi objective targets.



*Hadjerious et al. 2014. Predicting Total Dissolved Gas (TDG) for the Mid-Columbia River System.

Real-time and Autonomous Hydropower Water Quality Monitoring System

- PNNL is developing an autonomous mobile sensor platform that can operate in dangerous water environments near hydropower facilities (intake, tailrace, etc.) for water sampling at multiple locations
  - Partners: Cube Hydro, Southern Company, Sapere Consulting
- Goals:
  - Enable safe, timely, and comprehensive water-quality data collection to support more accurate predictive, real-time modeling for dissolved oxygen to optimize dam/river operations
  - Maximize power generation revenue with improved operation control
  - Reduce Federal Energy Regulatory Commission and state water quality monitoring costs for compliance

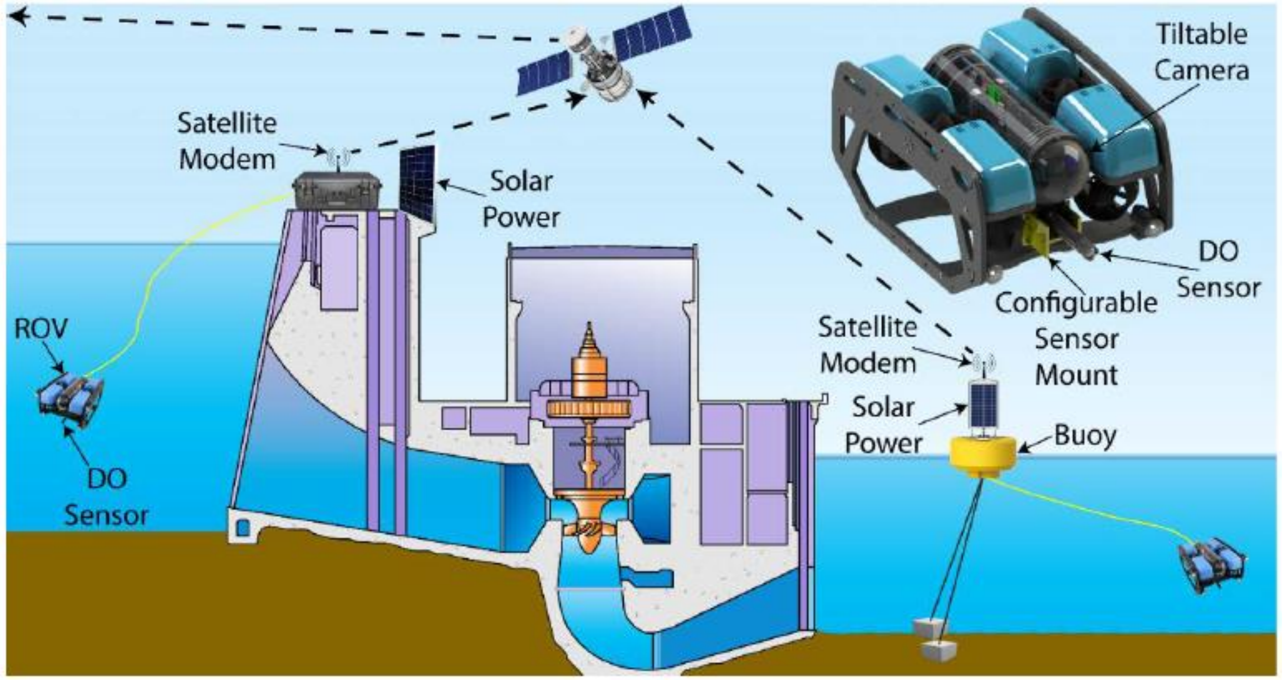


Figure 1. A visualization of the real-time and autonomous water quality monitoring system in operation.

System Features and Functions

Autonomous	*Takes pre-programed or real-time measurements at multiple locations*
Self-powered	*Harvests solar energy to support autonomous operation*
Wireless real-time communication	*Transmits measurement and maintenance data to an on-or-offsite computer*
Modular and expandable	*Carries various combinations of sensors (DO, TDG, temperature, etc.) via a modular mount configuration*
Remote monitoring of sensor	*Monitors onboard sensors through real-time video images to detect biofouling or other potential issues*
Ease of servicing	*Travels to shore--away from the dangerous water environment where it is deployed-- for maintenance*

Summary

- Regulation and monitoring are through a coordinated effort by many organizations including federal agencies, state and tribal governments, and research institutions
- Environmental factors have a large and variable impact on downstream forebay and tailrace TDG
- Every year presents unique challenges because of different flow patterns and environment factors
- A variety of research effort has been conducted including lab exposure, field observation, monitoring, and simulation

References

- Arntzen, E.V., Geist, D.R., Murray, K.J., Vavrinec, J., Dawley, E.M. and Schwartz, D.E., 2009. Influence of the hyporheic zone on supersaturated gas exposure to incubating chum salmon. *North American Journal of Fisheries Management*, *29*(6), pp.1714-1727.
- Arntzen, E.V., K.D. Hand, K.M. Carter, D.R. Geist, K.J. Murray, E.M. Dawley, V.I. Cullinan, R.A. Elston, and J. Vavrinec. 2009. Total Dissolved Gas Effects on Incubating Chum Salmon Below Bonneville Dam. PNNL-18081. Pacific Northwest National Laboratory, Richland, Washington.
- Arntzen E.V., R.J. Flaherty, A. Colotelo, R.A. Harnish, J. Vavrinec, S.A. Zimmerman, and J.D. Tagestad, et al. 2018. Assessment of the Effects of Total Dissolved Gas Exposure of Upper Willamette River Chinook Salmon and Steelhead Below Foster Dam. PNNL-27325. Richland, WA: Pacific Northwest National Laboratory.
- Geist, D.R., Linley, T.J., Cullinan, V. and Deng, Z.D., 2013. The effects of total dissolved gas on chum salmon fry survival, growth, gas bubble disease, and seawater tolerance. *North American Journal of Fisheries Management*, *33*(1), pp.200-215.
- Hadjerious, B., Bender, M.D., Politano, M., DeNeale, S. and Castro, A., 2014. Predicting Total Dissolved Gas (TDG) for the Mid-Columbia River System.
- Turner, D., 2019. 2018 spring spill report.
- USACE, USBR, and BPA. 2020 WATER MANAGEMENT PLAN. https://www.nwd.usace.army.mil/CRWM/Water-Quality/

Questions?