Columbia River System Operations
Final Environmental Impact Statement

Appendix D
Water and Sediment Quality

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ACRONYMS AND ABBREVIATIONS

°C	degrees Celsius
°F	degrees Fahrenheit
µg/L	micrograms per liter
1D	one-dimensional
2D	two-dimensional
AF/AT	average flow/average temperature
AF/LT	average inflow/low temperature
amsl	above mean sea level
BiOp	biological opinion
Bonneville	Bonneville Power Administration
Corps	U.S. Army Corps of Engineers
CRSO	Columbia River System Operations
CWA	Clean Water Act
DO	dissolved oxygen
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
FRM	flood risk management
$g/m^2/day$	grams per meter squared per day
HEC	Hydrologic Engineering Center
HEC-RAS	HEC River Analysis System
HF/LT	high inflow/low temperature
IDEQ	Idaho Department of Environmental Quality
kaf	thousand acre-feet
kcfs	thousand cubic feet per second
LF/AT	low flow/average temperature
LF/HT	low flow/high temperature
LSR	Lower Snake River
Maf	million acre-feet
Mcy	million cubic yards
MFWP	Montana Fish, Wildlife, and Parks
mg/L	milligrams per liter
MO	Multiple Objective Alternative
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
PCBs	polychlorinated biphenyls
Reclamation	U.S. Bureau of Reclamation
ResSim	Reservoir System Simulation
RM	River Mile

RSET	Northwest Regional Sediment Evaluation Team
SEF	Sediment Evaluation Framework
SOD	sediment oxygen demand
SRD	storage reservation diagram
SWS	selective withdrawal structure
TDG	total dissolved gas
TMDL	total maximum daily load
TN:TP	total nitrogen to total phosphorus
TSS	total suspended solids
U.S.	United States
USGS	U.S. Geological Survey
W2	CE-QUAL-W2 model

CHAPTER 1 - INTRODUCTION

The Columbia River System is composed of 12 U.S. Army Corps of Engineers (Corps) hydroelectric projects and 2 U.S. Bureau of Reclamation (Reclamation) hydroelectric projects located throughout the Pacific Northwest in the states of Idaho, Oregon, Montana, and Washington. Bonneville Power Administration (Bonneville) markets and transmits the hydropower generated from these projects. These projects are operated in a coordinated manner for purposes specifically authorized by Congress: flood risk management, navigation, fish and wildlife conservation, hydropower generation, recreation, irrigation, water quality, and municipal and industrial water supply. The system is operated for the maximum sustained benefit for the public good, and the equitable distribution of benefits through coordination with other project operators in the Columbia River Basin and with Bonneville. Through the National Environmental Policy Act (NEPA) process, water and sediment quality impacts resulting from operational and configuration changes, as identified in the environmental impact statement (EIS) alternatives, are evaluated to inform the selection of a preferred alternative.

Water and sediment quality are related, and human actions that affect water quality may also affect sediment quality. However, sediment is a distinct phase that is held in the watershed much longer than water. Most sediment moves downstream only periodically in response to high flow conditions, while water moves continually through the system. Because sediment tends to move more slowly, pollutants associated with the sediment are held in the system longer than pollutants in the water. Pollutants in the water can move into the sediment and sediment pollutants can move into the water, but not all of the pollutants and quality issues are the same for water and sediment. For example, total dissolved gas (TDG) is an issue for water but not for sediment. Water and sediment quality impacts are both discussed in this appendix, but they are addressed separately for each alternative.

Chapter 2 of this appendix describes the models and other methods used to predict impacts to water quality from each alternative. Subsequent chapters summarize predicted future water and sediment quality conditions for Columbia River System Operations (CRSO) EIS alternatives. Water quality parameters such as water temperature, TDG, dissolved oxygen, pH, specific conductivity, general water chemistry, water clarity, nutrients, contaminants, plankton, microbes, and chlorophyll are addressed.

Five alternatives are evaluated for water and sediment quality impacts, including the No Action Alternative and four Multiple Objective Alternatives (MOs; see Chapter 2 of the main EIS report for detailed descriptions of alternatives). Each MO includes specific measures intended to achieve those objectives; the MOs include proposed actions at multiple locations. The focus of this chapter is the water and sediment quality throughout the CRSO study area. The alternatives are not presented in order of preference. Water and sediment quality impacts are two of the many considerations for the selection of a preferred alternative. The recommendations for the implementation of any alternatives or actions are found in Chapter 7.

CHAPTER 2 - GENERAL METHODOLOGY

2.1 OVERVIEW

Impacts to water quality from CRSO EIS alternatives were evaluated using numerical modeling and qualitative analysis methods. Data, summarized in project-specific water quality and sediment quality technical reports, was also used to describe the affected environment and predict future changes to conditions. The technical reports can be found on the CRSO website at https://www.nwd.usace.army.mil/CRSO/#top. Numerical modeling was used to simulate the effects of the CRSO EIS alternatives on water temperature and TDG, while qualitative analysis methods were used to predict impacts to other physical, chemical, and biological processes. Numerical modeling is described in Sections 2.2 and 2.3, and qualitative analysis methods are discussed in Sections 2.4 and 2.5. Numerical modeling assumes a standard set of assumptions, and does not capture real-time adaptive management. So model results may be imprecise in some regards, but are useful tools to use in comparative studies like this EIS. The numerical models were also not used to predict future impacts from climate change. Instead, qualitative assessments were conducted to make predictions of the effects of climate change on water quality conditions. This information can be found in Chapter 4 of the EIS.

Numerical water quality modeling of rivers requires river condition, reservoir operation, and meteorological data (such as wind speed and direction, air temperature, and barometric pressure) to predict water temperature and TDG. River condition and reservoir operation data, including total discharge, spillway and powerhouse operations, miscellaneous discharge, and reservoir/tailwater elevation data, was derived from the Corps Hydrologic Engineering Center (HEC) Reservoir System Simulation (ResSim) model as informed by HydSim. ResSim is a Corps reservoir operation model while HydSim is a Bonneville hydropower operation model. The purpose of the Corps model is to evaluate flood risk management, whereas the Bonneville model is for determining hydropower operations. For this EIS, flow datasets from the ResSim model were used in the water quality models to simulate the effects that each EIS alternatives may have on water quality.

Sediment quality impacts were evaluated qualitatively. There are no sediment quality models for the CRSO EIS. Sediment quality was evaluated based on the known existing sediment characteristics and professional assessment of the impact of sediment movement on the conditions in the river. Estimates of sediment transport and channel bed changes were provided by the Geomorphology Team (Appendix C, *River Mechanics*).

2.2 STUDY AREA

The area considered in this water and sediment quality evaluation consists of the Columbia River and its tributaries (Snake, Clearwater, Pend Oreille, Flathead, and Kootenai Rivers) from the U.S.-Canada border to downstream of Bonneville Dam at Warrendale, Oregon. This includes the Federal dams of Hungry Horse, Libby, Albeni Falls, Grand Coulee, Chief Joseph, Dworshak, Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville (Figure 2-1).

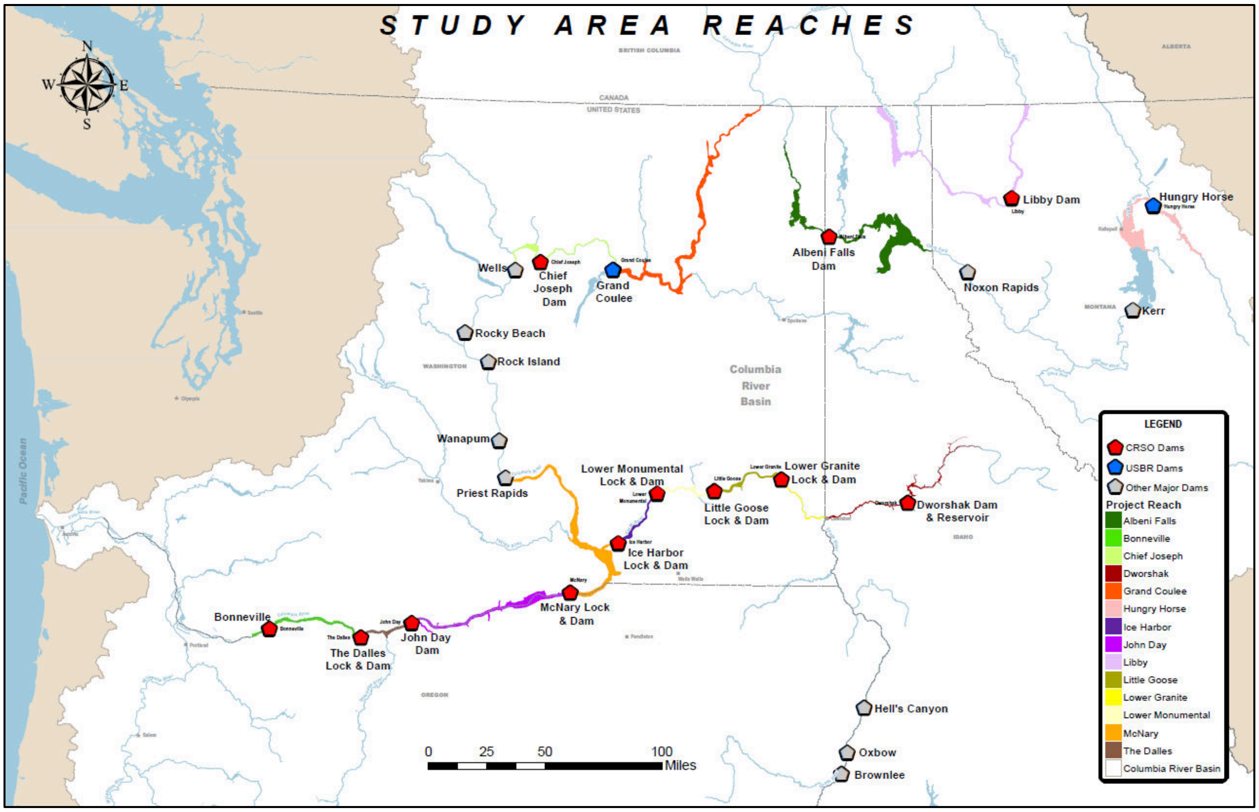


Figure 2-1. Columbia River System Operations Environmental Impact Statement Water Quality Study Area Map

As outlined in EIS Objective 1, the EIS is to improve juvenile fish passage (travel time, survival), rearing, and long term survival within the CRSO projects, including but not limited to configuration, flow management, and water quality to benefit ESA listed anadromous salmonids. Within the CRS, this is defined as the area located in forebay and tailwater of each dam for water quality. The area downstream of Warrendale, Oregon, to the outlet of the Columbia is not included in this evaluation of water quality, as the effects of CSRO on water quality downstream of the Columbia River System dams is considered out of scope. Sediment within the Columbia River Basin moves downstream, but the movement is interrupted by the dams and sediment in general does not move past Bonneville Dam, except for small amounts of fine suspended material that are carried to the ocean. It is recognized that the operation of the dams may impact the estuary and downstream Columbia River conditions, simply because the natural processes in the river system have been disrupted by the dams, but the effect of the presence of the dams on the estuary is not the issue addressed in this water quality analysis. Other downstream conditions, such as the water and sediment quality in the Portland, Oregon, area, are affected by factors outside the scope of this study and control of CRSO, and those downstream conditions may be more pertinent to the estuary conditions than the upstream dam operations.

A whole suite of water quality parameters have been measured for several years throughout the CRSO study area. For EIS analysis, water quality parameters are separated in three major categories: (1) water temperature, (2) TDG, and (3) other physical, chemical, and biological conditions. This information is presented in the paragraphs below and is compared to the no action results for each alternative in the sections below.

Montana, Idaho, Washington, and Oregon are the states within the CRSO study area. Each have established their own water quality criteria and monitoring programs in response to the mandate of the Clean Water Act (CWA). In addition, the Columbia River Basin is regulated by tribal and local agencies along specific river segments. These criteria are used as the metrics against which all results for EIS alternatives are compared.

2.2.1 Columbia River/Lower Snake Mainstem Modeling

The system water quality model uses two model software packages. The CE-QUAL-W2 (W2) model (Version 4.2) was used for reservoirs in the Columbia River System to simulate water temperature and TDG two-dimensionally (vertically and longitudinally), and the HEC River Analysis System (HEC-RAS) model (Version 5.0.3) was used for water temperature simulation of riverine sections in one dimension. (A one-dimensional [1D] model has changes only in one direction along the channel, while a two-dimensional [2D] model allows changes in two directions.) The model domain consists of the Columbia River mainstem from the U.S.-Canada border to Bonneville Dam; the Clearwater River/lower Snake River from Dworshak Reservoir on the North Fork of the Clearwater; the mainstem Clearwater River at Orofino, Idaho; and the Snake River at Anatone, Washington, to the mouth of the Snake River. The model includes 11 Federal dams: Grand Coulee, Chief Joseph, Dworshak, Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville. It also includes five non-Federal dams on the Columbia River mainstem: Wells, Rocky Reach, Rock Island, Wanapum and Priest Rapids. These five additional dams impact water quality (temperature and TDG) and are included in the modeling schema to more accurately describe the river conditions, however data related to these dams is not presented or discussed in this document. There are three longer river reaches not interrupted by dams: the Hanford Reach between Priest Rapids Dam and McNary Reservoir at Pasco, Washington, the Clearwater River upstream of Lower Granite Reservoir, and the Snake River upstream of the City of Asotin, Washington. These uninterrupted river sections function similarly to a free-flowing river (Figure 2-2).

The system model is limited by available data and run times, so modeling long-term record sets was not possible for EIS analysis. Instead, a 5-year period (2011–2015) that represent a wide range of environmental response to hydrology (wet, dry, average) and weather conditions (hot, cold, average) were selected to model each EIS alternative against. Dam operations, as described in each EIS alternative, were imposed on these selected years through the use of the ResSim model and fed into the system water quality model. The following years were selected for water and sediment quality analysis:

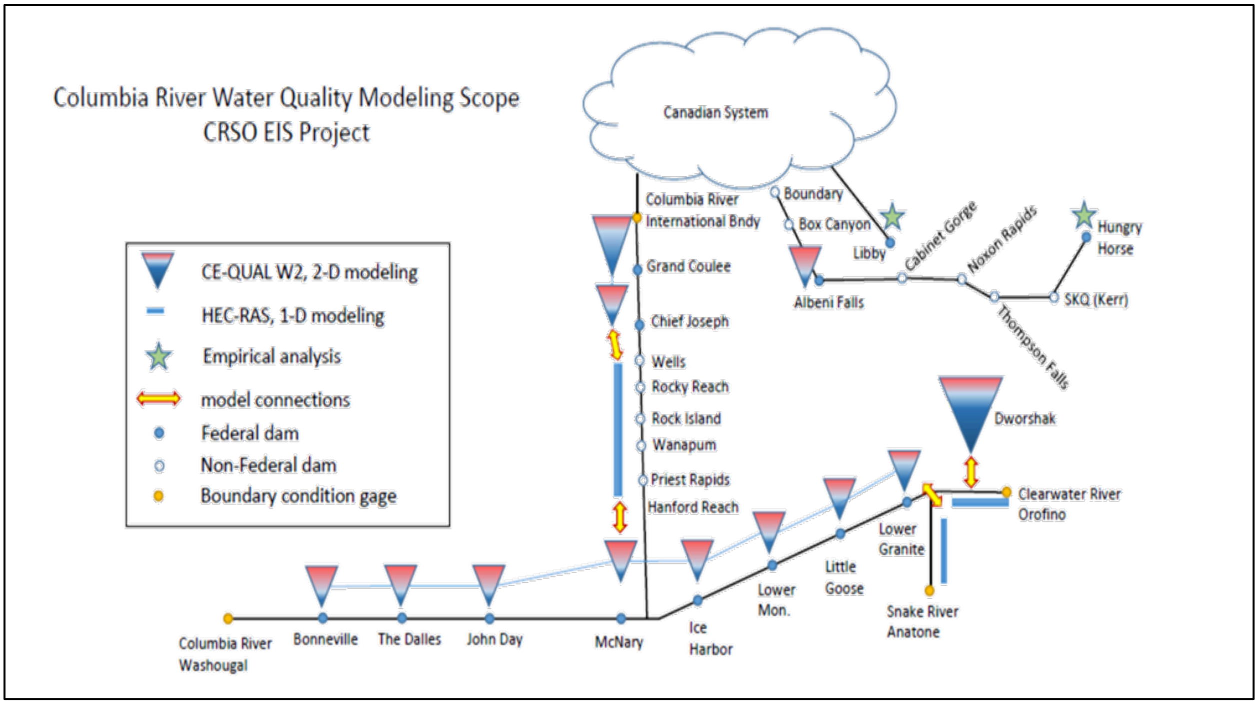


Figure 2-2. Columbia River System Operations Environmental Impact Statement Water Quality Modeling Framework

- 2011: During this year there were high values observed for the TDG metrics and comparatively low values for the water temperature metrics. There was adequate data for water temperature and TDG tailwater sites. It was a fairly extreme high-flow year but with a normal air temperature metric. The years 1996 and 1997 appear to be similar but do not have as much data.
- 2012: During this year there were high values observed for the TDG metrics and comparatively low values for the water temperature metrics. There was adequate data for temperature and TDG tailwater sites. It was a fairly average flow year with a normal air temperature metric.
- 2013: During this year there were high values observed for the air temperature metric with lower than average flow conditions. The water temperature response was near average, and TDG response was slightly below average.
- 2014: During this year there were high values observed for the air temperature metric with near average flow conditions. The water temperature response was near average, and TDG response was slightly below average.
- 2015: During this year there were comparatively high values observed for the temperature metrics (second highest for the average of the site exceedances, since 1995) and the lowest for TDG metrics. There is adequate data for temperature and TDG tailwater sites. It was a fairly extreme low-flow year but with slightly above average air temperature metrics. The year 2001 is similar but does not have as much data.

These years are represented in figures below as the following: 2011 = High Inflow/Low Air Temperature (HF/LT), 2012 = Average Inflow/Low Air Temperature (AF/LT), 2013 = Low Flow/Average Air Temperature (LF/AT), 2014 = Average Flow/Average Air Temperature (AF/AT), and 2015 = Low Flow/High Air Temperature (LF/HT).

Simulated water temperature and TDG data are compared to state, Federal and tribal temperature and TDG criteria to quantify expected changes under the No Action Alternative and MOs. This information is also used to inform impacts to other resources such as anadromous and resident fish, waterfowl, and tribal fishing and recreation.

2.2.2 Lower Snake River Model for the Multiple Objective 3 Alternative

The Multiple Objective Alternative 3 (MO3) Lower Snake River (LSR) Model was developed to evaluate the breaching of all four dams on the lower Snake River over a 5-year period, spanning 2011 to 2015. MO3 has several notable measures, the most significant of which is the breaching of the lower Snake River dams. The MO3 LSR Model, unlike other CRSO models used in the EIS, uses the 1D HEC-RAS model instead of the 2D W2 model. The driving force for this decision is the complexity of setting up a free-flowing riverine system in the W2 model. Details regarding development of the MO3 LSR model can be found in Annex A of this document.

Over the past two years, EPA has updated the RMB10 1D temperature model to assess Columbia and Snake River water temperatures and evaluate the impacts from the federal dams as part of the reinitiation of the TMDL project. Preliminary results have been shared across the region, which has led some stakeholders to compare the scenarios analyzed in the TMDL effort against CRSO EIS results. There are similarities in the TMDL and CRSO EIS modeling assessments of the Snake River, and both project teams have evaluated the similarities and differences in the models as part of uncertainty assessment. At the same time, direct comparisons are not appropriate given the differences between scenarios and assumptions made among the two projects. These differences are described so that the reader has a clear understanding of the two efforts (Table 2-1).

Table 2-1. Comparison of TMDL and CRSO EIS Analyses.

	Preliminary TMDL Analysis	CRSO EIS Analysis
Tools Utilized*	RBM10 (1D)	CE-QUAL W2 (2D) & HEC-RAS (1D)
Temperature Metric	Daily average	Daily maximum
Calibration Period	2011 – 2016	2011-2015
Time step	Daily	Hourly
Meteorological Data Inputs	Prioritized stations with long term dataset, i.e. airports (1970-2016)	Prioritized stations with highest spatial resolution, includes airports and Agrimet.
Focus of Analysis	Analysis is used as an assessment of the sources of thermal load.	Analysis is focused on operational changes (timing, magnitude and route of water passage) of the CRSO dams.

	Preliminary TMDL Analysis	CRSO EIS Analysis
Baseline Conditions	Existing Conditions: Observed flow and dam operations for 2011-2016.	No Action: 2016 dam operations and configuration overlaid on 2011-2015 meteorological conditions and channel geometry.
No Dams Conditions	RBM-10 was utilized for the "free-flowing" scenario. The free-flowing scenario includes the absence of Grand Coulee, Chief Joseph, the 5 mid-Columbia PUD dams, the lower four Columbia River and the lower four Snake River dams. Dworshak Dam is a boundary conditions and uses observed flows and temperatures. 2010 channel bathymetry is utilized throughout system. The TMDL assessment focused on quantifying the thermal load of the dams by comparing existing conditions to a free-flowing scenario.	HEC-RAS was utilized for the MO3 EIS Alternative for the lower Snake River; CE-QUAL W2 was used for the other mainstem CRSO dams. MO3 includes breaching the four lower Snake River dams in which the concrete sections of each dam is removed, leaving the earthen embankments in place. All other CRSO dams remain in place. Dworshak Dam uses modeled flows and temperature. 1934 (pre-dam) channel bathymetry is utilized throughout lower Snake River; 2010 geometry used elsewhere in the system. The CRSO EIS assessment focused on predicting water temperature and TDG conditions under the MO3 alternative, which included a measure for breaching all four lower Snake River dams.

2.2.3 Pend Oreille River (Albeni Falls Reach) Modeling

The Albeni Falls W2 model was run separately from the system model, since Albeni Falls Dam is located on the Pend Oreille River approximately 100 river miles upstream from its confluence with the Columbia River. Moreover, downstream of Albeni Falls Dam, the Pend Oreille River is influenced by two non-Federal U.S. dams and two Canadian dams before flowing into the Columbia River. The Albeni Falls W2 model was used to simulate impacts from the operation of Albeni Falls Dam only, and not impacts from dams such as Boundary or Box Canyon, which fall outside of the scope of this EIS. The Albeni Falls W2 model domain extends from the outlet of Lake Pend Oreille near Sandpoint, Idaho, downstream to Albeni Falls Dam. The model simulates water temperatures which are compared to temperature criteria for evaluation.

TDG production at Albeni Falls Dam is addressed qualitatively, since studies indicate that a direct relationship between spillway discharge and TDG exchange is not consistently observed (Schneider et al. 2007). The TDG saturations observed at the dam's fixed monitoring station are a weak function of spill discharge. Developing a reliable empirical model to estimate TDG saturations in the Pend Oreille River downstream of Albeni Falls Dam is not possible because of the lack of a relationship between spillway discharge and TDG production.

2.3 PERIOD OF RECORD MAPPING

Water quality modeling is a time and data intensive procedure. Recent data exist to calibrate water quality models for water temperature and TDG in the CSRO study area, but few observed water quality data are available to use these data-intensive models for historical years. Historical flow data do exist for the study area, and are used to predict water temperature and TDG outside of the water quality models for the selected period of record years of 1928 to 2008. This larger dataset feeds the Comprehensive Passage Model, the Comparative Survival Study fish model, and other fish impacts analysis for this EIS.

To predict water temperature and TDG data for the period of record, simulated water temperature data from the years 2011 to 2015 were mapped to the historical period. For water temperature, historical monthly water temperatures were generated based on monthly flow and air temperature data derived from long-term gaging stations located near Bonneville, Ice Harbor, and Priest Rapids Dams (Annex B). For TDG, the period of record data was estimated using the equations and parameters found within the W2 models. These equations calculate TDG directly below a dam (referred to as the tailwater), and the area just before the next downstream dam (referred to as the forebay). The initial conditions at a particular dam: upstream forebay TDG (estimated), total spill, total flow, forebay elevation, and tailwater elevation (simulated from the ResSim models), and long-term historical monthly average barometric pressure and wind speed. Changes to TDG through each reservoir reach are based on monthly average environmental conditions.

2.4 EMPIRICAL ANALYSIS TOOLS

Where numerical models do not exist or are too outdated to be easily updated for use in this EIS, empirical analysis tools have been developed to predict TDG generation at Libby and Hungry Horse Dams, while qualitative analysis is used to predict impacts to downstream water temperature management. The TDG tools use empirically derived TDG production equations to predict TDG generated under the various flow regimes as prescribed in the alternatives. A qualitative assessment is used to evaluate whether the various alternatives are likely to adversely impact the ability to continue managing downstream water temperatures using the selective withdrawal structures (SWSs) that exist at both dams. This is achieved through the evaluation of reservoir summary elevation hydrographs (storage diagrams) developed from ResSim model output. Specifically, the following approach was used for the water temperature impact assessment:

1. Evaluate whether an alternative falls within the range of historical water level conditions and operational range of the SWS (if water hydrologic and operational conditions fall within the historical ranges, it will be assumed that historical release temperatures can be assessed in the alternative);
2. Conduct a comparison between historical operations and operations under the specific alternative;

Conduct a comparison of reservoir drawdown elevations and the resulting temperature releases during summer months.

2.5 QUALITATIVE ANALYSIS

Outside of water temperature (with exceptions at Libby and Hungry Horse Dams) and TDG (with the exception of Albeni Falls), water quality impacts are assessed qualitatively using information of reservoir and river operations from ResSim paired with professional judgment based on experience with reservoir operations. Data from model output, multiple technical reports, past studies, and field data was considered. Information such as total discharge, spill, and reservoir elevation was used to predict how reservoir and river conditions may change under a given alternative, and how these changes may affect water quality parameters such as turbidity, and nutrient and contaminant loading.

2.6 IMPACT FRAMEWORK

A framework was developed to define the overall level of water temperature and TDG impact for each CRSO EIS alternative as compared to the No Action Alternative. For water temperature, the level of impact (negligible, minor, moderate, or major) was defined based on the absolute change in the maximum and minimum water temperatures as averaged over the five year simulation period (2011-2015). If the absolute change in water temperature between the MO Alternative and No Action Alternative was less than 0.4°F, the water temperature impact was considered negligible. If the absolute change in average minimum and maximum values was greater than 0.4°F, but less than 2°F, the impact was considered negligible, minor or moderate based on the time of year (season[1]) the impact occurred and whether the impact increased the number of days that State water quality criterion (WQS) criteria was not met and by how much. Absolute water temperature changes of >2°F, or an increase in water temperature WQS exceedances of greater than 10 days, were considered a major impact (Figure 2-3).

For total dissolved gas, the following decision criteria was used to determine level of impact:

- Negligible: <=1% change in the five year average maximum TDG as compared to the No Action Alternative.
- Minor: >=1% but <2% change in the five year average maximum TDG as compared to the No Action Alternative.
- Moderate: >=2% but <3% change in the five year average maximum TDG as compared to the No Action Alternative.
- Major: >=3% change in the five year average maximum TDG as compared to the No Action Alternative.

These descriptors are used to summarize the overall impact of each EIS Alternative as described in the sections below.

[1] Seasons are defined as winter = Dec - Feb; spring Mar - May; summer = Jun - Aug; fall= Sep - Nov.

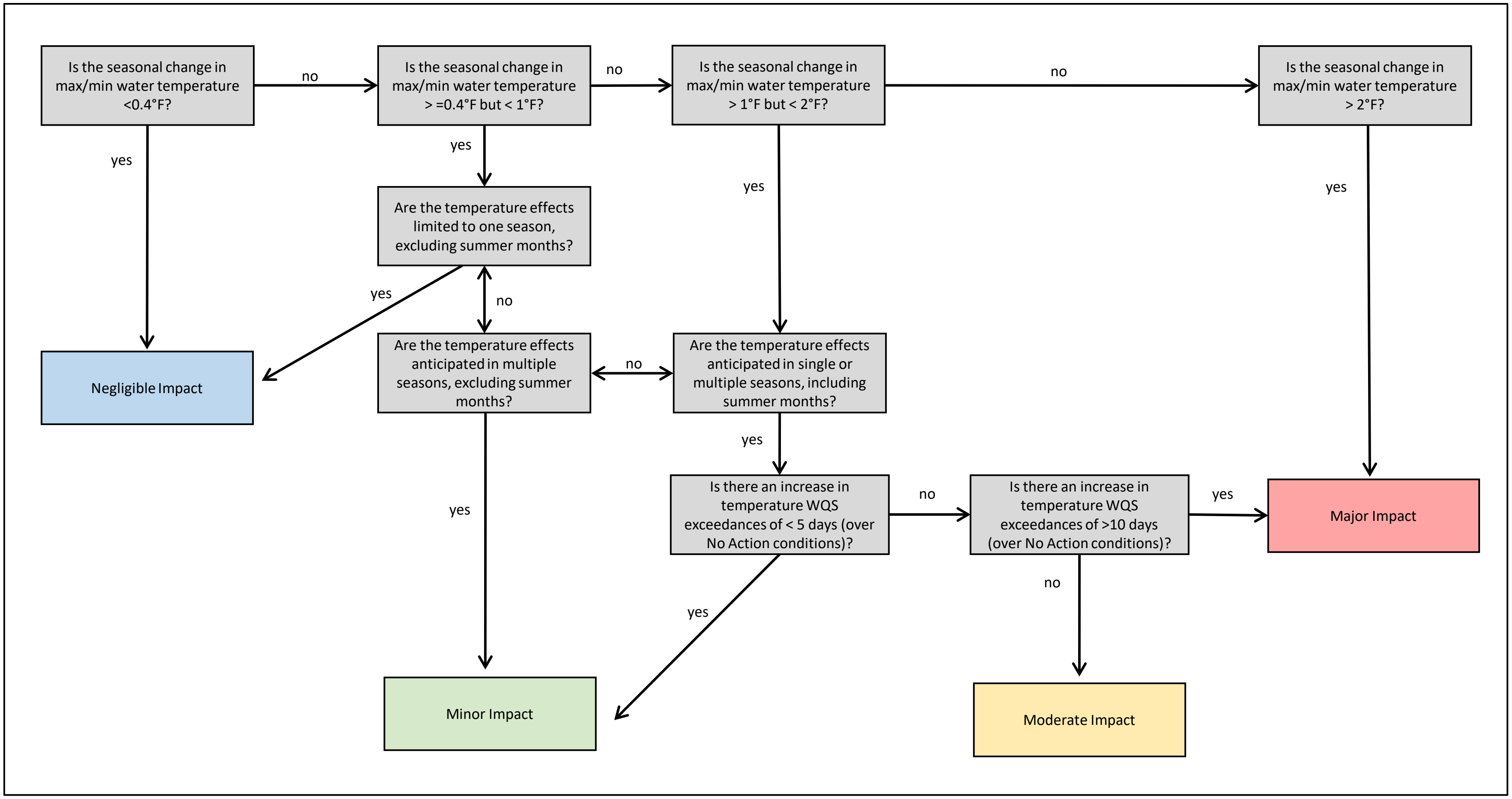


Figure 2-3. Water Temperature Impact Framework and Decision Criteria

2.7 LIMITATIONS, ASSUMPTIONS, AND UNCERTAINTY

2.7.1 Water Quality

- The Canadian portion of the Columbia River was not included in the evaluation. Operational changes from headwater Columbia River System projects (Libby, Hungry Horse, and Albeni Falls Dams) are represented as flow changes into the system water quality model but changes to inflowing water temperature and TDG are not contemplated, introducing uncertainty to the boundary condition of the system model.
- The impact of the non-Federal dams are not evaluated in this EIS. The mid-Columbia Public Utility District dams are represented in the model schema to more accurately describe the river conditions, however data related to these dams is not presented or discussed in this report.
- The estuary, including the reach from downstream of the Bonneville Dam tailrace to Astoria, is not include in the water quality analysis for this EIS.
- The impact of operations to temperature and TDG were quantified using mechanistic models. All models are simplifications of the real world and we have endeavored to represent the processes that are important to water temperature and TDG.
- Uncertainty is introduced into the model results through simplified representation of physical processes, inputs, parameters and applicability to new operations. Uncertainty was reduced and evaluated, to the extent practicable.
- The effects of nutrient cycling and algae on TDG are not included in our analysis of TDG; instead focus is given to the TDG produced by the operation of the Columbia River System dams.
- The analysis of other biological, physical, and chemical water quality constituents is qualitative; simulated water temperature and TDG data is used to inform changes to those constituents.

2.7.2 Sediment Quality

Throughout the evaluation of alternatives, some assumptions related to sediment quality are consistently made.

- Water quality changes (temperature, pH, dissolved gases) may affect sediment quality in minor ways, including changing the rate of biodegradation of pollutants or organic matter in the sediment, or affecting the oxidation state of metals. Minor impacts to sediment quality due to water quality changes are not evaluated.
- The total flow through a dam or river reach affects sediment movement; however, the distribution of that flow through the dam (spillway verses hydropower unit, for example) would not affect sediment movement in the channel. Because the total flow in the river channel is what affects sediment movement, alternatives that only change the distribution

of flows or location of discharges, but that do not change the total flow, are considered to have a negligible effect on sediment quantity and quality.

- Coarser-grained sediment settles to the bottom of the river or reservoir and is trapped behind the dams. Fine-grained sediment that remains in suspension may move downstream from a dam with the water that flows either as spill or through the hydropower units. Proposed actions or alternatives that do not affect the often coarser-grained, shoaled (settled) sediment are considered to have no impacts to sediment, because the fine materials that already move through the system will continue to do so. Sediment impacts evaluated are only impacts to the shoaled materials.
- Sediment movement and quantity is informed by river mechanics. Appendix C, River Mechanics, should be referenced for details on sediment movement, while this appendix is focused on the issues of sediment quality (pollutants) and management.

CHAPTER 3 - NO ACTION ALTERNATIVE

The No Action Alternative is defined as the future water quality condition within the CRSO study area, without any changes in system configuration or operation. In other words, the No Action Alternative shows what would happen if the proposed action was not taken (Bass, Henderson, and Bogdan 2001) and project operations and configuration remained the same as they were in 2016 (EIS Notice to Proceed date). For this No Action Alternative assessment, future water and sediment quality conditions are evaluated for the next 25 years using 2016 Fish Operations Plan spill operations in accordance with the 2014 National Oceanic and Atmospheric Administration (NOAA) Fisheries Federal Columbia River Power System Supplemental Biological Opinion (2014 BiOp)[2].

The 2008 National Marine Fisheries Service (NMFS) BiOp (2008 BiOp), supplemented in 2010 and 2014 (2014 BiOp), includes RPA action 29 that states that the Corps and Bonneville will provide spill to improve juvenile fish passage while avoiding high TDG supersaturation levels or adult fallback problems. Specific spill levels will be provided for juvenile fish passage at each project, not to exceed established TDG levels (either 110 percent TDG criterion, or as modified by State water quality waivers, currently up to 115 percent TDG in the dam forebay and up to 120 percent TDG in the project tailwater, or if spill to these levels would compromise the likelihood of meeting performance standards). The dates and levels for spill at each dam may be modified through the implementation planning process and adaptive management decisions[3] (Appendix O). Future Water Management Plans will contain the annual work plans for these operations and spill programs, and will be coordinated through the Technical Management Team. The Co-Lead Agencies will continue to evaluate and optimize juvenile spill passage survival to meet both the hydrosystem performance standards and the requirements of the CWA.

It is assumed that under the No Action Alternative, some existing projects related to water and sediment quality would continue. For example, use of Dworshak Dam for downstream water temperature management of the lower Snake River would continue to occur. Similarly, use of the SWS at Libby and Hungry Horse Dams would continue to provide as close to naturally occurring water temperatures as possible downstream of the dams for fish, including the

[2] The 2014 Supplemental BiOp considered the Co-Lead Agencies' 2014–2018 Implementation Plan and incorporates both the 2008 BiOp and the 2010 Supplemental BiOp.

[3] Spill operations have been in flux in recent years. On January 8, 2018, the U.S. District Court for the District of Oregon issued an Order (Court Order) for spring 2018 juvenile fish passage spill operations. The Court Order, along with the 2018 Spring Fish Operations Plan, describes Corps' project operations for juvenile fish passage at its four lower Snake and four lower Columbia River projects during the spring juvenile migration season, generally April 3 through June 20, 2018. The Court Order directed the Corps to maximize juvenile fish passage spill to the extent feasible in a manner consistent with the Oregon and Washington state water quality criteria for total dissolved gas (TDG) (i.e. Gas Cap spill). During the spring 2018 spill season, Washington's criteria adjustment for TDG allowed for 115 percent TDG as measured in the forebay and 120 percent TDG as measured in the tailraces of the dams. Oregon's criterion modification allowed for spill up to 120 percent TDG as measured in the tailraces of the dams. The Corps applies the more stringent criterion when operating under all applicable state TDG criteria. After spring, the Corps implemented the 2018 Summer Fish Operations Plan which was developed to be consistent with the 2008 BiOp.

endangered Kootenai River white sturgeon, and threatened bull trout and west-slope cutthroat trout fish populations. TDG control through operational and structural means would also continue, particularly at the lower eight dams during the downstream juvenile fish migration season. Areas which historically have required dredging (lock chamber approaches, the confluence of the Snake and Clearwater Rivers, harbor and port berthing areas and entrances) would still experience shoaling (the build-up of sediment into shallow areas that obstruct navigation). Navigation channel and private dockface/berthing area dredging conducted by the Corps to maintain navigation, would still occur. Sediment management activities in the Snake River (as described in the Programmatic Sediment Management Plan, Corps 2014 and other documents) would continue as currently planned. The Corps would periodically evaluate sediment quality following the Sediment Evaluation Framework (Northwest Regional Sediment Evaluation Team [RSET] 2018) or other applicable guidance, particularly as supporting documentation prior to the implementation of navigational maintenance dredging but also as part of other studies. It is also assumed that other agencies which may be involved in water or sediment studies (e.g., U.S. Environmental Protection Agency [EPA] and U.S. Geological Survey [USGS]) or soil/sediment management (e.g., National Resources Conservation Services) would continue their actions as directed and funded by Congress or by the states.

In a similar manner, existing environmental regulatory programs and actions would continue. The CWA would control point and non-point discharges; CWA Sections 401 and 404 would be the main controlling Federal regulation for sediment projects. State, Tribal and local water quality, natural resource, and land use regulations would also continue as currently implemented. As additional scientific information becomes available over time, standards may be updated and revised; future reservoir operations and future projects would be consistent with the regulations at the time of implementation. Remediation programs, at both the Federal and state level, would continue as authorized and funded.

Some of the existing water and sediment quality issues in the Columbia River Basin would be addressed under the No Action Alternative:

- Libby Dam-Lake Koocanusa Selenium Monitoring and Research Group, a partnership between the United States and Canada consisting of Federal, state, provincial, tribal, and mining groups, will research selenium and nitrate within Lake Koocanusa.
- EPA Cold Water Refuges is a study of cold water refuges along the lower Columbia River, and is mandated by the NOAA Biological Opinion on the Oregon temperature standard. The study will assess current refuge conditions and potential restoration methods. A final report is expected in 2020.
- Columbia and Lower Snake River Temperature Total Maximum Daily Load (TMDL), an EPA-led study aimed at developing a temperature TMDL for the Columbia and lower Snake Rivers. Partners include Idaho, Oregon, and Washington, the Confederated Tribes of the Colville Reservation, and the Spokane Tribe of Indians.
- The U.S. Department of State is leading an effort to negotiate with Canada to modernize the Columbia River Treaty. Key objectives include flood risk management through coordinated

operations of hydroelectric dams on both sides of the U.S.-Canada border, maintaining a reliable and economical power supply, and managing the Columbia River System in a way that improves ecosystem benefits.

- The Idaho Conservation League has petitioned EPA to review, disapprove, and revise the Snake River–Hells Canyon TMDL and provide full protection against phosphorus pollution loadings between River Mile (RM) 272.5 and 409.
- Lake Roosevelt sediment was contaminated by past smelter waste discharges. A remediation project to remove some slag contaminated materials has been implemented. Litigation continues and the litigants request additional cleanup actions (Washington Department of Ecology 2018).
- The Hanford Site is a former nuclear production site near Richland, Washington, located along the Columbia River upstream of its confluence with the Snake River. Cleanup of the Hanford site started in 1989 and is anticipated to continue (Hanford Site 2018).
- The Columbia River Restoration Act was authorized by Congress to provide funding to clean up pollutants in the Columbia River ecosystem. Funding is provided by grants to stakeholders who work cooperatively with EPA and other agencies.
- Existing water quality and fish tissue quality problems, identified under CWA Section 303d, would continue until the sources of the impairments are addressed. Fish tissue contaminants are related to sediment contamination. Although there are currently no basin-wide sediment contaminant removal/remediation projects for the Columbia River Basin, there are a few site specific projects occurring such as a Bradford Island.
- Through numerous Endangered Species Act (ESA) consultations over the last 25 years with NMFS and the U.S. Fish and Wildlife Service (USFWS), the Corps has implemented operational and structural measures to improve the survival of ESA-listed salmon and steelhead, Kootenai River white sturgeon, bull trout, other non-listed salmonids, Pacific lamprey, and burbot (a freshwater fish species in the Kootenai River). Starting in 1999, the NMFS BiOp, which focuses on ESA-listed salmon and steelhead, has included measures to spill at the Lower Snake and Lower Columbia dams during juvenile fish passage season. Operating the CRSO projects to meet the most current BiOps is expected to continue.
- A Flexible Spill Agreement (herein referred to as Spill Agreement) regarding 2019-2021 spill operations at the eight Federal dams on the lower Snake and Columbia Rivers has been signed by the states of Washington and Oregon, the Nez Perce Tribe, Bonneville, the Corps, and Reclamation. The Spill Agreement is supported by the states of Idaho and Montana, and the Columbia River Inter-Tribal Fish Commission. The purpose of the 2019-2021 Flex Spill Operation Agreement is to benefit juvenile spring fish passage, provide federal power system benefits no worse financially compared to the 2018 spring juvenile fish passage operations, and provide operational feasibility for implementation. This agreement reflects the intent of the signatory parties to work collaboratively on fish passage spill operations during the NEPA remand period or until the CRSO EIS is final.

- The flexible spill (Flex Spill) operations included in the Spill Agreement are contingent on short term modifications being issued from Oregon and Washington to provide juvenile fish passage spring spill. Washington will provide a short-term modification to the adjusted TDG criteria at Washington Administrative Code 173-201A-200(1)(f)(ii) for both 120% TDG in the tailrace in 2019 and up to 125% TDG in the tailrace starting in 2020 for the spring juvenile fish passage period. The flexible spill operations starting in 2020 is also contingent on a short-term modification of the Oregon TDG water quality standard to 125% tailrace for the spring juvenile fish passage period.

The list above is not intended to be an all-inclusive list, but instead, the major environmentally related actions and on-going multi-agency initiatives within the basin.

3.1 UPPER COLUMBIA RIVER BASIN

Study waterbodies in the upper basin include the Columbia River from the U.S.-Canada border to the tailwater of Chief Joseph Dam; the length of the Pend Oreille River system that includes the South Fork Flathead River (Hungry Horse Reservoir and tailwater), Flathead River and Lake, Clark Fork River, Lake Pend Oreille, and the Pend Oreille River from Lake Pend Oreille to the Albeni Falls Dam tailwater; and the length of the Kootenai River which includes Lake Koocanusa starting at the U.S.-Canada border to the Libby Dam tailwater.

3.1.1 Water Temperature

Water temperature varies longitudinally along a river and vertically within a lake or reservoir. It is well understood that the warming/cooling trends of large, deep reservoirs tend to lag behind the thermal response that is found in unregulated rivers, creating outflow temperatures that are cooler in the spring and warmer in the fall compared to natural or pre-dam thermal conditions. This is apparent in most reservoirs within the Upper Columbia River Basin.

3.1.1.1 Libby and Hungry Horse Dams and Reservoirs

Lake Koocanusa and Hungry Horse Reservoir both thermally stratify in the summer and can provide some downstream water temperature management through use of the SWSs equipped at both dams. Through BiOp agreements, water temperatures in the river reaches below these dams are purposefully managed to benefit threatened and endangered species.

The Libby Dam selective SWS is designed to take advantage of the seasonal, though variable, temperature stratification that occurs in the dam’s forebay. Temperature stratification is particularly important when the objective is to provide warmer discharge temperatures to support sturgeon spawning and early life-stage development. When temperature stratification occurs, the result is cooler, denser water deeper down in the vicinity of the powerhouse intake penstocks, and warmer, less dense water nearer the surface. The SWS provides some ability to manipulate where in the water column water entering the powerhouse penstocks is drawn from. This is accomplished by the placement of the bulkheads. When few or no bulkheads are deployed, powerhouse intake water will come from lower in the water column. When bulkheads are deployed close to the forebay water surface, powerhouse intake water will come from higher in the water column. SWS operating protocol calls for maintaining at least 30 feet of submergence over the top row of bulkheads for hydraulic stability.

The ability of the SWS to manage downstream water temperatures at Libby Dam is dependent on the temperature stratification present in the forebay. The reservoir generally becomes isothermic in December, and remains so until early April. Discharge temperatures cannot be managed to be warmer than the warmest temperatures present, or colder than the coldest temperatures present. The stratification of temperatures needed for effective temperature management, particularly for warmer discharge temperatures, has proven to be fragile. Meteorological conditions such as changes in air temperature and the presence, speed, and direction of wind can effectively mix the water in the forebay, eliminating or greatly reducing the degree of stratification.

The SWS only provides temperature management for powerhouse discharges. The other two discharge mechanisms, the spillway and the regulating outlets, are not equipped with temperature management capabilities. The selective withdrawal system is operated to provide a temperature range as close to a free flowing river temperature range as possible downstream in the Kootenai River throughout the year. However, given the presence of a large deep reservoir (which changes temperature slowly) as the source of water to the river, outflow temperatures can be cooler in the spring and warmer in the late fall compared to the natural pre-dam Kootenai River. Given this, the selective withdrawal system is operated to follow, as close as possible, temperature objectives (rule curve) developed by the Corps and Montana Fish, Wildlife, and Parks (MFWP). However, more recent operations in coordination with MFWP have diverged from these objectives in order to make the river warmer during the summer. The water temperature rule curve, developed using pre-dam daily temperatures collected in the Kootenai River from 1967 to 1972, is presented in Figure 3-1 together with a summary of release water temperatures from Libby Dam for a series of years chosen to be representative of the following conditions:

- Large Drawdown/High Inflow: 1999 and 2011
- Large Drawdown/Low Inflow: 2000
- Small Drawdown/High Inflow: 2006 and 2013
- Small Drawdown/Low Inflow: 2009 and 2010
- More recent operations: 2015 and 2018

In general, the SWS has the ability to manage discharge temperatures under a wide variety of drawdown and inflow conditions. However, downstream river temperatures during the fall and winter are generally several degrees warmer than pre-dam Kootenai River conditions, while water released from the dam during the spring and summer is generally several degrees cooler than natural river conditions.

Modeled forebay elevations under the No Action Alternative are predicted to be within the operating range of the SWS and similar to the ranges observed in the historical years presented in Figure 3-1. Given this, use of the SWS to manage discharge temperatures is expected to continue under the No Action Alternative.

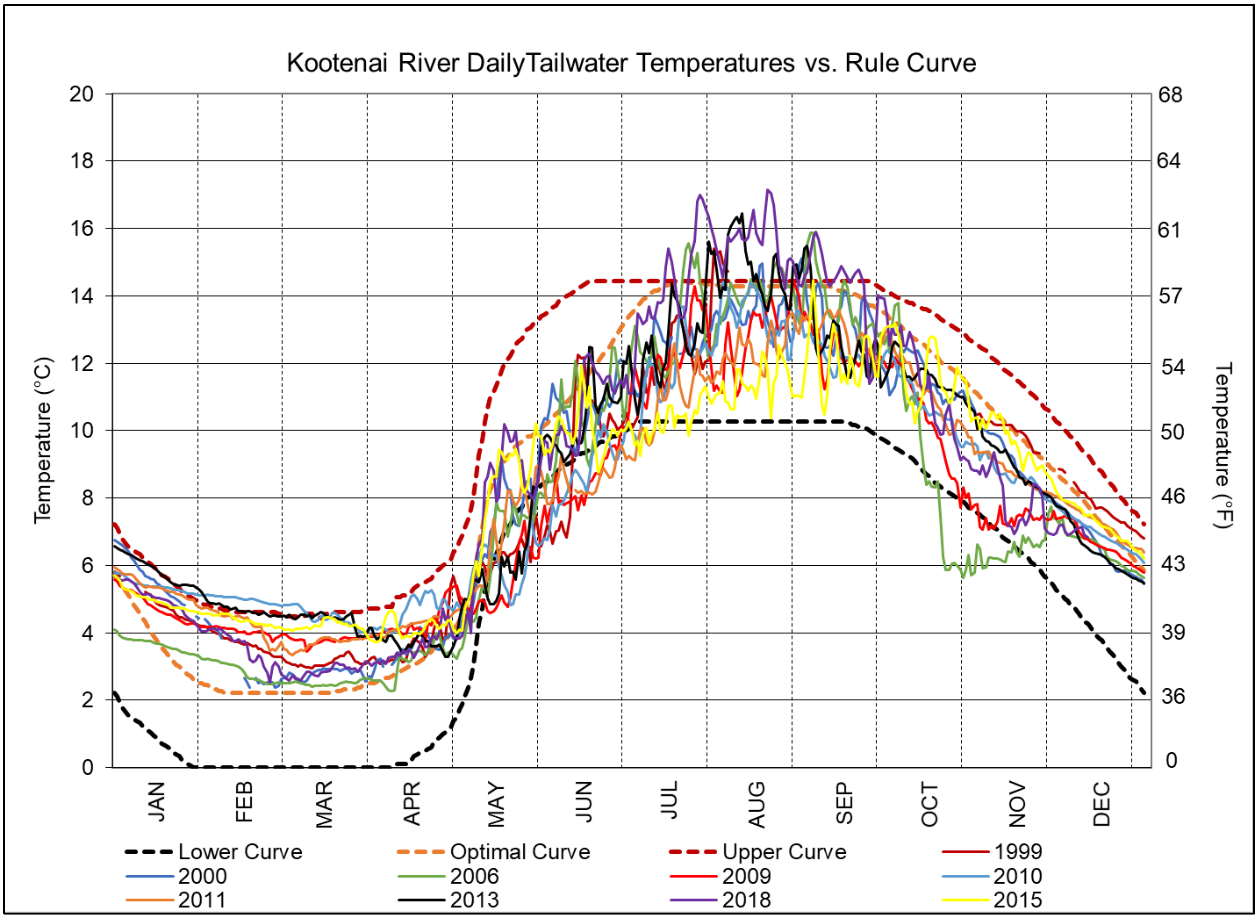


Figure 3-1. Kootenai River Temperatures Measured at Libby Dam Tailwater Over Several Years, Representative of Differing Drawdown and Inflow Conditions

Note: The MFWP temperature rule curve developed from pre-dam temperatures from 1967 to 1972 is shown.

The SWS at Hungry Horse Dam is operated from approximately June to the end of October to release warmer water that matches water temperatures on the Middle and North Fork Flathead Rivers for the benefit of resident fish. The SWS is composed of independent structures for each of the penstock intakes, allowing withdrawals of warmer waters from near the surface of the reservoir during the summer, when the reservoir is thermally stratified. The system performs over the full range of the reservoir, up to 160 feet below the maximum reservoir water surface elevation. When not in use, the control gates are lowered to their lowest position and the relief gates are raised to the top of the trash rack structure to minimize system head loss (Reclamation 2006).

Since completion of the SWS, thermal issues in the river have been minimal. An agreement with MFWP allows Reclamation to operate the SWS to achieve a temperature regime that mimics natural conditions (Christenson, Sund, and Marotz 1996). Historically, cooler discharges from Hungry Horse Dam lowered primary productivity and had cascading effects on cutthroat/bull trout growth rates, and lake trout predation. The current operation provides enhanced primary production and reduces the likelihood of lake trout predation on native cutthroat and bull trout. As presented in the Hungry Horse Selective Withdrawal System Evaluation Report (Reclamation 2006), temperatures between 50°F and 59°F (10°C and 15°C) are optimal for trout growth and the SWS has been successful in maintaining these optimum water temperatures during the summer months. The report notes how temperature (epilimnion thickness and thermocline strength) in the reservoir is relatively uniform from year to year, despite drastically different hydrologic conditions. However, during winter and spring months, the reservoir is nearly isothermal, making selective withdrawal operations ineffective. Under the No Action Alternative, it is likely that these conditions would continue.

3.1.1.2 Albeni Falls Dam and Reservoir

Although Lake Pend Oreille strongly stratifies in the summer, water temperatures downstream in the Pend Oreille River are generally more uniform and warmer because of the naturally shallow low water channel properties in the transitional reach from the lake to the river. A shallow low water channel acts as a barrier to the transport of much colder subsurface water from Lake Pend Oreille into the Pend Oreille River. Lake surface waters pass through Albeni Falls Dam followed by a series of non-Federal and Canadian projects downstream. A water temperature TMDL has been established for the Pend Oreille River from Lake Pend Oreille downstream to the U.S.-Canada border.

Water temperatures at Albeni Falls Dam forebay and tailwater under the No Action Alternative were modeled for the years 2004 to 2006 using W2.

Figure 3-2 shows the modeled temperatures using the ResSim flow datasets. As shown, there is little difference between predicted forebay and tailwater temperatures. It is expected that there would be little change in temperatures at Albeni Falls Dam under the No Action Alternative.

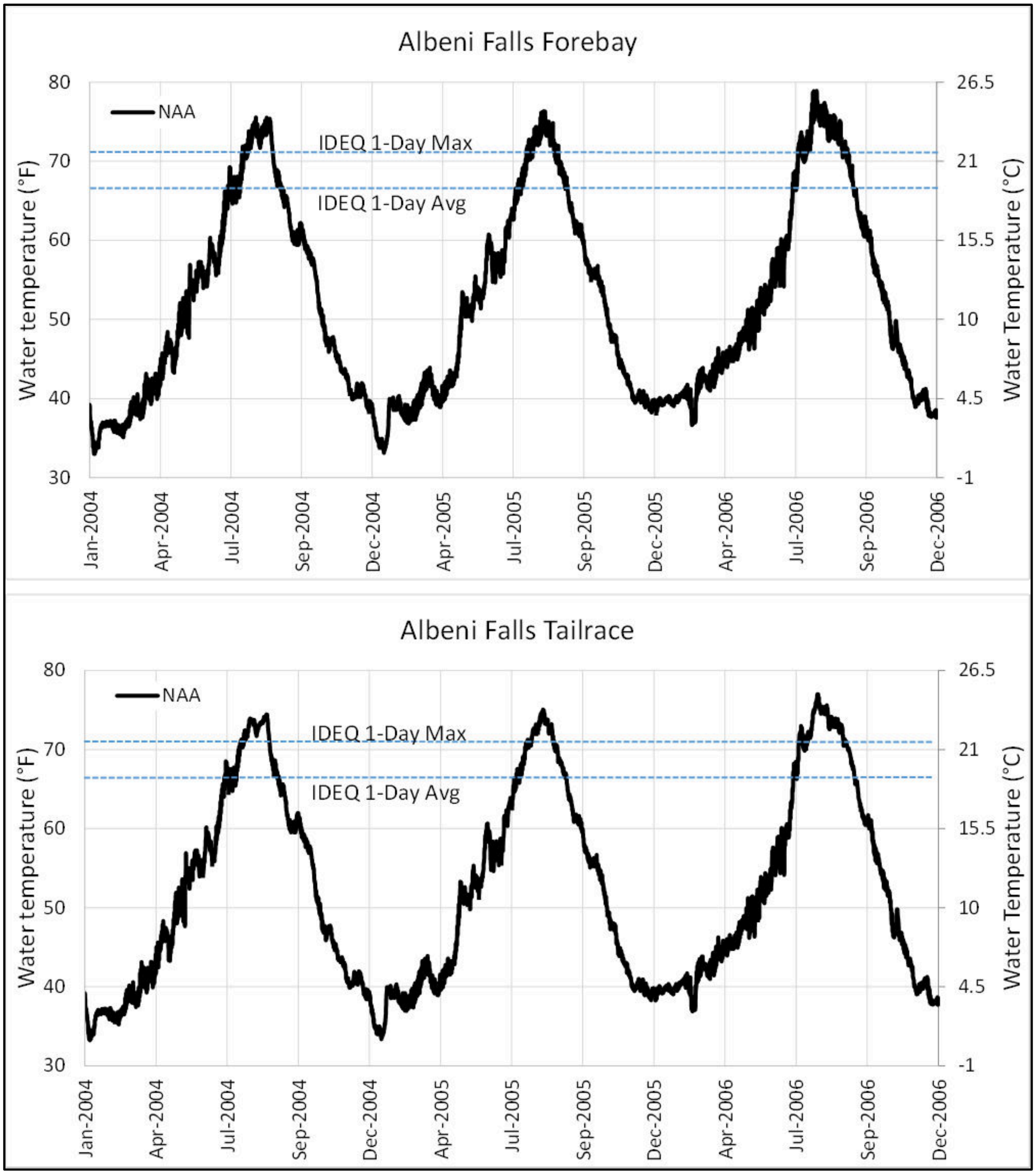


Figure 3-2. Modeled Water Temperature for the No Action Alternative at Albeni Falls Dam Forebay and Tailwater Under a 3-Year Range of River and Meteorological Conditions

3.1.1.3 Grand Coulee and Chief Joseph Dams and Reservoirs

Lake Roosevelt undergoes weak and shallow thermal stratification during late spring and early summer but is completely mixed (isothermal) part of the time (weakly stratified reservoirs are subject to periodic mixing, followed by restratification throughout the summer). Lake Rufus

Woods does not stratify due to the shallow character of the channel behind the dam, and the short residence time of water passing through this reach of river. Expected operations under the No Action Alternative would provide little opportunity for downstream water temperature management due to the weak to no thermal stratification observed in both reservoirs.

Grand Coulee Dam outflow water temperature has a temporal lag behind the warming/cooling trends observed at the U.S.-Canada border, representing the inflow to Lake Roosevelt. In general, water temperatures released from Grand Coulee tend to be cooler than reservoir inflows throughout much of the spring and early summer, and warmer in late summer/fall. Because Lake Rufus Woods does not stratify and has a residence time of about 4 days, it passes on the lagged water temperatures created by Lake Roosevelt.

The No Action Alternative was modeled for a 5-year period using W2 and river and reservoir operations data from ResSim. Figure 3-3 shows that daily maximum water temperatures downstream of Grand Coulee Dam generally range from about 36°F (2°C) in early February and peak around 68°F (20°C) in August. Lake Roosevelt is listed as impaired for temperature on the Washington State 303(d) list.

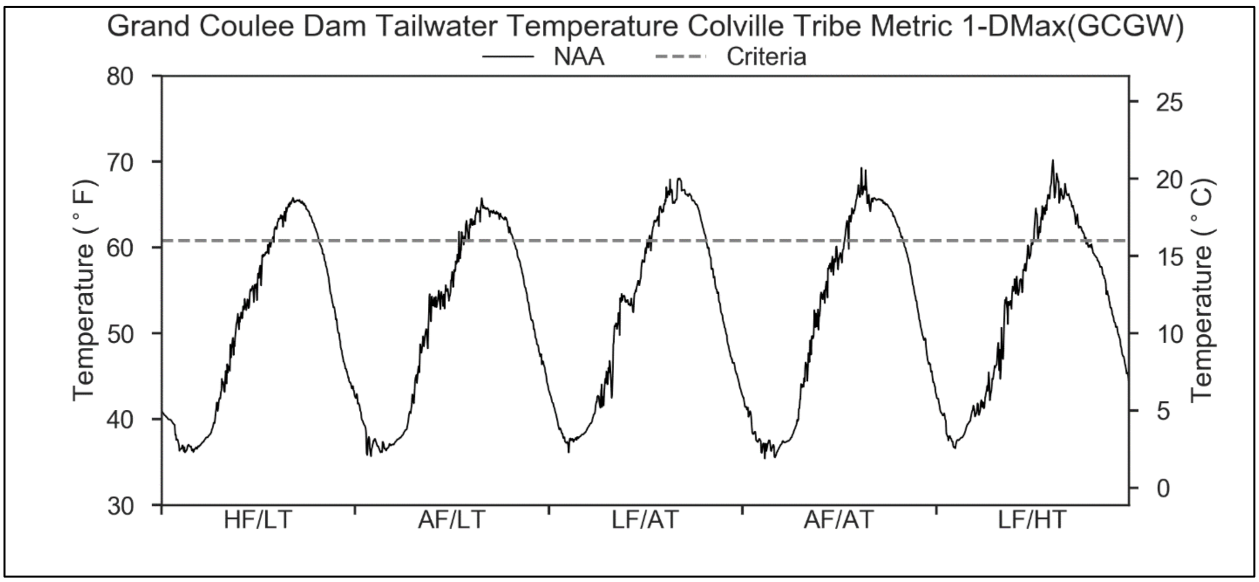


Figure 3-3. Modeled Tailwater Temperature for the No Action Alternative at Grand Coulee Dam Under a 5-year Range of River and Meteorological Conditions

Observed water temperatures measured immediately downstream of Chief Joseph Dam at tailwater station CHQW are generally greater than the Washington State standard of 63.5°F (17.5°C) as measured by the 7-day average of the daily maximum temperature from about the beginning of August through the end of September. Columbia River water temperatures under the No Action Alternative were modeled for the period 2011 to 2015 using the CE-QUAL W2 model which has been described in Section 2.2.1. This 5-year period was representative of a wide variety of flow and air temperature conditions, including HF/LT, AF/LT, LF/AT, AF/AT, and LF/HT.

Modeled temperatures under the No Action Alternative at Chief Joseph Dam tailwater are similar to what has been described under the Affected. There is little difference in temperature between Grand Coulee Dam (Figure 3-3) and Chief Joseph Dam (Figure 3-4) showing that water temperatures released from Lake Roosevelt are passed through Rufus Woods Lake and downstream of Chief Joseph Dam. In general water temperatures were greatest in the LF/HT year and lowest in the HF/LT year. Most of the temperature violations occur during low flow years and, specifically, in August and September (Table 3-1). Temperature conditions modeled for the No Action Alternative at Chief Joseph Dam tailwater, under a wide range of flow and air temperature conditions, are expected to be similar for the next 25 years.

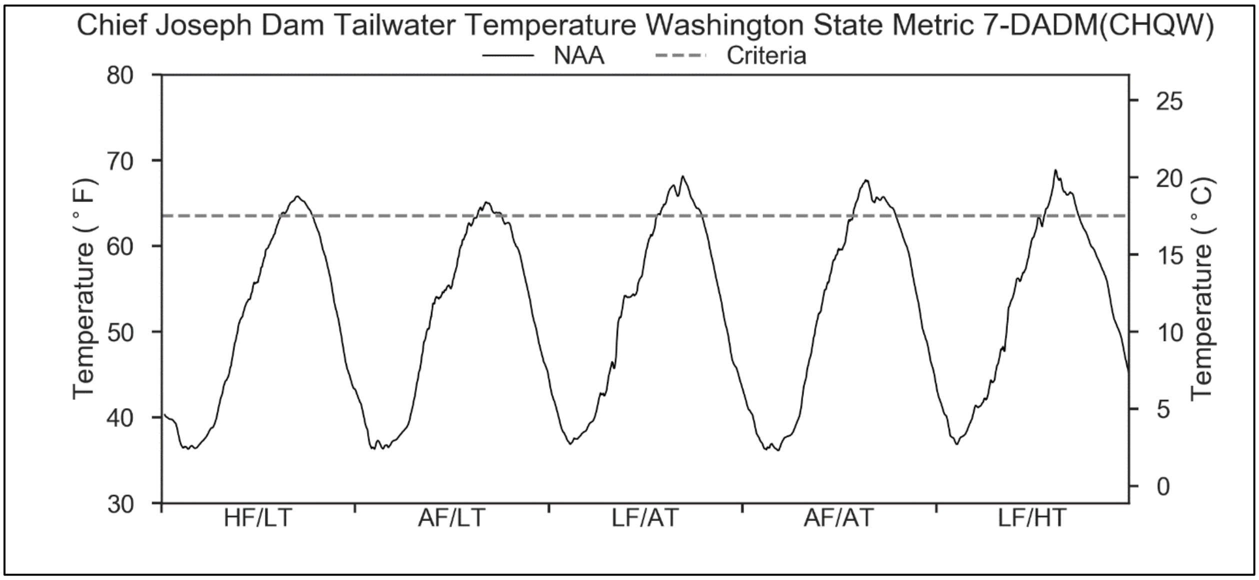


Figure 3-4. Modeled Tailwater Temperature for the No Action Alternative at Chief Joseph Dam Under a 5-Year Range of River and Meteorological Conditions

Table 3-1. Number of Days the Temperature Standard is Exceeded at Grand Coulee and Chief Joseph Tailwater Sites Under a 5-Year Range of River and Meteorological Conditions

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Grand Coulee	June	0	0	0	0	0
Grand Coulee	July	2	10	21	18	29
Grand Coulee	August	30	29	31	31	31
Grand Coulee	September	30	30	30	30	30
Grand Coulee	October	24	25	24	30	10
Chief Joseph	July	0	0	8	4	8
Chief Joseph	August	17	13	31	31	31
Chief Joseph	September	30	30	30	30	27
Chief Joseph	October	12	3	16	17	0

3.1.2 Total Dissolved Gas

TDG saturations in rivers are increased when dams release water through spillways and other non-turbine outlets. Spilling water at a dam results in increased TDG levels in downstream waters by plunging the aerated spill water to depths where hydrostatic pressure increases the solubility of atmospheric gases. Elevated TDG saturations, above the state water quality standard of 110% saturation, generated by spill releases from dams are of concern because high saturations can promote the potential for gas bubble trauma in downstream aquatic biota (Weitkamp and Katz 1980; Weitkamp et al. 2002).

3.1.2.1 Libby and Hungry Horse Dams and Reservoirs

Libby and Hungry Horse Dams are both high head dams that tend to generate TDG even when small discharges are released through their non-turbine outlets. Spill discharges at Libby are infrequent because Libby is managed to avoid spilling. Given this, TDG exceedances are not as commonly seen as in other parts of the CRSO study area. Spill discharges happen more frequently at Hungry Horse Dam as compared to Libby Dam. TDG during these spill events, which are often of short duration, rarely exceeds 110 percent.

A detailed TDG study at Libby Dam was conducted in 2002 (Schneider 2003). This investigation determined the TDG exchange in spillway flows ranged from 104 to 134 percent saturation and was a direct function of spillway discharge. The TDG saturation in spillway releases, as measured immediately below the stilling basin, increased as an exponential function of the spillway discharge, and increased abruptly from 104 to 129 percent saturation as spill discharges increased from 700 to 3,900 cfs. A mild increase in TDG saturations from 129 to 134 percent was observed as spillway discharges increased from about 3,900 to 15,500 cfs. The passage of water through the powerhouse did not change the TDG saturations in the Kootenai River, and TDG pressures in powerhouse releases measured during the test ranged from 102 to 104 percent.

The TDG characteristics in the Kootenai River below Libby Dam are dominated by the development of a mixing zone between spillway and powerhouse releases and in-river processes such as degassing at the air/water interface, lateral mixing, and thermal heat exchange. The rapid development of a mixing zone and in-river processes, results in decreasing TDG saturations in the Kootenai River downstream of the dam. TDG saturations in the Kootenai River are generally well mixed by about 8.7 miles (14 kilometers) downstream (Schneider 2003).

Historical data shows that Libby Dam spills infrequently. No Action Alternative ResSim modeled flows for the 80-year period from 1928 to 2008 are presented in Figure 3-5. The ResSim model predicts only two years with spill for the 80 year period. However, since the dam became operational in 1975, Libby Dam has experienced forced spill in 5 out of 44 years. The ResSim model appears to under predict the amount of spill at Libby Dam. Such differences are likely due to ResSim using different operational and forecasting procedures than previously used at Libby which have resulted in reduced spill in the modeling runs. Regardless, the frequency of spills from Libby Dam are not anticipated to change under the No Action Alternative.

TDG downstream of Hungry Horse Dam has been a concern in the past. TDG often does not meet the Montana state standard of 110 percent below the dam in high water years when inflows exceed the available storage and/or power generation capacity at the dam. Model results are presented in Figure 3-6. The figure summarizes spill and TDG from Hungry Horse Dam over the 80-year record under the No Action Alternative. The figure has three panels. The bottom panel shows the number of days, in each year modeled, that exceeded 110 percent TDG. This ranges between 0 to 57 days—with an average of about 3 weeks. Total discharge and corresponding expected TDG are shown in the middle and top panels, respectively. TDG in the river below the dam occurred in only the highest water years for durations of generally less than 3 weeks. TDG above 116 percent occurred 147 times over the 80-year period and never exceeded 120 percent.

Although the results presented in Figure 3-6 are realistic, they likely overestimate the amount of TDG that would actually occur in the South Fork of the Flathead River below the dam. The modeled results follow current water management plan rules and do not account for adaptive management. Adaptive management allows water managers to deviate from the water management rules by adjusting reservoir drafts (e.g., drafting deeper) in anticipation of potential high inflows or restricted outflows from the reservoir that would have otherwise required higher spill and TDG, had additional space in the reservoir not been created (Appendix O).

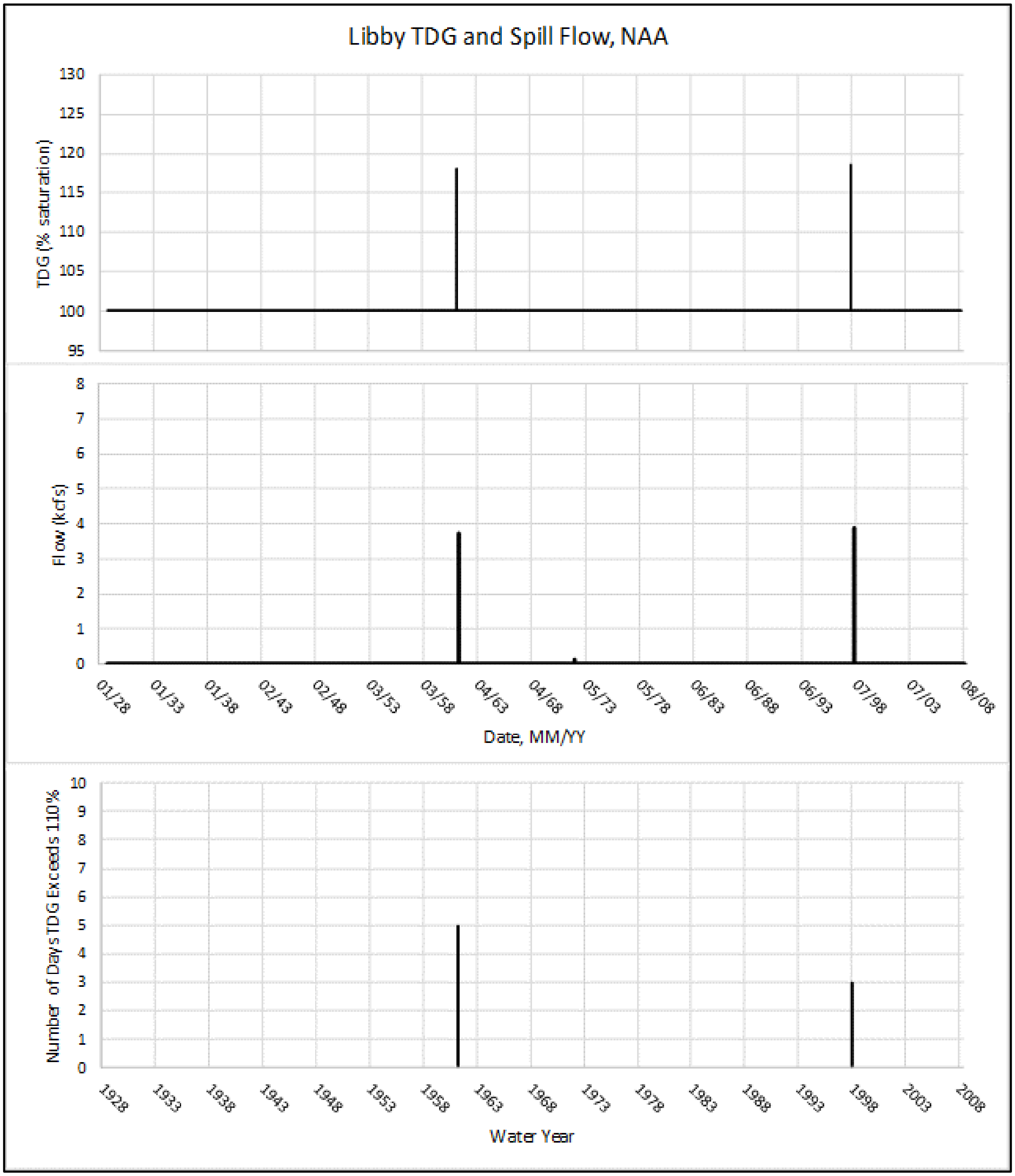


Figure 3-5. ResSim Modeled Spillway Flows and Number of Days Exceeding 110 Percent at Libby Dam for the 80-Year Period from 1928 to 2008

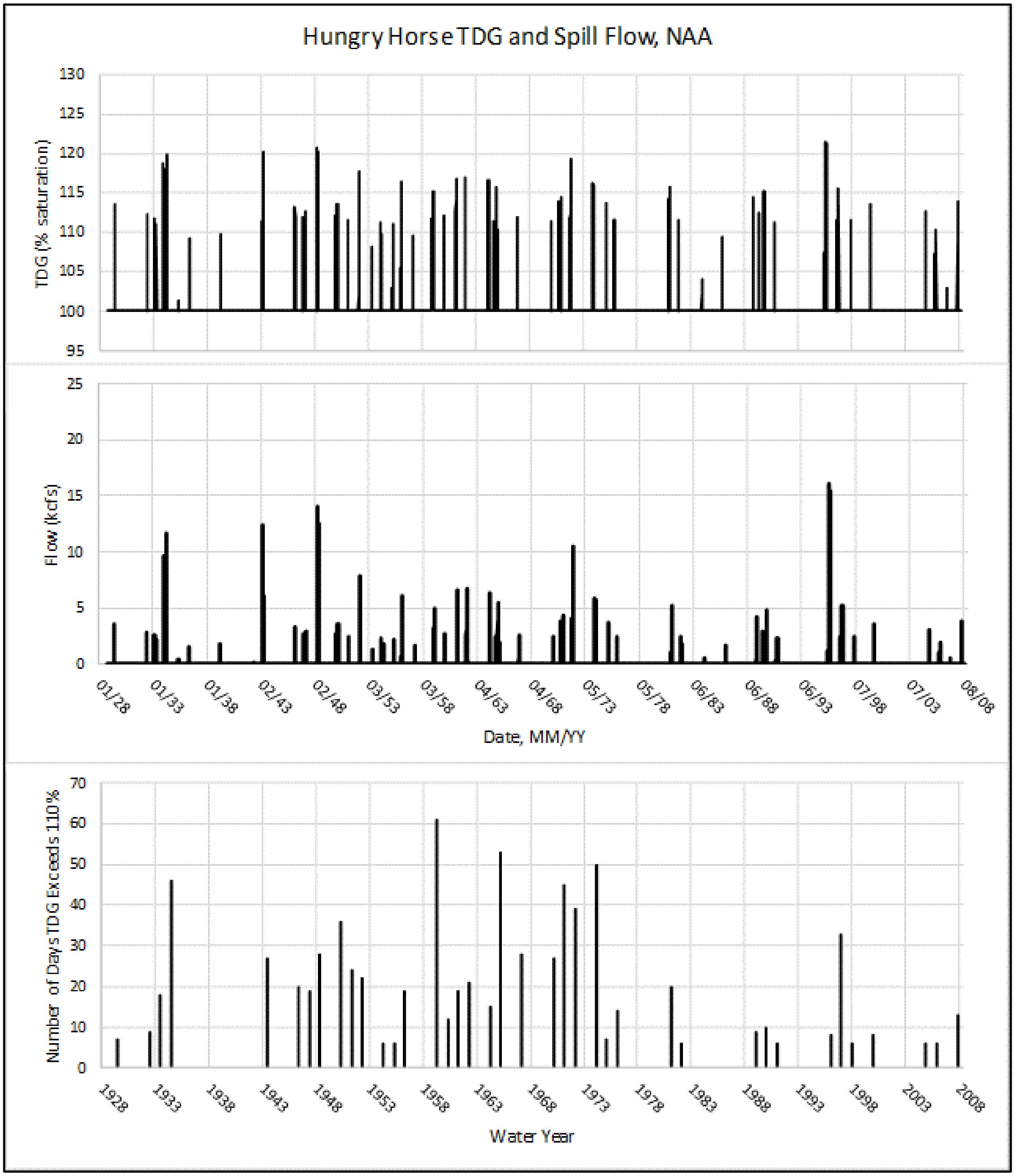


Figure 3-6. ResSim Modeled Spillway Flows and Number of Days Exceeding 110 Percent at Hungry Horse Dam for the 80-Year Period from 1928 to 2008

3.1.2.2 Albeni Falls Dam and Reservoir

TDG production at Albeni Falls Dam is addressed qualitatively, because past studies indicate a lack of consistent empirical relationship between spillway discharge and TDG (Schneider et al. 2007). The elevated TDG pressures observed below the spillway prior to dilution from powerhouse flows, are a function of the initial forebay TDG pressure, spill pattern, total project head, aerated depth of flow below the spillway, and downstream submergence of the spill gate lip. The lack of a direct empirical relationship between spill discharge and TDG production is attributed to the dam's low head, shallow stilling basin channel depth, wide spillway configuration, and the submergence of the spill gates. The TDG exchange associated with spillway operation at Albeni Falls Dam is best described by determining the increase in TDG pressure above the forebay levels (Schneider et al. 2007).

During high flow spring runoff periods, TDG in the Pend Oreille River upstream of Albeni Falls dam can be greater than 110 percent largely because of spillway releases from Cabinet Gorge Dam located on the Clark Fork River about 55 miles (88.5 kilometers) upstream of Albeni Falls Dam. In general, when spill is spread evenly across the spillway, spillway discharges up to about 10 kcfs can increase TDG saturations over forebay levels by about 1 to 2 percent. Spillway discharges between about 10,000 to 50,000 cfs can increase TDG saturations by about 5 to 9 percent below Albeni Falls Dam. However, when flows in the Pend Oreille River exceed about 50,000 to 60,000 cfs, the Albeni Falls Dam powerhouse operations are suspended and the spillway gates are raised, allowing the river to flow relatively un-impounded across the dam. Under these highflow conditions, Albeni Falls Dam produces no TDG as the river is essentially free flowing.

Spillway flows at Albeni Falls Dam were modeled under the No Action Alternative for the 80-year period from 1928 to 2008 using the ResSim model (Figure 3-7). In general, spillway flows were predicted to range between 1 and 50 kcfs in nearly every year at Albeni Falls Dam, with many years having spill exceed about 60 kcfs resulting in free-flowing conditions. These spillway conditions are similar to historical ones, and are not expected to change under the No Action Alternative.

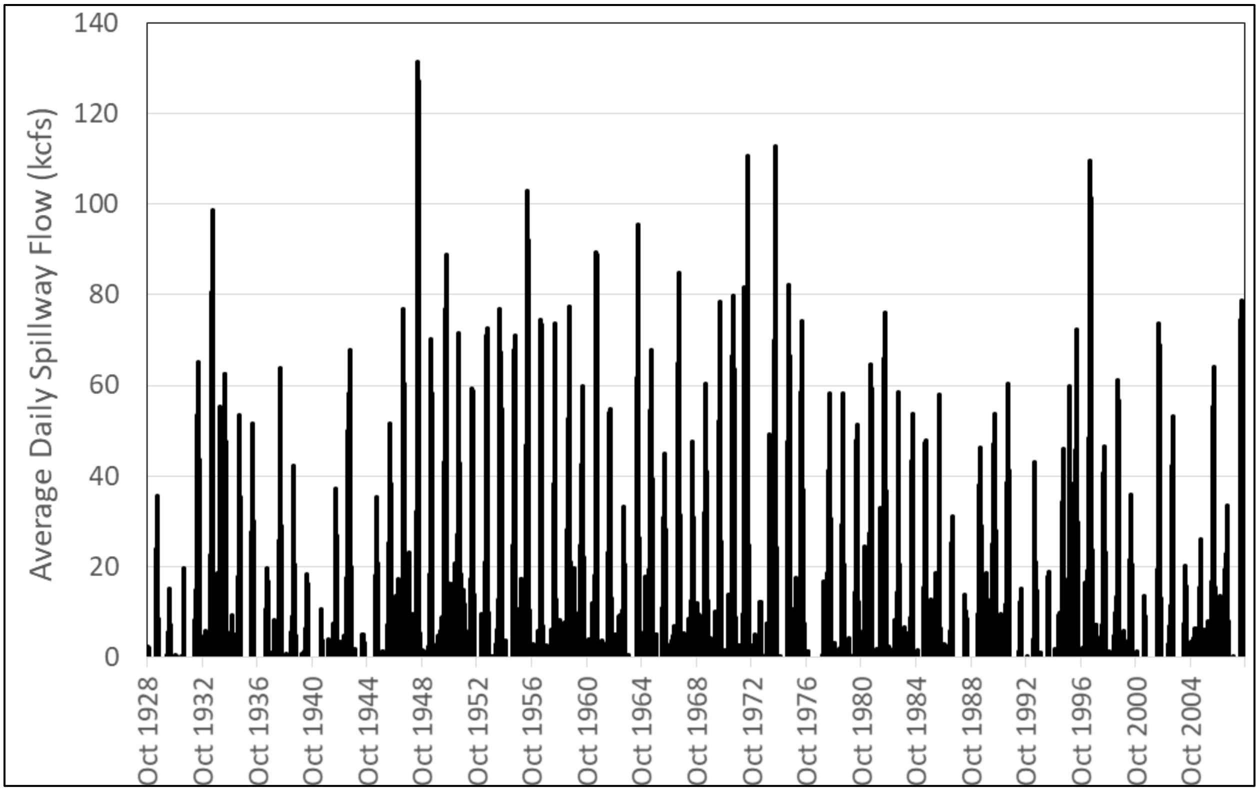


Figure 3-7. ResSim Spillway Flows Modeled at Albeni Falls Dam for the 80-Year Period from 1928 to 2008

3.1.2.3 Grand Coulee and Chief Joseph Dams and Reservoirs

The outlet tubes, and to a lesser extent the drum gates, at Grand Coulee Dam are known to produce elevated TDG when in operation. When reservoir elevations are greater than 1,266 feet above mean sea level (amsl), the 11 drum gates can be used to discharge water downstream. The drum gates generate much less TDG than the outlet tubes, and are the preferred outlet when available. The 40 regulating outlets are used to discharge water downstream when forebay elevation is below 1,266 feet, at which point the drum gates become inoperable. The 40 regulating outlets are configured in two distinct rows along the face of the dam: 20 regulating outlet tubes are located at 1,050 feet amsl and 20 regulating outlet tubes are located at 1,150 feet amsl. Operating the outlet tubes in a specific spill pattern, referred to as an overunder configuration, is currently employed to reduce the concentration of TDG produced by the outlet tubes. This operational measure can result in less TDG production in the river below.

TDG was modeled under the No Action Alternative to predict conditions above Grand Coulee Dam in the forebay and directly below the dam in the tailwater (Figure 3-8) using W2. Both figures show daily average TDG conditions over a 5-year period that vary in flow and climatic conditions. Results from No Action Alternative modeling show that TDG concentrations are lowest in winter and highest in late spring and early summer when spill is highest (June/July). Early summer spill generally occurs when water must be evacuated from the reservoir to maintain flood control space and/or when required discharge does not meet turbine capacity. Under the No Action Alternative, there is generally a shift in the timing of elevated TDG concentration to earlier in the water year under high flow water years. This is because space must be made in the reservoir to capture high spring runoff for flood control. The additional drawdown often requires large amounts of water to be passed through the dam in a short amount of time. As the forebay is drawn down below the elevation of 1,266 feet AMSL, drum gates become unusable and all water is discharged through turbines or spilled through the dam's regulating outlet works, which produce the greatest amount of TDG. Additionally, in high water years, elevated TDG levels in Lake Roosevelt due to the influence of upstream dams (that fall outside the scope of this EIS) are expected. The No Action Alternative model predicts that, under such operations, average daily forebay TDG concentrations will continue to range between 92 and 121 percent annually; TDG below the dam is expected to range between 94 and 130 percent. Realtime constraints and conditions, could result in TDG in excess of 130 percent when TDG is high in the forebay and large amounts of spill are required. Both Lake Roosevelt and the Columbia River below the Grand Coulee Dam are listed on the Washington State 303(d) list for TDG impairment.

TDG supersaturation is generated in the Columbia River during spillway flows at Chief Joseph Dam. Flow deflectors were added to all 19 spillbays in 2009. These deflectors are designed to reduce plunging flow from a spillway and create a skimming flow, thereby reducing the TDG saturations downstream. A detailed investigation of pre-deflector TDG exchange was conducted at Chief Joseph Dam in 1999 and an investigation of post-deflector TDG exchange was conducted in 2009 (Schneider and Carroll 1999; Schneider 2012). The pre-deflector study determined that TDG saturations in spillway flows ranged from about 111 to 134 percent and were an exponential function of spillway discharge, weakly related to tailwater depth of flow, and with little powerhouse entrainment. A post-deflector TDG study was conducted at Chief Joseph Dam in 2009 to determine TDG exchange characteristics for Chief Joseph Dam with deflectors. Results showed that TDG saturations during spillway operations with deflectors were greatly reduced compared to non-deflector operations, with measured TDG saturations ranging from about 110 to 120 percent during the study (Schneider 2012). TDG saturations were lowest for uniform spillway conditions and influenced by tailwater depth, with deeper tailwater resulting in greater TDG saturations. When forebay TDG saturations are greater than about 120 percent, spill over the deflectors at Chief Joseph Dam has been shown to degas the high incoming TDG to saturations less than 120 percent.

TDG at the forebay of Chief Joseph Dam is largely a function of the TDG saturations produced upstream from Lake Roosevelt and Grand Coulee Dam, because little degassing occurs in Rufus Woods Lake. High spill volumes via the outlet tubes at Grand Coulee Dam can increase TDG saturations in Rufus Woods Lake at the Chief Joseph Dam forebay to over 130 percent, especially when inflows entering Lake Roosevelt are already at elevated TDG levels. During periods of high TDG entering and exiting Lake Roosevelt, discharge of water over the Chief Joseph Dam spillway deflectors can degas supersaturated conditions generated upstream. Spilling at Chief Joseph Dam when incoming TDG levels are above approximately 120 percent can reduce downstream system TDG loading, therefore Chief Joseph Dam is often used to help manage overall system TDG production in the mainstem Columbia. In addition, to avoid spilling through the outlet tubes at Grand Coulee Dam, spill is often shifted from Grand Coulee Dam to Chief Joseph Dam to take advantage of the lower TDG produced by spilling over the deflectors. These operational strategies are expected to continue under the No Action Alternative.

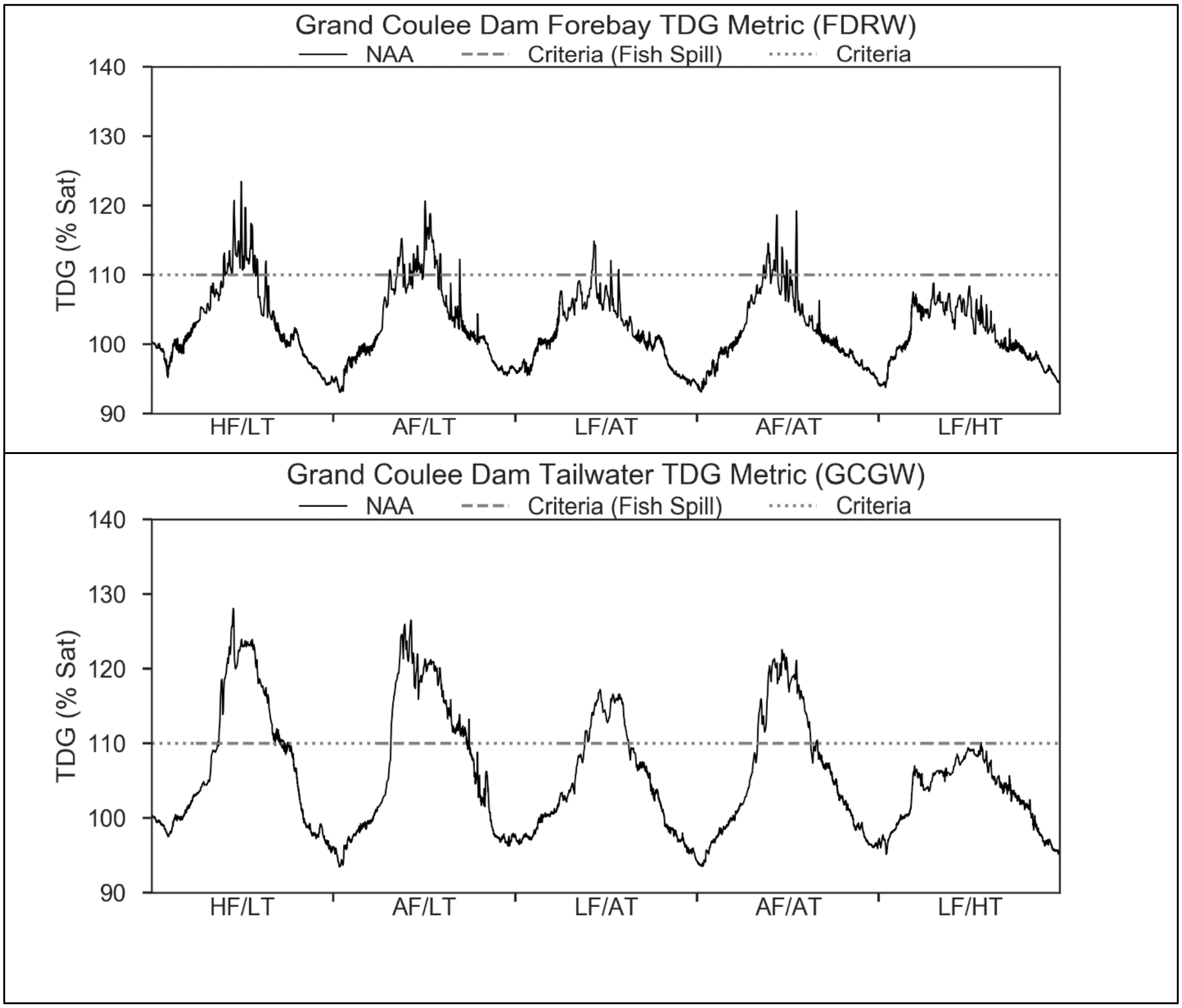


Figure 3-8. Modeled Total Dissolved Gas, in Percent Saturation, for the No Action Alternative Above and Below Grand Coulee Dam Under a 5-Year Range of River and Meteorological Conditions

Chief Joseph Dam TDG saturations at the forebay and tailwater were modeled under the No Action Alternative using flows from the ResSim model (Figure 3-9). Predicted forebay and tailwater TDG levels show that the greatest TDG saturations occurred during HF/LT year and the lowest TDG saturations during the LF/HT year.

Under the No Action Alternative, the model predicts a decrease in TDG saturations between the forebay and tailwater at Chief Joseph during high flow and high spill years. This decrease in tailwater TDG saturations, when the forebay TDG is elevated, is due to the spillway deflectors at

Chief Joseph Dam, and is similar to historical conditions monitored at the dam. It is expected that under the No Action Alternative, Chief Joseph Dam will continue to decrease TDG during high flow years when elevated TDG saturations occur in the forebay. In addition, spilling at Chief Joseph Dam when forebay TDG saturations are low, will continue to generate elevated saturations up to about 120 percent downstream of the dam. Table 3-2 and Table 3-3 show that the under the No Action Alternative, the TDG criteria is exceeded quite often, especially during May through August.

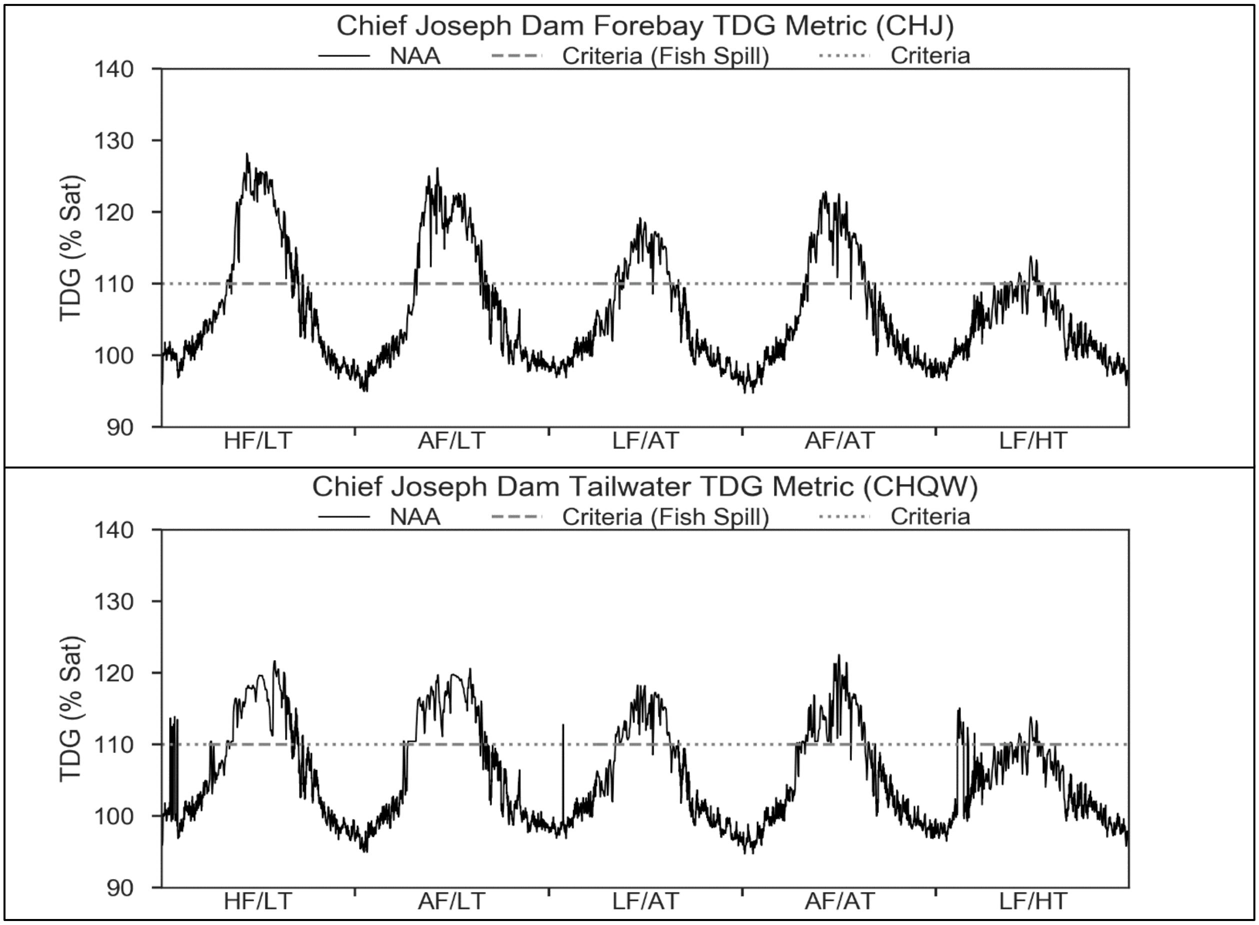


Figure 3-9. Modeled Total Dissolved Gas, in Percent Saturation, for the No Action Alternative Above and Below Chief Joseph Dam Under a 5-Year Range of River and Meteorological Conditions

Table 3-2. Number of Days the Total Dissolved Gas Standard is Exceeded at Grand Coulee and Chief Joseph Forebay Sites Under a 5-Year Range of River and Meteorological Conditions

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Grand Coulee	April	0	0	0	0	0
Grand Coulee	May	2	11	0	10	0
Grand Coulee	June	29	15	4	15	0
Grand Coulee	July	31	29	0	0	0
Grand Coulee	August	2	0	0	0	0

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Chief Joseph	April	0	6	0	1	0
Chief Joseph	May	25	31	20	30	6
Chief Joseph	June	30	30	30	30	13
Chief Joseph	July	31	31	30	30	13
Chief Joseph	August	31	28	18	22	0
Chief Joseph	September	12	1	0	0	0

Table 3-3. Number of Days the Total Dissolved Gas Standard is Exceeded at Grand Coulee and Chief Joseph Tailwater Sites Under a 5-Year Range of River and Meteorological Conditions

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Grand Coulee	April	0	5	0	0	0
Grand Coulee	May	17	31	11	29	0
Grand Coulee	June	30	30	30	30	0
Grand Coulee	July	31	31	31	31	1
Grand Coulee	August	31	31	16	20	0
Grand Coulee	September	18	27	0	0	0
Grand Coulee	October	1	0	0	0	0
Chief Joseph	January	7	0	1	0	0
Chief Joseph	February	0	0	0	0	12
Chief Joseph	March	0	0	0	0	2
Chief Joseph	April	3	23	0	11	0
Chief Joseph	May	26	31	25	31	6
Chief Joseph	June	30	30	30	30	13
Chief Joseph	July	31	31	30	30	13

3.1.3 Other Physical, Chemical, and Biological Processes

Watershed land use can significantly affect surface water quality. Urban runoff, agriculture, mining, atmospheric deposition of pollutants, and industry can pollute rivers and streams, creating an unhealthy environment for fish and other aquatic biota. Past impacts from human activity in the upper Columbia River Basin include contamination, and increased sediment and nutrient loading from mining activities, and are expected to continue to impact future water quality.

3.1.3.1 Libby and Hungry Horse Dams and Reservoirs

Lake Koocanusa is classified as an oligotrophic to lower mesotrophic waterbody based on summer concentrations of total phosphorus, chlorophyll a, and transparency. The reservoir experiences weak thermal stratification, and is well oxygenated throughout the entire water column, although lower dissolved oxygen concentrations (4 to 6 milligrams per liter [mg/L]) periodically occur near the water bottom in a shallow reach near the U.S.-Canada border.

Total phosphorus concentrations in Lake Koocanusa are low and increase during spring runoff, then decrease during the summer and fall. Total phosphorus concentrations are typically two to five times greater at the U.S.-Canada border than near Libby Dam, suggesting that Lake Koocanusa is a phosphorus sink. Low annual total phosphorus concentrations downstream in the Kootenai River further support this conclusion.

Concentrations of nitrate have been increasing at all stations in Lake Koocanusa since the early 2000s. Median nitrate concentrations in the epilimnion and hypolimnion increased between two-fold and three-fold from 2006 to 2016. Concentrations are only slightly greater at the U.S.-Canada border compared to near Libby Dam, suggesting that nitrate is moving through the reservoir. The major change in the Lake Koocanusa watershed over the past 20 years is an increase in coal mining operations in the Elk and Fording River watersheds in British Columbia, and a corresponding increase in nitrate loading from the waste spoils runoff. The estimated amount of waste spoils from coal mining operations increased ten-fold from 1997 to 2016.

Despite rising nitrate concentrations in both hypolimnetic and epilimnetic waters, algal blooms (measured as chlorophyll a) appear to have been kept in check by strong phosphorus limitation, as indicated by low phosphorus concentrations and high total nitrogen to total phosphorus(TN:TP) ratios at all stations in Lake Koocanusa. However, these conditions also indicate that the lake could be susceptible to increased algal blooms, including blooms dominated by nuisance species, if phosphorus loading increases significantly in the future. Such increases could come from changes in upstream land uses that result in soil erosion, or additional waste inputs.

The USGS has estimated that increased coal mining in the Elk and Fording Rivers has increased selenium loading to Lake Koocanusa fivefold over the past 20 years. There does not appear to be a substantial seasonal trend in water column selenium data, but concentrations were generally higher in the spring and fall, and lower in the summer at all stations. Median selenium concentrations in the epilimnion and hypolimnion at the border (1.0 and 1.1 micrograms per liter [µg/L], respectively) were slightly greater than at the forebay (0.8 and 1.03 µg/L, respectively).

Lake Koocanusa water column phytoplankton populations were dominated by a wide mixture of diatoms, cryptophytes, and chrysophytes at all stations from 2008 to 2013 and by select diatoms and chrysophytes from 2014 to 2016. A substantial increase in phytoplankton biovolume and density was measured at all stations from 2014 to 2016. Although biovolumes were high from 2014 through 2016, species diversity was relatively low with often only one or two dominant phytoplankton species. From 2014 to 2016, the phytoplankton assemblage was largely dominated by a few diatoms (*Cyclotella* spp., *Fragilaria* spp., and *Synedra* spp.) and the chrysophyte, *Dinobryon* spp. The large increase in phytoplankton biovolume and density from 2014 to 2016 may be partly due to the increased nitrogen loadings and the relatively stable loadings of phosphorus, resulting in extremely high nitrogen to phosphorus ratios. Additionally, the changes in species diversity and composition measured since 2014 may also be due to the increased nitrogen loadings to Lake Koocanusa.

The composition of zooplankton in Lake Koocanusa has shown seasonal and annual differences. Zooplankton densities from 2006 through 2010 were dominated by copepods, which accounted for about 40 to 90 percent of the total density depending on the month. However, from 2011 to 2014 rotifers have dominated the Lake Koocanusa zooplankton population accounting for about 40 to nearly 100 percent of the total density depending on the month. In general, rotifers were dominated by *Keretella* spp., *Kellicottia longispina*, and *Polyarthra* spp.; copepods were dominated by *Nauplii* and *Diacyclops* spp.; while cladocerans were dominated by *Daphnia* spp. and *Bosmina longirostris*.

Over the next 25 years, it is expected that mining, such as the coal production in the Kootenai River watershed above Libby Dam, may continue as it has over the past 20 years (https://www.nwd.usace.army.mil/CRSO/Documents/). It is possible that without water quality treatment, the increased coal mining may lead to additional selenium contamination and nitrate loading into Lake Koocanusa. Increased selenium loading may impact fish and wildlife species in the Lake Koocanusa area. In addition, increased nitrate concentrations may alter the phytoplankton and zooplankton density and dominant species, possibly resulting in impacts to the local fishery.

Hungry Horse Reservoir has no known water quality issues. The reservoir is an oligotrophic waterbody with high water quality. It is located high in the watershed. Only a few processes are likely to influence water quality with respect to nutrients and/or sediment: forestry operations, road building, natural disasters (e.g., forest fires) and atmospheric deposition. Water quality and associated processes are expected to remain unchanged under the No Action Alternative.

3.1.3.2 Albeni Falls Dam and Reservoir

Lake Pend Oreille is the largest and deepest lake in Idaho and the fifth deepest lake in the United States. In general, summer total phosphorus concentrations are low, water clarity is high, and algal growth (as determined by chlorophyll a concentrations) is moderate. Lake Pend Oreille would be classified as oligotrophic based on summer concentrations of these parameters, and oligotrophic/mesotrophic based on annual concentrations. Solar heating is sufficient to develop thermal stratification and a thermocline in the deeper regions of the lake during the spring and summer months. However, a shallow, low water outlet channel acts as a barrier to the transport of cold subsurface water from the deeper regions of Lake Pend Oreille into the Pend Oreille River. In general, both the lake and river are well oxygenated throughout the entire water column.

Pend Oreille River pH values measured at the forebay of Albeni Falls Dam are occasionally greater than the downstream State of Washington standard of 8.5. These elevated pH values are uniformly distributed in the water column and are likely the result of photosynthetic activity. In general, concentrations of dissolved metals in Lake Pend Oreille and the Pend Oreille River are near or below the laboratory detection limits, with the exception of aluminum, and periodic detections of copper and zinc.

Total phosphorus concentrations in Lake Pend Oreille and the Pend Oreille River are low, and follow a similar seasonal pattern of increasing during spring runoff and decreasing during the summer and fall. In general, total phosphorus concentrations are greatest at the inflow and slightly reduced in the lake and downstream river. This slight reduction in total phosphorus from the inflow, to the lake, to the downstream river, indicates that Lake Pend Oreille is retaining some total phosphorus. Summer nearshore nutrient concentrations were similar to epilimnetic concentrations measured in Lake Pend Oreille. An increase in total nitrogen and concurrent decrease in total phosphorus has been measured in the lake since 2014. The TN:TP ratio suggests that phosphorus is the limiting nutrient in the Pend Oreille system.

Lake Pend Oreille water column phytoplankton populations were dominated by a mixture of diatoms, cryptophytes, and chrysophytes from 2005 to 2014, with few cyanobacteria detected. However, from 2015 to 2016, phytoplankton was largely dominated by a few diatoms (*Cyclotella spp.*, and *Fragilaria spp.*), cyanobacteria (*Aphanocapsa* spp., *Aphanothece* spp., and *Planktolyngbya* spp.), and the chrysophyte, *Dinobryon* spp. The increase in phytoplankton biovolume and density in 2015 and 2016, together with a substantial increase in cyanobacteria, may be partly due to an increase in the TN:TP ratio in Lake Pend Oreille and the Pend Oreille River measured during this period. The cyanobacteria species that has dominated Lake Pend Oreille and the Pend Oreille River since 2015 (*Planktolyngbya* spp.) is non-heterocystous and cannot fix nitrogen.

A nearshore TMDL for nutrients was developed for Lake Pend Oreille in 2002 in response to increasing nuisance algal growth in nearshore areas. Elevated nutrients in nearshore areas is likely due to human activity (stormwater runoff, wastewater treatment, land use). It is possible that if nearshore nutrient concentrations increase, nuisance aquatic growth may further impair beneficial uses. Increased nutrient concentrations in Lake Pend Oreille and the Pend Oreille River will likely continue to be a concern under the No Action Alternative.

3.1.3.3 Grand Coulee and Chief Joseph Dams and Reservoirs

Lake Roosevelt has a total storage capacity of about 9 million acre-feet (Maf) of water; annual flows through the lake average nearly 80 Maf per year, which results in some dilution of local water pollution. Lake Roosevelt, however, is listed on the Washington State 303(d) list for dioxin impairment. A TMDL for dioxin was completed by the state in 1991 and is still in effect.

Lake Roosevelt exhibits low nitrogen, phosphorus, and chlorophyll a concentrations and high water clarity, which act collectively as proxies for primary productivity and classify Lake Roosevelt as oligotrophic. Populations of phytoplankton and zooplankton are also found in low concentrations. The notable exception to the low nutrient levels, is in the reach of reservoir where the Spokane River flows in, which is more productive due to municipal and agricultural nutrient inputs. Data suggests that phosphorous concentrations in the overall reservoir have remained relatively stable; however, primary productivity has trended slightly.

Lake Roosevelt is listed on the State of Washington 303(d) list for dissolved oxygen impairment. The Columbia River between Grand Coulee Dam and Chief Joseph Dam is also listed. Dissolved oxygen in the main portion of the reservoir is generally above the required Washington State dissolved oxygen standard of 9.5 mg/L; however, concentrations can periodically decrease below that threshold during the summer months. Dissolved oxygen where the Spokane River flows in to the reservoir, tends to be well below the standard for several months each year.

Turbidity, a measure of water clarity, in Lake Roosevelt is well below the Washington State standard. The processes that would likely increase turbidity in Lake Roosevelt are sediment additions to the waterbody through mass wasting events such as landslides and rill erosion, or wave action on unprotected shorelines. Reservoir fluctuations, which average 90 feet annually, create bank shoaling and erosion of shorelines. Increased landslides have also been correlated with past drawdowns that exceeded 1.5 feet per day (Reidel et al. 1997). Rill and wave action sedimentation and turbidity increases are highest when large vertical extents of shoreline are exposed (e.g., during periods of lower lake elevations).

Water level fluctuations may also influence mercury cycling in a waterbody. Recent studies of reservoir systems along the Snake River suggest that exposing lake sediments that contain mercury may oxidize the toxic metal and make it available to higher-order organisms (USGS 2016). These can bioaccumulate in fish and other large biota through the process of methylation in the waterbody. Additionally, the timing of elevation fluctuations may increase methylation rates. Most fish species exhibit their greatest growth rates from January to July when reservoir fluctuations generally occur. The modeled No Action Alternative water elevations are depicted in Figure 3-10.

Water temperature, dissolve oxygen concentrations, and trophic status are expected to continue as described above and not change under the No Action Alternative. Climate change effects, as described in Chapter 4, could impact future conditions.

Rufus Woods Lake is classified as oligotrophic to oligo/mesotrophic based on summer concentrations of total phosphorus, chlorophyll a, and transparency. The lake is a well oxygenated, near neutral to slightly basic pH waterbody with low to moderate nutrient concentrations. Small increases in total phosphorus and ammonia concentrations measured downstream of aquaculture facilities in Rufus Woods Lake suggest that these facilities may be a source of these nutrients. In general, Rufus Woods Lake metal concentrations are low and below the laboratory detection limit. However, periodic detections of copper at low concentrations have occurred. Water column phytoplankton populations are dominated by diatoms and cryptomonads at all stations. Very little cyanobacteria has been detected in water column phytoplankton samples. Zooplankton populations are dominated by rotifers in the spring and early summer, and by copepods in the late summer and fall.

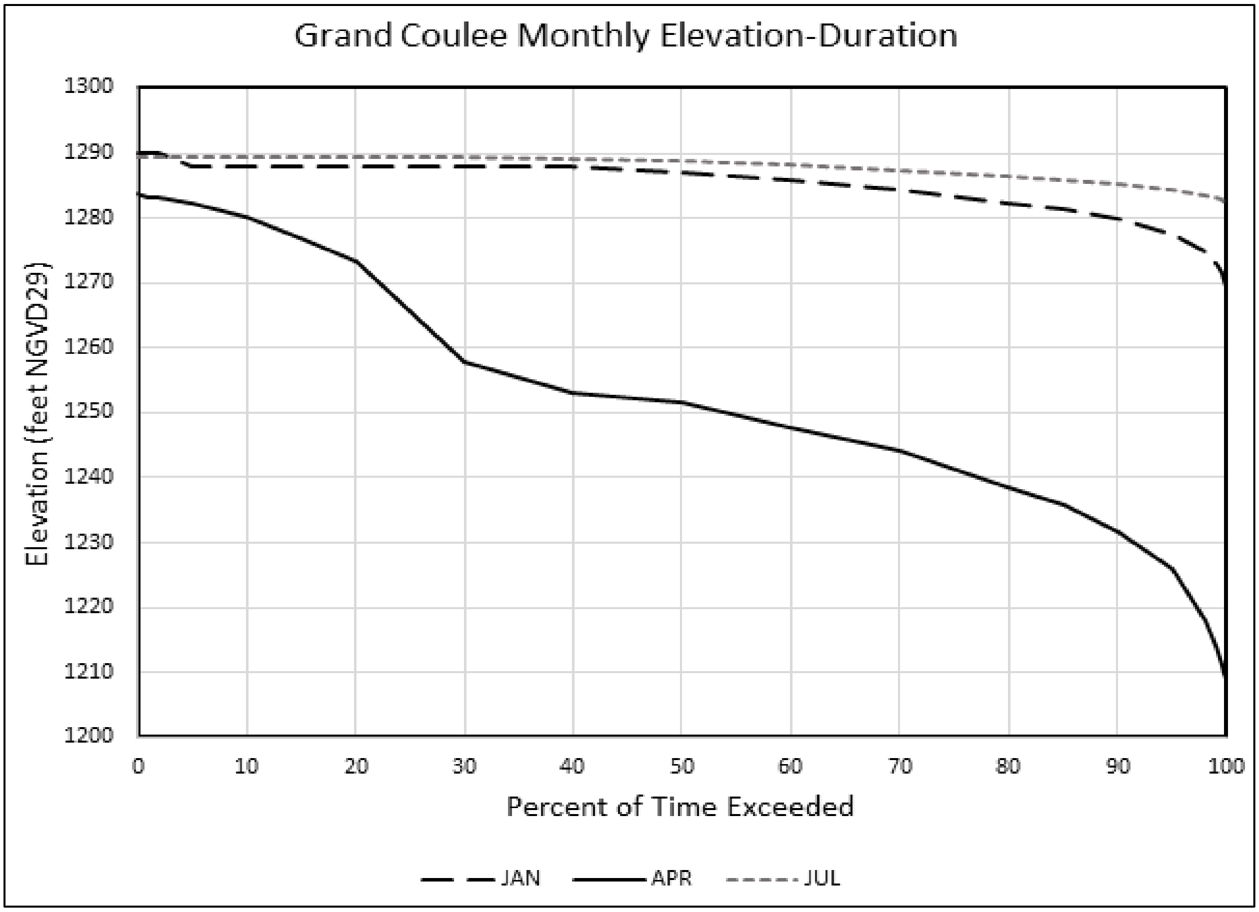


Figure 3-10. Exceedance Plot of Water Surface Elevation (feet NGVD29) for Select Months

Note: April and July are the lowest and highest water surface elevation months each year, respectively. The January exceedance plot displays the water surface elevation before drawdown occurs in the early spring. In this prediction at the 50 percent exceedance interval, the water surface elevation varies approximately 35 feet between max drawdown and max refill, the reservoir takes approximately 3 months to drawdown, and remains low for much of April and May, then takes approximately 2 months to refill. Data from ResSim results from system operations modeling.

Since 2011, Rufus Woods Lake has experienced annual harmful algae blooms characterized by floating algal surface mats and the algal toxin, anatoxin-a. The floating surface mats are dominated by diatoms and cyanobacteria, with the dominant cyanobacteria being *Oscillatoria sp.* Other cyanobacteria occasionally found in the floating mats are *Anabaena sp.* and *Aphanizomenon sp*. The presence of these harmful algae blooms upstream of aquaculture facilities, suggests that they are not attributed to these facilities. It is not known why the blooms are occurring, and based on their regular occurrence since 2011 they are expected to continue to occur annually under the No Action Alternative.

3.2 LOWER SNAKE RIVER BASIN

The lower Snake River Basin includes the North Fork Clearwater River at Dworshak Dam downstream to the confluence with the Snake River, and the Snake River below the Hells Canyon Complex, from Lower Granite Dam to downstream of Ice Harbor Dam and the confluence of the Snake River with the Columbia River. Dworshak Dam is a high head, cold water project with a maximum depth of 650 feet. The lower four Snake River dams are considered run-of-river and, from upstream to downstream, are Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams.

3.2.1 Water Temperature

Water temperatures in the lower Snake River are primarily determined by a combination of the temperature of the water originating from the middle Snake River and the Clearwater River. Lower and middle Snake River maximum summer temperatures exceeded the current 68°F (20°C) Washington standard before the dams were constructed (Corps 2002, Peery et al. 2003). Historical temperatures in the lower Snake River basin prior to the construction of the lower Snake River dams and the Hells Canyon Complex show that temperatures in the free-flowing lower Snake River often exceeded 68°F (20°C) in July and August and occasionally exceeded 25°C. These measurements were taken near the mouth of the Snake River from 1955 to 1958. Cold-water releases from Dworshak Dam have been used successfully to reduce water temperatures at Lower Granite Dam to the 68°F (20°C) criteria since the early 1990s. However, the cooling effect of the Dworshak releases are attenuated as the Snake River flows towards the confluence with the Columbia River.

3.2.1.1 Dworshak Dam and Reservoir

Dworshak is a deep reservoir that typically starts to thermally stratify in the late spring or early summer as air temperatures increase. Surface temperatures remain above 68°F (20°C) in the upper 20 to 26 feet during the summer, but can exceed 77°F (25°C) in August. However, the deeper, colder layer of the reservoir that accounts for up to 70 percent of the volume remains cold at 40°F to 48°F (4°C to 9°C). During the first two decades of operation, the project's selective withdrawal structures were used to keep the outflow temperatures between 48°F and 54°F (9°C and 12°C) to meet the needs of the downstream Dworshak National Fish Hatchery. However, since the mid-1990s there has been a greater emphasis on operating the project to provide a larger volume of cold water through the lower dam outlets during the summer to reduce water temperatures in the Lower Snake River. Summer release water temperatures are now typically between 43°F and 46°F (6°C and 8°C), and the average maximum summer temperatures in the downstream mainstem of the Clearwater River are approximately 16 degrees Fahrenheit less than they were prior to construction of the dam. Complete mixing of the upper two-thirds of the reservoir occurs in the fall, and part of that reach is typically covered with ice during the winter. The lower 20 miles of the reservoir does not mix completely until February, and usually does not ice over.

Current operations do not change the thermal structure of the reservoir, and temperature stratification is not anticipated to change under the No Action alternative.

Dworshak Dam releases will continue to be used to moderate water temperatures in the Lower Snake River during the summer under the No Action Alternative. The model results for the five representative years show that tailwater temperatures would be less than the State of Idaho's

Cold Water Communities Salmonid Spawning (COLD/SS) standard of 55.4°F (13°C) for every condition (Figure 3-11).

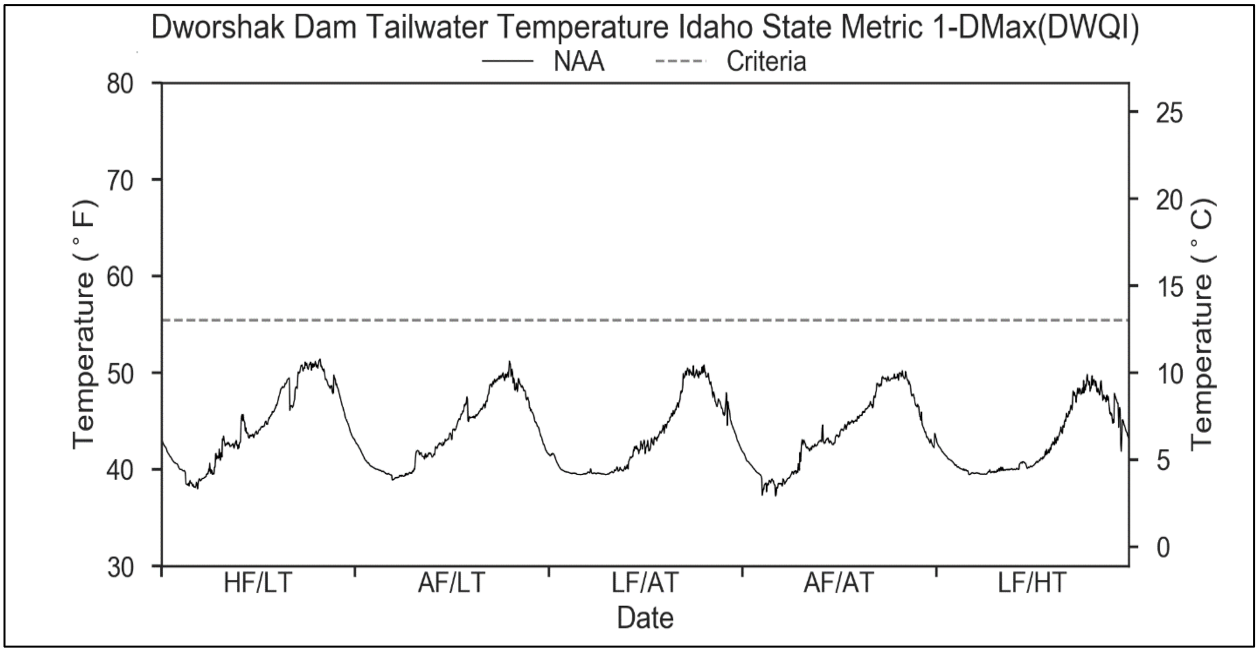


Figure 3-11. Modeled Tailwater Temperature for the No Action Alternative at Dworshak Dam Under a 5-year Range of River and Meteorological Conditions

3.2.1.2 Lower Granite, Little Goose, Lower Monumental and Ice Harbor Dams and Reservoirs

Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Reservoirs do not thermally stratify to the extent that Dworshak Reservoir and other deep reservoirs do. This is attributed to their short residence, wind and flow-induced turbulent diffusion, and convective mixing. However, vertical temperatures gradients can exist and are more pronounced in the reservoirs now than they were prior to the implementation of cold-water releases from Dworshak Dam. The effect from these cold-water releases are most apparent at Lower Granite Dam, but is observed as far downstream as Ice Harbor Dam. These releases are expected to continue for the period considered under the No Action Alternative.

The modeled results show that water temperatures increase downstream for each flow/temperature condition (Figure 3-12 and Figure 3-13). At Lower Granite Dam, water temperatures greater than the Washington state standard of 68°F (20°C) are not expected to occur during high-flow and average-flow years. The standard would be surpassed for about 5 days during a LF/AT year, and 17 days during a LF/HT year. At the Little Goose and Lower Monumental Projects, the frequency of exceeding the standard downstream from the dam during either average-flow year condition is 38 and 45 days, respectively. The frequency of exceedances would increase during low flow years: 47 and 60 days with average temperature and high temperatures, respectively, at Little Goose Dam and 69 days at Lower Monumental Dam regardless of the air temperatures (Figure 3-14 and Table 3-4). Water temperatures downstream from Ice Harbor Dam would be warmer than at the other three dams, with the frequency of exceeding 68°F (20°C) ranging from 28 days during a high flow year to 73 days during a LF/HT year. Tailwater temperatures could surpass 72°F (22°C) at Ice Harbor Dam during AF /AT and LF /HT years.

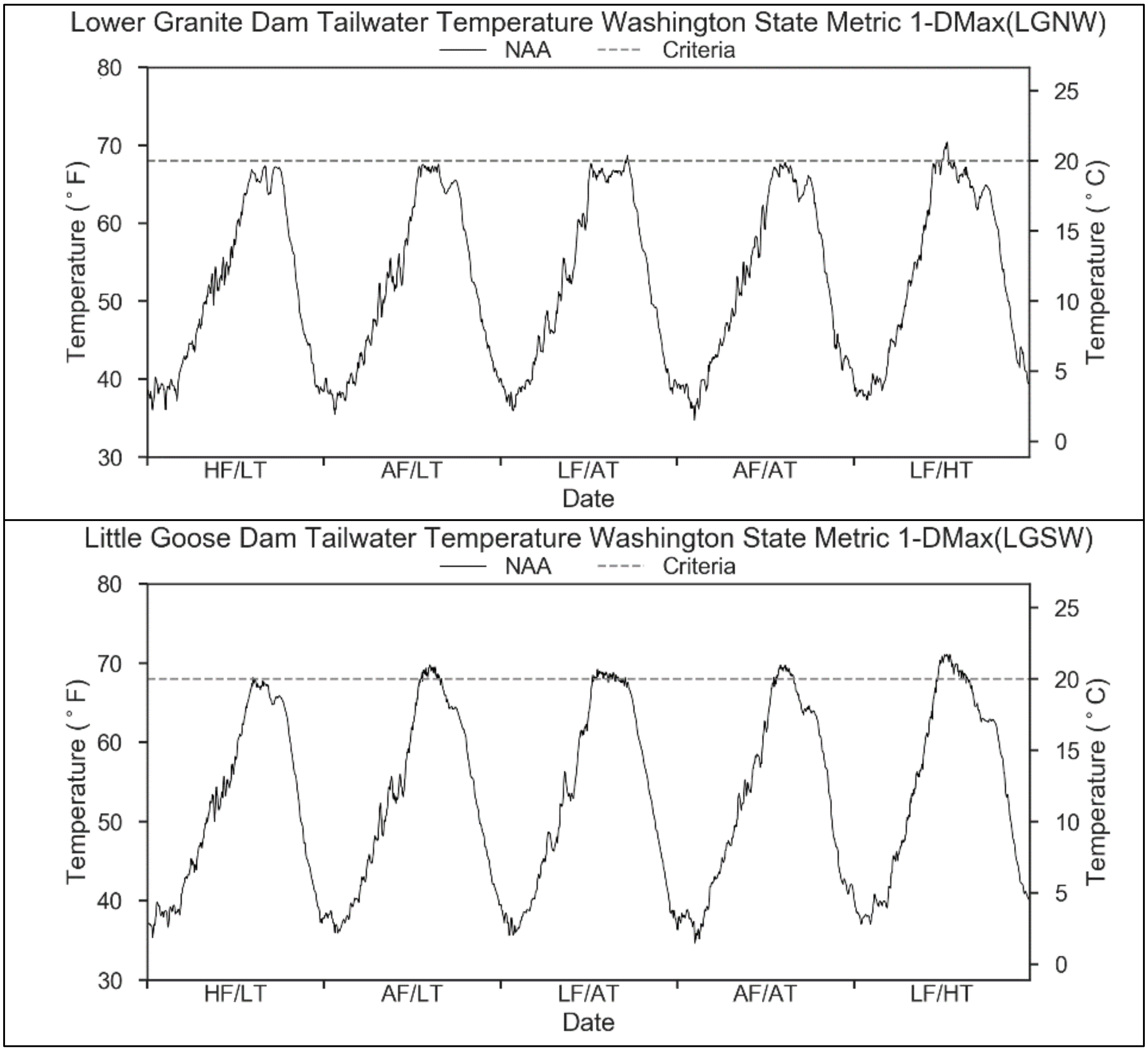


Figure 3-12. Modeled Tailwater Temperatures for the No Action Alternative at Lower Granite and Little Goose Dams Under a 5-Year Range of River and Meteorological Conditions

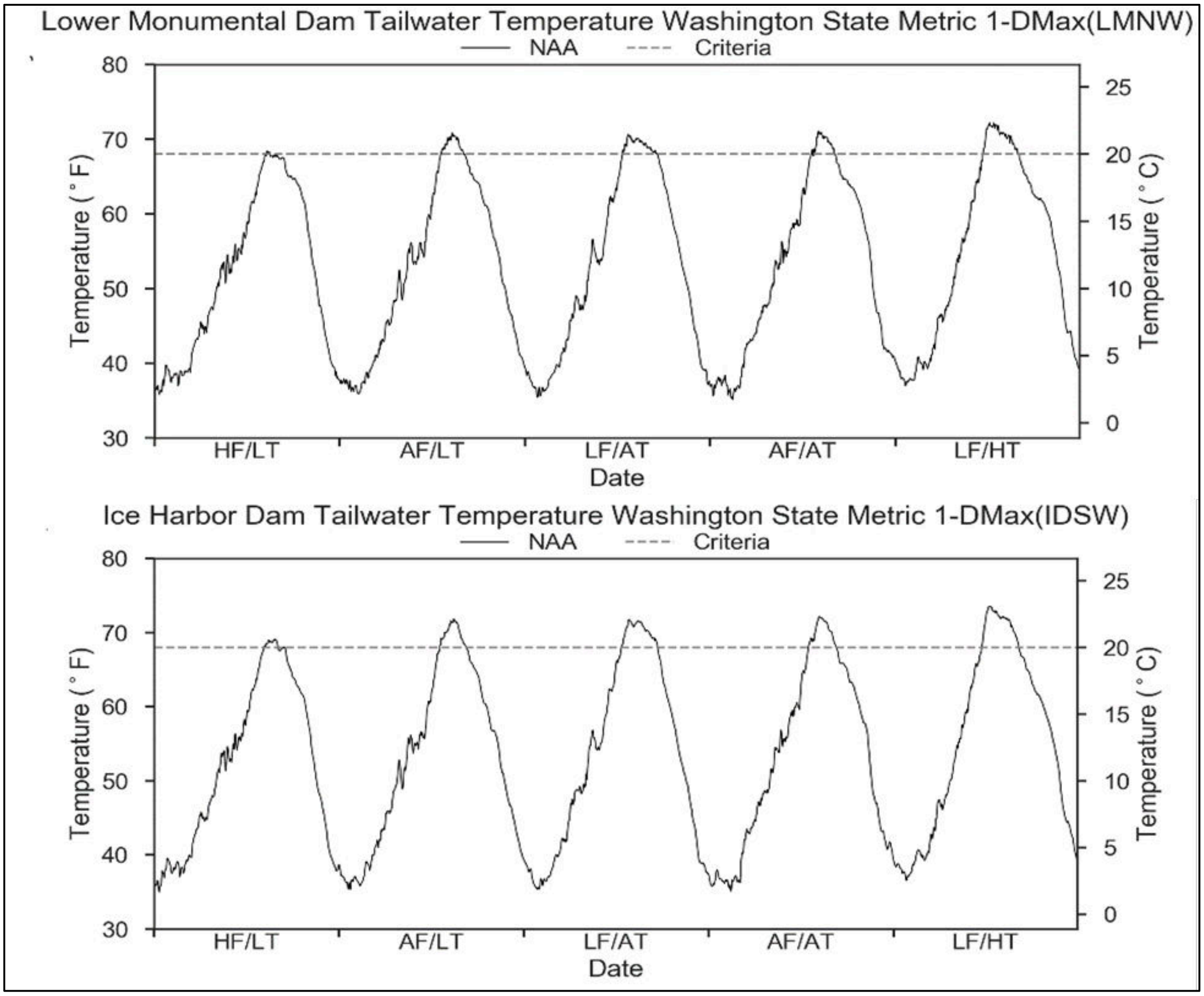


Figure 3-13. Modeled Tailwater Temperatures for the No Action Alternative at Lower Monumental and Ice Harbor Dams Under a 5-Year Range of River and Meteorological Conditions

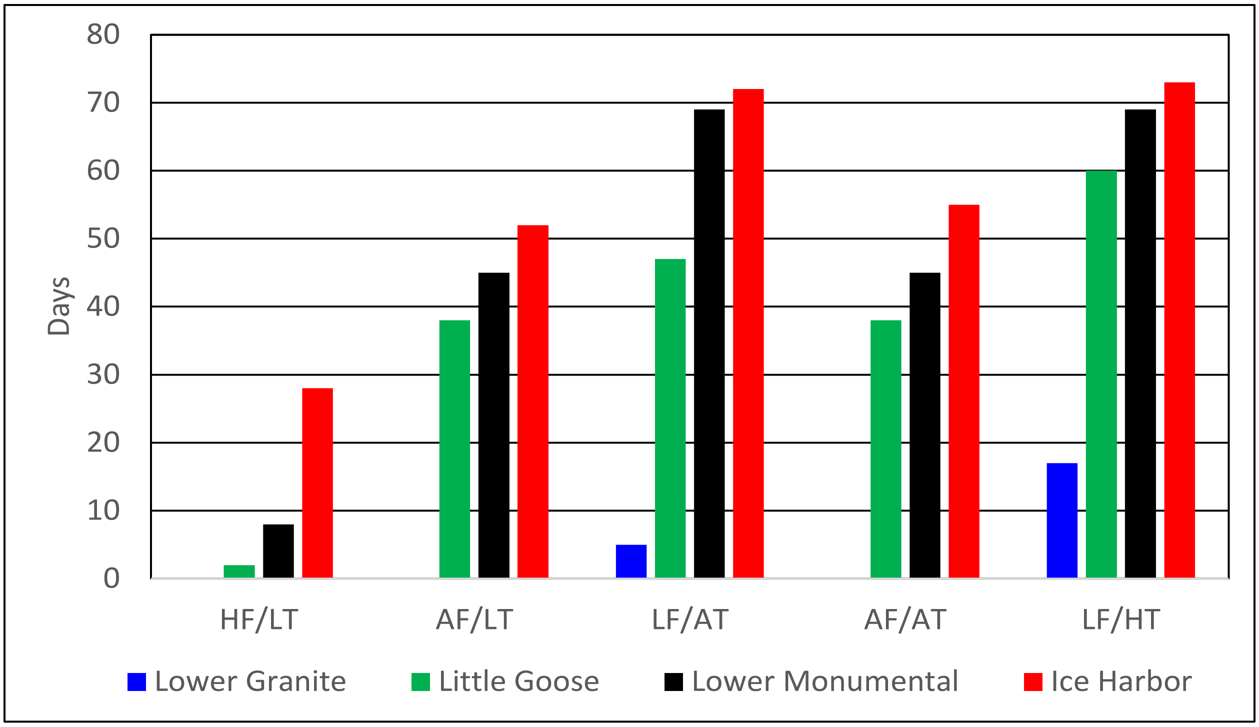


Figure 3-14. Frequency Distributions of the Temperature Greater than the 68°F Washington Standard that Would Occur at the Four Lower Snake River Dam Tailwater Fixed Monitoring Stations for Each Flow/Temperature Condition

Table 3-4. Number of Days the Temperature Standard is Exceeded at Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Tailwater Sites Under a 5-Year Range of River and Meteorological Conditions

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Lower Granite	June	0	0	0	0	3
Lower Granite	July	0	0	0	0	14
Lower Granite	September	0	0	5	0	0
Little Goose	June	0	0	0	0	8
Little Goose	July	0	11	19	9	31
Little Goose	August	2	27	27	29	21
Little Goose	September	0	0	1	0	0
Lower Monumental	June	0	0	0	0	8
Lower Monumental	July	0	13	20	11	31
Lower Monumental	August	8	31	31	31	29
Lower Monumental	September	0	1	18	3	1
Ice Harbor	June	0	0	0	0	6
Ice Harbor	July	0	13	19	15	31
Ice Harbor	August	25	31	31	31	31
Ice Harbor	September	3	8	22	9	5

3.2.2 Total Dissolved Gas

High TDG is infrequently measured below Dworshak Dam, but does occur during high flow events when total discharges exceed powerhouse capacity. Spill for juvenile fish passage does not occur at Dworshak Dam. Conversely, the lower Snake River dams are operated for juvenile fish passage during the months of April through August. During the juvenile fish passage season, the co-lead agencies manage spill levels for juvenile fish passage to avoid exceeding 120 percent TDG in project tailraces, and 115 percent TDG in the forebay of the next project downstream, consistent with the current State of Washington percent TDG limits[4]. Generally, TDG exceedances above these thresholds are uncommon during the juvenile fish passage season, and can be attributed to the structural enhancements and operational strategies that have been implemented over the years. A TMDL for TDG for the Lower Snake River was completed by the state in 2003 and is still in effect.

3.2.2.1 Dworshak Dam and Reservoir

Discharges from the spillway gates or regulating outlets are the primary sources of TDG generation at Dworshak Dam; TDG saturations above Idaho's state water quality criterion of 110 percent are typically exceeded when spill through these outlets is greater than 14 kcfs. Additionally, powerhouse flows can increase gas saturation when turbine units are operated at low flows of less than about 1.6 kcfs. Under these circumstances vacuum breakers within the units admit air into the turbine hub and draft tube to prevent cavitation. The Corps generally operates Dworshak Dam outside of these conditions to minimize TDG exceedances above the 110 percent threshold. Since elevated TDG is detrimental to fish, the Dworshak National Fish Hatchery, located at the confluence of the North Fork and mainstem Clearwater Rivers downstream of Dworshak Dam, installed a degassing system to strip TDG from water that is pumped into the hatchery from the river.

Operation of the dam to stay below Idaho's 110 percent TDG criterion, as well as the de-gassing system installed at the hatchery are expected to continue under the No Action Alternative. The primary deviations will occur during spring of average and high flow years (Figure 3-15), when additional water is released for flood control purposes to keep the reservoir elevation aligned with the rule curve, as well as aiding the outmigration of hatchery releases.

[4] The 2014 Supplemental BiOp provides: "Specific spill levels will be provided for juvenile fish passage at each project, not to exceed established TDG levels (either 110 percent TDG criterion, or as modified by State water quality waivers, currently up to 115 percent TDG in the dam forebay and up to 120 percent TDG in the project tailwater…". In February 2009, Oregon modified its 5-year waiver to remove the 115 percent forebay TDG limit, but Washington did not. The Corps will continue to manage to 120 percent and 115 percent (the Washington TDG criterion) which is the more restrictive TDG limit in effect during juvenile fish passage spill season in 2016.

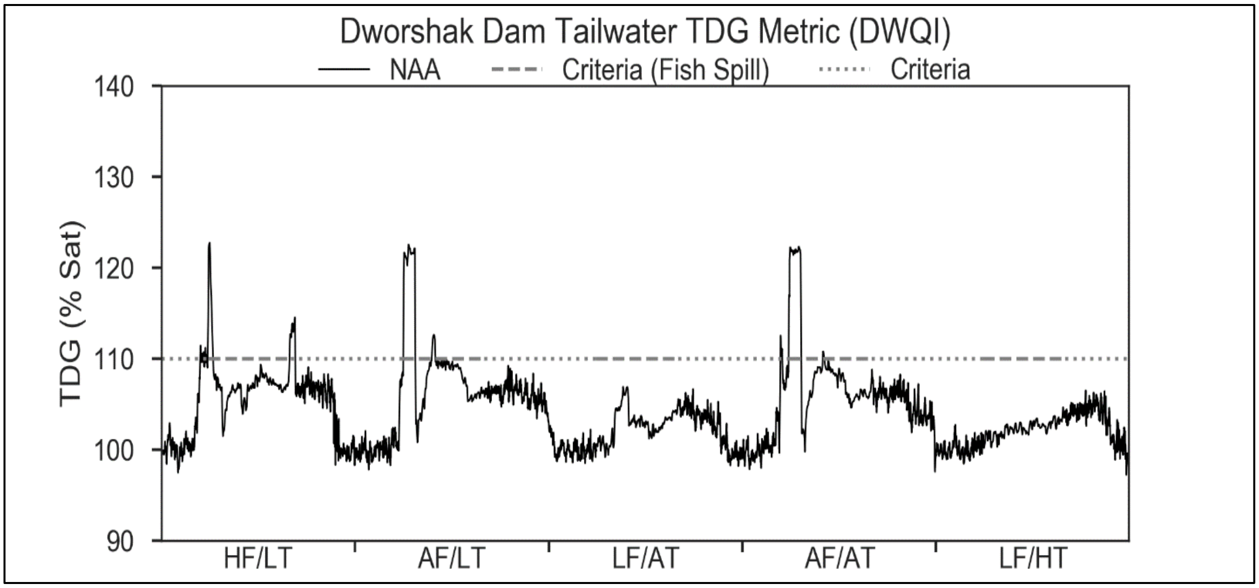


Figure 3-15. Modeled Tailwater Total Dissolved Gas for the No Action Alternative at Dworshak Dam Under a 5-year Range of River and Meteorological Conditions

An evaluation of the frequency of exceedances provides additional information regarding the timing and levels of gas saturation that would occur under the No Action Alternative (Figure 3-16 and Table 3-5). During an average flow year, the TDG criterion would be exceeded approximately 500 hours (~22 days) during April. The criterion would be exceeded more than 200 hours (~10 days) in March and September during a high flow year, but none would occur during May, June, and July. No exceedances would be anticipated during any month of a low flow year, regardless of the temperature conditions.

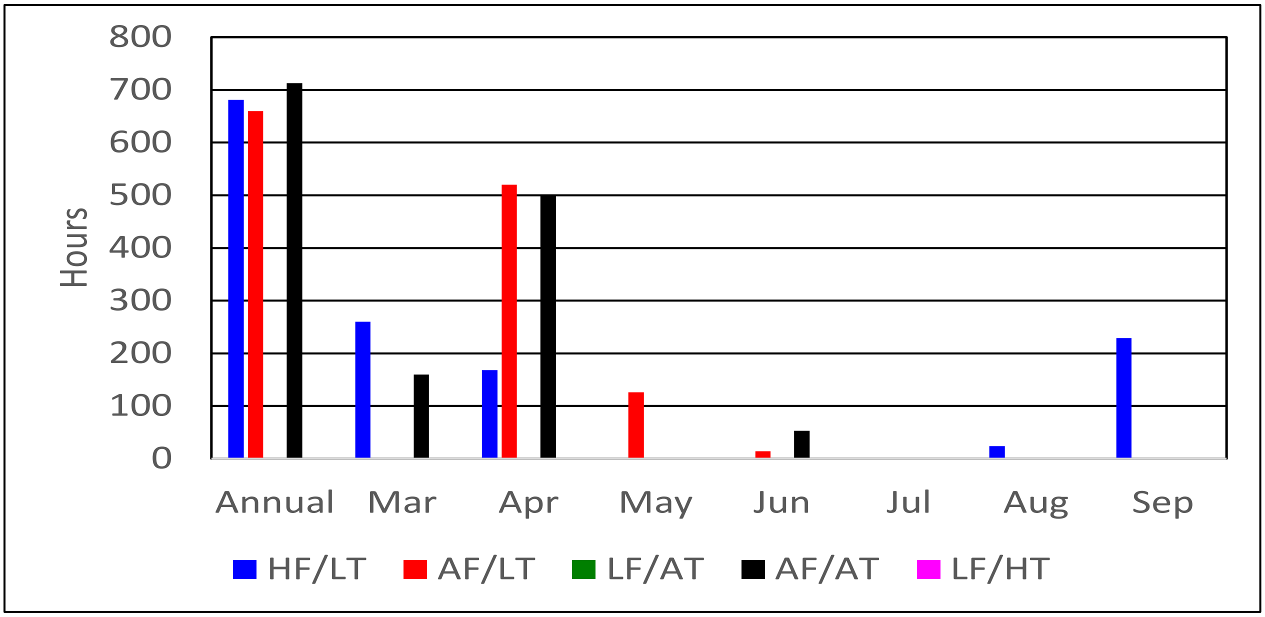


Figure 3-16. Frequency Distributions of the Hourly Total Dissolved Gas Values Greater than Idaho's 110% Water Quality Criterion that Would Occur at the Dworshak Dam Tailwater Fixed Monitoring Station for Each Flow/Temperature Condition

Table 3-5. Number of Days the Total Dissolved Gas Criterion is Exceeded at Dworshak Tailwater Site Under a 5-Year Range of River and Meteorological Conditions

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Dworshak	March	11	0	0	7	0
Dworshak	April	8	23	0	22	0
Dworshak	May	0	6	0	0	0
Dworshak	June	0	1	0	4	0
Dworshak	July	0	0	0	0	0
Dworshak	August	1	0	0	0	0
Dworshak	September	10	0	0	0	0

3.2.2.2 Lower Granite, Little Goose, Lower Monumental and Ice Harbor Dams and Reservoirs

To minimize TDG production during the juvenile fish passage spill season and during flood events, spillway deflectors were installed at the spillbays of all four dams. These deflectors help to redirect the spill jet from a plunging flow that transports air bubbles deep into the stilling basin to a horizontal jet that maintains entrained air much closer to the water surface. Other TDG abatement measures include limiting the amount of spill that is released from the dams and implementing spill patterns that distribute spillbay flows uniformly across the entire spillway.

It is expected that juvenile downstream fish passage spill operations will continue to be implemented for the years encompassed by the No Action Alternative. These operations are regionally supported since they have proven beneficial for downstream juvenile fish passage. In the future, it is unknown how impacts to water quality, namely TDG, may limit spill at the lower four Snake River dams. There has been an increasing interest by some stakeholders to loosen constraints on TDG water quality state waivers, and increase spill released from the lower Snake River dams. These stakeholder efforts are expected to continue under the No Action Alternative.

Tailwater gas saturation at the four Lower Snake River projects were modeled for the five flow/air temperature conditions considered for the No Action Alternative. The W2 simulations for each project tailwater are shown in Figure 3-17 and Figure 3-18. The number of days when the 120 percent Washington criterion that applies during the fish spill season would be exceeded, is similar at each project under a given flow/temperature scenario (Figure 3-19 and Table 3-6). The highest occurrence was determined for the HF/LT scenario when the criterion would be exceeded for more than 50 days between April 1 and August 31 at each project. The frequency decreases to less than 10 days at each dam for the AF/LT condition. No exceedances are predicted for the LF/AT, AF/AT, and LF/HT conditions during the fish spill season.

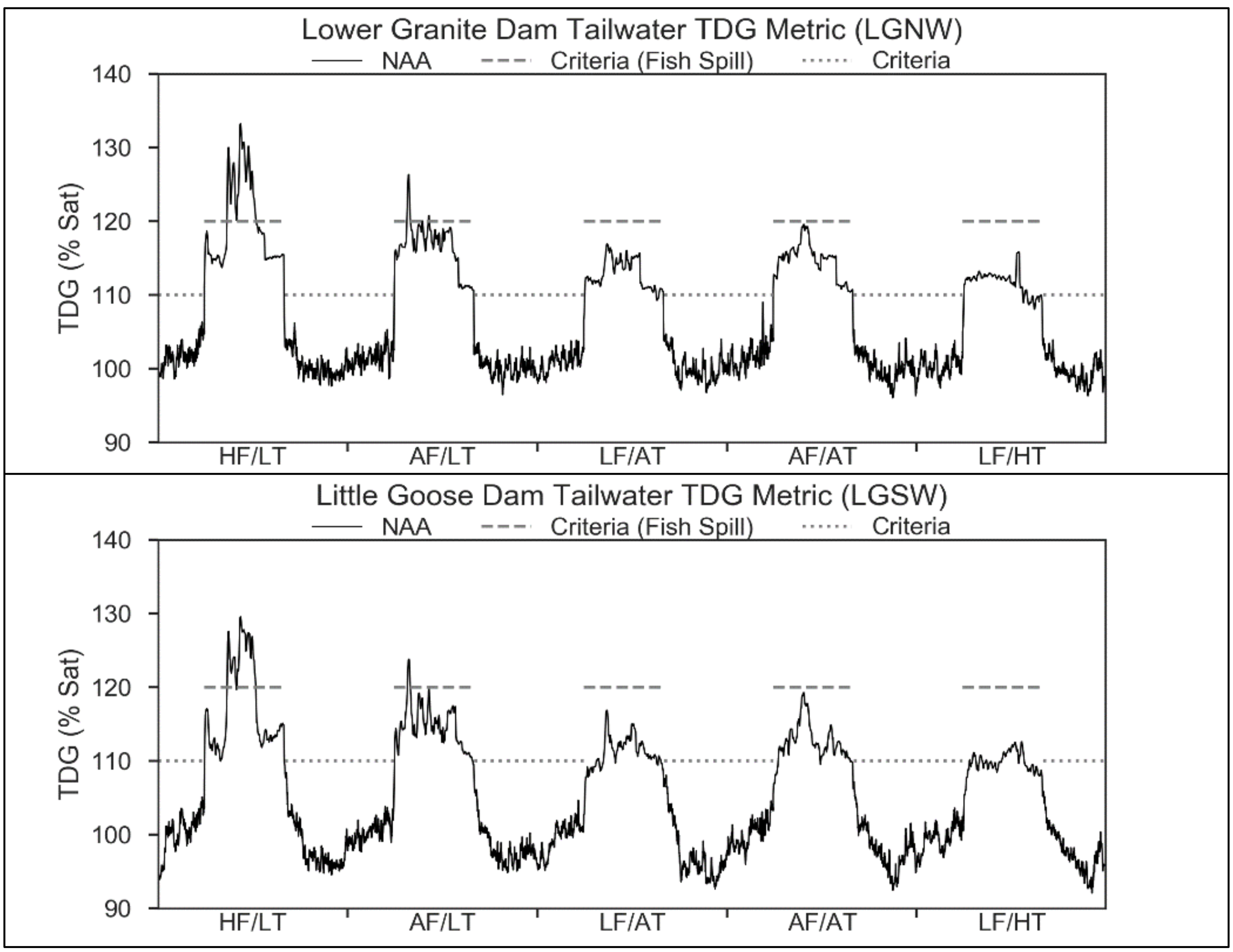


Figure 3-17. Modeled Tailwater Total Dissolved Gas for the No Action Alternative at Lower Granite and Little Goose Dams Under a 5-Year Range of River and Meteorological Conditions

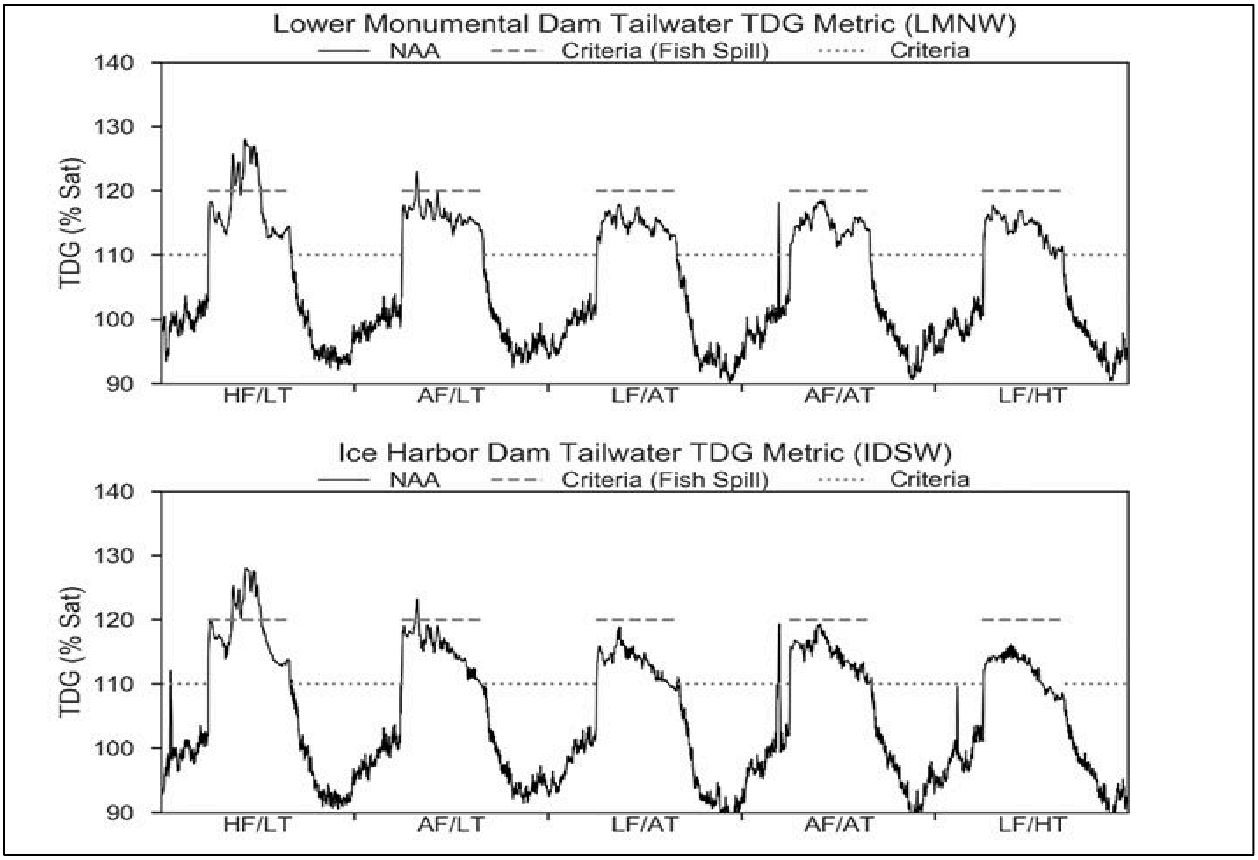


Figure 3-18. Modeled Tailwater Total Dissolved Gas for the No Action Alternative at Lower Monumental and Ice Harbor Dams Under a 5-Year Range of River and Meteorological Conditions

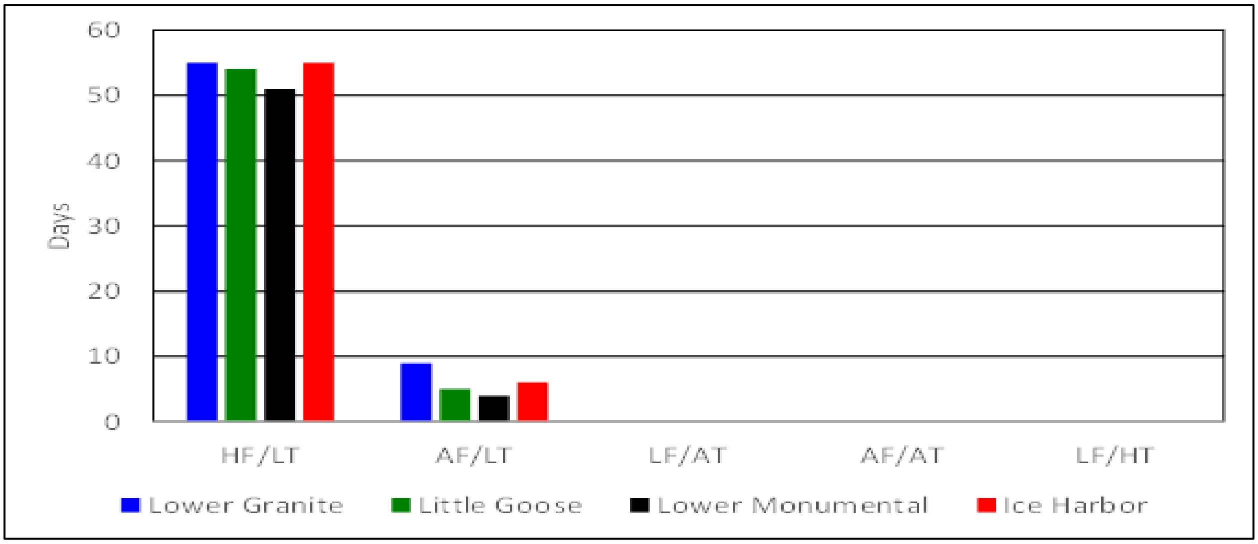


Figure 3-19. Frequency Distributions of the Daily 12-hour Maximum Average Total Dissolved Gas Values Greater than Washington's 120 Percent Criteria at the Four Lower Snake River Dam Tailwater Fixed Monitoring Stations for each Flow/Temperature Condition Between April 1 and August 31

Table 3-6. Number of Days the Total Dissolved Gas Criterion is Exceeded at Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Tailwater Sites Under a 5-Year Range of River and Meteorological Conditions

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Lower Granite	February	0	0	0	0	0
Lower Granite	March	0	0	0	0	0
Lower Granite	April	0	6	0	0	0
Lower Granite	May	18	2	0	0	0
Lower Granite	June	30	2	0	0	0
Lower Granite	July	8	0	0	0	0
Little Goose	March	0	0	0	0	0
Little Goose	April	0	5	0	0	0
Little Goose	May	18	0	0	0	0
Little Goose	June	29	0	0	0	0
Little Goose	July	8	0	0	0	0
Little Goose	September	0	0	0	0	0
Lower Monumental	February	0	0	0	0	0
Lower Monumental	March	0	1	0	2	0
Lower Monumental	April	0	5	0	0	0
Lower Monumental	May	16	0	0	0	0
Lower Monumental	June	29	0	0	0	0
Lower Monumental	July	8	0	0	0	0
Lower Monumental	September	3	0	0	0	0
Ice Harbor	January	1	0	0	0	0
Ice Harbor	February	0	0	0	0	0
Ice Harbor	March	1	1	0	3	0
Ice Harbor	April	0	6	0	0	0
Ice Harbor	May	17	0	0	0	0
Ice Harbor	June	30	0	0	0	0
Ice Harbor	July	8	0	0	0	0
Ice Harbor	September	1	0	2	1	0

Forebay TDG is dependent on several factors, including tailwater TDG at the upstream dam, the amount of degassing that occurs between projects, and water temperatures. The modeled TDG conditions show that the 115 percent Washington TDG criterion that applies during the juvenile fish spill season would not be exceeded at Lower Granite Dam during any scenario (Figure 3-20). However, the frequency of exceedances would increase at each successive downstream project regardless of the flow/temperature condition modeled (Figure 3-22). At the Little Goose and Lower Monumental Projects the greatest number of exceedances would occur during HF/LT conditions, followed by an AF/LT year. For both of these projects, the lowest number of exceedances would occur during a LF/HT year (Figure 3-21 and Table 3-7). Ice Harbor forebay is expected to have the highest number of exceedances for any condition, with approximately 70 days during AF/LT, LF/AT, and LF/HT years. The frequency of exceedances would be least during an AF/AT year, but still number more than 50 days per spill season. In Table 3-7, Lower Granite is not shown because there are no exceedances for the forebay site as can be seen in Figure 3-20.

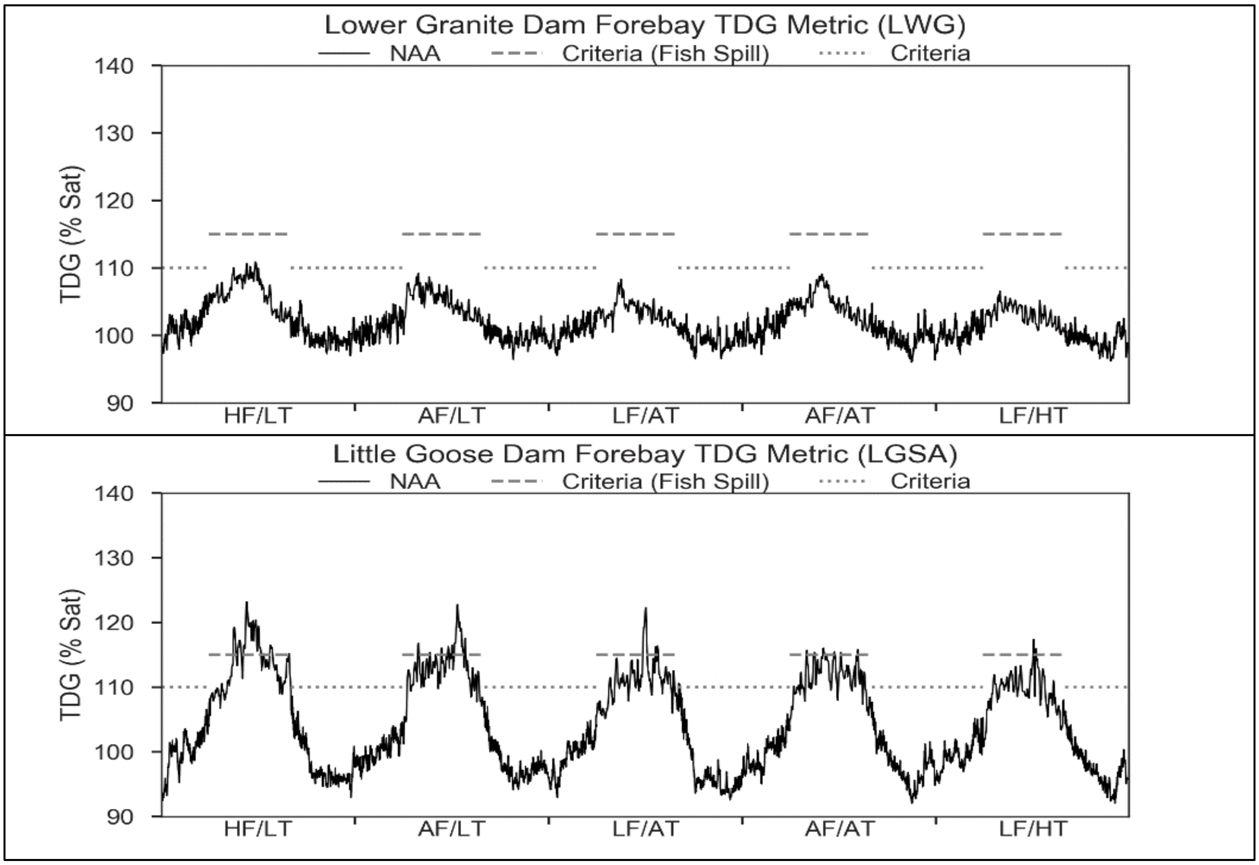


Figure 3-20. Modeled Forebay Total Dissolved Gas for the No Action Alternative at Lower Granite and Little Goose Dams Under a 5-Year Range of River and Meteorological Conditions

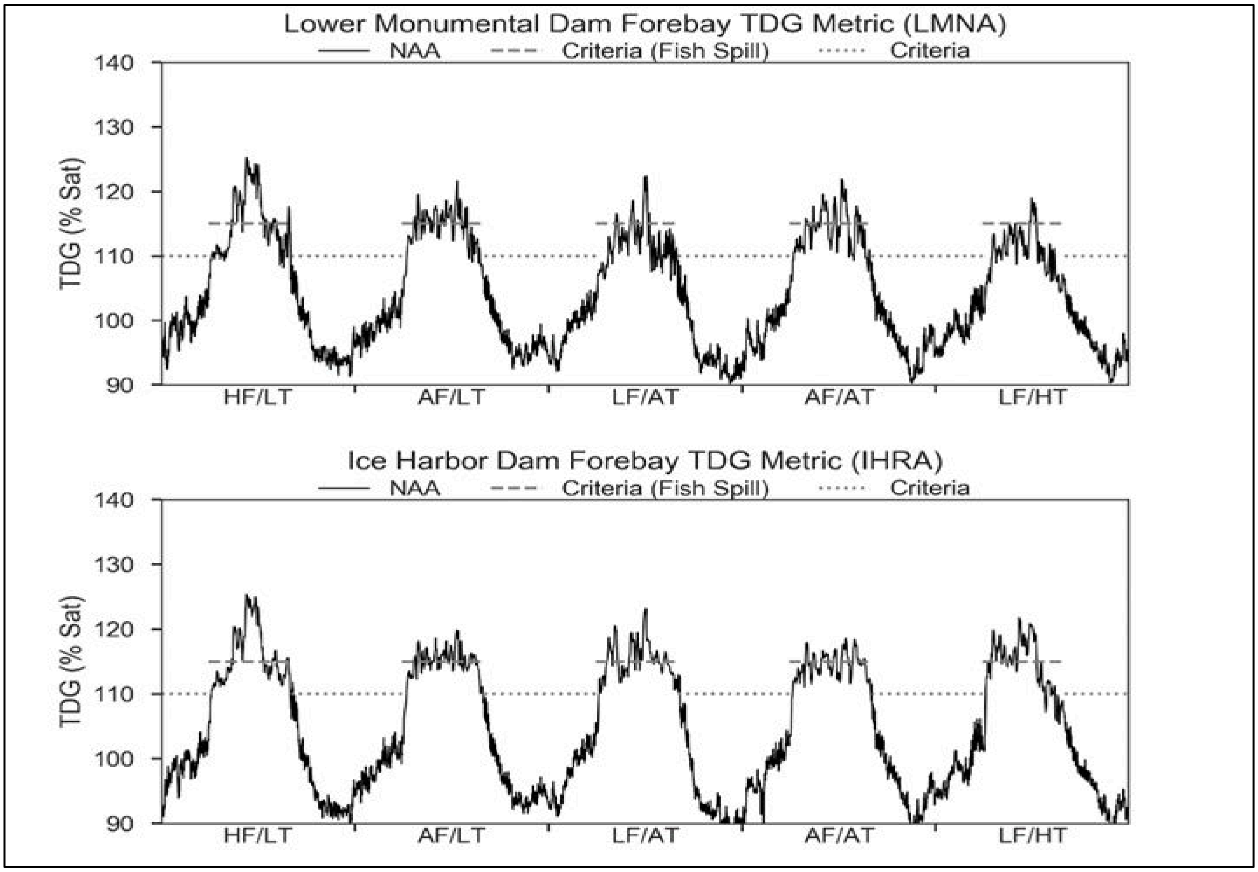


Figure 3-21. Modeled Forebay Total Dissolved Gas for the No Action Alternative at Lower Monumental and Ice Harbor Dams Under a 5-Year Range of River and Meteorological Conditions

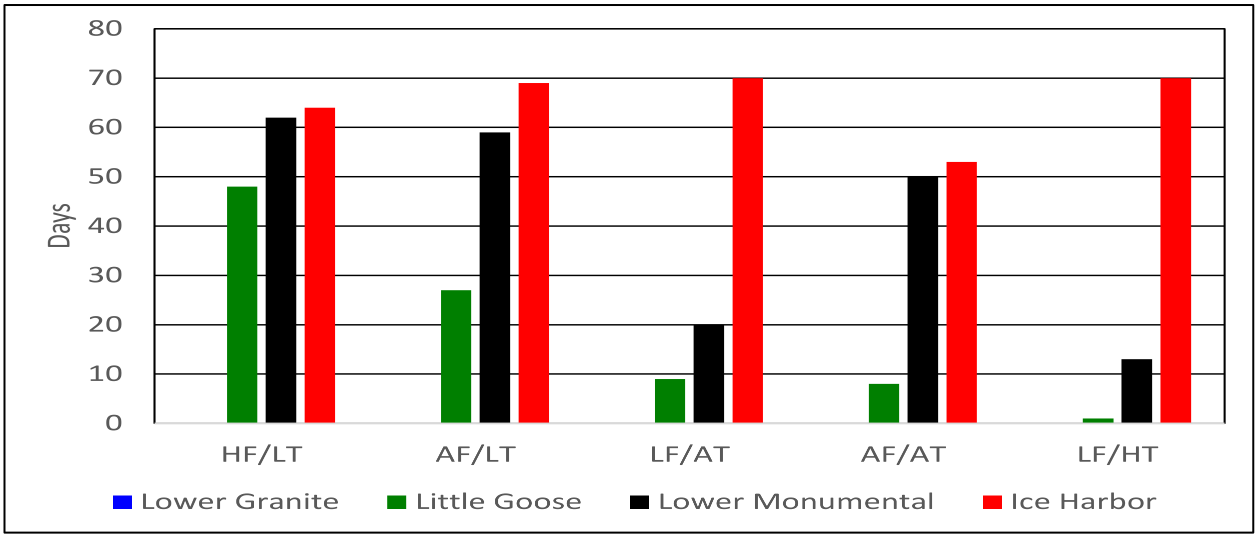


Figure 3-22. Frequency Distributions of the Daily 12-hour Maximum Average Total Dissolved Gas Values Greater than Washington's 115 Percent Criteria at the Four Lower Snake River Dam Forebay Fixed Monitoring Stations for Each Flow/Temperature Condition Between April 1 and August 31

Table 3-7. Number of Days the Total Dissolved Gas Criterion is Exceeded at Little Goose, Lower Monumental, and Ice Harbor Forebay Sites Under a 5-Year Range of River and Meteorological Conditions

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Little Goose	March	0	0	0	0	0
Little Goose	April	0	2	0	0	0
Little Goose	May	12	3	0	4	0
Little Goose	June	26	8	3	6	0
Little Goose	July	15	24	9	2	3
Little Goose	August	2	0	0	2	0
Little Goose	September	0	0	1	0	0
Lower Monumental	March	0	0	0	0	0
Lower Monumental	April	0	6	0	0	0
Lower Monumental	May	17	21	5	12	2
Lower Monumental	June	29	22	12	18	3
Lower Monumental	July	19	21	8	15	9
Lower Monumental	August	7	0	0	9	0
Lower Monumental	September	0	0	0	0	0
Ice Harbor	March	0	0	0	0	0
Ice Harbor	April	0	6	10	0	15
Ice Harbor	May	17	19	9	10	24
Ice Harbor	June	30	26	25	20	26
Ice Harbor	July	14	19	26	16	10
Ice Harbor	August	9	13	6	14	0
Ice Harbor	September	1	0	5	1	0

3.2.3 Other Physical, Chemical, and Biological Processes

The physicochemical and biological characteristics of the reservoirs are influenced by natural processes and human activities. Organic and inorganic materials from upland erosion and atmospheric deposition are transported to the reservoirs along with runoff. A portion of these materials will be used by the biota, and the remainder will either settle to the bottom or be transported downstream to the next reservoir or river. These erosive processes are accelerated as a result of wildfire, which will also change the chemical composition of the runoff. Human activities contribute to the sediment, nutrient, and chemical loading of the reservoirs via agricultural practices, timber harvesting, mining, and urban runoff.

3.2.3.1 Dworshak Dam and Reservoir

Dworshak Reservoir is long, relatively narrow, and ranges from oligotrophic to lower-mesotrophic due to low nutrient concentrations and primary productivity rates. In 2007, the Corps, in conjunction with Idaho Fish and Game, began a nutrient fertilization project to increase the biological productivity in the reservoir. Concentrations of nitrate, total phosphorus, and chlorophyll a have decreased throughout the reservoir since samples were collected in the mid-1990s and mid-2000s, but it is not clear whether these decreases are due to the nutrification program, different analytical techniques, and/or nutrient loading. Diatom biovolume has also decreased throughout the reservoir, with a concurrent shift towards more edible forms. Ephemeral blooms consisting of 60 to 80 percent blue-green *Anabaena* sp. blooms are common but declining in some areas of the reservoir, while other species of blue-green algae, as well as green algae, have become more prevalent. Zooplankton consume algae; *Daphnia* are a primary food source for planktivorous fish, and their biomass has increased at some areas of the reservoir, but remained the same, or decreased, at other locations. Similarly, copepod density has increased at most of the sampling stations.

Dissolved oxygen concentrations in the reservoir are dependent on several factors, including algae. Percent saturation in the epilimnion is usually close to 100 percent and occasionally increases to 120 percent (probably a result of algal photosynthesis). However, episodes of low dissolved oxygen in the metalimnion are becoming more common, and may be due to an increase in oxygen demand during the decay of dead phytoplankton biomass that sinks to denser metalimnion waters. There will likely continue to be shifts in the chemical and biological characteristics of the reservoir during the period considered for the No Action Alternative. The nutrification program is now funded annually, and some water quality monitoring will continue. This action should help identify whether the identified shifts are due to the nutrification program, changes related to the inflows, natural aging of the lake, or other unidentified causes.

3.2.3.2 Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams and Reservoirs

The physicochemical and biological attributes of the lower Snake River reservoirs are, to a large extent, governed by the inflowing Snake River. Total suspended solids concentrations are highest during peak runoff events, whereas the concentrations of dissolved constituents are highest during low flow conditions. The concentrations of these constituents, as well as Secchi disk depth, are similar for the entire length of the lower Snake River. Chlorophyll a concentrations and algal biovolume typically increase from the upper end of Lower Granite Lake to the mid-reaches of Lake Bryan and Lake Herbert G. West, and then gradually decline at the downstream reservoirs. However, growing season median concentrations are not demonstrably different due to the variability within the datasets. The algal community is dominated by the diatoms, although blue-green algal blooms also occur periodically in each reservoir, especially in the forebay and swim areas, but it is unknown if toxins such as anatoxin, saxitoxin, and microcystin are produced by these blooms. Blue-green algal blooms will be more prevalent during LF/HT conditions when the water is warmer and the hydrologic residence time of the reservoirs increase. Zooplankton biomass also tends to increase from the upper reaches of Lower Granite Lake to Lake Herbert G. West and decrease thereafter. Copepods are consistently present and usually account for the largest percentage of the biomass. However, cladocera, primarily *Daphnia retrocurva*, usually surpasses the combined biomass of all other zooplankton during the summer months.

It is unlikely that the lower Snake River reservoirs would become truly eutrophic with each reservoir remaining in the mesotrophic to eutrophic state. This premise is based primarily on comparisons of the 2008 - 2010 datasets to analogous information collected in the mid-1990s, and in some cases the mid-1970s. The results show that inter-annual variability does occur, but there are no definitive temporal changes. Additionally, the reservoirs experience high water velocities with each spring freshet, and fine organic material containing nutrients is largely flushed from the river and prevented from accumulating. Given this, existing water quality impairments are likely to continue.

3.3 LOWER COLUMBIA RIVER

The lower Columbia River includes the Columbia River at the confluence of the Columbia and Snake Rivers above McNary Dam, extending to Bonneville Dam (the downstream limit of this study). Similar to the lower Snake River, the lower Columbia River dams are operated for juvenile fish passage during the months of April through August.

3.3.1 Water Temperature

Water temperatures in the lower Columbia River are highly influenced by upstream dams, and are similar in all of the lower Columbia River reservoirs. The four lower Columbia River reservoirs show weak (McNary and John Day) to no (The Dalles and Bonneville) thermal stratification during the summer months, largely due to the short residence time, wind and flow-induced turbulent diffusion, and convective mixing that occurs in the reservoirs. All four reservoirs are on the Washington and/or Oregon 303(d) lists for impaired water temperatures due to high water temperatures that exist during the late summer/early fall. When high water temperatures occur in the lower Columbia River, many adult anadromous fish will seek cool water, referred to as "cold water refuges," in tributaries to the mainstem river, which may impact their ultimate migration and spawning success (High et al. 2006; Palmer 2017). For example, steelhead that pass Bonneville Dam in late July/early August have been observed to delay their upstream migration until September while seeking refuge in cold water areas between Bonneville Dam and The Dalles Dam (Palmer 2017). The management of water temperatures in a manner similar to the strategies used on the lower Snake River is not effective in this river reach since there is not an upstream source of very cold water. Thus, access to off-channel thermal refugia is critical; protecting and restoring these cold water refuges is likely to be important for the recovery of salmon and steelhead populations in the Columbia River Basin. The importance of protecting and restoring these cold water refuges may take on more significance due to climate change, which is expected to increase the water temperatures in both the tributaries and the Columbia River (Palmer 2017).

The tailwater temperatures for the No Action Alternative at McNary, John Day, The Dalles, and Bonneville Dams were modeled under a 5-year range of river and meteorological conditions (Figure 3-23 and Figure 3-24). The modeled results show that tailwater temperatures can exceed 68°F (20°C) at all four dams during any of the years and conditions presented, and maximum water temperatures and the number of water temperature exceedances would be higher during a year when river flows were lower than normal, and summer ambient air temperatures were higher (such as in 2015). Thus, the high water temperatures that exist in each reservoir during the late summer/early fall are expected to continue under the No Action Alternative for a wide range of river and meteorological conditions. Table 3-8 shows the actual number of days the temperature criteria is exceeded over the 5-year range of river and meteorological conditions. The number of exceedances increases as the water moves downstream and is also higher during the peak summer months of the lower flow years.

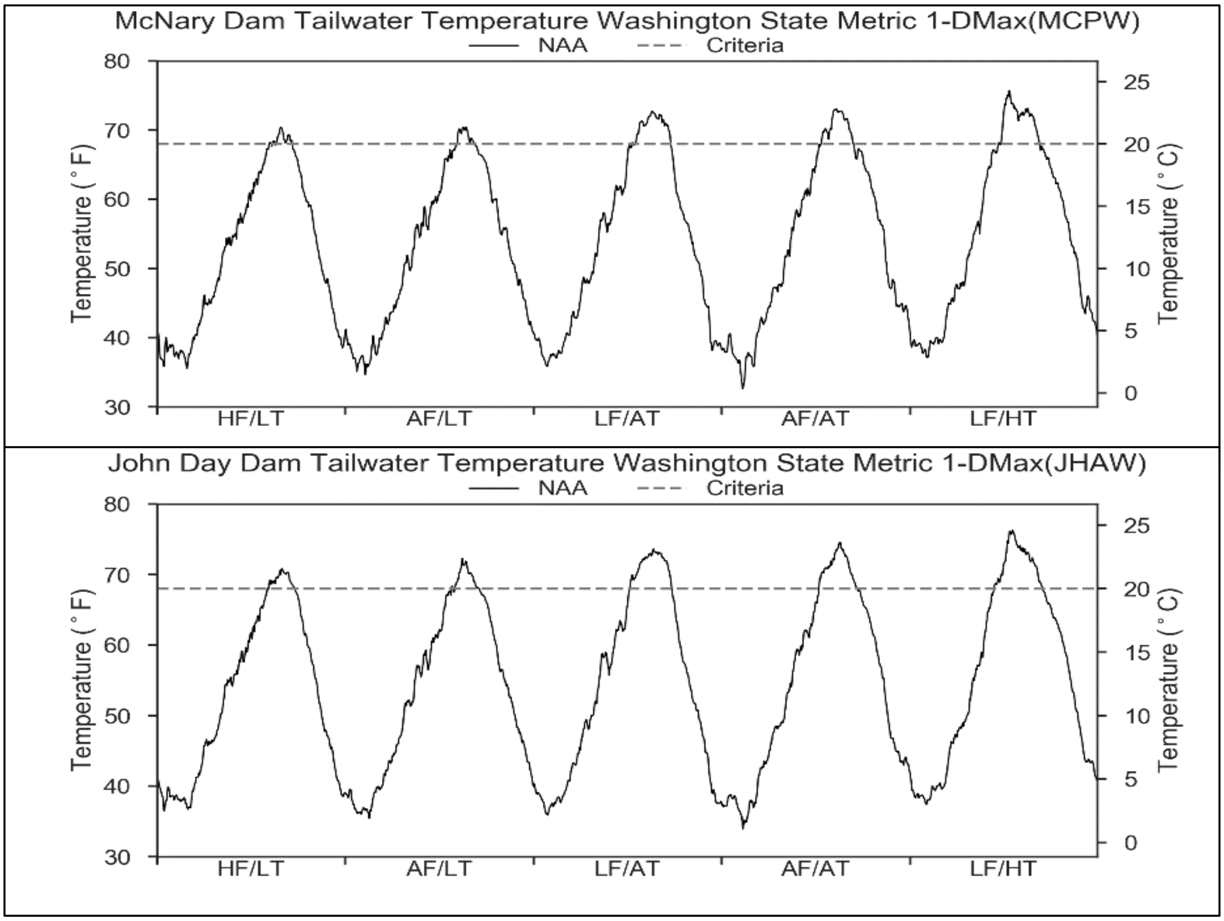


Figure 3-23. Modeled Tailwater Temperature For the No Action Alternative at McNary and John Day Dams Under a 5-Year Range of River and Meteorological conditions

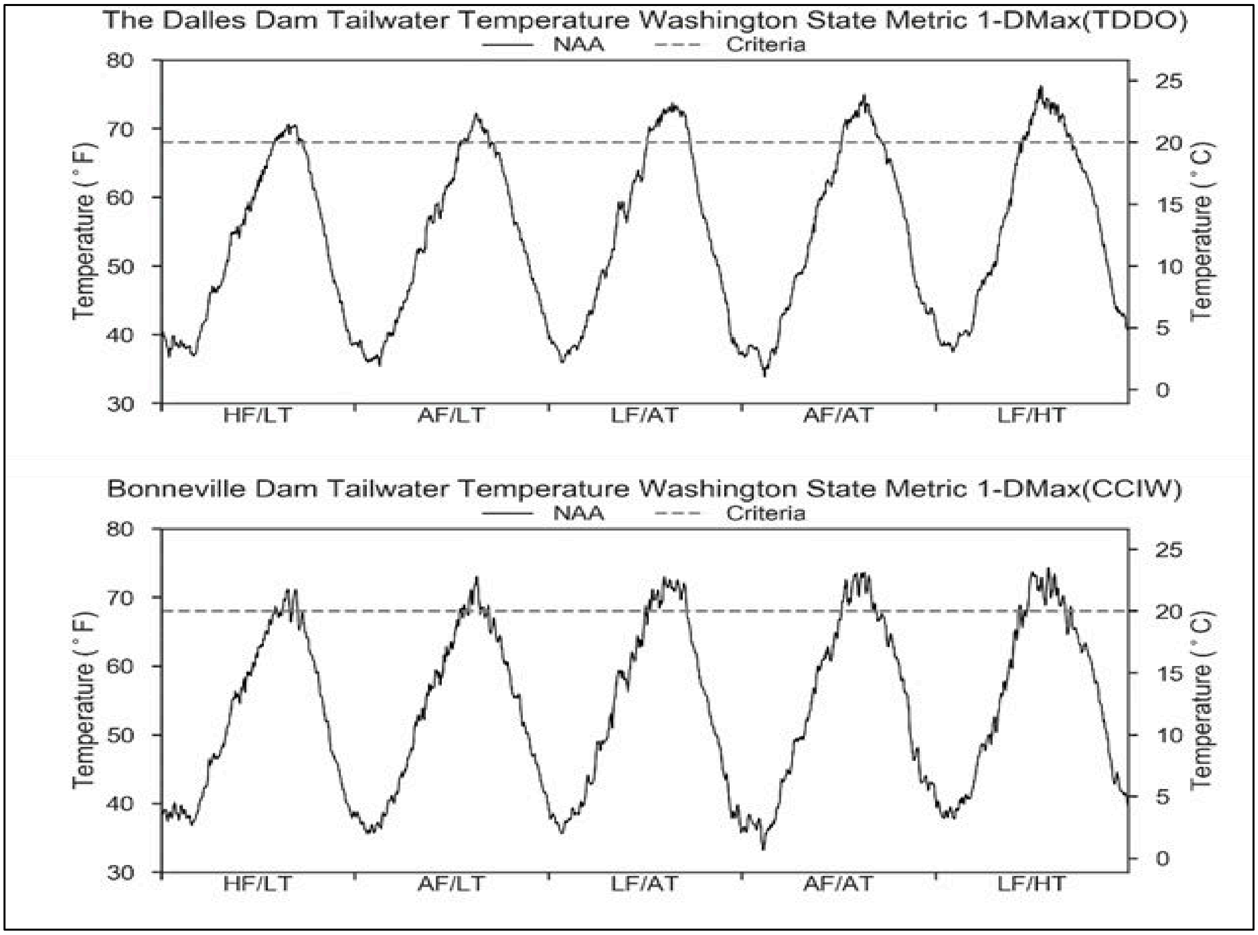


Figure 3-24. Modeled Tailwater Temperature For the No Action Alternative at The Dalles and Bonneville Dams Under a 5-Year Range of River and Meteorological conditions

Table 3-8. Number of Days the Temperature Criterion is Exceeded at McNary, John Day, The Dalles, and Bonneville Tailwater Sites Under a 5-Year Range of River and Meteorological Conditions

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary	June	0	0	0	0	6
McNary	July	0	0	19	20	31
McNary	August	21	26	31	31	31
McNary	September	20	6	23	12	9
John Day	June	0	0	0	0	18
John Day	July	0	2	26	24	31
John Day	August	27	31	31	31	31
John Day	September	25	16	25	20	15
The Dalles	June	0	0	0	0	17
The Dalles	July	0	7	26	25	31

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
The Dalles	August	29	31	31	31	31
The Dalles	September	23	11	24	22	14
Bonneville	June	0	0	0	0	13
Bonneville	July	0	8	26	25	31
Bonneville	August	21	28	31	31	31
Bonneville	September	11	4	17	9	4

3.3.2 Total Dissolved Gas

The lower Columbia River dams are operated for juvenile fish passage during the months of April through August. These spill operations are managed to keep TDG saturation levels at or below state water quality criterion waivers of 120 percent in the downstream tailwater and 115 percent in the next downstream forebay. For the most part, TDG exceedances above these thresholds are minimal during the juvenile fish passage and this success can be attributed to the structural enhancements (e.g., spill deflectors at some dams) and/or operational strategies (e.g., spill pattern, spill priority list) that have been implemented over the years. Nonetheless, there are TDG TMDLs in place at all four lower Columbia River reservoirs. A joint TMDL for TDG for the Lower Columbia River was completed by the states in 2002 and is still in effect.

To minimize TDG production during the juvenile fish passage spill season and during flood events, spillway deflectors were installed at the spillbays of all four dams. These deflectors help to redirect the spill jet from a plunging flow that transports air bubbles deep into the stilling basin, to a horizontal jet that maintains entrained air much closer to the water surface. Other TDG abatement measures include limiting the amount of spill that is released from the dams and implementing spill patterns that distribute spillbay flows uniformly across the entire spillway.

Under the No Action Alternative, it is expected that juvenile downstream fish passage operations will continue to be implemented over the next 25 years. These operations are regionally supported as they have proved to be an important tool for safe downstream juvenile fish passage. In the future, it is unknown how impacts to water quality, namely TDG, may limit spill at the lower four Columbia River dams. There has been an increasing interest by some stakeholders to loosen constraints on TDG water quality state waivers and increase spill released from the lower Columbia River dams.

Forebay TDG for the No Action Alternative at McNary, John Day, The Dalles, and Bonneville Dams were modeled under a 5-year range of river and meteorological conditions (Figure 3-25 and Figure 3-26). The modeled results show that forebay TDG saturations can exceed 115 percent at all four dams during most of the years and conditions presented. The only exception was for The Dalles Dam which had zero modeled forebay TDG exceedances in 2015, a year when river flows were lower than normal, and summer ambient air temperatures were higher. Maximum forebay TDG saturation would be higher during a year when river flows were higher than normal, and summer ambient air temperatures were lower (such as in 2011). The number of modeled forebay TDG exceedances within a particular year would be highest at Bonneville Dam, though the maximum modeled forebay TDG saturation would be observed at McNary or John Day Dam.

Modeled results for tailwater TDG for the No Action Alternative (Figure 3-27 and Figure 3-28) show that tailwater TDG saturations can exceed 120 percent at all four dams depending on the years and conditions presented. Tailwater TDG exceedances would be expected at McNary and The Dalles Dams under all conditions except lower than normal flow and higher air temperature (such as in years 2011 to 2014). At John Day Dam, tailwater TDG exceedances would be expected only under high or average flow conditions and lower than normal air temperature (such as in years 2011 to 2012). TDG exceedances would be expected in the Bonneville tailwater under the full range of modeled river and meteorological conditions. Generally, the number of expected exceedances decreases as flow decreases and air temperature increases. Maximum TDG saturations would be higher during a year when river flows were higher than normal, and summer ambient air temperatures were lower (such as in 2011). Under average and low flow conditions (such as in years 2012 to 2015), the maximum modeled tailwater TDG saturation would be observed at Bonneville Dam. Under high flow conditions (such as in year 2011), the maximum modeled tailwater TDG saturation would be highest at McNary Dam (though only slightly higher than at Bonneville Dam).

Table 3-9 and Table 3-10 shows the number of exceedances at each of the lower Columbia forebay and tailwater sites, respectively. The number of exceedances increases drastically as the water moves downstream to Bonneville. The highest number of exceedances, as expected, occurs during the high flow year with the lowest number of exceedances occurring during the low flow years. The total number of exceedances that occurs in the lower Columbia sites are higher outside of the juvenile fish spill season (April 1 – August 30) by about 57%.

In summary, the modeling results show that, under the No Action Alternative, TDG saturation exceedances can occur during spill season, but vary depending on inflow, meteorological conditions, and spill operations. This would be expected to continue into the future.

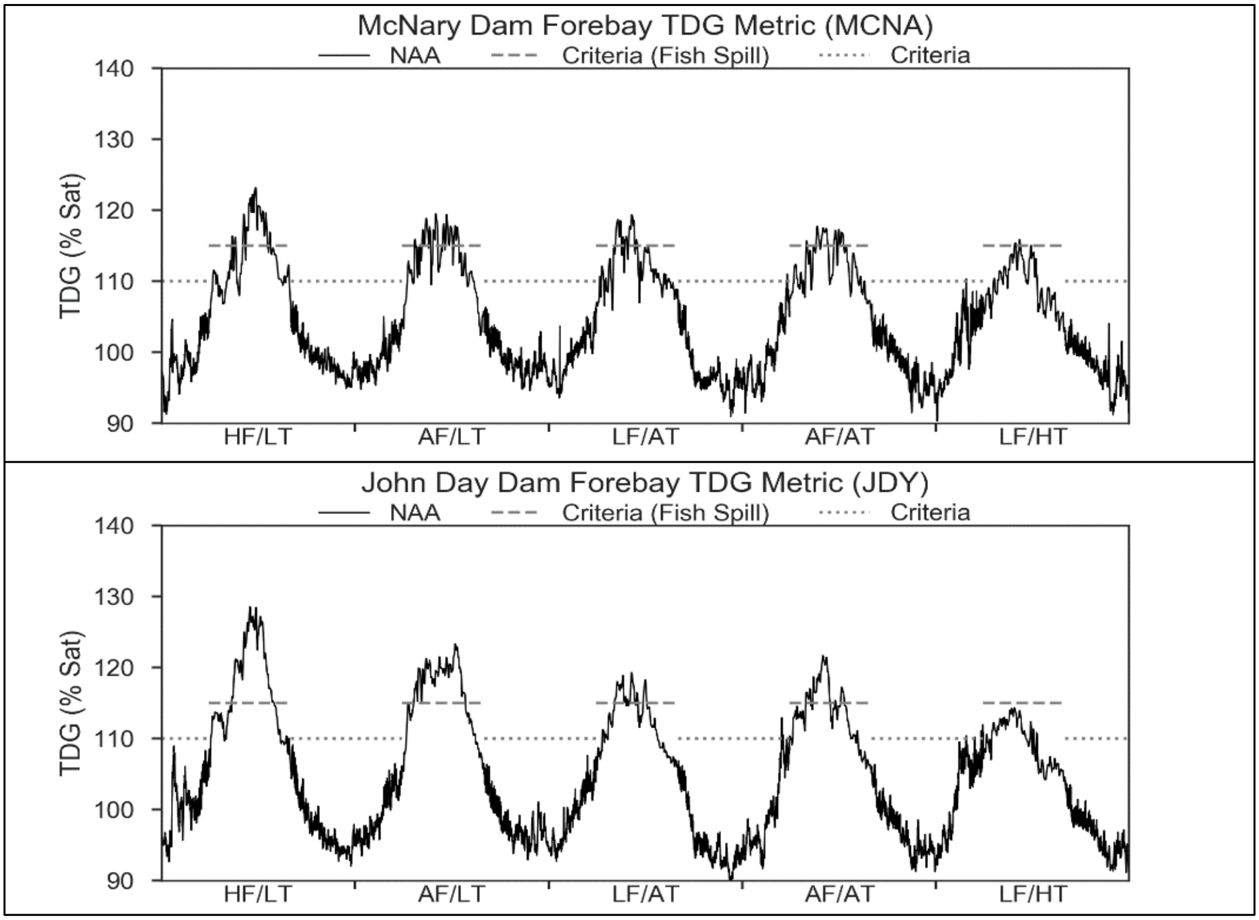


Figure 3-25. Modeled Forebay Total Dissolved Gas for the No Action Alternative at McNary and John Day Dams Under a 5-Year Range of River and Meteorological Conditions

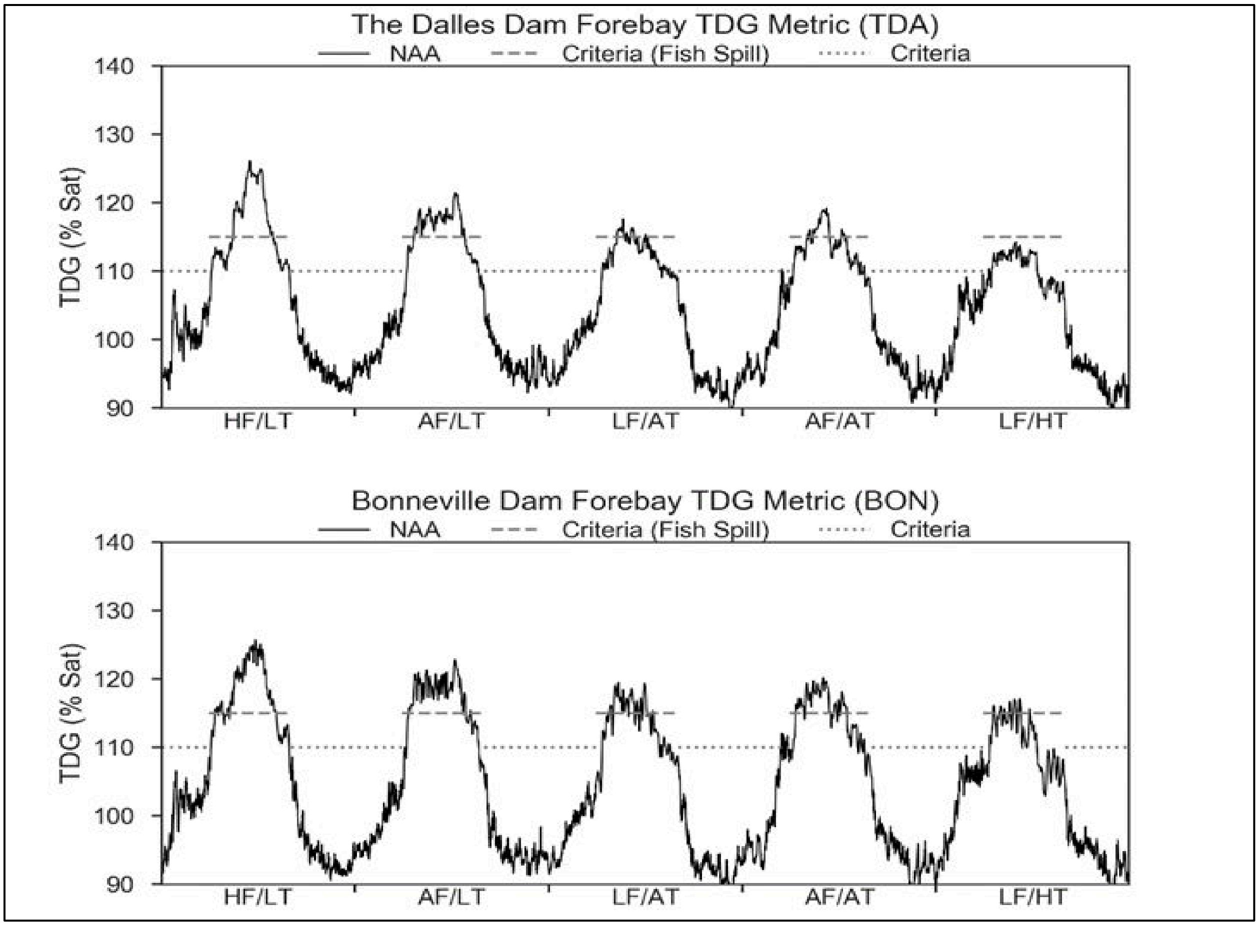


Figure 3-26. Modeled Forebay Total Dissolved Gas for the No Action Alternative at The Dalles and Bonneville Dams Under a 5-Year Range of River and Meteorological Conditions

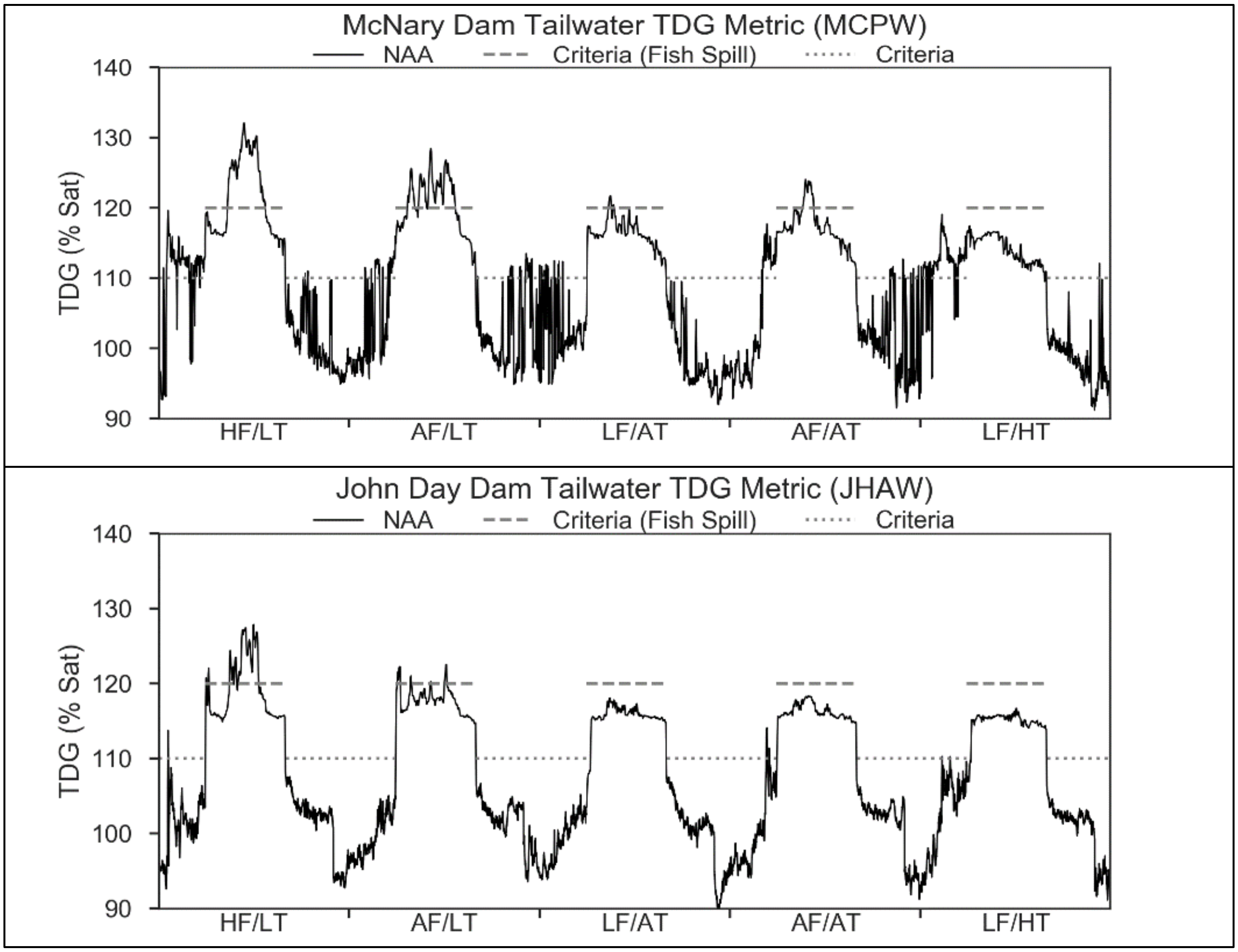


Figure 3-27. Modeled Tailwater Total Dissolved Gas for the No Action Alternative at McNary, and John Day Dams Under a 5-Year Range of River and Meteorological Conditions

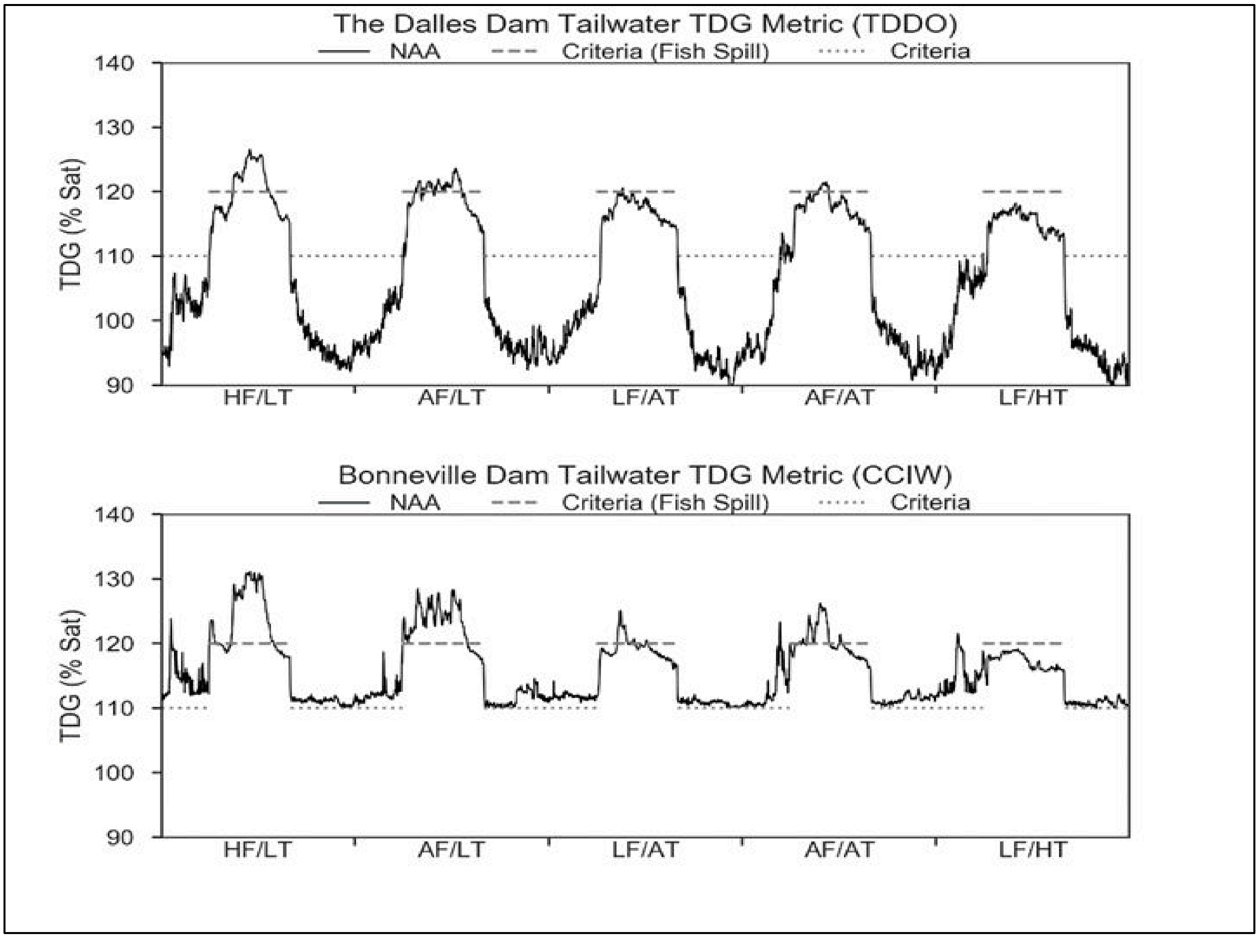


Figure 3-28. Modeled Tailwater Total Dissolved Gas for the No Action Alternative at The Dalles and Bonneville Dams Under a 5-Year Range of River and Meteorological Conditions

Table 3-9. Number of Days the Total Dissolved Gas Criterion is Exceeded at McNary, John Day, The Dalles, and Bonneville Forebay Sites Under a 5-Year Range of River and Meteorological Conditions

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary	February	0	0	0	0	0
McNary	March	0	0	0	1	0
McNary	April	0	2	0	0	0
McNary	May	4	21	18	11	2
McNary	June	25	20	13	17	4
McNary	July	23	13	0	11	0
John Day	February	0	0	0	0	0
John Day	March	0	0	0	2	1
John Day	April	0	11	0	0	0
John Day	May	18	30	24	27	0
John Day	June	30	30	19	17	0
John Day	July	31	27	4	7	0

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
John Day	August	1	0	0	0	0
John Day	September	0	0	0	0	0
The Dalles	March	0	0	0	0	0
The Dalles	April	0	10	0	0	0
The Dalles	May	16	30	17	22	0
The Dalles	June	30	30	7	14	0
The Dalles	July	30	26	2	8	0
The Dalles	August	0	0	0	0	0
The Dalles	September	0	0	0	0	0
Bonneville	March	0	0	0	8	0
Bonneville	April	12	19	5	17	4
Bonneville	May	25	31	28	31	15
Bonneville	June	30	30	23	21	7
Bonneville	July	31	27	7	16	0
Bonneville	August	5	3	0	0	0
Bonneville	September	0	0	0	0	0

Table 3-10. Number of Days the Total Dissolved Gas Criterion is Exceeded at McNary, John Day, The Dalles, and Bonneville Tailwater Sites Under a 5-Year Range of River and Meteorological Conditions

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary	January	17	0	5	0	18
McNary	February	26	10	2	0	28
McNary	March	22	15	0	28	26
McNary	April	0	9	0	0	0
McNary	May	19	23	8	11	0
McNary	June	30	30	1	10	0
McNary	July	24	23	0	0	0
McNary	August	0	0	0	0	0
McNary	September	0	0	0	0	0
McNary	October	1	0	0	0	0
McNary	November	0	6	0	8	0
McNary	December	0	10	0	1	1
John Day	January	1	0	0	0	0
John Day	February	0	0	0	0	1
John Day	March	0	1	0	3	0
John Day	April	3	8	0	0	0
John Day	May	13	0	0	0	0
John Day	June	28	2	0	0	0

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
John Day	July	11	5	0	0	0
John Day	August	0	0	0	0	0
The Dalles	February	0	0	0	0	0
The Dalles	March	0	0	0	17	0
The Dalles	April	0	5	0	0	0
The Dalles	May	16	20	2	7	0
The Dalles	June	30	30	0	13	0
The Dalles	July	23	20	0	0	0
The Dalles	August	0	0	0	0	0
The Dalles	September	0	0	0	0	0
Bonneville	January	31	31	31	31	31
Bonneville	February	28	29	28	28	28
Bonneville	March	31	31	31	31	31
Bonneville	April	19	30	0	9	0
Bonneville	May	19	31	19	27	0
Bonneville	June	30	30	5	15	0
Bonneville	July	31	31	6	4	0
Bonneville	August	0	0	0	0	0
Bonneville	September	30	30	30	30	30
Bonneville	October	31	31	31	31	30
Bonneville	November	30	30	30	30	30
Bonneville	December	31	31	31	31	29

3.3.3 Other Physical, Chemical, and Biological Processes

Suspended solids concentrations and turbidity are generally highest when flow is also high, though both are rarely observed at levels of concern. At any given time, the concentrations of total and dissolved constituents, as well as Secchi disk depth, conductivity, and other physical parameters, are not markedly different from one end of the lower Columbia River System to the other. Water in the main channel is well oxygenated; rarely is dissolved oxygen below 7.5 mg/L, but it is sometimes quite high (13-15 mg/L), likely due to photosynthetic activity. PH is typically a bit higher than neutral, varies spatially only minimally, and has no obvious temporal trend. Additionally, pH can be considered high at times as it has been measured above 8.5 at least once within the last 10 years in each of the reservoirs. High pH and/or dissolved oxygen in portions of the reach from The Dalles to Bonneville Dams resulted in the inclusion of these parameters in the Washington or Oregon 303(d) lists. Chlorophyll a is highly variable both spatially and temporally. Based on summer concentrations of total phosphorus, chlorophyll a, and transparency, each of the reservoirs is typically mesotrophic, though occasionally slightly oligotrophic or slightly eutrophic depending on the location. Phytoplankton and zooplankton data are limited to older, single datasets in each of the McNary and John Day Reservoirs; data from multiple sampling events in similar locations were not available to make temporal comparisons.

Pollutants in the lower Columbia River are widely distributed and are derived from a variety of point and non-point sources. Some portions of all four reservoirs have TMDLs for dioxin and are included in the Washington or Oregon 303(d) lists for polychlorinated biphenyls (PCBs). Relatively high uranium concentrations, related to upstream activities, were present in all four reservoirs, though data was only available for one sampling event in 2009. Atmospheric deposition from urban areas also contributes pollutants to the lower river, such as mercury. Bonneville Lake and Lake Celilo (The Dalles and Bonneville Reservoirs) were included in the Oregon 303(d) list for mercury. The Oregon Health Authority recommends limiting the amount of resident fish species consumed from Ruckel Creek (about 1 mile upstream of Bonneville Dam) upstream to McNary Dam due to moderate levels of mercury and PCBs in fish tissue. Consumption of resident fish is not advised in this portion of the reach from Bonneville Dam to Ruckel Creek due to high levels of PCBs in fish tissue. Salmon, steelhead, lamprey and shad are not included in either of these fish advisories. Legacy pesticides from agricultural runoff have also been found in all lower Columbia River reservoirs, with higher concentrations found near tributary junctions.

The introduction of pollutants and excess nutrients from farming and industrial activities as well as urban runoff and atmospheric deposition is expected to continue. Emerging contaminants such as pharmaceuticals and new pesticides will also likely become more prevalent. The lower Columbia River contains a wide variety of human-sourced compounds, including metals and organic compounds. This condition is expected to remain generally unchanged and, thus, it is expected that these impairments would continue under the No Action Alternative.

3.4 SEDIMENT THROUGHOUT THE SYSTEM

Upland sediment sources are expected to generally remain as they are currently identified in the Affected Environment. In-water processes that affect sediment movement, such as seasonally high flows, are expected to generally remain as well. Sediment erosion and accretion would continue following similar patterns with no great change in magnitude or extent since no major structures (dams, locks, or other large structures) are expected to be added or removed from the Columbia River under the No Action Alternative.

3.4.1 Upper Columbia River Basin

Libby Dam has greatly influenced the sediment transport in the Kootenai River. Lake Koocanusa is estimated to trap 94 to 97 percent of incoming sediments during average flow conditions and about 88 percent under peak flow conditions. Historical and current point source discharges of contaminants that may impact sediments in Lake Koocanusa and the Kootenai River exist in the watershed. Two major sources of sediment contamination in the watershed, an ammonium phosphate fertilizer plant and a kraft pulp mill, have been closed or substantially improved. However, coal mining operations have expanded in the watershed in British Columbia with a ten-fold increase in waste spoils. Studies have shown an increase in the loadings of selenium and nitrogen to Lake Koocanusa from coal mining operations.

Sediment metals concentrations in both the Canadian portion of the reservoir and in Montana are low, with no metals concentrations exceeding the Pacific Northwest regional sediment screening levels, suggesting that adverse effects to the benthic community would not be expected. For most metals, concentrations in benthic sediments were significantly greater than corresponding shoreline sediments, suggesting that metals may be accumulating in Lake Koocanusa. Downstream of Libby Dam, sediment metals, organochlorine pesticides, polycyclic aromatic hydrocarbons (PAHs), PCBs, and asbestos concentrations are low. River sediment metal concentrations are similar to Lake Koocanusa, while PCBs were below laboratory detection limits, and PAHs were low. Concentrations of organochlorine pesticides detected in the river were very low, with most organochlorine pesticides (including DDT + metabolites) well below any Pacific Northwest regional sediment evaluation screening levels (https://www.nwd.usace.army.mil/CRSO/Documents/).

Sixty-five percent of the watershed upstream of Hungry Horse Dam lies within a wilderness area and the rest of the basin is sparsely developed. The watershed is largely unaffected by human activities and there has been little concern for contaminant issues.

Extensive mining has occurred in the Clark Fork-Pend Oreille watershed since the late 1800s. Elevated concentrations of metals such as cadmium, copper, lead, and zinc in sediments have been documented in the Clark Fork-Pend Oreille River watershed as far downstream as the Priest River, just upstream of Albeni Falls Dam. These data suggest that metal contamination from the Clark Fork River has been transported downstream through Lake Pend Oreille and into the Pend Oreille River. The limited amount of sediment organic contaminant data collected in the Clark Fork-Pend Oreille River system upstream of Albeni Falls Dam, suggests that little contamination is present. Downstream of Albeni Falls Dam, sediment metals concentrations for lead and zinc in the Lower Pend Oreille River were low to moderate and did not exceed the Pacific Northwest regional screening levels suggesting that adverse effects to the benthic community would not be expected (RSET 2018). For most metals, concentrations measured in the lower Pend Oreille River were similar to or slightly lower than concentrations measured upstream of Albeni Falls Dam. Concentrations of organochlorine pesticides and PCBs measured in selected sediment samples were all below laboratory reporting limits (https://www.nwd.usace.army.mil/CRSO/Documents/).

Grand Coulee Dam is an efficient sediment trap and little suspended material moves through the dam and downstream. Sediment eroded from the landscape washes into the river during naturally occurring landslides, although Lake Roosevelt drawdown operations can increase the possibility of anthropomorphically caused landslides. Lake Roosevelt water levels are closely managed to prevent landslides, and would continue to be in the future.

Lake Roosevelt sediments are polluted from metals mining and smelting operations. From 1896 to 1995, smelting waste products (primarily slag and wastewater) were discharged into the Columbia River a few miles north of the U.S.-Canada border, introducing zinc, mercury, arsenic, lead, and other metals and contaminants into the lake. Contaminated smelting wastewater continues to be discharged into the river. Some metals have bioaccumulated through the food chain of plants and animals in and surrounding the lake, with the greatest levels of bioaccumulation occurring closest to the location of smelting operations. Movement of slag, wastewater, and sediments that have been contaminated by these materials has not been sufficiently characterized. However, elevated surface water metal concentrations associated with wastewater releases have been reported near Grand Coulee Dam. Additionally, during high flow events, the surface waters of downstream Rufus Woods Lake can have elevated levels of zinc, suggesting that flow events can facilitate downstream movement of smelting wastewater contaminants. Sediment in Rufus Woods Lake contains elevated levels of metals such as zinc, lead, mercury, and cadmium. Elevated concentrations of metals can bioaccumulate and if concentrations are very high can kill aquatic organisms, and fish consumption advisories are made when levels of contaminants in fish tissue render their consumption a health hazard. Mobilization and exposure of contaminated bed sediments is affected by Lake Roosevelt drawdown depths and durations. Under the No Action Alternative, the management of Lake Roosevelt would largely be unaltered, and drawdown depths and durations would remain similar to those that already occur. Impacts to sediment transport and aquatic biota under the No Action Alternative would therefore be similar to those under current conditions (https://www.nwd.usace.army.mil/CRSO/Documents/).

In addition to mining and smelting pollution originating north of the U.S.-Canada border, sites of historical mining operations on the Spokane River, which enters the Columbia River in Lake Roosevelt, are sources of contaminated sediments entering in to Lake Roosevelt. Levels of PCBs in the tissue of fish from the Spokane River have exceeded guidelines for human consumption (https://ecology.wa.gov/Water-Shorelines/Water-quality/Water-improvement/Assessment-of-state-waters-303d). Fish tissue concentrations of compounds may reflect water and sediment quality. It is unknown at what rate PCBs are entering Lake Roosevelt from the Spokane River, but it is not anticipated to increase in the future as long as upstream land and dam management practices do not change.

3.4.2 Lower Snake River

This stretch includes the Clearwater River below Dworshak Dam downstream to the confluence with the Snake River, and the Snake River beginning at the Hells Canyon Complex downstream to Ice Harbor Dam. Based on the Programmatic Sediment Management Plan (Corps 2014), the majority of sediment entering the lower Snake River (into the Lower Granite Reservoir) comes from the upper Snake River – Hells Canyon area, with less material provided by the Clearwater River. There is some evidence that erosion and sediment inputs have increased over the several decades (Corps 2014), which has been attributed to wildfires and agricultural practices. Wildfires occur at unpredictable intervals, and can denude forested areas leaving them susceptible to erosion from rainfall and snowmelt runoff (USFS 2017).

The Snake River runs along the Idaho-Oregon border and the watershed extends far into Idaho. Idaho has a Nonpoint Source Management Plan which discusses nonpoint source categories and nonpoint source pollution prevention. (Idaho Department of Environmental Quality [IDEQ] 2015) Nonpoint source pollution categories include agriculture, livestock grazing, natural resource extraction (mining), timber/silviculture management, urban and suburban development, and transportation. The Idaho plan includes the implementation of best management practices and pollution abatement practices as methods for meeting nonpoint goals. Sedimentation/siltation and total suspended solids are pollutant categories that are identified in the Idaho 303d integrated report as causing stream impairments (IDEQ 2014). A statewide implementation of nonpoint pollution controls could reduce human-induced sediment loading to streams, especially sediment sources related to land uses. Similarly, the Corps has committed to coordinating with the local sediment management group and other land managing agencies to explore opportunities to implement additional upland sediment reduction projects when feasible (Corps 2014).

Below Lower Granite Dam, the Snake River receives much less sediment input due to the flatter terrain and generally lower precipitation. (Corps 2014) Several tributaries provide sediment to the various reservoirs, but at a much lower rate than the input to Lower Granite Reservoir. Land uses include some suburban population areas as well as agriculture and grasslands; these are potential sources of sediment and pollutants due to point and non-point discharges. The sediment is generally considered to be affected by pesticides as evidenced by the 303d listings for fish tissue impairments. USGS tracks pesticide occurrence in major rivers; see for example Williamson (1998) and similar publications for information on pesticides in the Columbia River Basin. Pesticide occurrence is expected to continue similar longterm (increasing) trends as those identified by Ryberg and Gilliom (2015).

3.4.3 Lower Columbia River

The lower Columbia River includes the Columbia River below the middle reach non-Federal dams and the Snake River below the Ice Harbor Dam, extending to Bonneville Dam (the downstream limit of this project). The bed of the main channel is composed of fine and medium grained sands (0.125 to 0.500 millimeter). Between 80 to 90 percent of the sediment transported through the lower Columbia River is composed of suspended fine-grained sediment. The natural riverbanks consist of 10 to 20 feet of clay-silt, overlying much deeper sand deposits. At the downstream end (below Bonneville Dam), sandy beaches occur where dredged material has been placed along the shore (USACE 2020).

The lower Columbia River drainage area is more heavily populated than the upper watershed, with several larger population centers (e.g., Kennewick). In general, land use transitions from rural and agricultural to urban/suburban downstream (approaching Portland) although large tracts of protected and forested lands exist. The downstream end (Bonneville Dam area) has experienced numerous wildfires, including the 2017 Eagle Creek fire. Burned land is more erodible due to the lack of vegetation and other changes in the surface soil. For example, post-fire flood flows on Eagle Creek are expected to increase by 412 percent and the rate of soil erosion is projected to increase from essentially zero before the fire to over 4 tons per acre

(U.S. Forest Service 2017). The general pattern of increasing erosion would be expected to occur throughout the basin after major fires.

Sediment pollutants in the lower Columbia River are widely distributed and derived from a variety of point and non-point sources. The Hanford site is a well-known active remediation area. Urban and agricultural runoff is the source of a variety of pollutants. Atmospheric deposition also contributes pollutants from urban areas; notably mercury. In general, the lower Columbia River contains a wide variety of anthropogenic compounds including metals and organic compounds. This condition is expected to remain generally unchanged. As with sediment in the rest of the basin, pollutants would be expected to remain and to be toxic to some benthic organisms (MacDonald et al. 2012). Bioaccumulation of some compounds, as demonstrated in fish advisories and 303d listings, would also be expected to continue for the future.

3.4.4 Chemicals of Concern

Major land uses throughout the watershed include agriculture, forest/timber, and industrial and urban/suburban development. Over the next 25 years, the general land use is expected to remain largely the same partly due to the large tracts of publicly held lands that are not available for development. Population growth is concentrated mostly in the metropolitan counties of the state (Washington Office of Financial Management 2018). The current patterns of predominately agricultural land use, agriculture and forest product manufacture, and navigation would continue, driving the need for future sediment management in navigation channels. It is anticipated that pesticides – the specific compounds, the patterns of use, and the quantity of applied materials – would change over time as additional experience is gained with currently used chemicals and as new commercially available options are developed. Older pesticides would cease to be used, resulting in a slow change to the composition of chemical contaminants found in the sediment. However, deeply shoaled materials, such as those immediately behind the dams, would continue to be a reservoir of historical pesticides and pesticide degradation products.

Current chemicals of concern would remain concerns. This includes metals, PAHs, volatile organic compounds, pesticides and pesticide degradation products, PCBs, dioxins, radionuclides, and nutrients (ammonia). Existing pollution that has accumulated would not completely biodegrade or chemically react, although some compounds would at least start to break down (the now banned pesticide DDT would slowly become the degradation products DDE or DDD, for example). Metals do not biodegrade and would remain in the sediment. Ongoing research is likely to identify new sediment contaminants that would be regulated, such as current work on the occurrence of trace pharmaceuticals (Nilsen et al. 2014). The presence of these compounds in sediment is not well studied, but it is anticipated that new chemicals of concern may be identified. Future sediment quality may reflect changes in environmental regulation on water discharges. Note that pesticide use and quantities applied can be obtained through the Pesticide General Permit annual reports submitted to the USEPA or to State environmental regulatory agencies.

Sediment management and dredging under the No Action Alternative is the same as the sediment management for the affected environment. Where re-occurring dredging is needed (such as at the confluence of the Snake and Clearwater Rivers), it is assumed that dredged materials would continue to be of sufficient quality for either in-water or upland beneficial use, for habitat creation, or as upland fill. Sediment characterization following the Sediment Evaluation Framework (RSET 2018), or other applicable guidance, would continue to be required for any new dredging or sediment related projects.

3.5 WATER AND SEDIMENT QUALITY CONCLUSIONS

Under the No Action Alternative, reservoir and hydropower operations are assumed to continue in essentially the same manner as current operations.

CHAPTER 4 - MULTIPLE OBJECTIVE ALTERNATIVE 1

Multiple Objective Alternative 1 (MO1) was developed with the goal to benefit or avoid adverse effects to congressionally-authorized purposes while also benefiting ESA-listed fish species relative to the No Action Alternative. To meet multiple objectives, a wide array of measures are included in this alternative. The large number of measures would be implemented throughout the project study area. See Chapter 2 of the main EIS report for a complete description of MO1.

4.1 UPPER COLUMBIA RIVER BASIN

4.1.1 Water Temperature

In general, water temperature response at the Libby and Hungry Horse Dams are expected to be similar to the No Action Alternative. However, slight changes in water temperatures downstream of Libby Dam could occur due to the *December Libby Target Elevation* and *Modified Draft at Libby* measures.

4.1.1.1 Libby and Hungry Horse Dams and Reservoirs

Under MO1, Libby Dam's draft and refill operations will be modified. The end of December sliding scale variable draft will be eliminated and replaced with a single draft target, and a summer sliding scale draft will be implemented. In general, MO1 would result in higher water elevations in Lake Koocanusa for most of the year, but the draft would be deeper for those years with a drier water forecast in April. It should be noted that these changes do vary by water year, water forecast, and time of year. A summary hydrograph for Lake Koocanusa, representing the probability of the reservoir elevation on any given day under MO1 and the No Action Alternative is shown in Figure 4-1. Based on the median, MO1 Lake Koocanusa elevations are similar to No Action Alternative elevations from October through the end of November, and held higher from December through the middle of February. MO1 median elevations are drafted slightly deeper in the spring from March through the end of May, held similar during June and July, and generally held higher by about 1 to 4 feet in August through September. In years with high water supply forecasts (represented by 75 percent and 99 percent in Figure 4-1.) draft rates are similar but generally delayed by a couple of weeks. In years with low water supply forecasts (25 percent and 1 percent in Figure 4-1), MO1 drafts are deeper than the No Action Alternative.

Historical temperature data suggests that holding the pool higher in the winter results in colder spring and summer reservoir temperatures and difficulty for the SWS to achieve downstream temperatures objectives. When the pool is drafted deeper in the winter, the pool volume is less, thereby allowing for greater warming in the spring from warmer inflows and warming air temperatures.

In general, MO1 largely impacts Libby Dam outflows and Kootenai River flows in the winter and spring. Modeled outflows presented in Figure 4-2 show the greatest difference between MO1 and No Action Alternative flows from December through May. In this figure, the 1 percent exceedance represents the highest flows and the 99 percent the lowest flows. Modeling results showed that for the median flows, MO1 releases are expected to be similar in October and November, lower in December, higher from January through March, and relatively similar from April through August. High and low outflows follow a similar pattern with the exception that in June and July, there is an increase in the highest releases under MO1, which translates to an increase in spill from 1 to 2 percent under MO1.

Changes in downstream temperatures from Libby Dam to Bonners Ferry may be a result of MO1 increasing the median monthly flows in January through March to draft the pool at a more aggressive rate. During the cold winter months, Kootenai River water can cool by several degrees between Libby Dam and Bonners Ferry if flows are held low. By increasing the flows to draw the pool down aggressively in the winter, MO1 may prevent the natural cooling of the river as it moves downstream. These higher winter temperatures in the Kootenai River may be detrimental for certain fish species, such as burbot, which require near freezing river temperatures (<35°F or <2°C) to spawn.

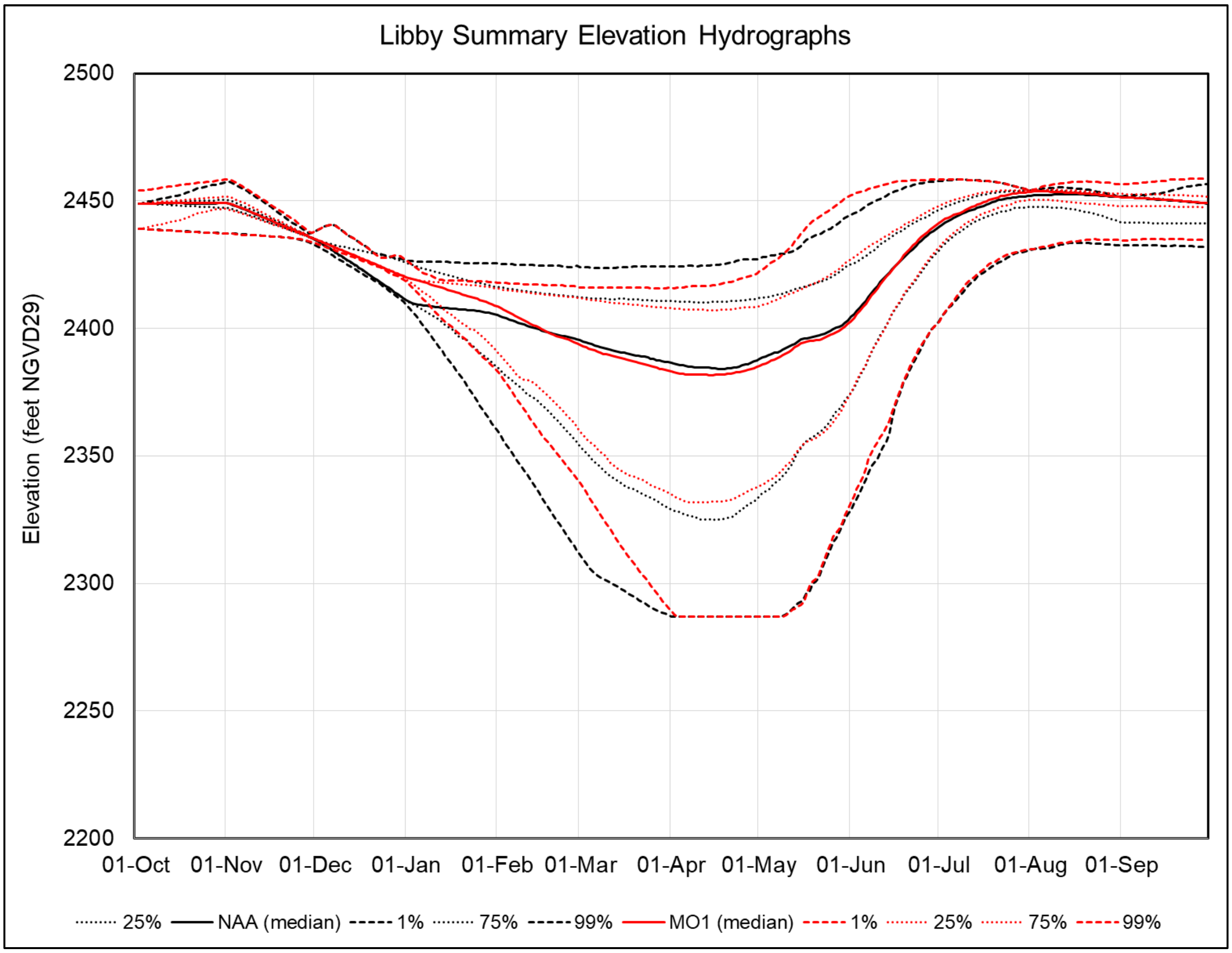


Figure 4-1. Libby Dam-Lake Koocanusa Summary Forebay Elevations for Multiple Objective Alternative 1 Versus No Action Alternative

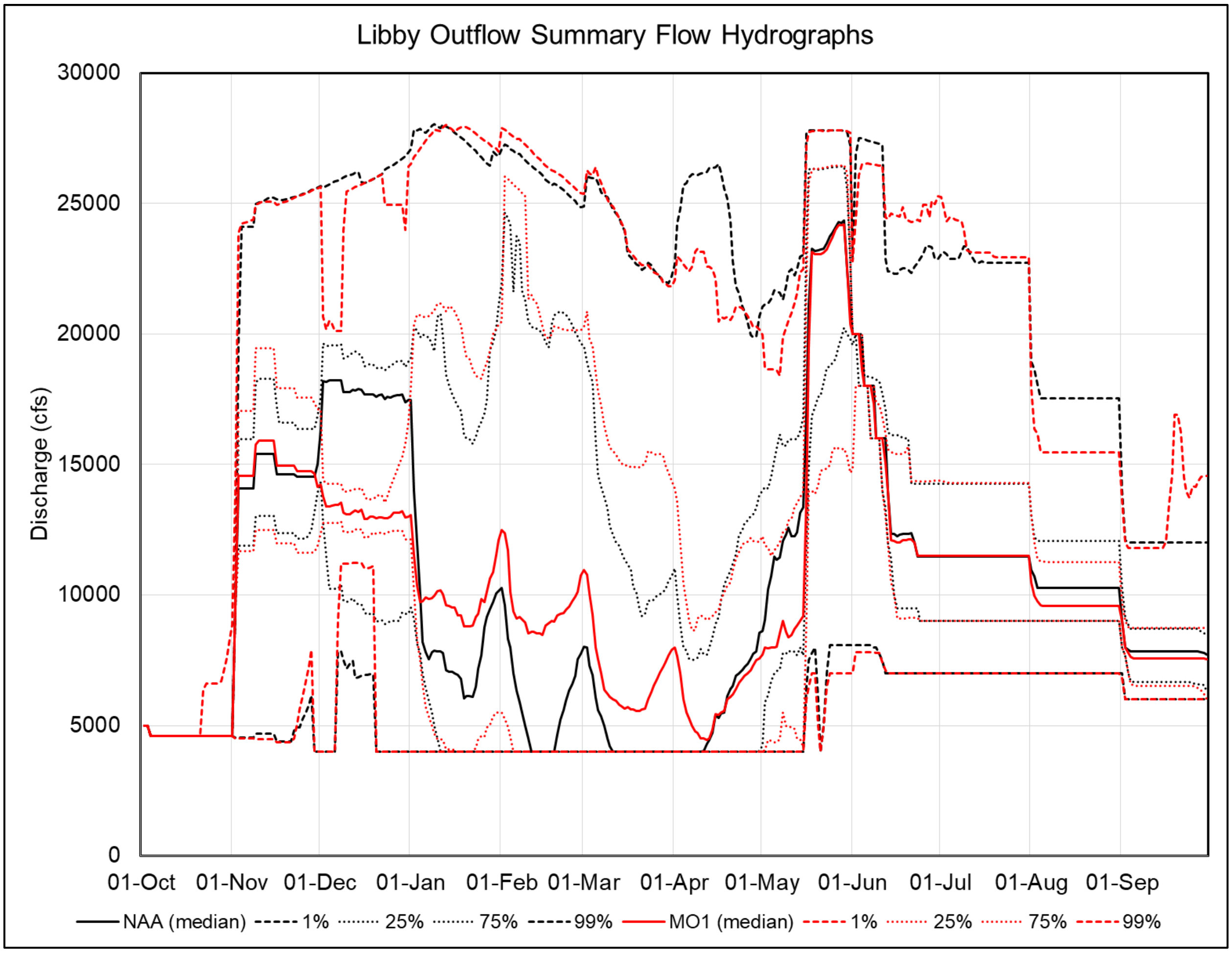


Figure 4-2. Libby Dam-Lake Koocanusa Summary Outflows for Multiple Objective Alternative 1 Versus No Action Alternative

Libby Dam's SWS provides some ability to manipulate where in the water column water entering the powerhouse penstocks is drawn from. The range of the SWS bulkheads are from elevation 2,409 feet to 2,200 feet. Because SWS protocol maintains at least 30 feet of submergence over the top row of the bulkheads for hydraulic stability, the SWS has the ability to perform under the full range of possible MO1 drawdown operations with a similar efficiency as under the No Action Alternative. Modeled forebay elevations under MO1 are predicted to be slightly different than under the No Action Alternative but within the operating range of the SWS and similar to the ranges observed in historical years. As such, use of the SWS to manage downstream water temperatures seen under the No Action Alternative is expected to continue under MO1.

The ability of the SWS to manage downstream water temperatures under a variety of drawdown and inflow conditions will continue under MO1. However, under the No Action Alternative, downstream river temperatures during the fall and winter are generally several degrees warmer than pre-dam Kootenai River conditions, while water released from the dam during the spring and summer is generally several degrees cooler than natural river conditions

(See Figure 3-1). The limitations of the SWS that exist for the No Action Alternative are expected to continue for MO1.

Under MO1, modeled water temperatures in the South Fork Flathead River below Hungry Horse Dam would be similar to conditions expected under the No Action Alternative. Only two operational measures in MO1 apply to Hungry Horse:

- Sliding Scale at Libby and Hungry Horse
- Hungry Horse Additional Water Supply

These measures would implement a sliding scale draft and allow for the additional release of 90 kaf of stored water from April 1 to October 30. Since water temperature in the downstream river is managed through the use of a SWS, neither of these operational measures would likely have an impact on meeting downstream water temperature objectives (Figure 4-3).

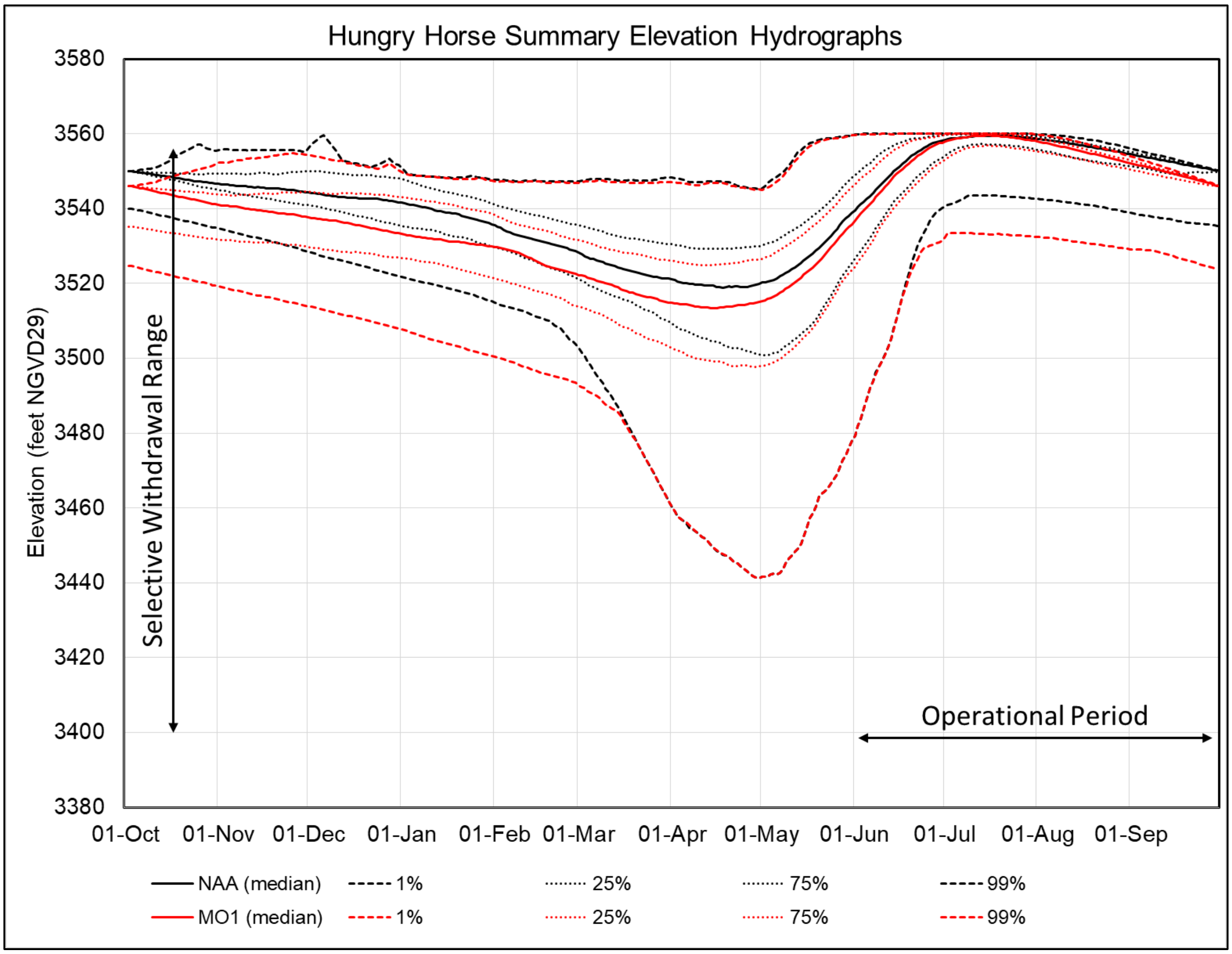


Figure 4-3. Hungry Horse Summary Forebay Elevations for Multiple Objective Alternative 1 Versus No Action Alternative Showing the Operational Range of the Selective Withdrawal Structure.

Hungry Horse Reservoir thermally stratifies in the summer and can provide some downstream water temperature management through use of the SWS. The SWS at Hungry Horse Dam is operated from approximately June to end of September. The SWS can be made/modified to operate over a pool elevation range from full (3,560 feet) down 160 feet (3,400 feet), with the lower operating position providing for a control gate submergence of 20 feet. However, major modification to the structure(s) is required to enable function over the lower 60 feet of this range, including removal of the upper and intermediate stationary gates. The ability of the SWS to manage discharge temperatures under a variety of drawdown and inflow conditions will continue under all of the Multiple Objective Alternatives. Similar to Libby, the SWS relies on the thermal stratification of the reservoir for downstream water temperature management. The onset of thermal stratification is difficult to predict and can vary from year to year because of reasons such as inflow volumes, inflow temperatures, reservoir drawdown elevation, discharge volumes and weather conditions. Historical temperature data suggests that holding the pool higher results in colder reservoir temperatures and difficulty meeting downstream water temperatures in the spring. When the pool is drafted deeper, the pool volume is less, thereby allowing for greater warming in the spring and summer from warmer inflows and warming air temperatures.

The change in drawdown elevations under MO1 are not likely substantial enough to result in a significant change in forebay temperatures and thermal stratification compared to the No Action Alternative. The limitations of the SWS that exist for the No Action Alternative are expected to continue for all of the Multiple Objective Alternatives.

4.1.1.2 Albeni Falls Dam and Reservoir

Under MO1, there are no changes to operations at Albeni Falls Dam. Any changes in flow from Hungry Horse Dam under MO1 that move downstream through the basin are diluted and become small by the time they enter the Pend Oreille River Basin. As such, there are no expected changes in Lake Pend Oreille elevations or Pend Oreille River flows between MO1 and the No Action Alternative. Model results show little change in temperature at Albeni Falls Dam between MO1 and No Action Alternative with the majority of temperature differences between the two alternatives of about ± 0.35 degree Fahrenheit (± 0.2 degree Celsius) (Figure 4-4 and Figure 4-5). Modeled temperatures under both MO1 and the No Action Alternative would continue to exceed the IDEQ Pend Oreille River temperature criteria (1-Day Maximum of 71.6°F and 1-Day Average of 66.2°F) during the summer.

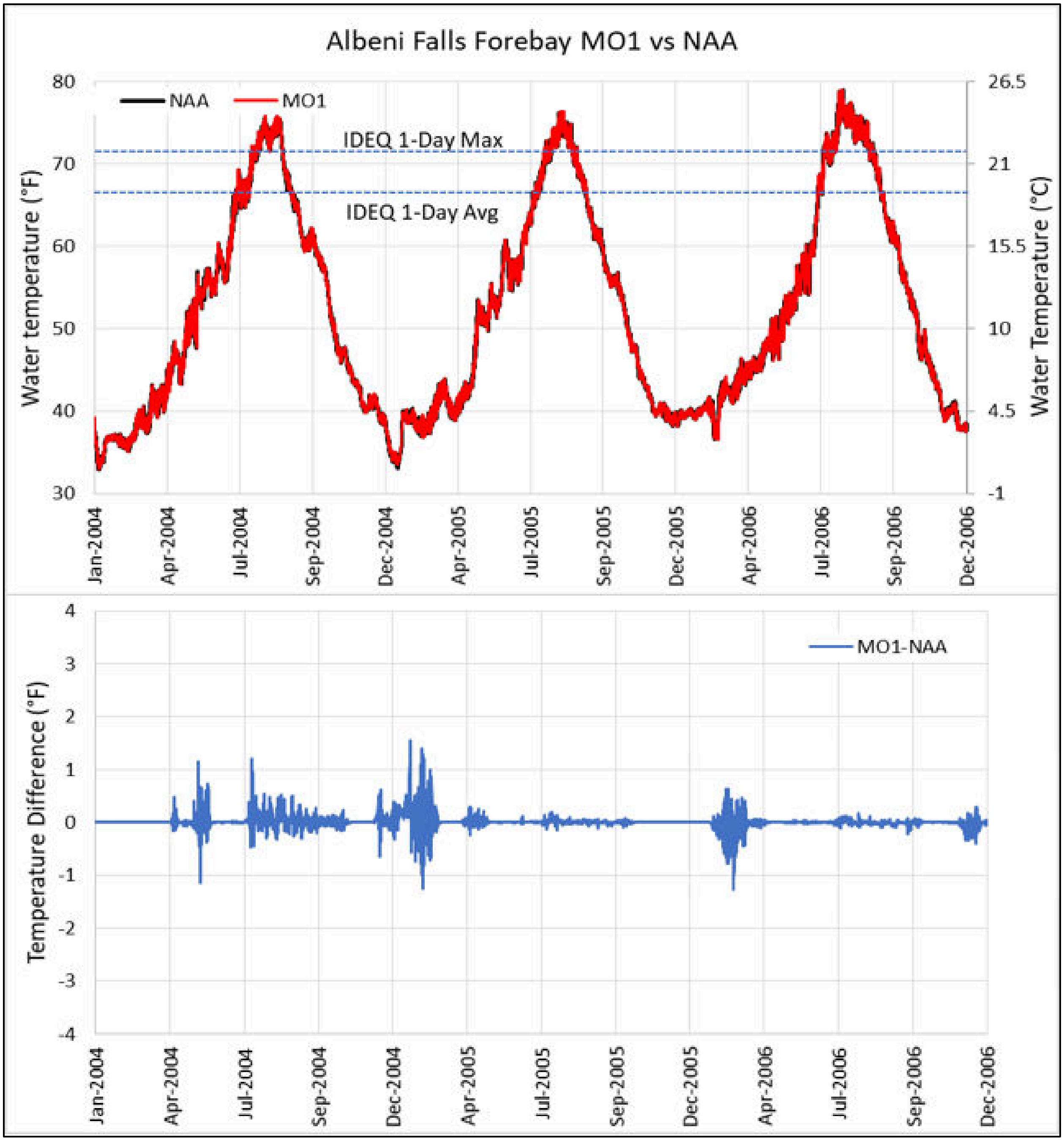


Figure 4-4. Modeled Forebay Temperatures for the No Action Alternative and Multiple Objective Alternative 1 at Albeni Falls from 2004 to 2006

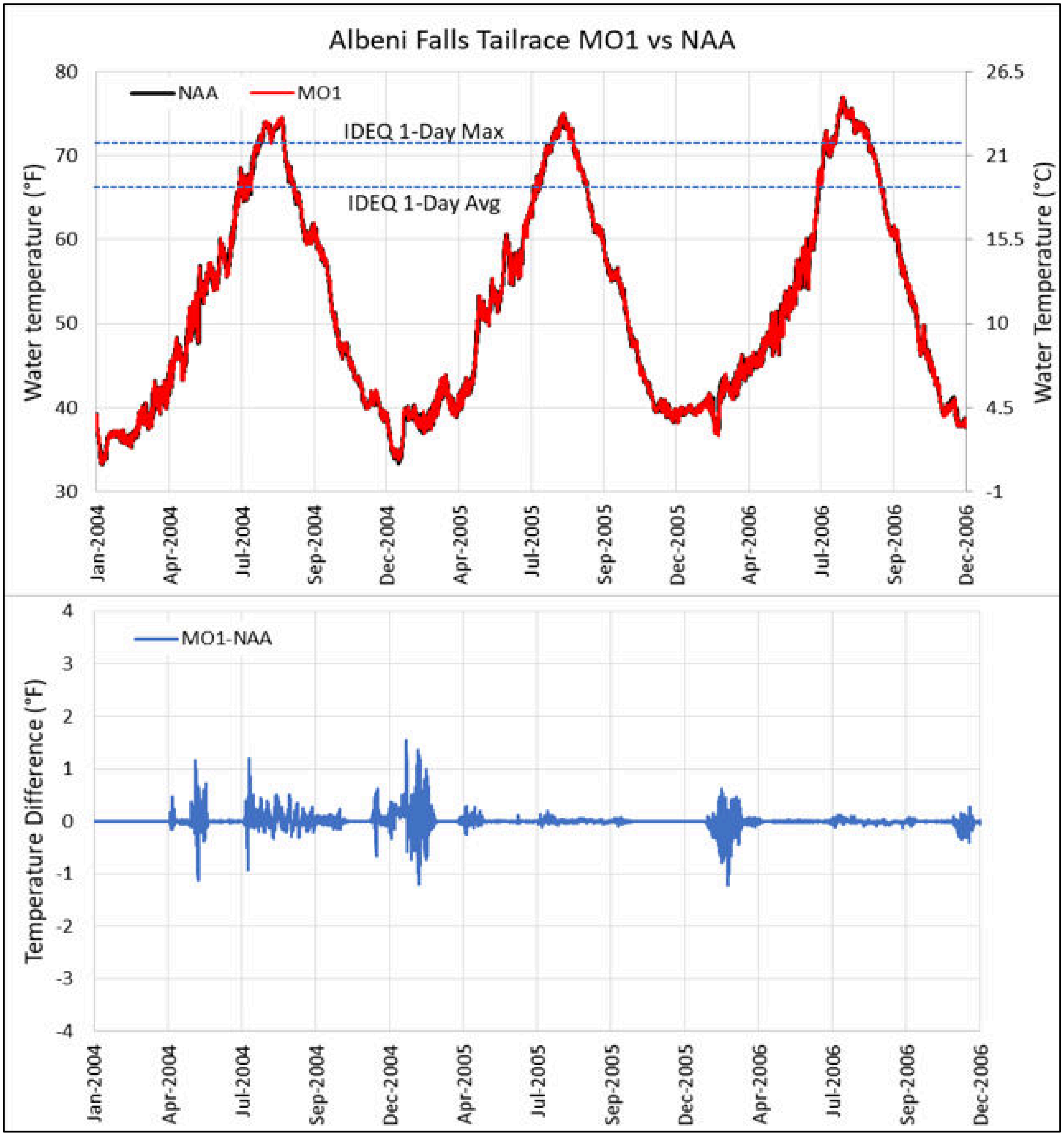


Figure 4-5. Modeled Tailwater Temperatures for the No Action Alternative and Multiple Objective Alternative 1 at Albeni Falls from 2004 to 2006

4.1.1.3 Grand Coulee and Chief Joseph Dams and Reservoirs

Under MO1, five operational measures apply to changes in management at Grand Coulee Dam as compared to the No Action Alternative:

- *Update System Flood Risk Management (FRM) Calculation;*
- *Grand Coulee Maintenance Operations;*
- *Planned Draft Rate at Grand Coulee;*
- *Winter System FRM Space, and;*
- *Lake Roosevelt Additional Water Supply*.

Combined, these measures would result in Lake Roosevelt being drafted 650,000 acre-feet deeper in December, combining with other FRM measures to be deeper than the No Action Alternative January through March, and a removal of an additional 1.15 Maf of water (about 1.5 percent of total average inflow into Lake Roosevelt from April to October) from the reservoir for water supply purposes.

Overall, temperatures in the reservoir are predicted to remain largely the same as the No Action Alternative. The changes that do occur are short in duration or low in magnitude. In general, impacts are greatest at Grand Coulee Dam and are reduced toward the U.S.-Canada border wherein the impacts from MO1 are almost unnoticeable at Hall Creek.

Figure 4-6 shows predicted water temperatures below Grand Coulee Dam under MO1 as compared to the No Action Alternative. Water temperatures are similar under both alternatives, but model results suggest there would be a slight increase in water temperatures, particularly in the spring, under MO1 in the LF/HT type years. For the LF/HT type years, the modeled water temperature downstream of Grand Coulee Dam during the spring/early summer months is approximately 0.3 degree Fahrenheit warmer (for the period from May through July) than the No Action Alternative, but releases range from plus or minus several degrees. The temperature differences are likely due to a combination of the water year type (extreme low flow year with high temperatures susceptible to changes in operations) and operational changes resulting in reduced outflows (FRM and water supply measures). An additional factor influencing spring and summer temperatures in some years may be winter and spring operations that decrease storage during that period, which would potentially reduce the cold water mass that would influence the inflowing temperature signal from upstream.

Model results predict little change in Rufus Woods Lake forebay elevations for MO1 when compared to the No Action Alternative (Figure 4-7). Consequently, modeled temperatures under MO1 at Chief Joseph Dam tailwater are similar to the No Action Alternative with the majority of temperature differences in the ±1 degree Fahrenheit range (Figure 4-8). In general, temperatures modeled for MO1 are similar or slightly cooler than the No Action Alternative for most river and climate conditions. An exception is for the low flow scenarios (LF/AT and LF/HT) where river temperatures in the spring are expected to be up to 1 degree Fahrenheit greater under the MO1 alternative. Tailwater temperatures under both the MO1 and No Action Alternative are predicted to exceed the Washington State criterion of 63.5F (17.5°C) as measured by the 7-day average of the daily maximum temperature in August and September. Similar to the No Action Alternative, there is little difference in temperature between Grand

Coulee Dam (Figure 4-6) and Chief Joseph Dam (Figure 4-8) under MO1 showing that water temperatures released from Lake Roosevelt are passed through Rufus Woods Lake unchanged.

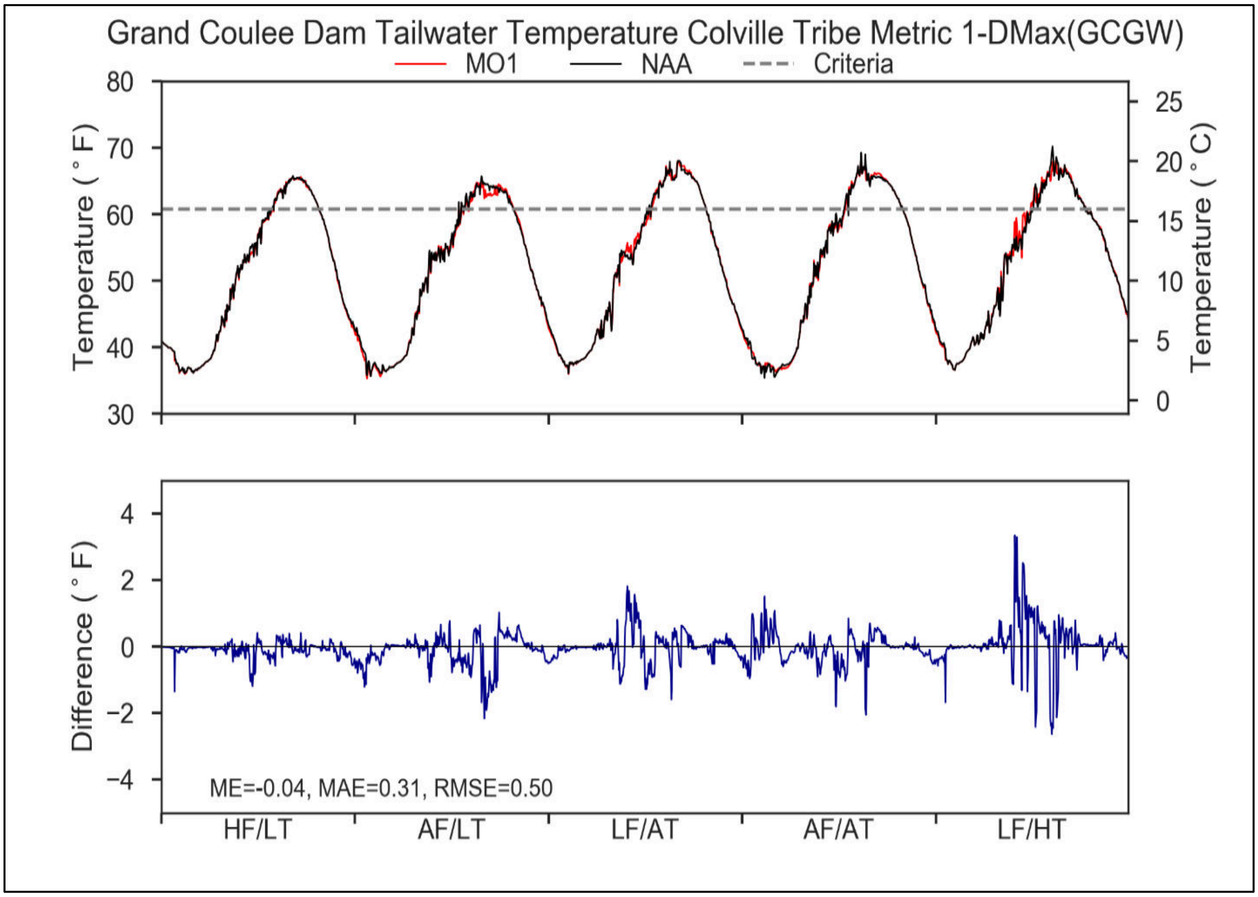


Figure 4-6. Modeled Tailwater Temperature for the No Action Alternative and Multiple Objective Alternative 1 at Grand Coulee Dam Under a 5-year Range of River and Meteorological Conditions Compared to the Confederated Colville Tribe 1-D Maximum Water Quality Criterion

Note: HF/LT = high flow/low air temperature; AF/LT = average flow/low air temperature; LF/AT= low flow/average air temperature; AF/AT = average flow/average air temperature; and LF/HT = low flow/ high air temperature.

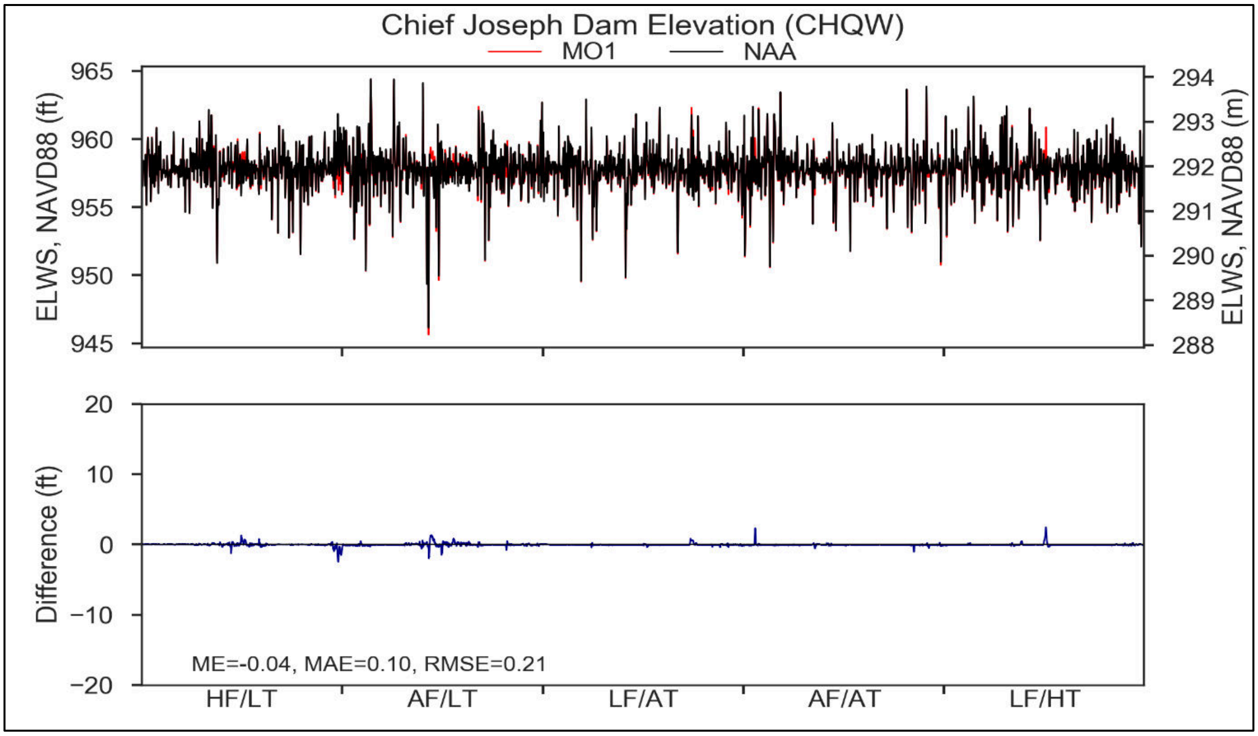


Figure 4-7. Chief Joseph Dam-Rufus Woods Lake Forebay Elevations Multiple Objective Alternative 1 Versus No Action Alternative

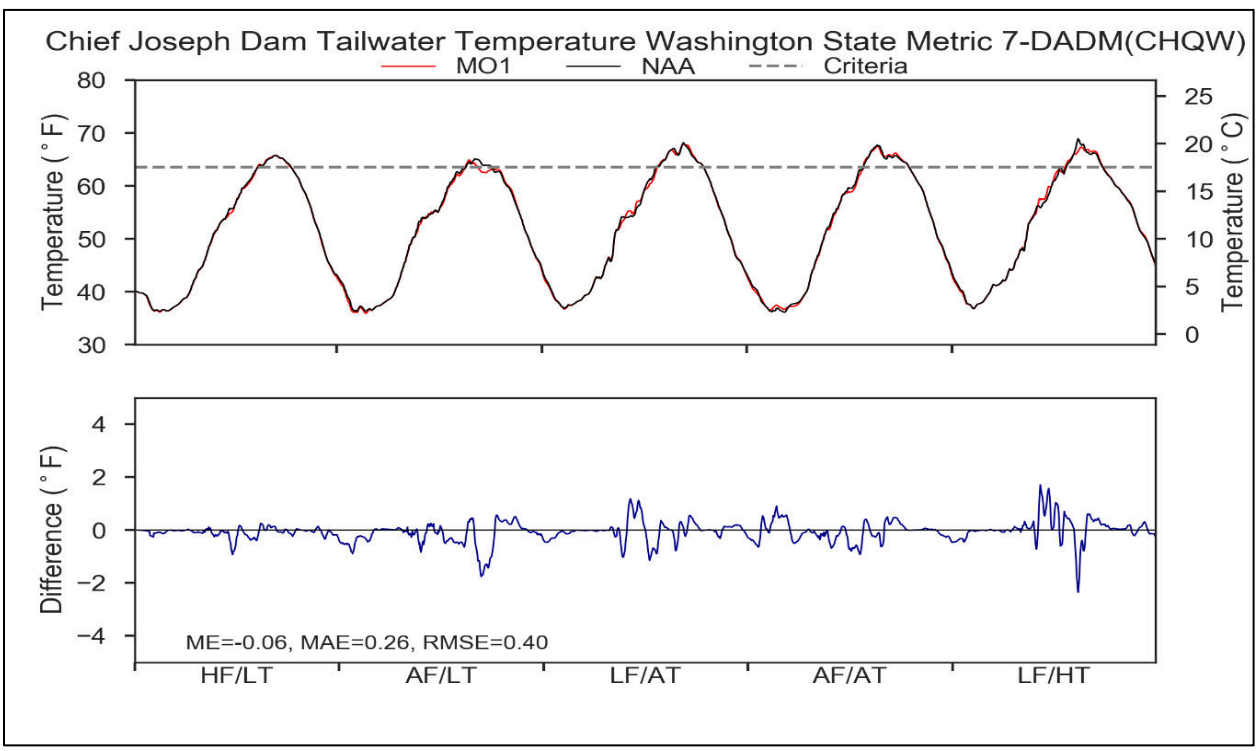


Figure 4-8. Modeled Tailwater Temperature for the No Action Alternative and Multiple Objective Alternative 1 at Chief Joseph Dam Under a 5-Year Range of River and Meteorological Conditions

The operational changes for MO1 do cause a few temperature differences as can be seen in the figures above. In terms of the actual number of days of the criteria being exceeded, those changes can be seen in Table 4-2. The blue highlighted cells show when an increased number of exceedances occurs as compared to NAA. Only the months where the criteria is exceeded is shown in the table. If a month has all zeroes shown, it is only because that month has exceeded the criteria under a different alternative. The most significant times of change occur during the late summer and early fall under average to low temperature conditions. September shows the most improvement, 21 less days of exceeding the temperature criteria, under MO1 when compared to the NAA.

Table 4-1. Difference in Number of Days the Temperature Criteria is Exceeded at Grand Coulee and Chief Joseph Forebay and Tailwater for the Multiple Objective 1 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Grand Coulee	June	0	0	0	0	0
Grand Coulee	July	-2	-4	-4	-2	0
Grand Coulee	August	0	0	0	0	0
Grand Coulee	September	0	0	0	0	0
Grand Coulee	October	0	**2**	0	0	0
Chief Joseph	July	0	0	-2	0	0
Chief Joseph	August	**2**	**1**	0	0	0
Chief Joseph	September	0	-21	0	0	0
Chief Joseph	October	-1	-3	0	0	0

4.1.2 Total Dissolved Gas

There are a few measures within MO1 that could change TDG produced by the operation of the upper basin dams. These changes are most noticeable at Grand Coulee, as discussed below.

4.1.2.1 Libby and Hungry Horse Dams and Reservoirs

Libby Dam is operated to minimize spill. Under MO1, Libby Dam's draft and refill operations will be modified resulting in an increase in the highest releases from the dam. This operational change is predicted to increase the chance of spill at Libby Dam from about 1 to 2 percent. The MO1 modeled spill flows and the TDG for the 80-year period from 1928 to 2008 are presented in Figure 4-9. The model predicts six years with spill for MO1 versus only three years with spill for the No Action Alternative (Figure 3-5) over the 80-year period. Under the No Action Alternative, the maximum TDG saturation is about 118 percent while under MO1, the maximum TDG saturation is predicted to be about 124 percent. The number of days exceeding the State of Montana 110 percent TDG criteria increased from 8 days for the No Action Alternative to 35 days for MO1 over the entire 80-year record. Although spill from Libby Dam for the 80-year model period are predicted to increase under MO1, the frequency of spill is still very small.

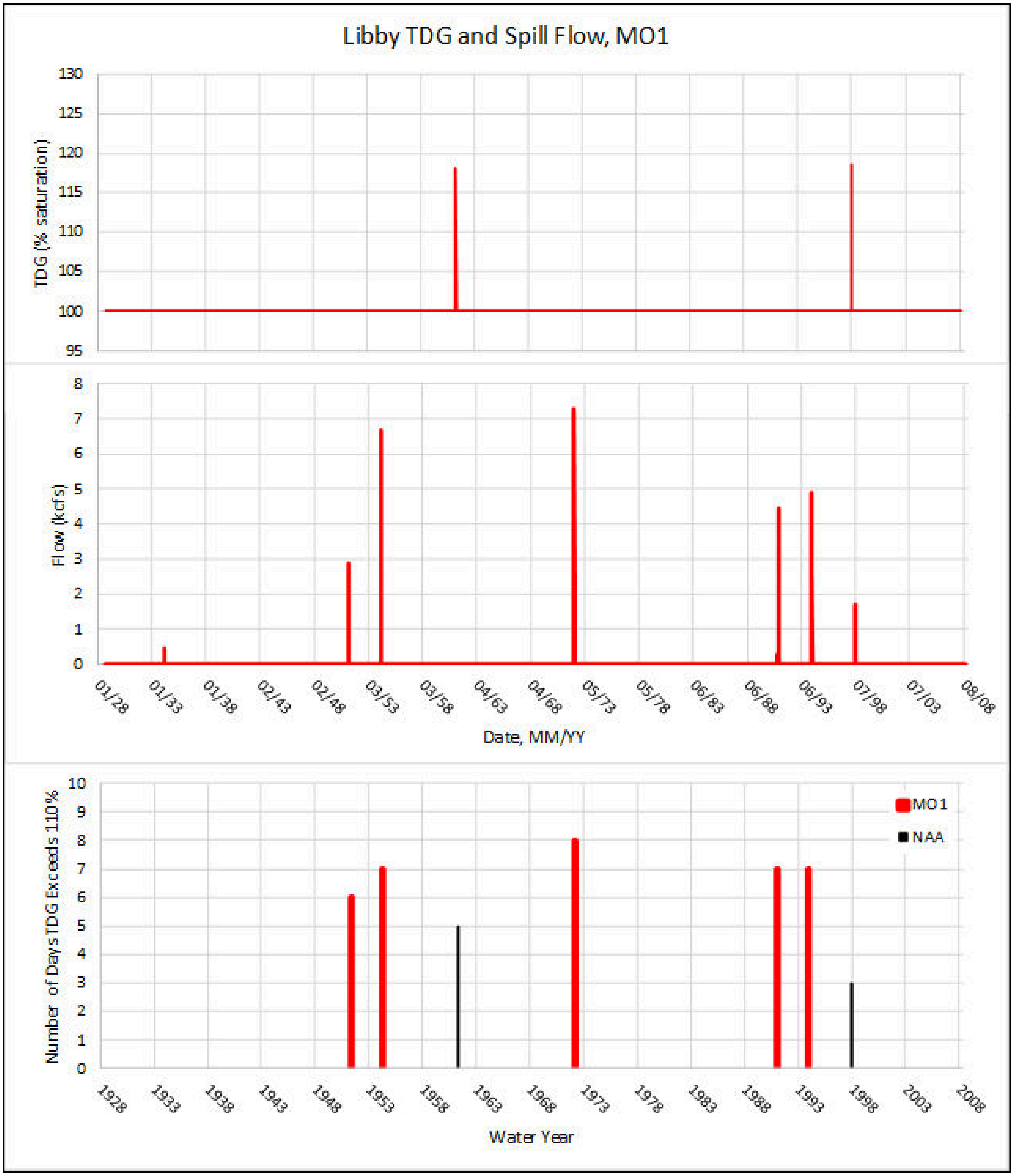


Figure 4-9. Modeled Tailwater Total Dissolved Gas and Spillway Flows for the No Action Alternative and Multiple Objective 1 at Libby Dam over an 80-Year Period

Figure 4-10 shows the number of days that TDG is anticipated to exceed 110 percent below Hungry Horse Dam under MO1. As shown, spill releases and some violations in the State of

Montana water quality criterion would be similar to the No Action Alternative. The MO1 model predicts 763 exceedances over the 80 year period, while the NAA predicts 809 exceedances.

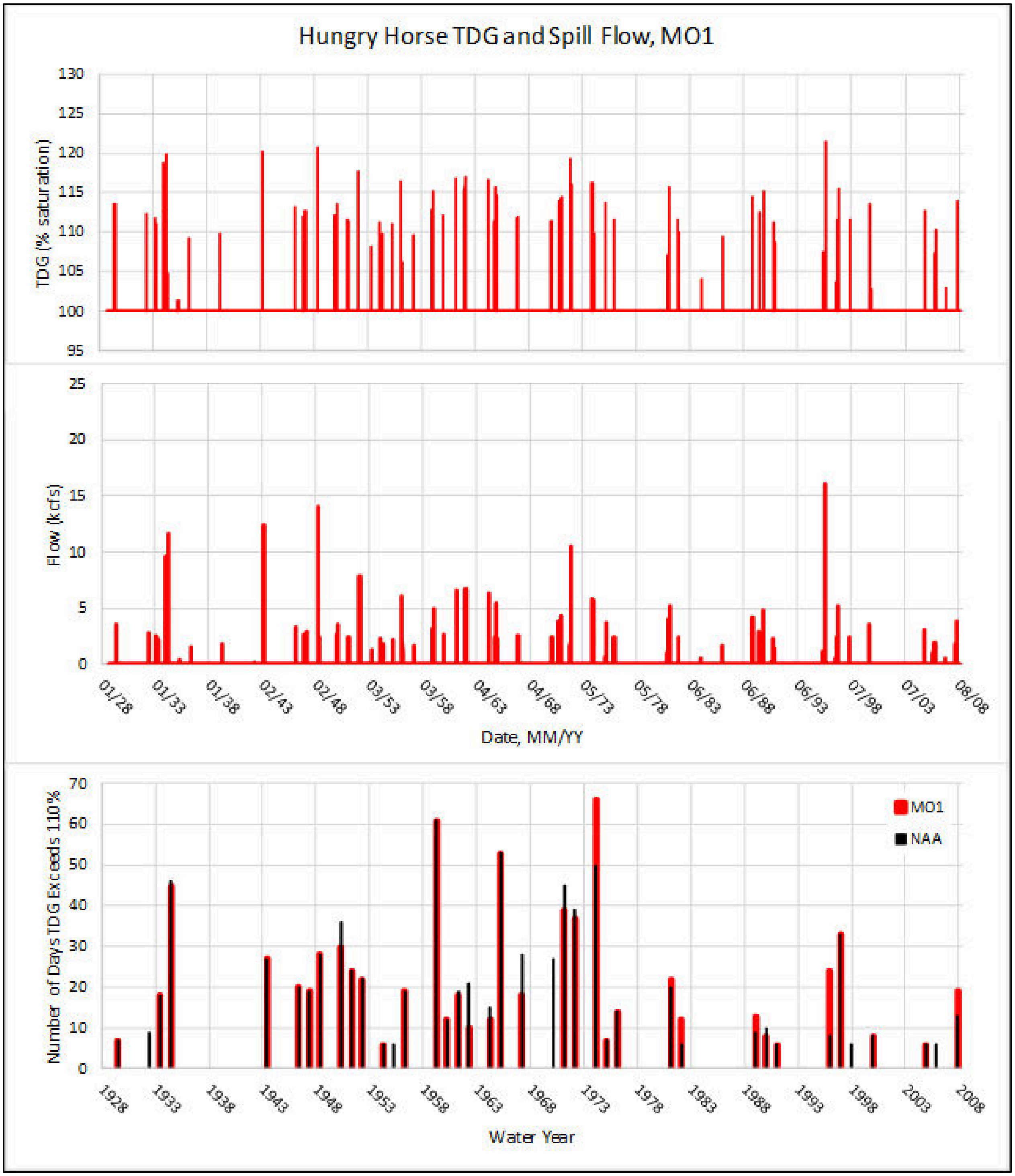


Figure 4-10. Number of Days that Total Dissolved Gas is Above the 110 Percent State Water Quality Criterion Under the No Action Alternative and Multiple Objective Alternative 1 at Hungry Horse Dam

4.1.2.2 Albeni Falls Dam and Reservoir

During high flow spring runoff periods, TDG in the Pend Oreille River upstream of Albeni Falls Dam can be greater than 110 percent largely because of spillway releases from Cabinet Gorge Dam located on the Clark Fork River about 55 miles upstream of Albeni Falls Dam. In general, when spill is spread evenly across the spillway, spillway discharges up to about 10 kcfs can increase TDG saturations over forebay levels by about 1 to 2 percent. Spillway discharges between about 10 to 50 kcfs can increase TDG saturations by about 5 to 9 percent below Albeni Falls Dam. However, when flows in the Pend Oreille River exceed about 50 to 60 kcfs, the Albeni Falls dam powerhouse operations are suspended and the spillway gates are raised, allowing the river to flow relatively un-impounded across the dam. Under these high flow conditions, Albeni Falls Dam produces no TDG as the river is essentially free flowing. Spillway flows at Albeni Falls Dam were modeled under MO1 and the No Action Alternative for the 80 year period from 1928 to 2008 using the ResSim model (Figure 4-11). In general, there was no difference in spillway flows under MO1 and the No Action Alternative. For both alternatives, spillway flows were predicted to range between 1 and 50 kcfs in nearly every year at Albeni Falls Dam, with many years having spill exceed 60 kcfs resulting in free-flowing conditions. These similar spillway flows under MO1 and the No Action Alternative are expected to produce nearly identical TDG saturations downstream of Albeni Falls Dam.

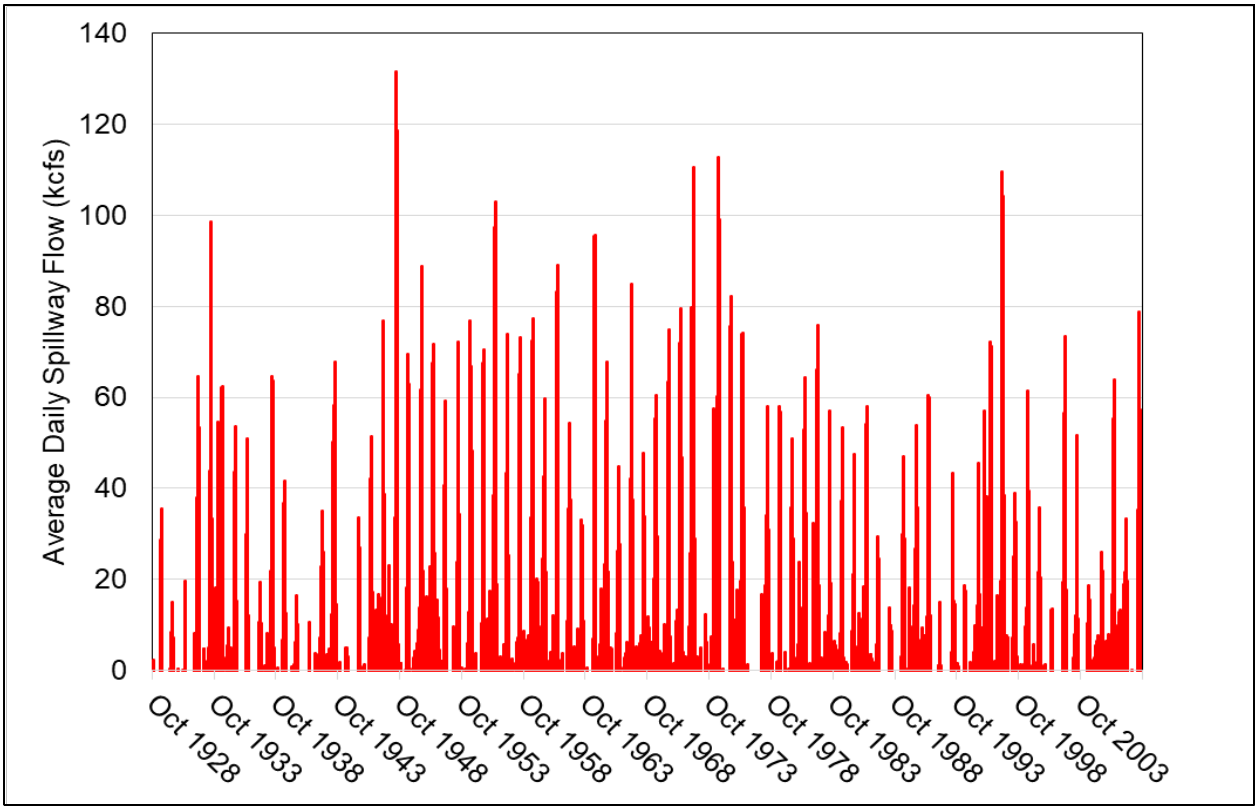


Figure 4-11. Modeled Tailwater Spillway Flows for the No Action Multiple Objective Alternative 1 at Albeni Falls Dam over an 80-Year Period

Note: Free-flowing is point where powerhouse operations are suspended and the spillway gates are raised, representing no spill.

4.1.2.3 Grand Coulee and Chief Joseph Dams and Reservoirs

MO1 operational measures, specific to Grand Coulee Dam, include the *Update System FRM Calculation, Grand Coulee Maintenance Operations, Planned Draft Rate at Grand Coulee* measure, *Winter System FRM Space* measure, and the *Lake Roosevelt Additional Water Supply* measure. In addition to these, changes in operations of upstream projects result in changes to inflows at Grand Coulee, which may have minor impacts on inflowing TDG but are not captured by the system modeling. These changes to inflow also impact Grand Coulee outflows.

During average to above-average water years, the additional storage may reduce the need to spill water at the dam between mid-December to March, reducing the associated downstream TDG. The *Grand Coulee Maintenance Operations* and *Lake Roosevelt Additional Water Supply* measure could also affect TDG concentrations below Grand Coulee Dam. *Grand Coulee Maintenance Operations* could create additional spill due to a decrease in power plant capacity from turbine maintenance. This could increase TDG from April to July due to a reduction in the number of turbines available to pass water. On the other hand, the *Lake Roosevelt Additional Water Supply* measure could decrease potential spill during this same timeframe. Starting in March, the increase in water withdrawal (0.6 kcfs) from Lake Roosevelt under operational measure Lake Roosevelt Additional Water Supply also decreases outflows and spill from Grand Coulee; however, this influence is not significant until April (3.2 kcfs increase in pumping and decrease in outflows) and continues through the summer period. As shown in Figure 4-12, the measures partially offset each other in the analysis of the overall alternative, and in some cases create a reduction in TDG. Under MO1, TDG concentrations tend to be slightly lower, particularly in the average water years.

As stated above, the operational measure for *Grand Coulee Maintenance Operation* has the potential to increase spill through the reduction in the hydraulic capacity of the powerhouse at Grand Coulee. The *Grand Coulee Maintenance Operation* in isolation could result in significant increases in spill and TDG, in some cases producing TDG in excess of 130 percent; however, this effect is largely offset in the spring and early summer by the other measures. An additional impact expected from the *Grand Coulee Maintenance Operation* measure is the potential for slightly deeper spill over the drum gates (when the forebay elevation is greater than 1,267 feet, MSL). Information to assess the magnitude of water quality impacts directly related to this measure is unavailable but would likely result in small increases in TDG. In wet conditions, it is anticipated that potential maintenance activities could be delayed in advance of spill to allow spill over more gates. Another factor not considered in the analysis is that as maintenance occurs, there would be an increase to hydraulic capacity as more units become available. This would result in reduced spill and TDG in some cases; however, the other actions would have a larger impact on outflows and associated spill.

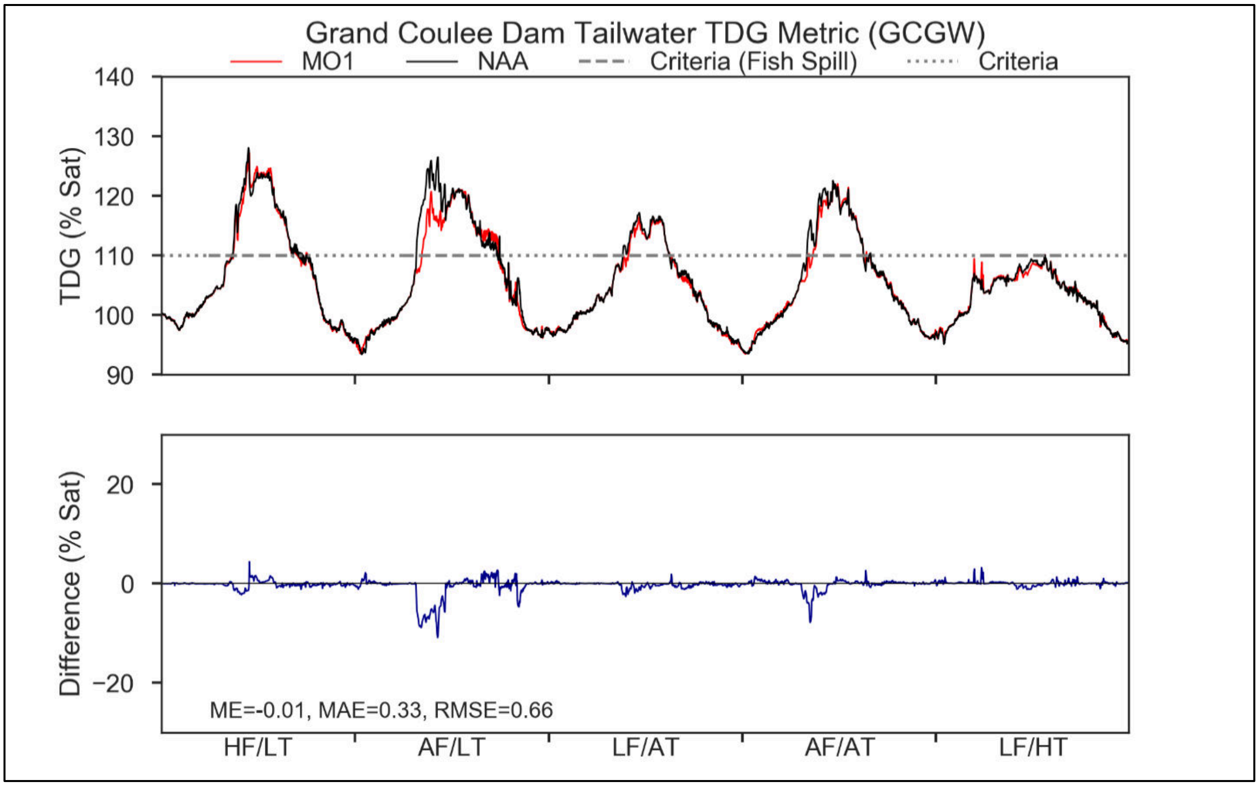


Figure 4-12. Modeled Tailwater Total Dissolved Gas for the No Action Alternative and Multiple Objective Alternative 1 at Grand Coulee Dam Under a 5-Year Range of River and Meteorological Conditions

TDG at the forebay of Chief Joseph Dam is largely a function of the TDG saturations released upstream from Lake Roosevelt and Grand Coulee Dam because little degassing occurs in Rufus Woods Lake. High spill volumes via the outlet tubes at Grand Coulee Dam can increase TDG saturations in Rufus Woods Lake at the Chief Joseph Dam forebay to over 130 percent. In addition, during high flows, TDG saturations entering Lake Roosevelt from Canada can be elevated to greater than 120 percent. During these high TDG periods, spill at Chief Joseph Dam over the deflectors can degas supersaturated conditions discharged by Grand Coulee Dam. Spilling at Chief Joseph Dam when incoming TDG levels are above 120 percent can reduce downstream system TDG loading. Therefore, Chief Joseph Dam is often used to help manage overall system TDG production in the mainstem Columbia River. In addition, to avoid spilling through the outlet tubes at Grand Coulee Dam, spill is often shifted from Grand Coulee to Chief Joseph to take advantage of the lower TDG produced by spilling over the deflectors. This operational strategy is expected to continue under MO1.

Chief Joseph Dam TDG saturations predicted at the forebay and tailwater were modeled under MO1 and compared to the No Action Alternative (Figure 4-13 and Figure 4-14). In general, predicted forebay and tailwater TDG levels under MO1 operations are similar to or less than under No Action Alternative operations. It is expected that under MO1, Chief Joseph Dam would continue to decrease TDG during high flow years when elevated TDG saturations occur in the forebay.

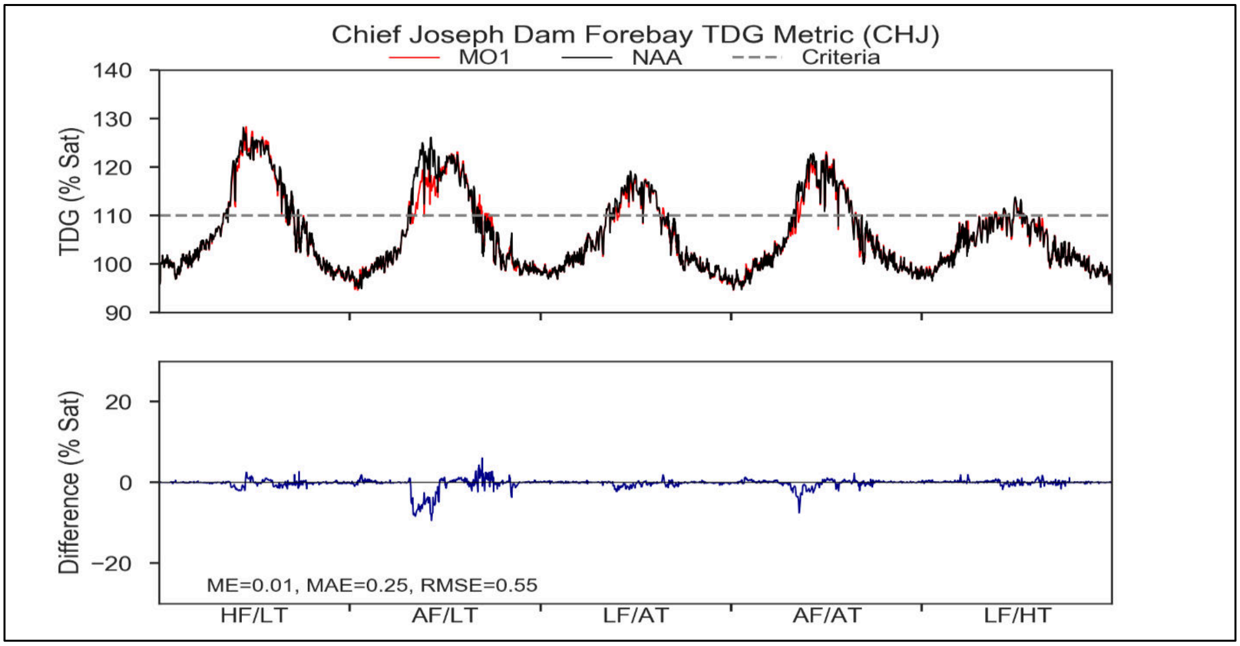


Figure 4-13. Modeled Forebay Total Dissolved Gas Saturations for the No Action Alternative and Multiple Objective Alternative 1 at Chief Joseph Dam Under a 5-Year Range of River and Meteorological Conditions

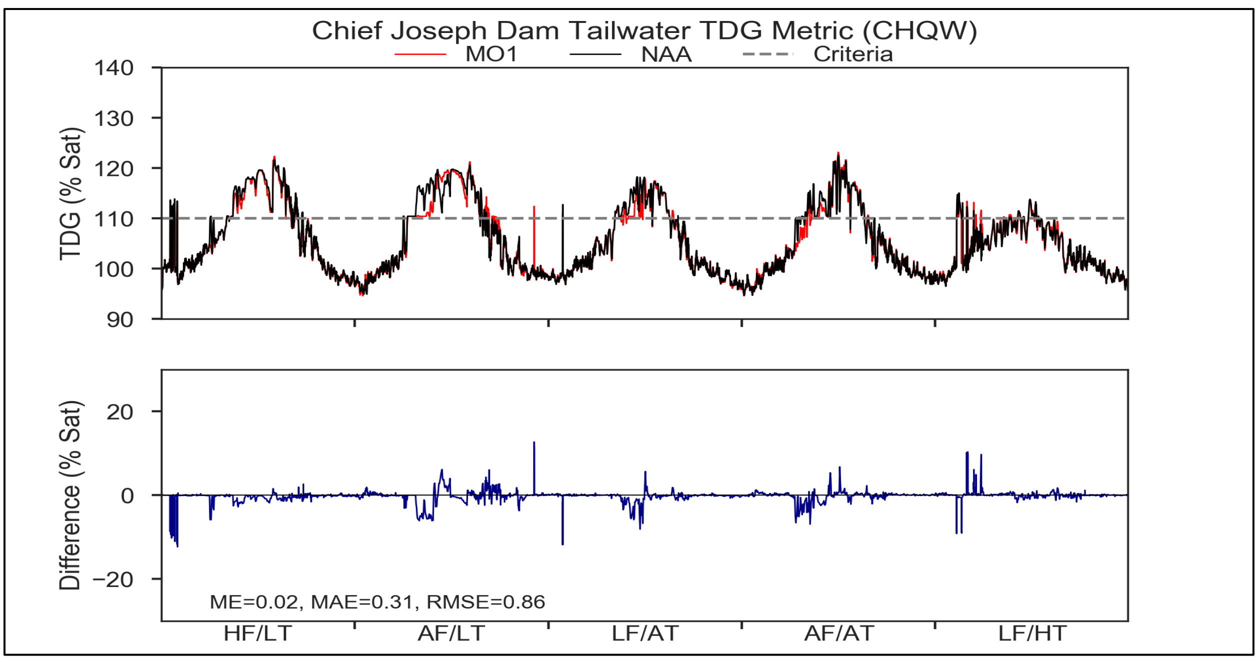


Figure 4-14. Modeled Tailwater Total Dissolved Gas Saturations for the No Action Alternative and Multiple Objective Alternative 1 at Chief Joseph Dam Under a 5-Year Range of River and Meteorological Conditions

The operational changes for MO1 do cause a few TDG differences as can be seen in the figures above. In terms of the actual number of days of the criteria being exceeded, those changes can be seen in Table 4-2 and Table 4-3. The blue highlighted cells show when an increased number of exceedances occurs as compared to NAA. Only the months where the criteria is exceeded is shown in the table. If a month has all zeroes shown, it is only because that month has exceeded the criteria under a different alternative. The most significant times of change occur during the summer under average to low flow conditions.

Table 4-2. Difference in Number of Days the TDG Criteria is Exceeded at Grand Coulee and Chief Joseph Forebays for the Multiple Objective 1 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Grand Coulee	April	0	0	0	0	0
Grand Coulee	May	**1**	0	0	-3	0
Grand Coulee	June	**1**	-10	**3**	0	0
Grand Coulee	July	0	-3	0	0	0
Grand Coulee	August	**1**	0	0	0	0
Grand Coulee	September	0	0	0	0	0
Chief Joseph	April	0	-1	0	-1	0
Chief Joseph	May	0	-3	-5	-5	**2**
Chief Joseph	June	0	0	0	0	-2
Chief Joseph	July	0	0	0	0	-1
Chief Joseph	August	-1	**1**	**3**	0	**1**
Chief Joseph	September	-2	**8**	0	0	0
Chief Joseph	October	0	0	0	0	0

Table 4-3. Difference in Number of Days the TDG Criteria is Exceeded at Grand Coulee and Chief Joseph Tailwaters for the Multiple Objective 1 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Grand Coulee	April	0	-5	0	0	0
Grand Coulee	May	0	-6	-10	-9	0
Grand Coulee	June	0	0	0	0	0
Grand Coulee	July	0	0	0	0	0
Grand Coulee	August	0	0	0	-2	0
Grand Coulee	September	-3	0	0	0	0
Grand Coulee	October	**2**	0	0	0	0
Chief Joseph	January	-1	0	0	0	0
Chief Joseph	February	0	0	0	0	-1
Chief Joseph	March	0	0	0	0	**3**
Chief Joseph	April	-3	0	0	-11	0
Chief Joseph	May	-1	0	-7	-5	**2**
Chief Joseph	June	0	0	-1	0	-2
Chief Joseph	July	0	0	0	0	-1

4.1.3 Other Physical, Chemical and Biological Processes

4.1.3.1 Libby and Hungry Horse Dams and Reservoirs

There are no known sources of contamination in Hungry Horse Reservoir or in the South Fork Flathead River. Additionally, there is insufficient information to determine if Hungry Horse Reservoir, and the South Fork Flathead River downstream of the dam, would experience any significant impacts to physical, chemical, or biological processes compared to the No Action Alternative. Although operational measure *Sliding Scale at Libby and Hungry Horse* and *Hungry Horse Additional Water Supply* could result in deeper drafts and lower reservoir elevations, stratification and thermocline depths in the reservoir are not expected to change.

Water level fluctuations in reservoirs may increase methyl-mercury concentrations in the waterbody as seasonally inundated areas of a reservoir have higher rates of methylation activity when compared to permanently inundated areas of a reservoir (Willacker et al. 2016). Studies suggest that methyl-mercury has a greater probability of entering the food web during the spring and summer growing seasons (January through July) (Willacker et al. 2016). Under MO1, the measures don't change the cyclic occurrence of inundation and exposure but do result in earlier and longer exposure of sediments that may have some impact on mercury methylation in Hungry Horse Reservoir. However, unlike other downstream locations such as Lake Roosevelt, mercury has not been recorded as a concern at Hungry Horse Reservoir as the only likely mercury input at this location is through airborne pollution.

MO1 modifies operations at Libby Dam resulting in changes in the drafting depth and water elevations of Lake Koocanusa that may impact physical, chemical, and biological water quality parameters when compared to existing conditions and the No Action Alternative. MO1 reservoir elevations and outflows during average water supply years will be relatively similar to existing conditions and the No Action Alternative, and water quality changes are not anticipated. However, for high water supply forecast years, the reservoir would be drafted shallower, meaning there would be a greater volume of water in Lake Koocanusa during the spring runoff. Conversely, for low water supply years, the reservoir would be drafted deeper, meaning there would be a lesser volume of water in Lake Koocanusa during the spring runoff.

Retention time, which is the inverse of the flushing rate, refers to the length of time water remains in a waterbody. Lake volume, inflow, and outflow are important factors in determining the overall retention time in a waterbody. In general, shorter retention times allow for the rapid exchange and movement of inflow chemical constituents through the lake. Longer retention times allow for the accumulation and transformations of inflow chemical constituents in sediments and lake water, and their cycling through the ecosystem. For a long, narrow, deep waterbody like Lake Koocanusa, shorter retention times may allow certain chemical constituents in inflowing waters, such as total phosphorus, to move farther down reservoir toward the forebay before settling out or transforming.

Water quality chemical and biological parameters of concern in Lake Koocanusa that may be impacted by MO1 changes in the reservoir elevation and retention times include nutrients, metals such as selenium, and phytoplankton such as cyanobacteria and diatoms. It is likely that winter drawdown elevation and the corresponding reservoir volume, as well as spring runoff volume and the corresponding suspended sediment/total phosphorus concentrations, are all factors in determining how far down-reservoir suspended sediments/total phosphorus reaches. Historical data show that Lake Koocanusa is a sink for phosphorus, with little inflow sediment/phosphorus moving down-reservoir past Libby Dam. Conversely, Lake Koocanusa does not appear to be a sink for nitrogen, and most of the inflowing nitrate passes down-reservoir to the forebay and Kootenai River regardless of reservoir elevations and retention times. Increased nitrate loadings to Lake Koocanusa, largely due to coal mining operations in British Columbia, and low phosphorus concentrations have created a large imbalance in the nitrogen-to-phosphorus ratio, with the ratio often exceeding 100:1 at the forebay, resulting in strong phosphorus limitation.

Despite rising nitrate concentrations in Lake Koocanusa, phytoplankton blooms appear to have been kept in check by the strong phosphorus limitation under existing conditions and the No Action Alternative. However, these conditions also indicate that the lake could be susceptible to increased phytoplankton blooms if phosphorus concentrations increase in the future or if there are further changes in the nitrogen-to-phosphorus ratio. It is possible that the operational changes proposed for MO1 may impact the nutrient dynamics in Lake Koocanusa, which could result in seasonal changes in phytoplankton densities and functional types. Shorter retention times for low water supply years may result in greater total phosphorus concentrations while longer retention times for high water years may result in lower phosphorus concentrations. However, these operational changes in retention times are small and only occur during more extreme water years (high/low water supply), which likely would reduce potential nutrient and phytoplankton impacts from MO1 at Libby Dam.

Increasing selenium concentrations and other associated metals (cadmium and lead) in Lake Koocanusa from coal mining operations in British Columbia are a concern for existing conditions and the No Action Alternative. The USGS has estimated that increased coal mining in the Kootenai River watershed above Libby Dam have increased selenium loading to Lake Koocanusa fivefold over the past 20 years. Over the next 25 years, it is expected that coal production in the Kootenai River watershed will continue. Although there does not yet appear to be an increasing trend in water column selenium concentrations in the reservoir, there is concern that the continued selenium loadings to Lake Koocanusa may lead to additional selenium contamination. It is possible that the changes in reservoir elevation, flow, and retention time under MO1 may alter the movement, cycling, and transformation of selenium and other associated metals (cadmium and lead) in the reservoir and downstream in the Kootenai River, possibly resulting in water and sediment quality impacts. However, such operational changes would only occur during more extreme high/low water supply years.

4.1.3.2 Albeni Falls Dam and Reservoir

Under MO1, there are no changes to operations at Albeni Falls Dam. The physical, chemical, and biological water quality of Lake Pend Oreille and the Pend Oreille River described under the No Action Alternative are expected to remain unchanged.

4.1.3.3 Grand Coulee and Chief Joseph Dams and Reservoirs

Under MO1, model results indicate that flow through Lake Roosevelt would slightly decrease from March through May; however, retention time would largely remain unchanged during the rest of the year, with the exception of slightly shorter retention time in the winter, partially due to the winter draft for Winter System FRM Space (Figure 4-15). In general, Lake Roosevelt tends to display relatively low primary productivity throughout the year. With similar or shorter retention times, changes in primary productivity are not expected.

The *Planned Draft Rate At Grand Coulee* measure changes the planning drawdown rate (as depicted in the storage reservation diagram [SRD]) from 1.0 foot per day to a target of 0.8 feet per day. Mass wasting, such as small local landslides within Lake Roosevelt, has been related to the rate of drawdown at Grand Coulee Dam. Decreases in these mass wasting events that introduce sediment in pulses to the reservoir should result in decreases in turbidity under MO1.

Water level fluctuations in Lake Roosevelt may have an impact on mercury cycling within the reservoir, especially when the lowest lake levels occur from April through July. Water level fluctuations in reservoirs may increase methyl-mercury concentrations in the waterbody as seasonally inundated areas of a reservoir have higher rates of methylation activity when compared to permanently inundated areas of a reservoir (Willacker et al. 2016). Studies suggest that methyl-mercury has a greater probability of entering the food web during the spring and summer growing seasons (January through July) (Willacker et al. 2016). Due to the deeper winter draft proposed by MO1, a larger variation of water elevation is anticipated in the spring, which may promote a higher rate of mercury cycling. The lower panel of Figure 4-15. shows that, under MO1, average reservoir elevations are expected to remain about 7 feet lower than the No Action Alternative. Therefore, MO1 may slightly increase the rate of mercury cycling within Lake Roosevelt.

MO1 includes modified operations at Grand Coulee Dam that could result in some changes in monthly outflows to Rufus Woods Lake and Chief Joseph Dam. However, only minor changes to operational conditions at Chief Joseph Dam are expected. Reservoir elevations and river flows will be relatively similar between the No Action Alternative and MO1. As such, the physical, chemical, and biological water quality of Rufus Woods Lake and the Columbia River downstream of Chief Joseph Dam under MO1 are expected to remain relatively unchanged from the No Action Alternative. The harmful algae blooms at this location described under the affected environment and the No Action Alternative would continue in the future under MO1.

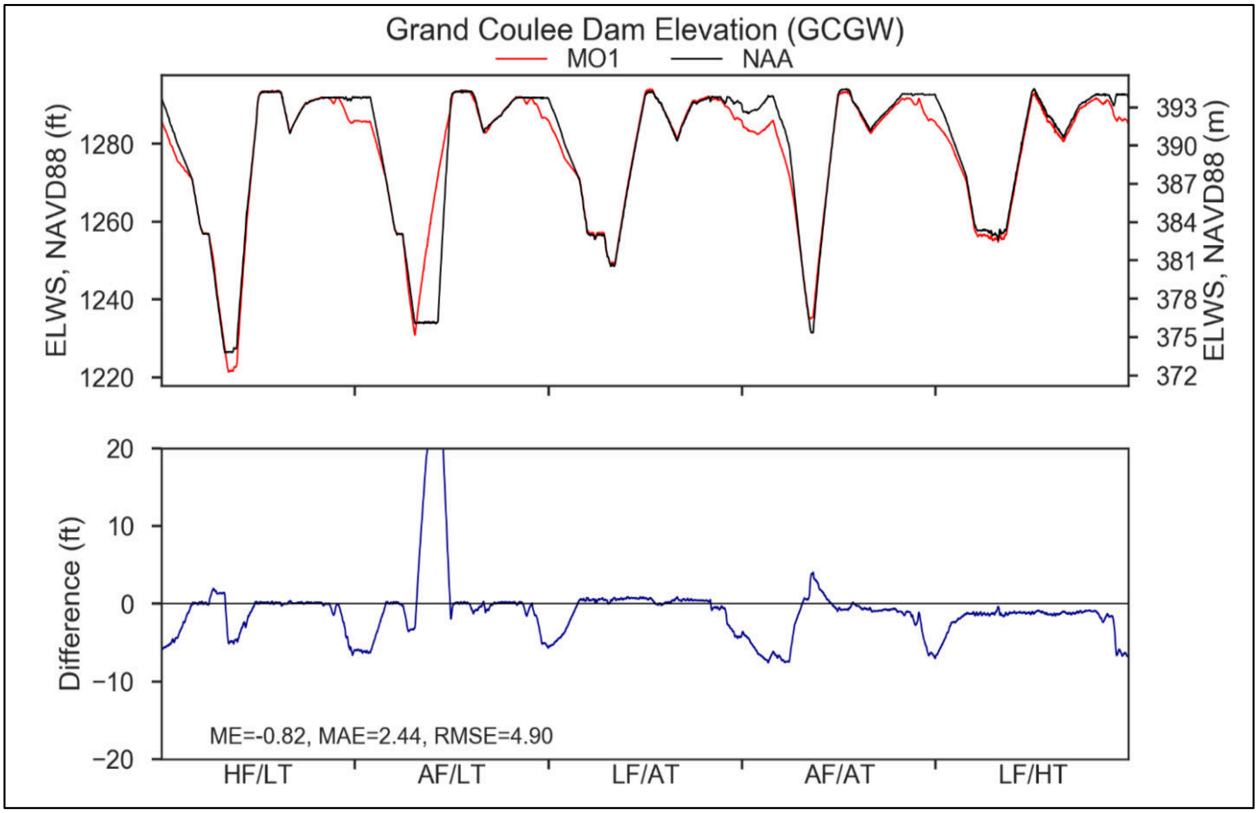


Figure 4-15. Modeled Forebay Elevations for the No Action Alternative and Multiple Objective 1 at Grand Coulee Dam Under a 5-Year Range of River and Meteorological Conditions

4.2 LOWER SNAKE RIVER BASIN

The timing of summer releases from Dworshak Dam would change under MO1 from the *Modified Dworshak Summer Draft* measure, which would alter not only the timing of outflow from Dworshak Dam, but in the lower Snake River as well. The intent would be to begin drafting the reservoir June 20 rather than July 1, continue releasing water to the 110 percent spill cap through July, reduce outflow by about 48 percent in August, and then increase the median September outflow by approximately 37 percent. There would be minimal changes to outflow during the remainder of the year. Flows in the lower Snake River would increase by 2 and 8 percent in July and September, and decrease by about 16 percent in August.

4.2.1 Water Temperature

It is not anticipated that fish ladder water temperature improvements at Lower Monumental and Ice Harbor Dams (the *Lower Snake Ladder Pumps* measure) would have any meaningful impact to downstream river water temperatures. These structural changes are anticipated to affect fish ladder conditions only.

The *Modified Dworshak Summer Draft* measure is likely to change water temperatures that would occur during the summer and early fall months in the lower Snake River. Details are described below.

4.2.1.1 Dworshak Dam and Reservoir

The temperature changes that would occur with implementation of MO1 relative to the No Action Alternative are shown in Figure 30. The primary shifts would occur in July, August, September, and October under most of the flow/temperature conditions. Median increases ranging from 0.3 to 1.3 degrees Fahrenheit would occur under MO1 for the AF/LT, LF/AT, AF/AT, and LF/HT conditions between July 1 and August 10. No temperature changes would occur during this time period for the HF/LT conditions. Median MO1 temperature decreases that would occur during the September/October time frame range from 0.2 degree Fahrenheit for the HF/LT condition to 0.9 degree Fahrenheit for the LF/AT condition. The maximum daily decrease would occur for the LF/AT condition at 3.7 degrees Fahrenheit and range from 2.0 to 2.6 degrees Fahrenheit for the other conditions. However, the model results for the five representative conditions show that tailwater temperatures would continue to be less than the State of Idaho's COLD/SS criterion of 55.4°F (Figure 4-16).

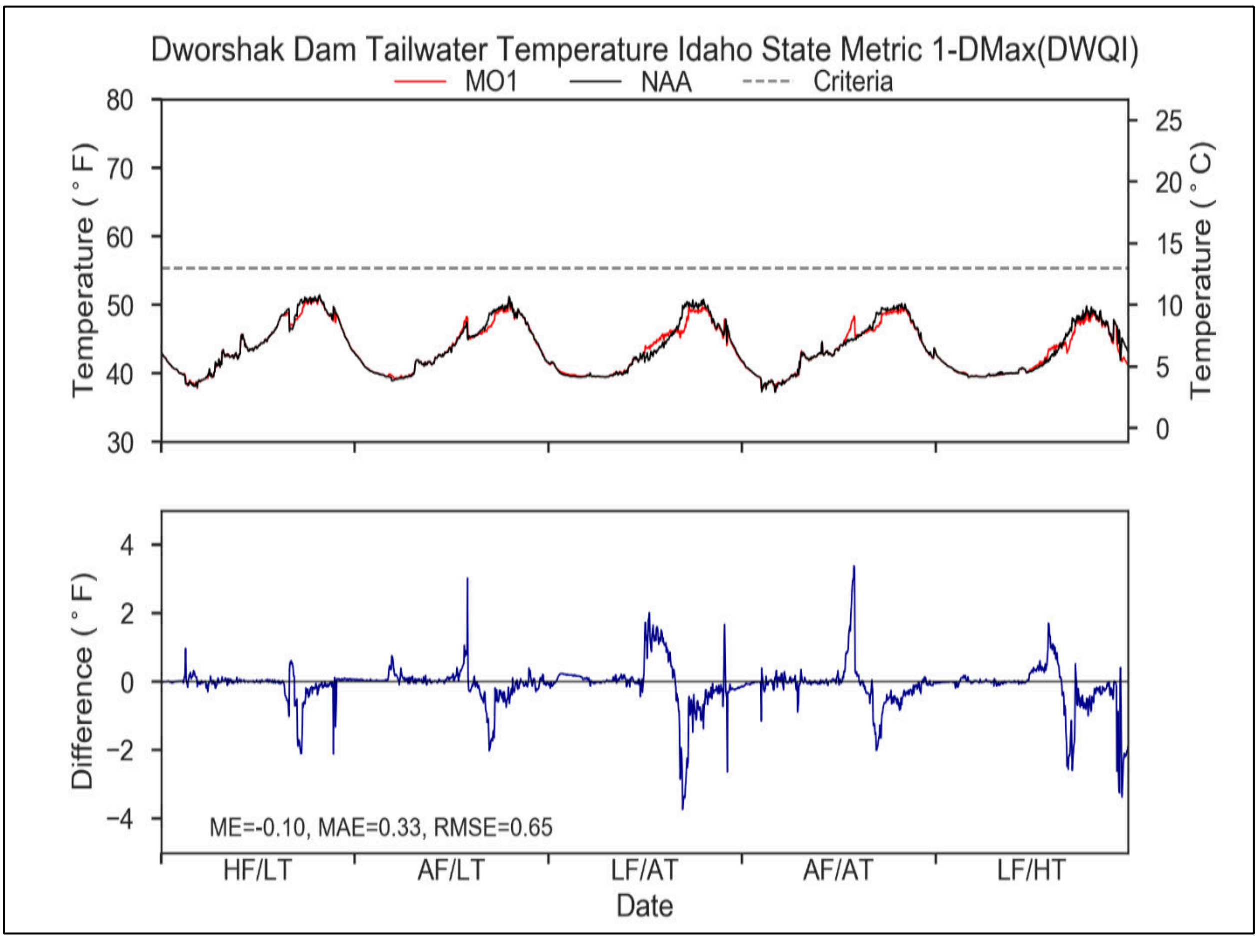


Figure 4-16. Modeled Tailwater Temperature for the No Action Alternative and Multiple Objective Alternative 1 at Dworshak Dam Under a 5Year Range of River and Meteorological Conditions

4.2.1.2 Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams and Reservoirs

Tailwater temperatures would increase, primarily during August, to varying degrees at the four lower Snake River projects under MO1 relative to the No Action Alternative (Figure 4-17 - Figure 4-20). The least amount of change would occur during HF/LT conditions when there would be approximately 12 to 13 additional days when water temperatures would increase over No Action Alternative conditions by more than 1 degree Fahrenheit at the three upstream projects (Figure 4-21). There would only be three additional days downstream from Ice Harbor Dam when temperatures would increase by the same amount. For the remaining four flow/temperature conditions, it is anticipated there would be 32 to 37 additional days when temperatures would be greater than 1 degree Fahrenheit over No Action Alternative conditions at Lower Granite Dam and decrease toward Ice Harbor Dam, where there would be 22 to 30 additional days.

Similarly, Washington's 68°F temperature criterion would be exceeded more often at Lower Granite Dam for most of the flow/temperature conditions than at the other lower Snake River projects (Figure 4-22). This is due to changes in Dworshak operations under MO1 and the direct effect that the *Modified Dworshak Summer Draft* measure has on Lower Granite Reservoir and tailwater temperatures. The influence of the Dworshak operations lessen as water moves downstream, with the least amount of change in water temperatures (between MO1 and No Action Alternative) at Ice Harbor Dam. The model results indicate there would be 21 to 27 additional days when the criteria would be exceeded at Lower Granite Dam, with water temperatures of 70°F to 73°F and 2 to 8 days at Ice Harbor Dam (maximum temperatures ranging from 71°F to 74°F during the AF/LT, LF/AT, AF/AT, and LF/HT conditions). Additional exceedances at the Little Goose and Lower Monumental projects would generally be intermediate, ranging from 2 to 14 days for the same conditions, but daily maximum temperatures would still range from 70°F to 73°F. The HF/LT conditions would not lead to additional days of elevated temperatures at Lower Granite and Little Goose dams, and only 2 to 3 days at the Lower Monumental and Ice Harbor projects, which is within the models margin of error.

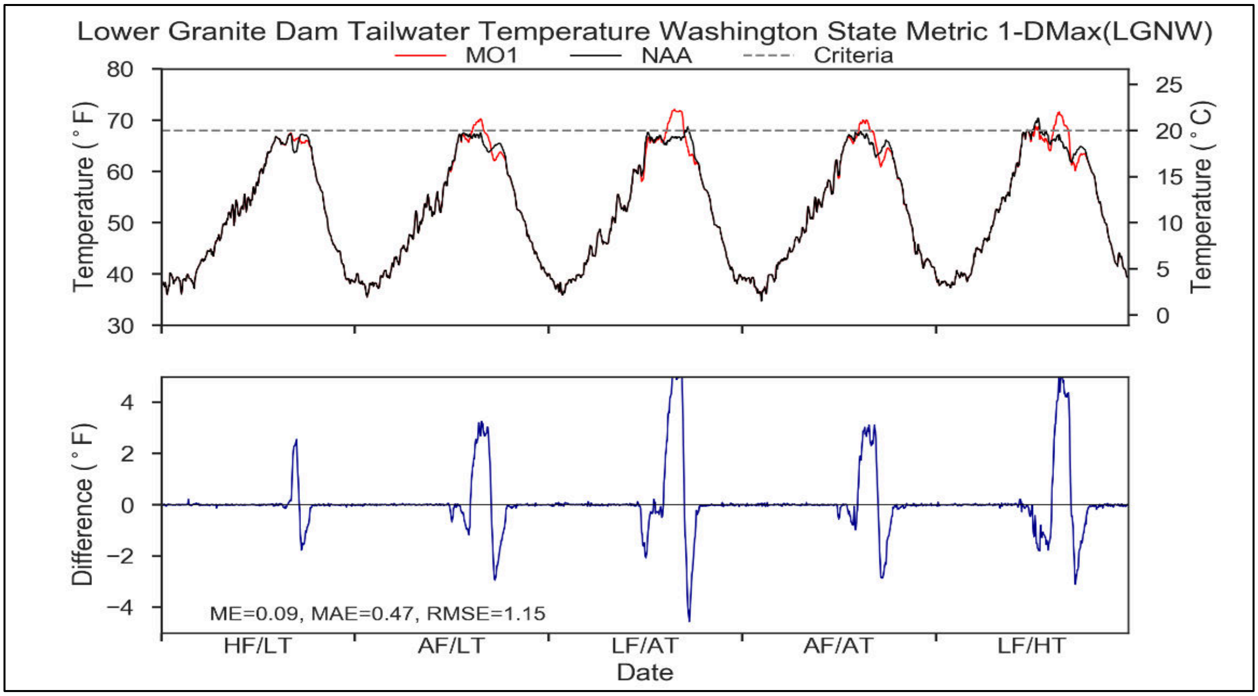


Figure 4-17. Modeled Tailwater Temperatures for the No Action Alternative and Multiple Objective Alternative 1 at Lower Granite Dam Under a 5Year Range of River and Meteorological Conditions

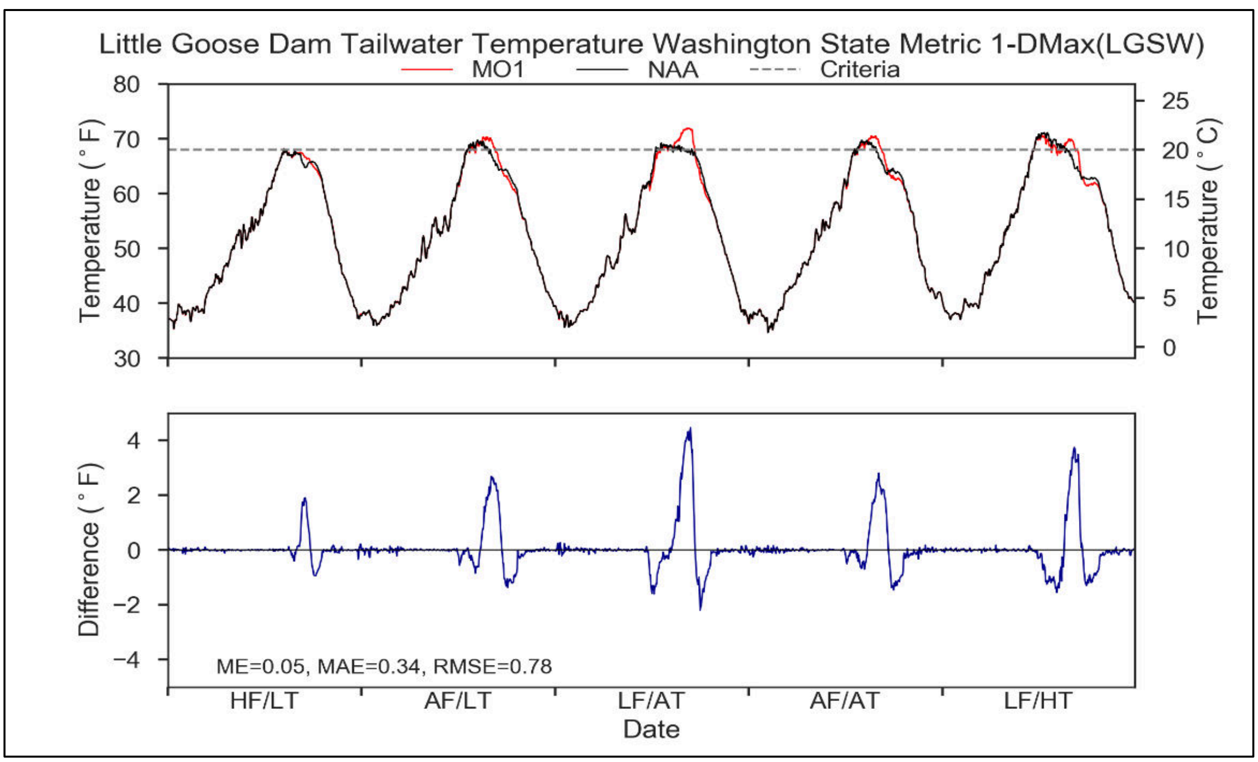


Figure 4-18. Modeled Tailwater Temperatures for the No Action Alternative and Multiple Objective Alternative 1 at Little Goose Dam Under a 5Year Range of River and Meteorological Conditions

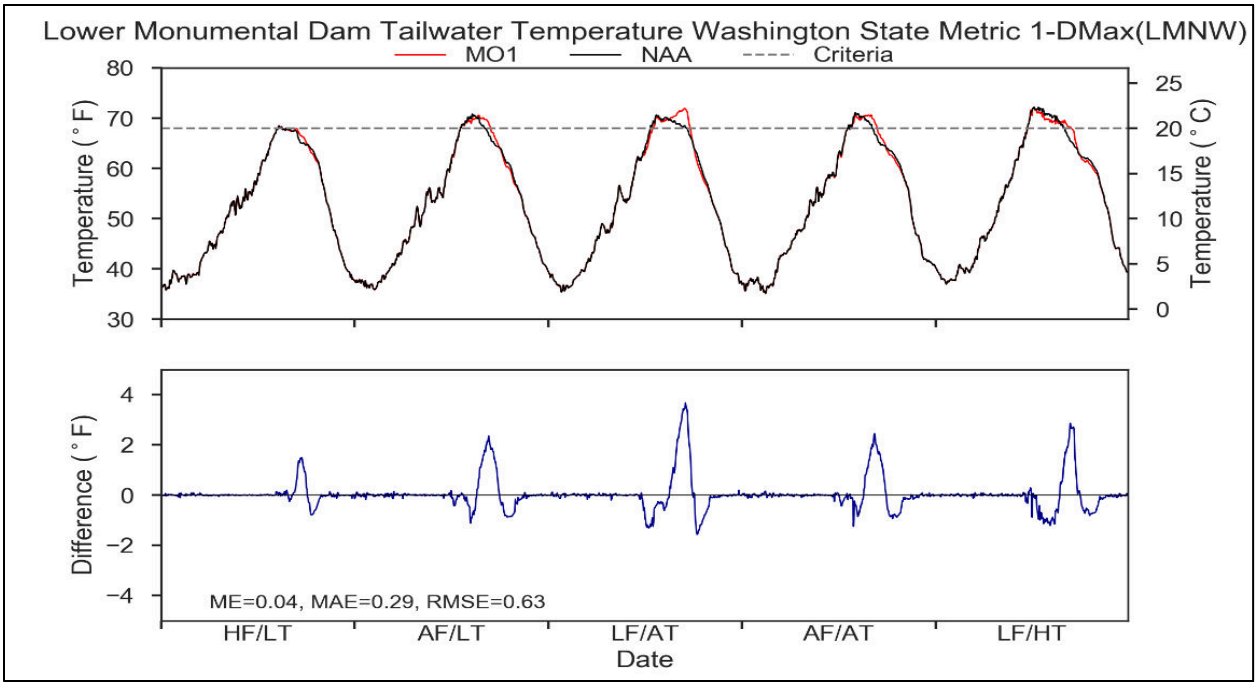


Figure 4-19. Modeled Tailwater Temperatures for the No Action Alternative and Multiple Objective Alternative 1 at Lower Monumental and Ice Harbor Dams Under a 5-Year Range of River and Meteorological Conditions

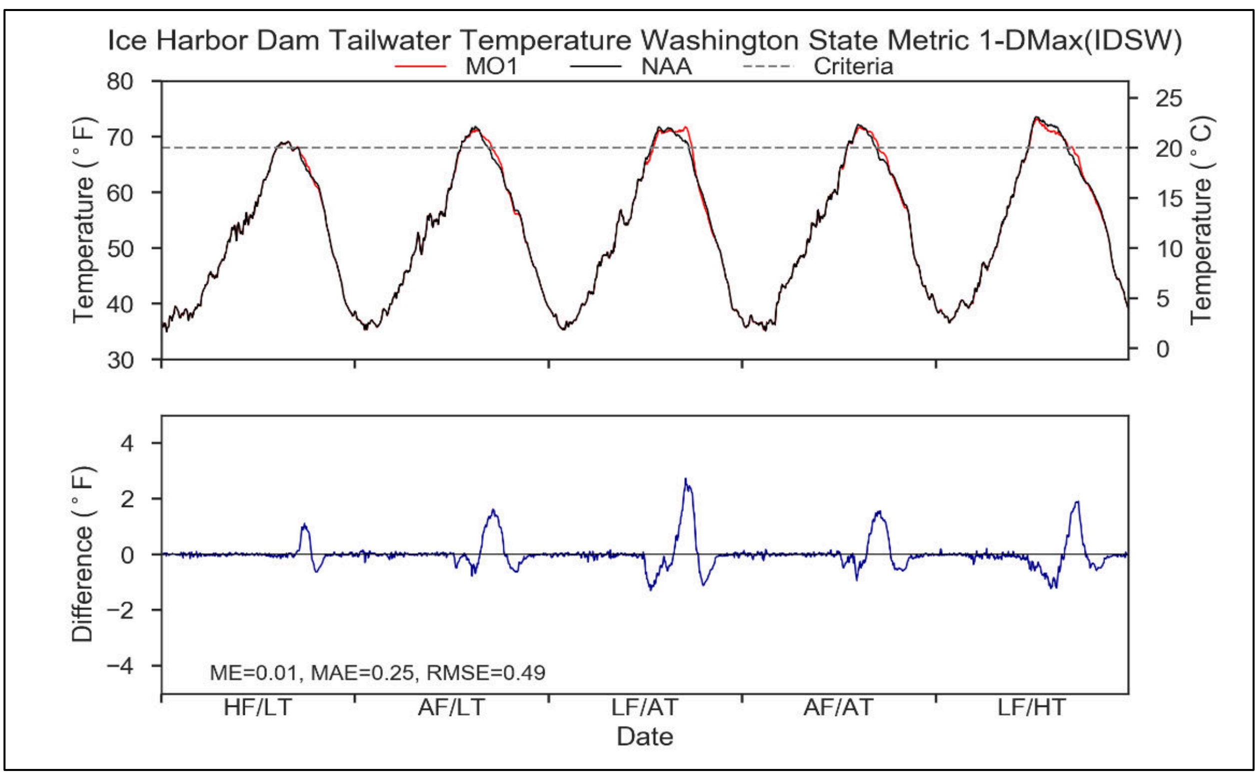


Figure 4-20. Modeled Tailwater Temperatures for the No Action Alternative and Multiple Objective Alternative 1 at Lower Monumental and Ice Harbor Dams Under a 5-Year Range of River and Meteorological Conditions

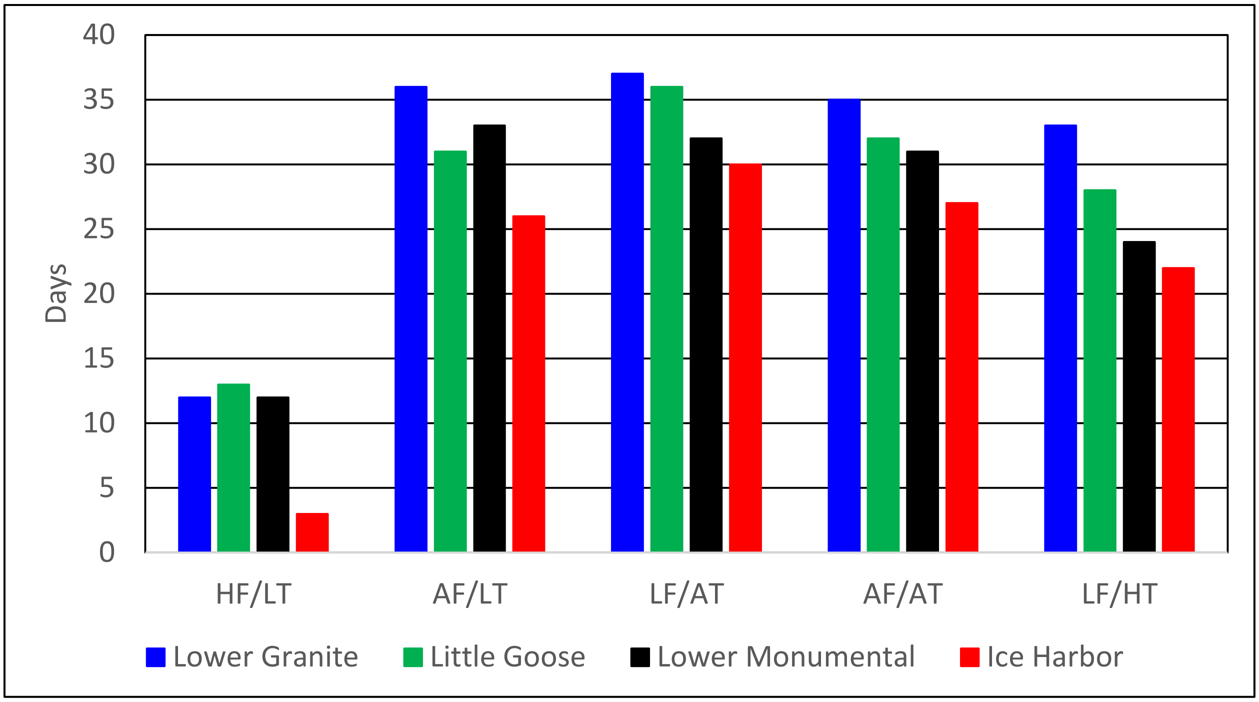


Figure 4-21. Number of Days During the Year when There Would be Greater than One Degree Temperature Increase at the Four Lower Snake River Dam Tailwater Locations Under Multiple Objective Alternative 1 Relative to the No Action Alternative

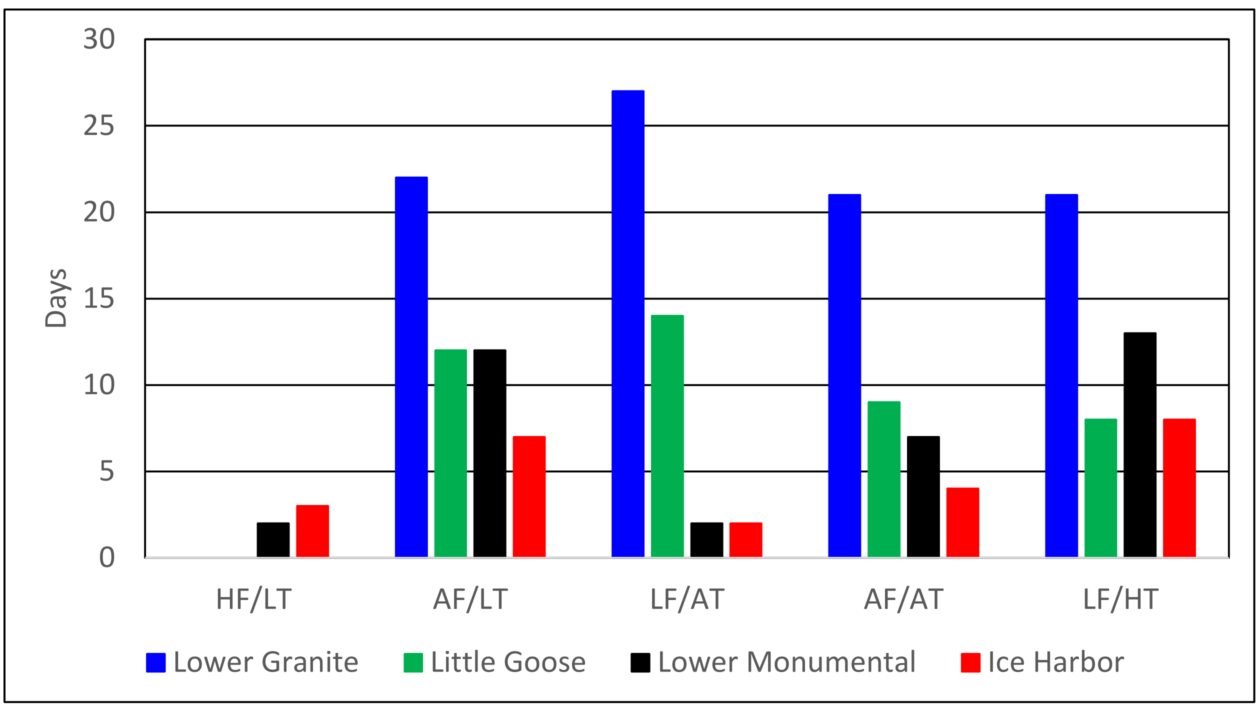


Figure 4-22. Number of Additional Days During the Year when the Washington 68 °F Temperature Criterion Would be Exceeded at the Four Lower Snake River Dam Tailwater Locations Under Multiple Objective Alternative 1 relative to the No Action Alternative

The operational changes for MO1 do cause a few temperature differences as can be seen in the figures above. In terms of the actual number of days of the criteria being exceeded, those changes can be seen in Table 4-4. The blue highlighted cells show when an increased number of exceedances occurs as compared to NAA. Only the months where the criteria is exceeded is shown in the table. If a month has all zeroes shown, it is only because that month has exceeded criteria under a different alternative. In general, the difference in the number of exceedances decreases as the water moves through the river.

Table 4-4. Difference in Number of Days the Temperature Criteria is Exceeded at the Tailwater Sites of Lower Granite, Little Goose, Lower Monumental, and Ice Harbor for the Multiple Objective 1 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Lower Granite	June	0	0	0	0	0
Lower Granite	July	0	0	0	0	0
Lower Granite	August	0	**22**	**20**	**21**	0
Lower Granite	September	0	0	**7**	0	0
Little Goose	June	0	0	0	0	0
Little Goose	July	0	0	-7	-1	0
Little Goose	August	0	**3**	**2**	**2**	0
Little Goose	September	0	**9**	**19**	**8**	0
Lower Monumental	June	0	0	0	0	0
Lower Monumental	July	0	0	-5	-2	0
Lower Monumental	August	**2**	0	0	0	0
Lower Monumental	September	0	**12**	**7**	**9**	0
Ice Harbor	June	0	0	0	0	0
Ice Harbor	July	0	0	-4	-1	0
Ice Harbor	August	0	0	0	0	0
Ice Harbor	September	**3**	**7**	**6**	**5**	0

4.2.2 Total Dissolved Gas

There are two measures within MO1 that modify juvenile fish passage spill operations in the lower Snake River (the *Block Spill Test* and *the Summer Spill Stop Trigger* measures); no fish spill operations are included in MO1 for Dworshak Dam. The *Block Spill Test* measure calls for a spill test to evaluate the latent mortality hypothesis; spill operations switch between performance (base) spill and a test spill operation within a given season. The *Spill Stop Trigger* measure calls for the modification, or early end to summer juvenile fish passage spill operations at the lower Snake River projects. Ending dates vary from August 6 to August 21, depending on the dam. Due to the within-season switch between operations, in conjunction with an assumed higher amount of lack of market spill in the No Action Alternative, model results do not show a notable differences in TDG in MO1 as compared to the No Action Alternative. Details are described below.

4.2.2.1 Dworshak Dam and Reservoir

The predicted TDG saturation in the Dworshak Dam tailwater under MO1 would be similar to No Action Alternative, with a few exceptions (Figure 4-23). The highest gas saturation would still occur during spring releases. Increases would range from 11 to 18 hours during March for the HF/LT and AF/AT conditions, respectively, under MO1 (Figure 4-24). June increases would range from 10 to 30 hours for AF/LT and AF/AT conditions, respectively. All of these changes would be minimal since they only account for approximately one to four percent of the time in any of the months. A more notable change would occur during September during HF/LT conditions when a reduction of 229 hours above the criterion would be expected—equivalent to a 32 percent decrease for the month. Table 4-5 shows the difference in the number of days that tailwater TDG exceeds the Idaho criterion of 110%.

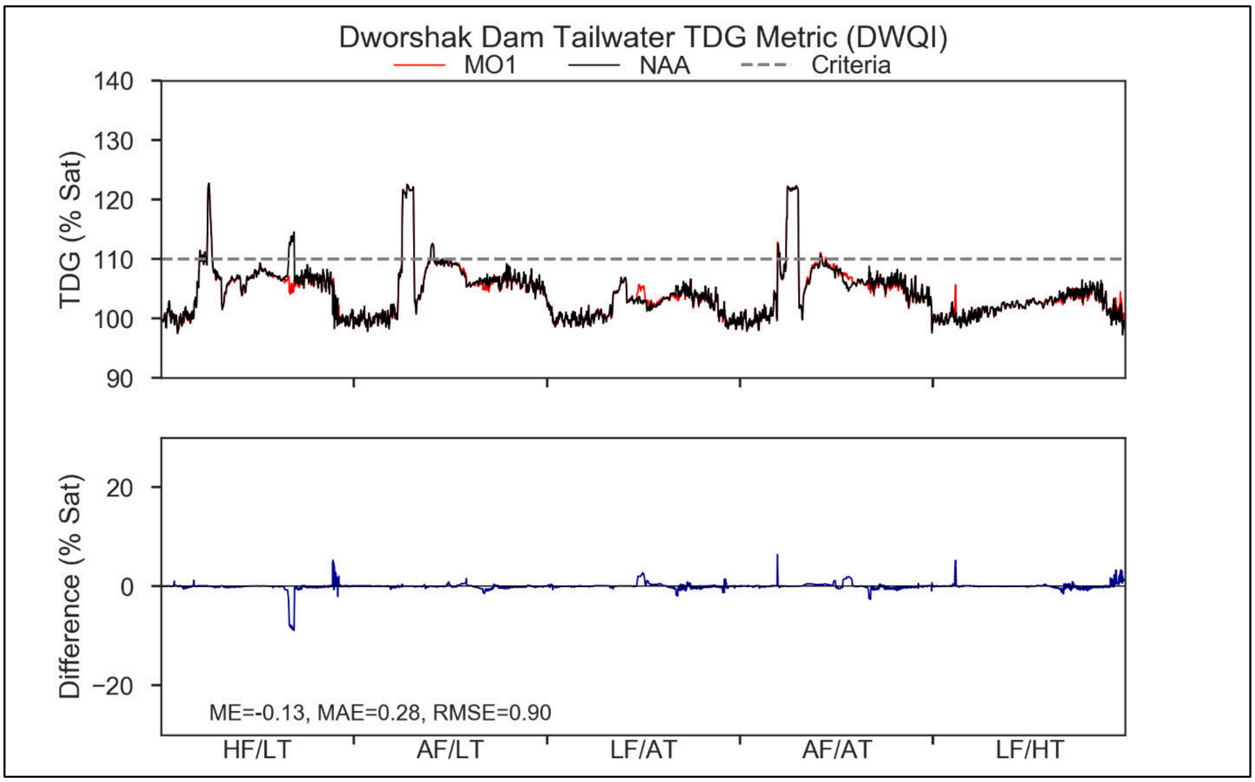


Figure 4-23. Modeled Tailwater Total Dissolved Gas for the No Action Alternative and Multiple Objective Alternative 1 at Dworshak Dam Under a 5-Year Range of River and Meteorological Conditions

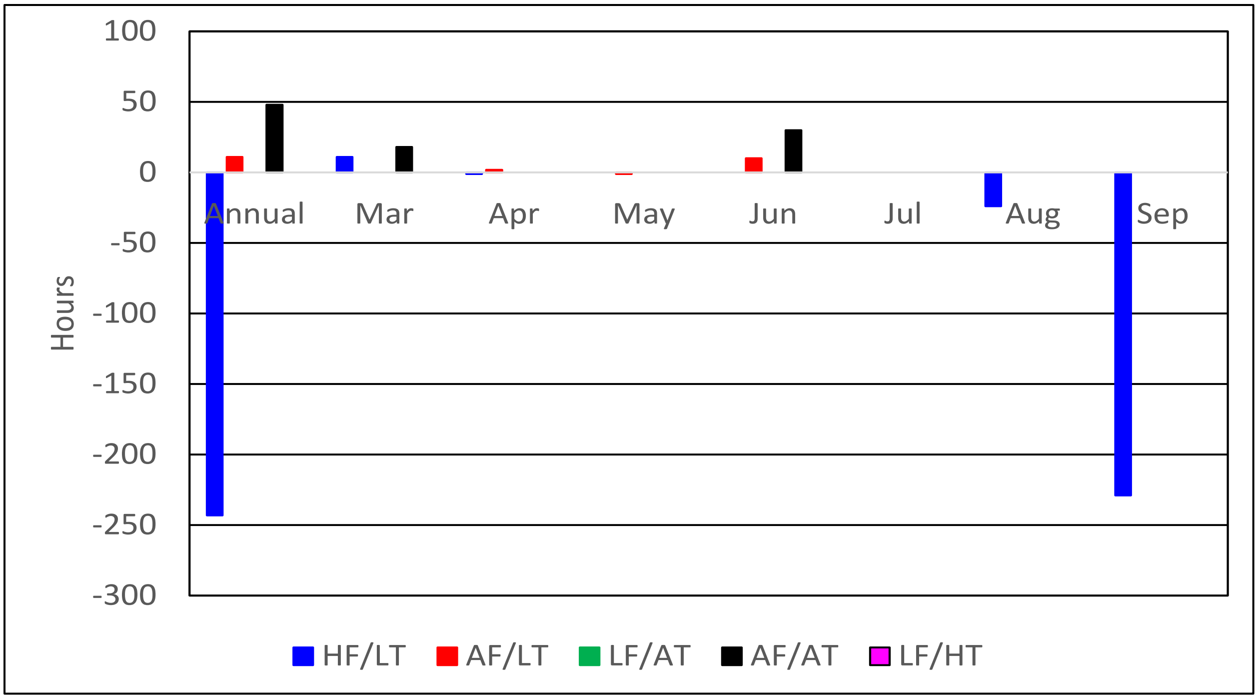


Figure 4-24. Increases and Decreases in the Number of Hours the Idaho 110 Percent Total Dissolved Gas Criterion Would be Met at the Dworshak Dam Tailwater Location for Each Flow/Temperature Condition Under Multiple Objective Alternative 1 Relative to the No Action Alternative

Table 4-5. Difference in Number of Days the TDG Criteria is Exceeded at Dworshak Dam Tailwater for the Multiple Objective 1 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

Month	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
April	0	0	0	0	0
May	0	0	0	0	0
June	0	**2**	0	**2**	0
July	0	0	0	0	0
August	-1	0	0	0	0

4.2.2.2 Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams and Reservoirs

Total gas saturation at the tailwater stations of the four lower Snake River dams under MO1 would be similar to the No Action Alternative with a few exceptions (Figure 4-25 through Figure 4-28). April through August TDG would be less than the Washington 120 percent waiver for the LF/AT, AF/AT, and LF/HT conditions. The only possible exceptions are the additional 3 days at Ice Harbor Dam during LF/AT conditions and 2 days at Lower Granite Dam during AF/AT conditions (Figure 4 30.). However, both of these are within the margin of error for the model. Larger changes would occur during HF/LT and AF/LT conditions at Lower Monumental Dam when an additional 7 and 12 days, respectively, would exceed the criterion. TDG exceedances at the Ice Harbor Dam tailwater location would also increase by 7 days under the AF/LT condition.

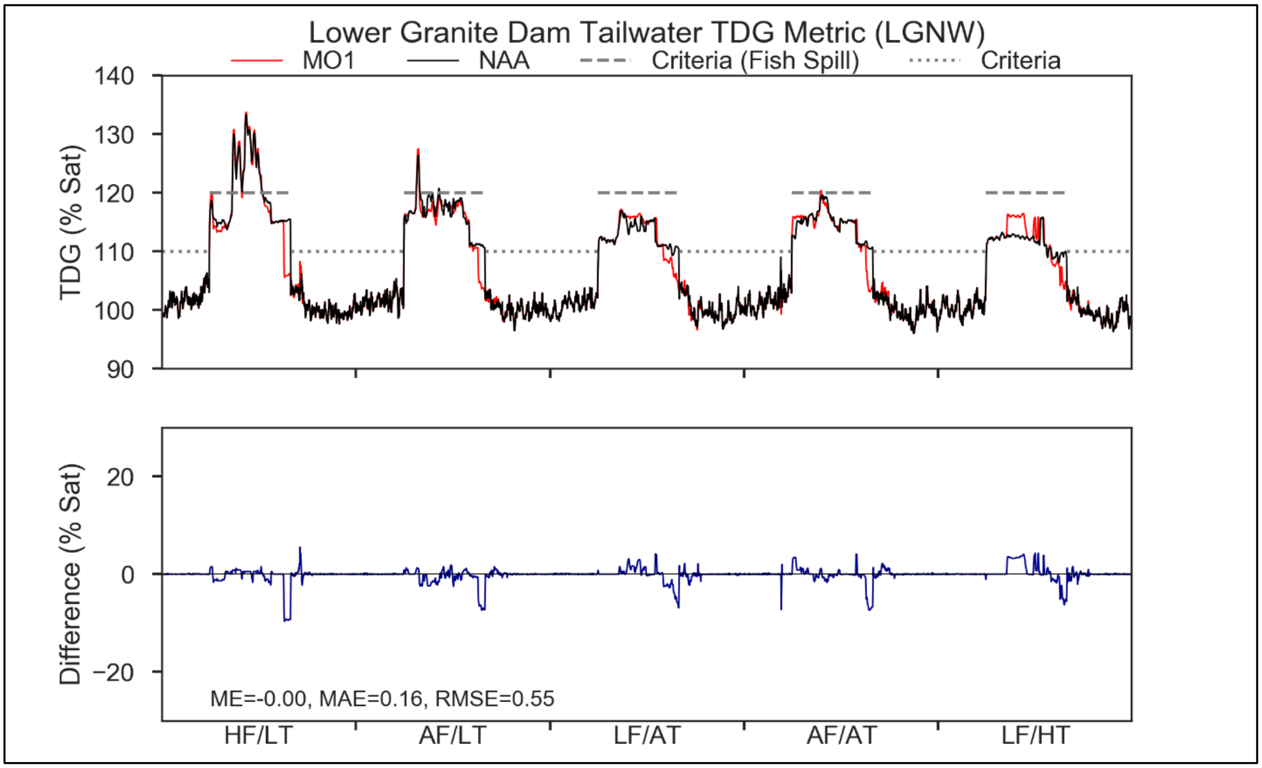


Figure 4-25. Modeled Tailwater Total Dissolved Gas for the No Action Alternative and Multiple Objective Alternative 1 at Lower Granite Dam Under a 5-Year Range of River and Meteorological Conditions

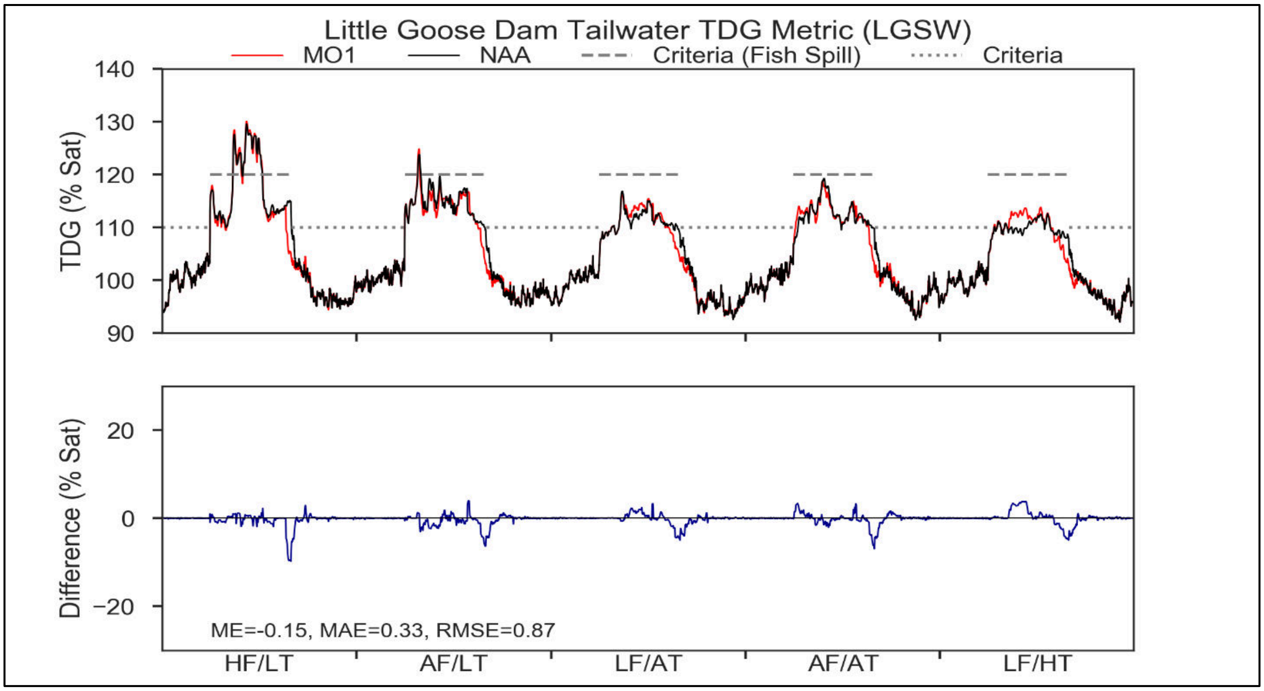


Figure 4-26. Modeled Tailwater Total Dissolved Gas for the No Action Alternative and Multiple Objective Alternative 1 at Little Goose Dam Under a 5-Year Range of River and Meteorological Conditions

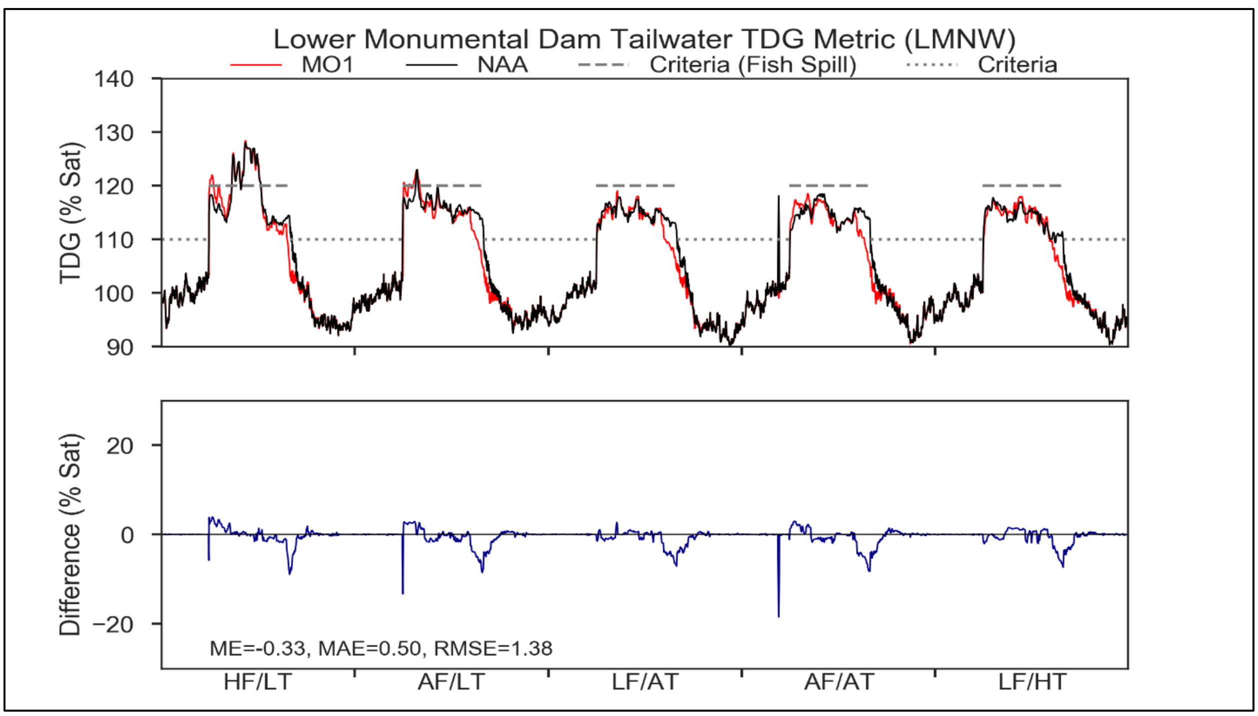


Figure 4-27. Modeled Tailwater Total Dissolved Gas for the No Action Alternative and Multiple Objective Alternative 1 at Lower Monumental Dam Under a 5-Year Range of River and Meteorological Conditions

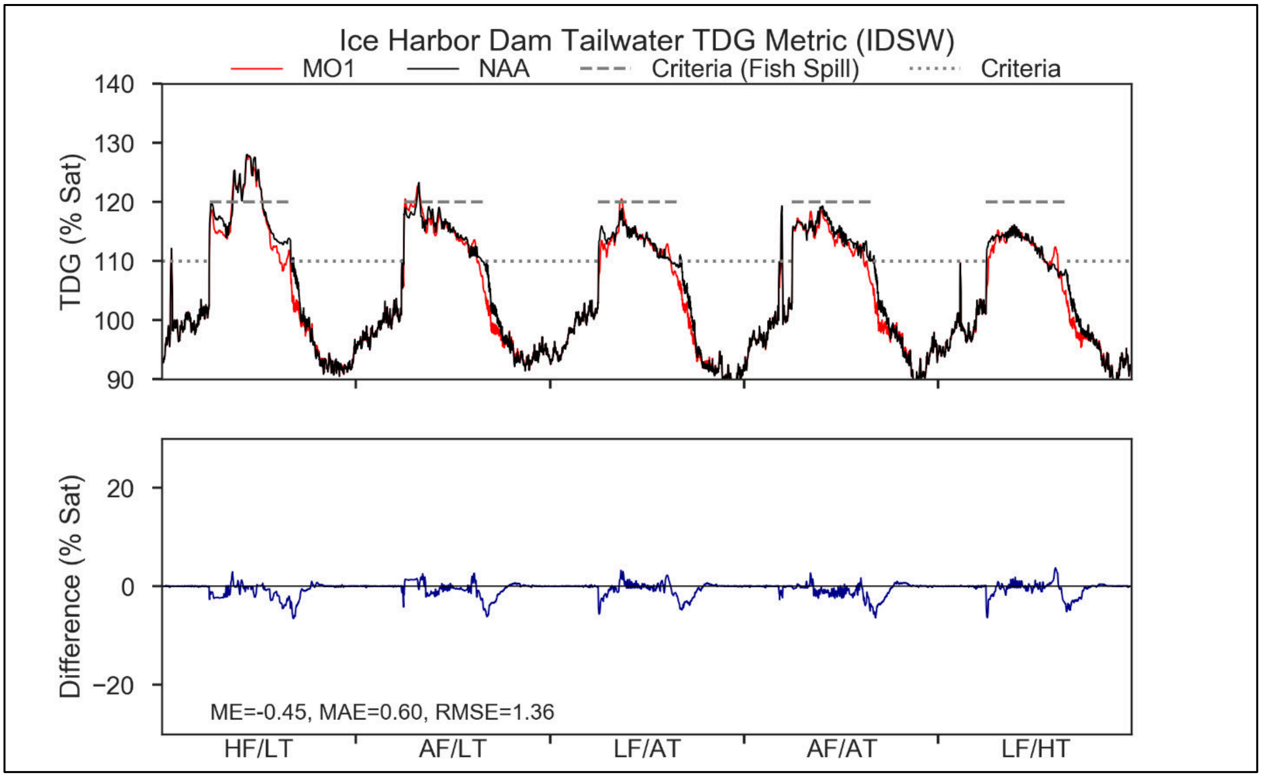


Figure 4-28. Modeled Tailwater Total Dissolved Gas for the No Action Alternative and Multiple Objective Alternative 1 at Ice Harbor Dam Under a 5-Year Range of River and Meteorological Conditions

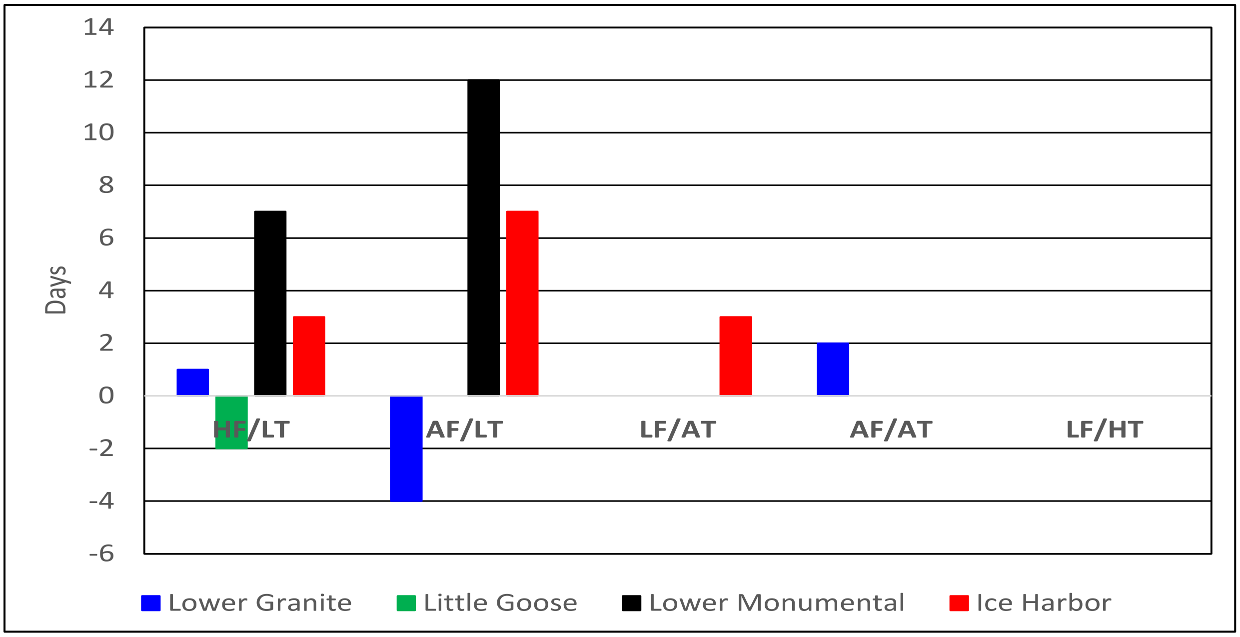


Figure 4-29. Increases and Decreases in the Number of Days the Washington 120 Percent Total Dissolved Gas Criterion Would be Met at the Lower Snake River Dam Tailwater Locations for each Flow/Temperature Condition Under Multiple Objective Alternative 1 Relative to the No Action Alternative

The model results for forebay TDG at the four lower Snake River dams under MO1 are in many ways similar to the previous results for the No Action Alternative (Figure 4-30 through Figure 4-33). TDG saturation at Lower Granite Dam would remain below Washington's April through August 115 percent waiver during each flow/temperature condition. The number of days that the criterion would be exceeded would decrease by one to 11 days at Little Goose, Lower Monumental, and Ice Harbor dams during HF/LT, AF/LT, and AF/AT conditions (Figure 4-34). Increases in forebay TDG would be greatest under MO1 at Little Goose and Lower Monumental dams under a LF/HT condition.

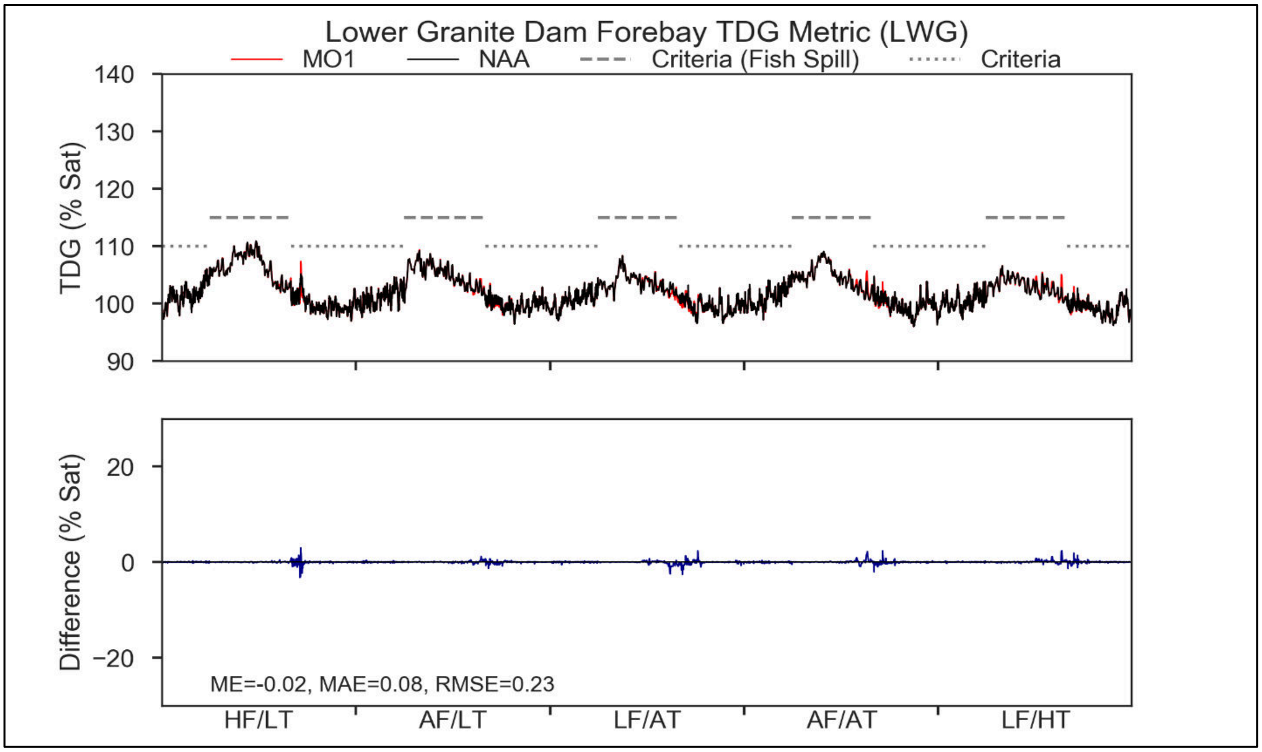


Figure 4-30. Modeled Forebay Total Dissolved Gas for the No Action Alternative and Multiple Objective Alternative 1 at Lower Granite Dam Under a 5-Year Range of River and Meteorological Conditions

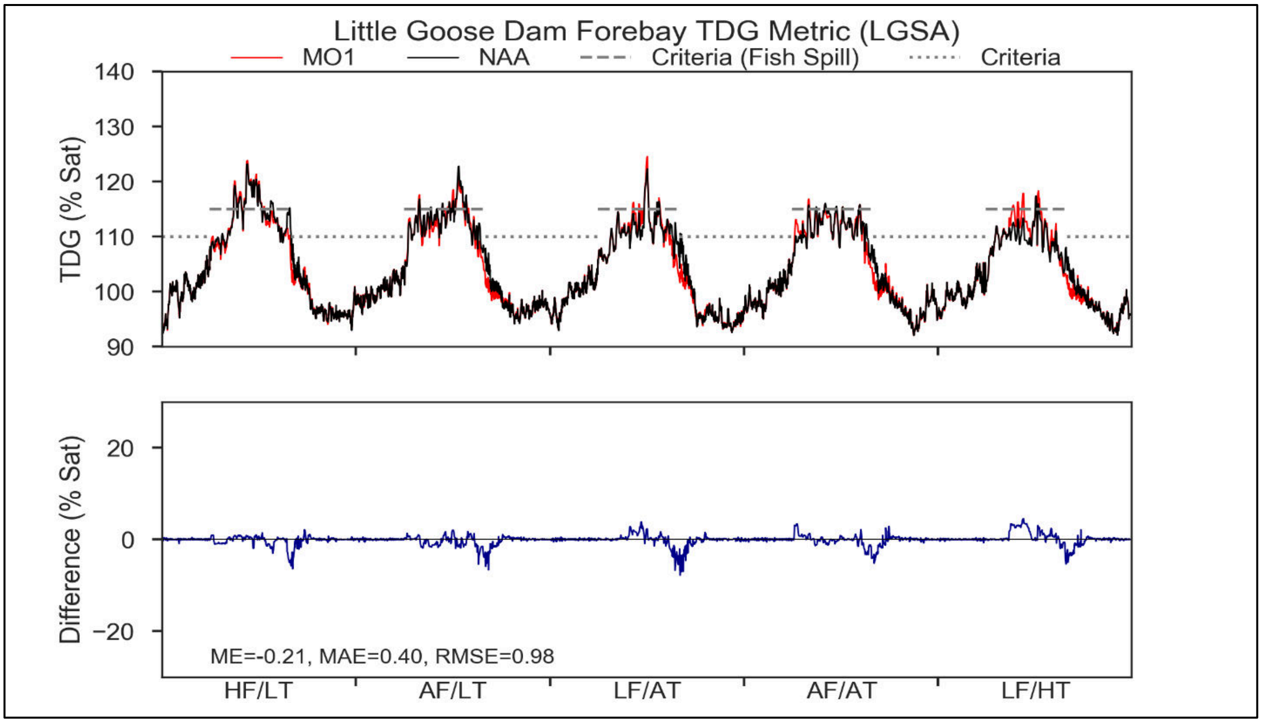


Figure 4-31. Modeled Forebay Total Dissolved Gas for the No Action Alternative and Multiple Objective Alternative 1 at Little Goose Dam Under a 5-Year Range of River and Meteorological Conditions

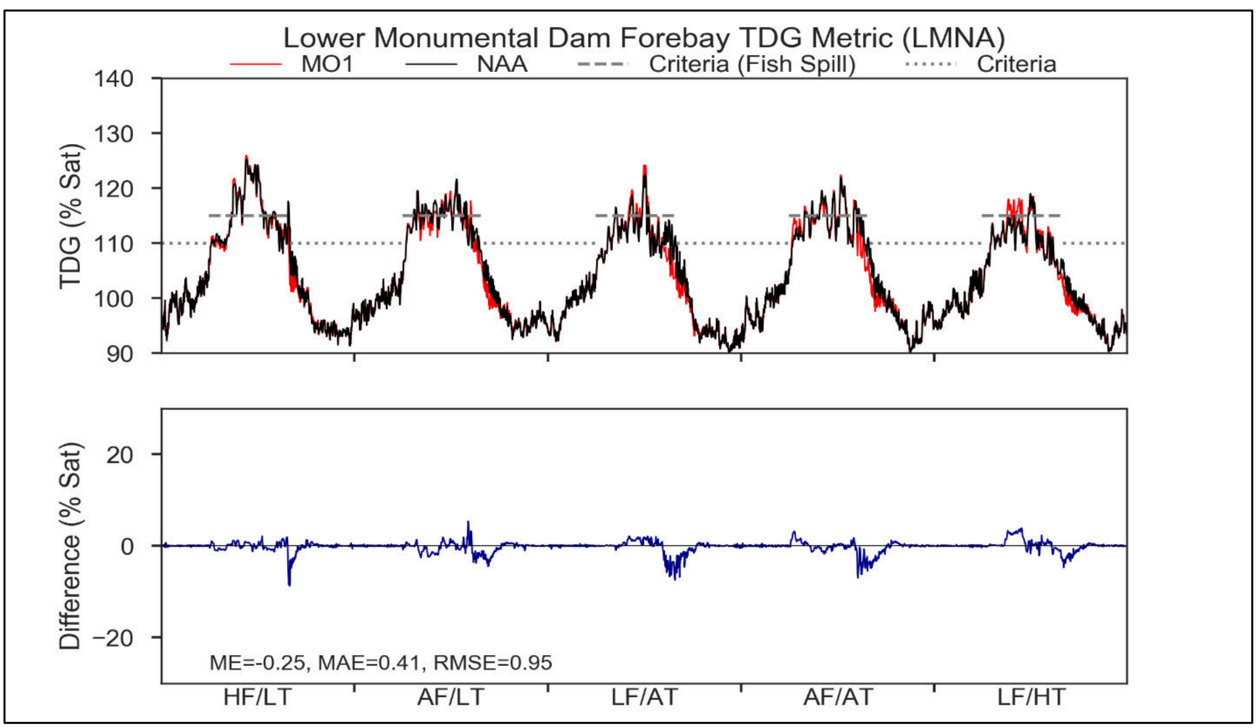


Figure 4-32. Modeled Forebay Total Dissolved Gas for the No Action Alternative and Multiple Objective Alternative 1 at Lower Monumental Dam Under a 5-Year Range of River and Meteorological Conditions

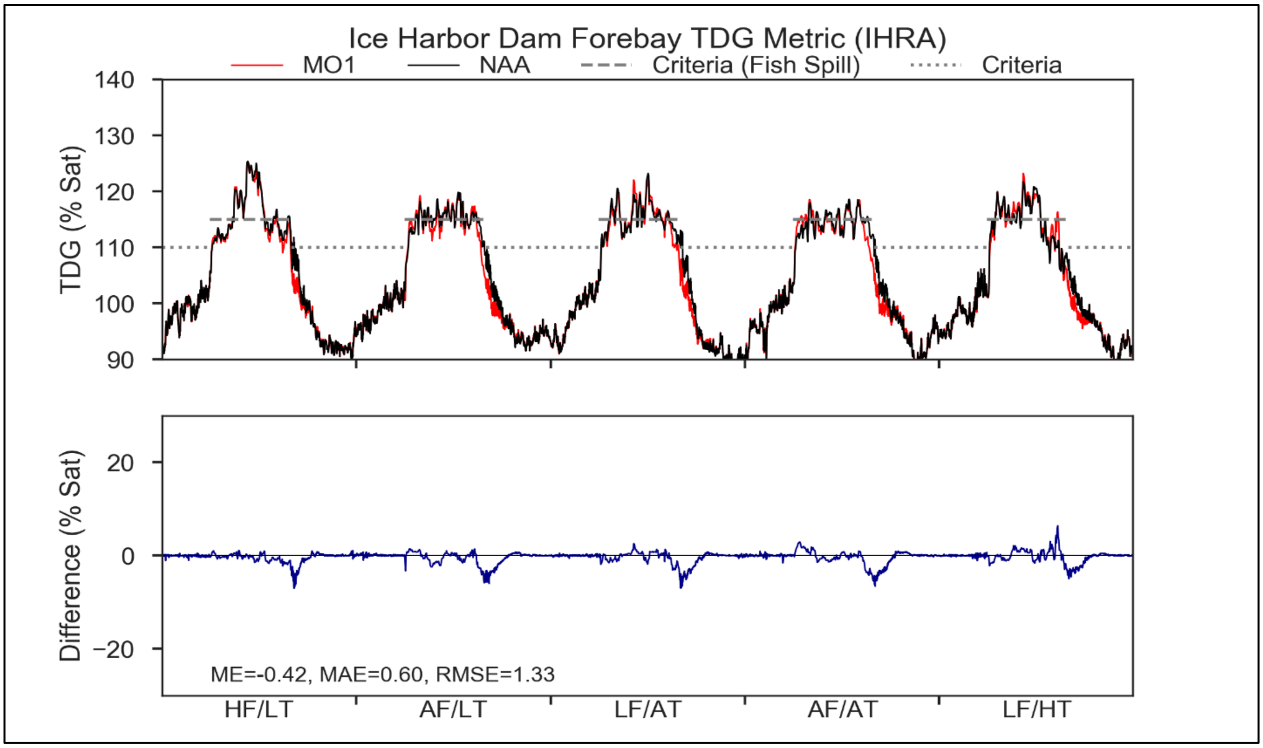


Figure 4-33. Modeled Forebay Total Dissolved Gas for the No Action Alternative and Multiple Objective Alternative 1 at Ice Harbor Dam Under a 5-Year Range of River and Meteorological Conditions

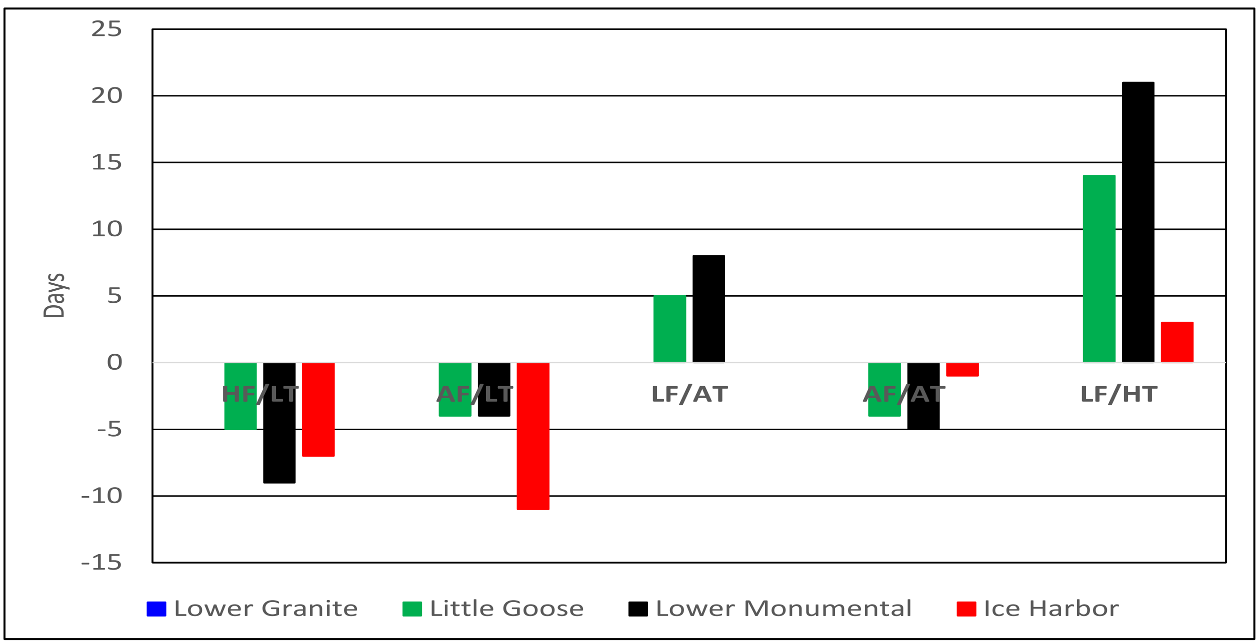


Figure 4-34. Increases and Decreases in the Number of Days the Washington 115 Percent Total Dissolved Gas Criterion Would be Met at the Lower Snake River Dam Forebay Locations for each Flow/Temperature Condition Under Multiple Objective Alternative 1 Relative to the No Action Alternative

The operational changes for MO1 do cause a few TDG differences as can be seen in the figures above. In terms of the actual number of days of the criteria being exceeded, those changes can be seen in Table 4-6. The blue highlighted cells show when an increased number of exceedances occurs as compared to NAA. Only the months where the criteria is exceeded is shown in the table. If a month has all zeroes shown, it is only because that month has exceeded criteria under a different alternative. The forebay sites tend to show a higher number of differences than at the tailwater sites

Table 4-6. Difference in Number of Days the TDG Criteria is Exceeded at the Forebay Sites of Lower Granite, Little Goose, Lower Monumental, and Ice Harbor for the Multiple Objective 1 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Little Goose	March	0	0	0	0	0
Little Goose	April	0	**1**	0	0	0
Little Goose	May	**1**	-2	0	-2	**5**
Little Goose	June	**1**	0	**5**	-3	**5**
Little Goose	July	-5	-3	0	0	**4**
Little Goose	August	-2	0	0	**1**	0
Little Goose	September	0	0	-1	0	0
Lower Monumental	March	0	0	0	0	0
Lower Monumental	April	0	0	0	0	0
Lower Monumental	May	**1**	-11	0	-1	**9**
Lower Monumental	June	0	**2**	**7**	0	**12**
Lower Monumental	July	-4	**2**	**1**	-1	0
Lower Monumental	August	-6	**3**	0	-3	0
Lower Monumental	September	0	0	0	0	0
Ice Harbor	March	0	0	0	0	0
Ice Harbor	April	0	**2**	-2	**13**	-1
Ice Harbor	May	**1**	-7	0	**1**	-1
Ice Harbor	June	0	-4	-3	-10	**2**
Ice Harbor	July	-1	0	**3**	**1**	0
Ice Harbor	August	-7	-2	**2**	-6	**3**
Ice Harbor	September	-1	0	-5	-1	0

Table 4-7. Difference in Number of Days the TDG Criteria is Exceeded at the Tailwater Sites of Lower Granite, Little Goose, Lower Monumental, and Ice Harbor for the Multiple Objective 1 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Lower Granite	February	0	0	0	0	0
Lower Granite	March	0	0	0	0	0
Lower Granite	April	**1**	0	0	0	0
Lower Granite	May	0	-2	0	**2**	0
Lower Granite	June	-1	-2	0	0	0
Lower Granite	July	**1**	0	0	0	0
Little Goose	March	0	0	0	0	0
Little Goose	April	0	0	0	0	0
Little Goose	May	-2	0	0	0	0
Little Goose	June	0	0	0	0	0
Little Goose	July	0	0	0	0	0
Little Goose	September	0	0	0	0	0
Lower Monumental	February	0	0	0	0	0
Lower Monumental	March	0	-1	0	-2	0
Lower Monumental	April	**7**	**9**	0	0	0
Lower Monumental	May	0	**3**	0	0	0
Lower Monumental	June	0	0	0	0	0
Lower Monumental	July	0	0	0	0	0
Lower Monumental	September	-3	0	0	0	0
Ice Harbor	January	0	0	0	0	0
Ice Harbor	February	0	0	0	0	0
Ice Harbor	March	0	0	0	-1	0
Ice Harbor	April	0	**5**	0	0	0
Ice Harbor	May	**2**	**2**	**3**	0	0
Ice Harbor	June	0	0	0	0	0
Ice Harbor	July	**1**	0	0	0	0
Ice Harbor	September	-1	0	-2	-1	0

4.2.3 Other Physical, Chemical, and Biological Processes

4.2.3.1 Dworshak Dam and Reservoir

Reduced outflow during August would increase the hydrologic residence time of the reservoir during that month which could lead to an increase in phytoplankton growth, including cyanobacteria (blue-green algae). However, since the nutrient fertilization program that adds liquid nitrogen to modify the nitrogen to phosphorus ratio would continue, adjustments to the application rate would be made to mitigate formation of these blooms in most of the reservoir. Other parameters such as Secchi disk depth and chlorophyll a concentrations would remain within normal inter-annual variability.

4.2.3.2 Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams and Reservoirs

The reduced outflows from Dworshak Dam during August would lead to higher water temperatures, an increase in hydrologic residence times, and higher concentrations of nutrients due to a greater contribution of total flow from the middle Snake River. These conditions could promote increased primary production, including nuisance growth of aquatic algae or cyanobacteria. These effects might be especially pronounced where waters are more quiescent and where contact recreation is common, such as swimming areas or sheltered boat launches. However, such effects are highly uncertain and cannot be confidently predicted with available information.

4.3 LOWER COLUMBIA RIVER

4.3.1 Water Temperature

There are no specific structural or operational measures in MO1 that are expected to influence water temperatures in the lower Columbia River. Details are provided below.

4.3.1.1 McNary, John Day, The Dalles, and Bonneville Dams and Reservoirs

The tailwater temperatures for MO1 at McNary, John Day, The Dalles, and Bonneville Dams were modeled under a 5-year range of river and meteorological conditions, and compared to the modeled results for the No Action Alternative (Figure 4-35 through Figure 4-38). Just as with the No Action Alternative model results, the MO1 model results show that tailwater temperatures can exceed 68°F at all four dams during any of the years and conditions presented, and maximum water temperatures and the frequency of water temperature exceedances of state water quality criterion would be higher during a year when river flows were lower than normal and summer ambient air temperatures were higher (as in LF/HT). The shift in the timing of releases from Dworshak Dam to provide cooler water both earlier and later in the summer to the lower Snake River appears to have little or no effect on water temperatures in the lower Columbia River. The average frequency of water temperature exceedances to the State water quality criterion would be nearly identical for the No Action Alternative and MO1 for all four lower Columbia River dams (Figure 4-39). Generally, there would not be a significant difference in tailwater temperatures under the No Action Alternative and MO1.

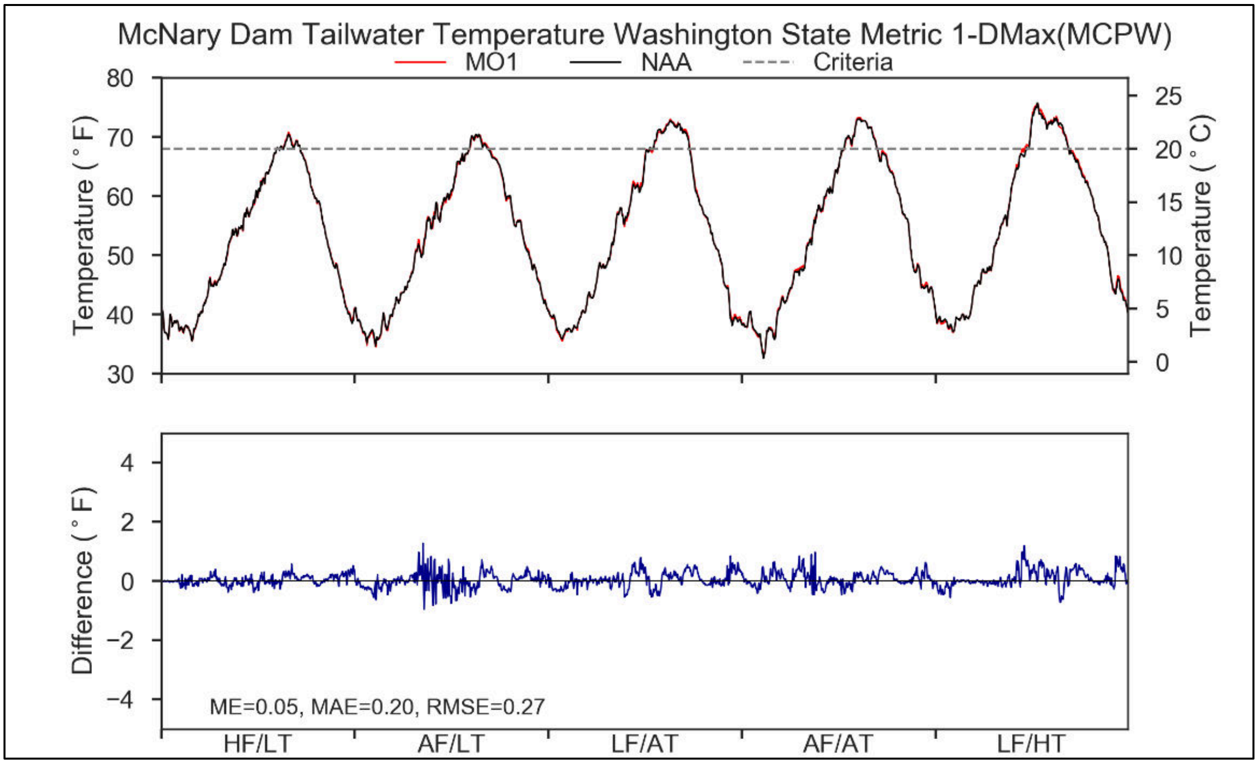


Figure 4-35. Modeled Tailwater Temperature for Multiple Objective Alternative 1 at McNary Dam Under a 5-Year Range of River and Meteorological Conditions

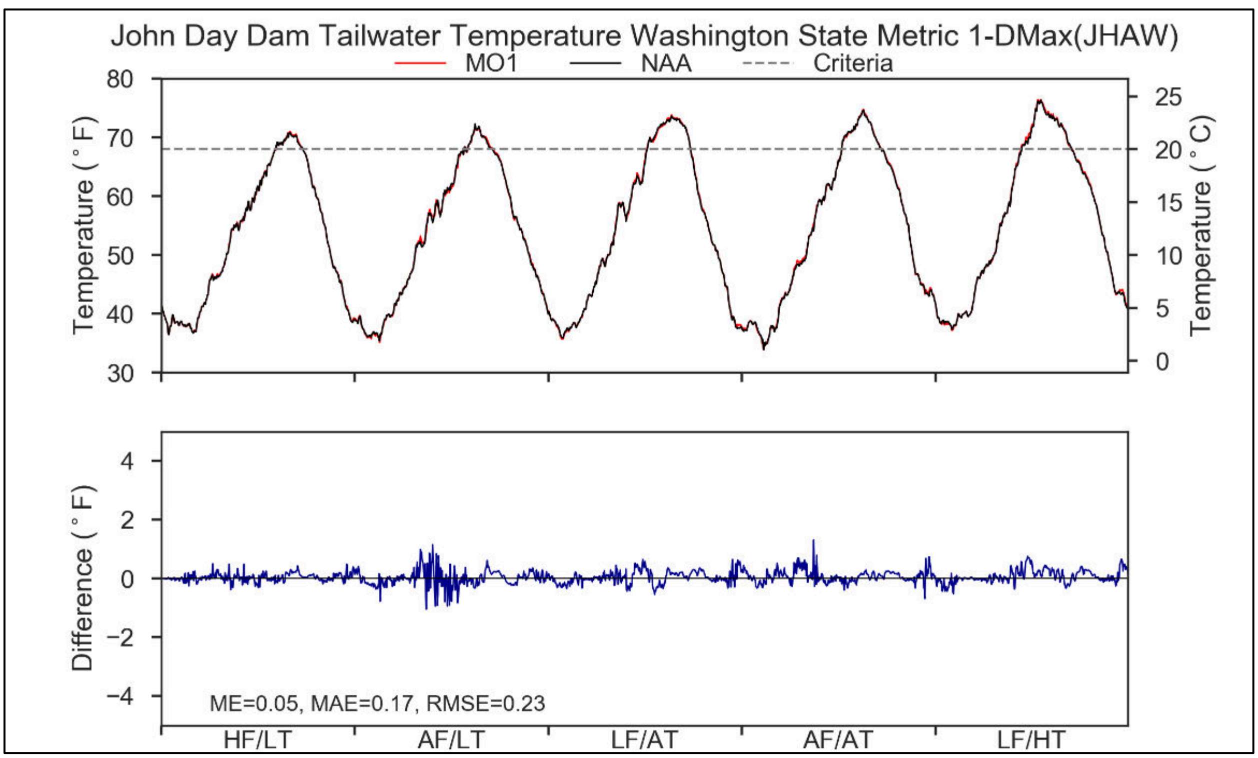


Figure 4-36. Modeled Tailwater Temperature for Multiple Objective Alternative 1 at John Day Dam Under a 5-Year Range of River Meteorological Conditions

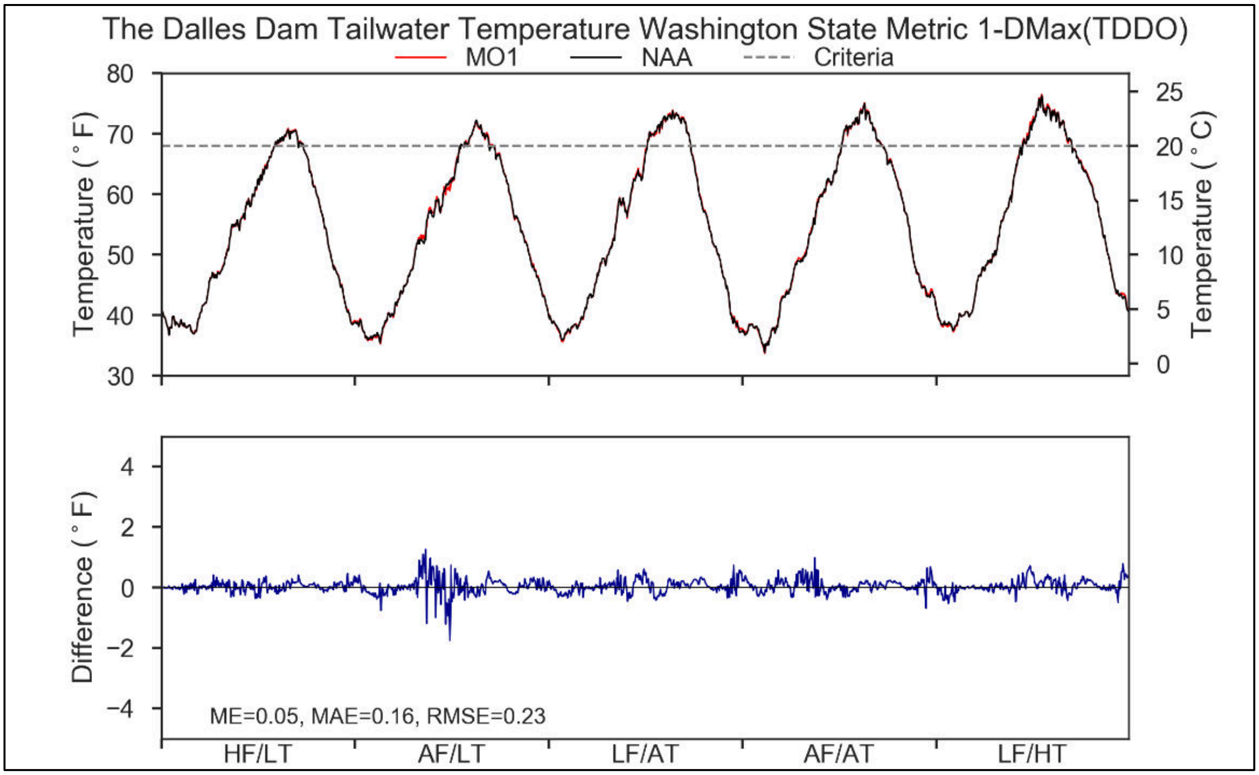


Figure 4-37. Modeled Tailwater Temperature for Multiple Objective Alternative 1 at The Dalles Dam Under a 5-Year Range of River and Meteorological Conditions

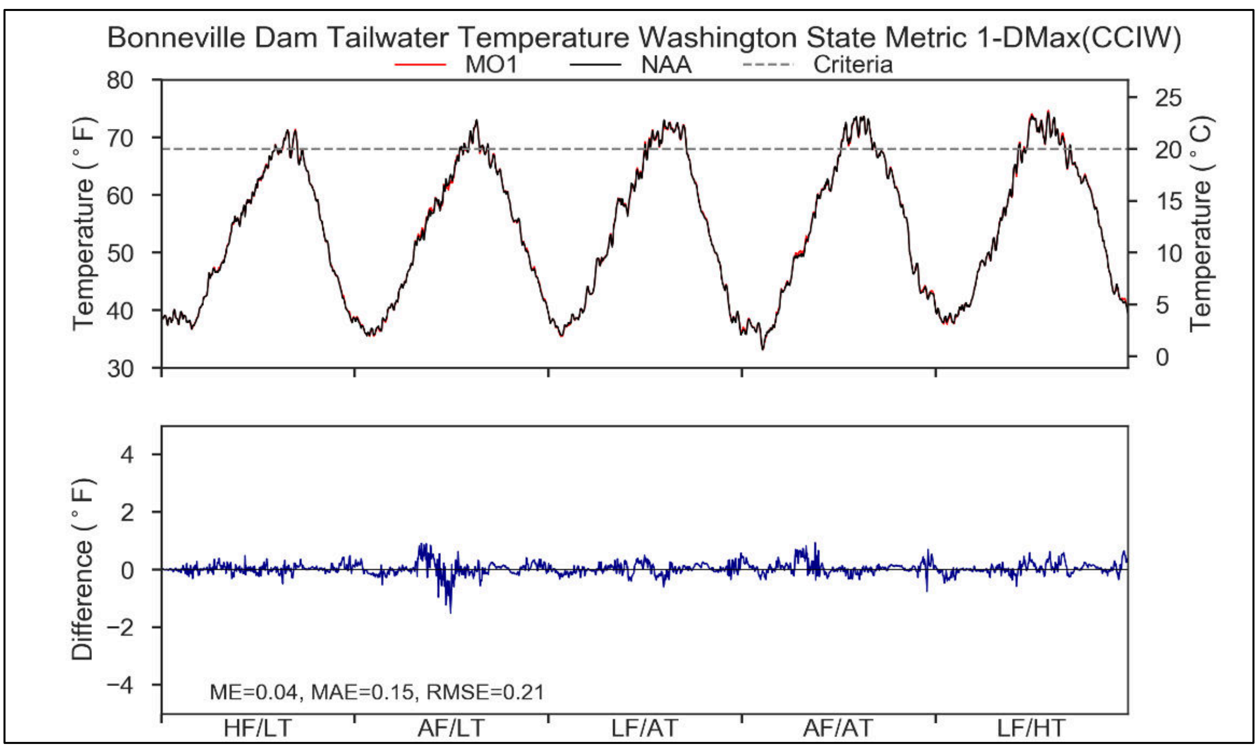


Figure 4-38. Modeled Tailwater Temperature for Multiple Objective Alternative 1 at Bonneville Dam Under a 5-Year Range of River and Meteorological Conditions

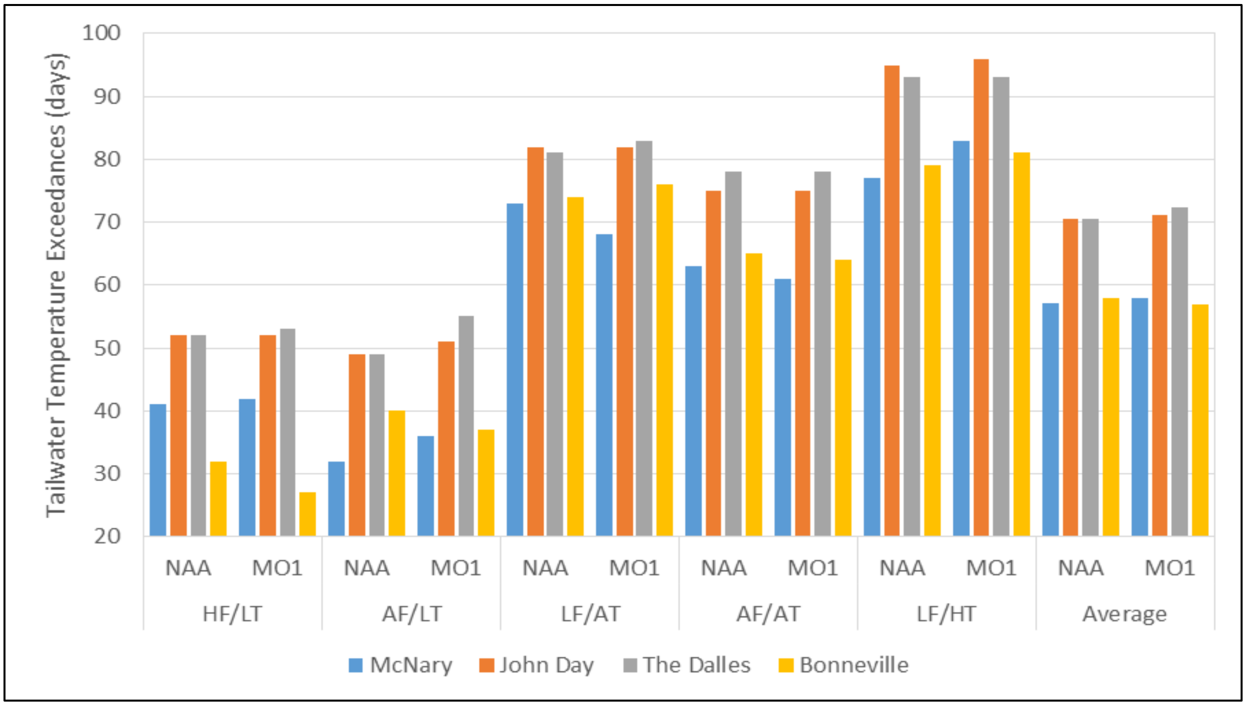


Figure 4-39. Frequency of Modeled Tailwater Temperature Violations of State Water Quality Criterion for the No Action Alternative and Multiple Objective Alternative 1 at McNary, John Day, The Dalles, and Bonneville Dams Under a 5-Year Range of River and Meteorological Conditions

The operational changes for MO1 do cause a few temperature differences as can be seen in the figures above. In terms of the actual number of days of the criteria being exceeded, those changes can be seen in Table 4-8. The blue highlighted cells show when an increased number of exceedances occurs as compared to NAA. Only the months where the criteria is exceeded is shown in the table. In general, the difference in the number of exceedances is negligible except under low temperature conditions.

Table 4-8. Difference in Number of Days the Temperature Criteria is Exceeded at the Tailwater Sites of McNary, John Day, The Dalles, and Bonneville for the Multiple Objective 1 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary	June	0	0	0	0	0
McNary	July	0	0	-6	-2	0
McNary	August	**1**	0	0	0	0
McNary	September	0	**4**	**1**	0	0
John Day	June	0	0	0	0	0
John Day	July	0	**1**	0	-1	0
John Day	August	0	0	0	0	0
John Day	September	0	**1**	0	**1**	0

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
The Dalles	June	0	0	0	0	0
The Dalles	July	0	**1**	**1**	0	0
The Dalles	August	-1	0	0	0	0
The Dalles	September	**2**	**5**	**1**	0	0
Bonneville	June	0	0	0	0	0
Bonneville	July	0	0	**1**	0	0
Bonneville	August	-4	-2	0	0	0
Bonneville	September	-1	-1	**1**	-1	0

4.3.2 Total Dissolved Gas

The *Block Spill Test* measure calls for a spill test to evaluate the latent mortality hypothesis in the lower Columbia River. Under this measure, spill operations switch between performance (base) spill and a test spill operation within a given season. Due to the within season switch between operations, in conjunction with an assumed higher amount of lack of market spill in the No Action Alternative, model results do not show a notable difference in TDG in MO1 as compared to the No Action Alternative. Details are described below.

4.3.2.1 McNary, John Day, The Dalles, and Bonneville Dams and Reservoirs

Forebay TDG saturations for MO1 at McNary, John Day, The Dalles, and Bonneville Dams were modeled under a 5-year range of river and meteorological conditions and compared to the modeled results for the No Action Alternative (Figure 4-40 through Figure 4-43). The MO1 model results show that forebay TDG saturations can exceed 115 percent at all four dams during all of the years and conditions presented. Maximum forebay TDG saturation would be higher during a year when river flows were higher than normal and summer ambient air temperatures were lower (as in 2011). Forebay TDG saturations would be similar in MO1 as compared to No Action Alternative for all four dams. Differences between the frequencies of various TDG ranges at the forebay sites between No Action Alternative and MO1 are minor (Table 4-9).

MO1 model results show that tailwater TDG saturations can exceed 120 percent at all four dams depending on the river and meteorological conditions, though there are conditions where exceedances do not occur for McNary and John Day Dams (Figure 4-44 through Figure 4-47). Maximum tailwater TDG saturation would be higher during a year when river flows were higher than normal and summer ambient air temperatures were lower (HF/LT). Tailwater TDG saturations in MO1 as compared to the No Action Alternative are fairly similar for all four dams. Differences between the frequencies of various TDG ranges at the tailwater sites between No Action Alternative and MO1 are minor (Table 4-10).

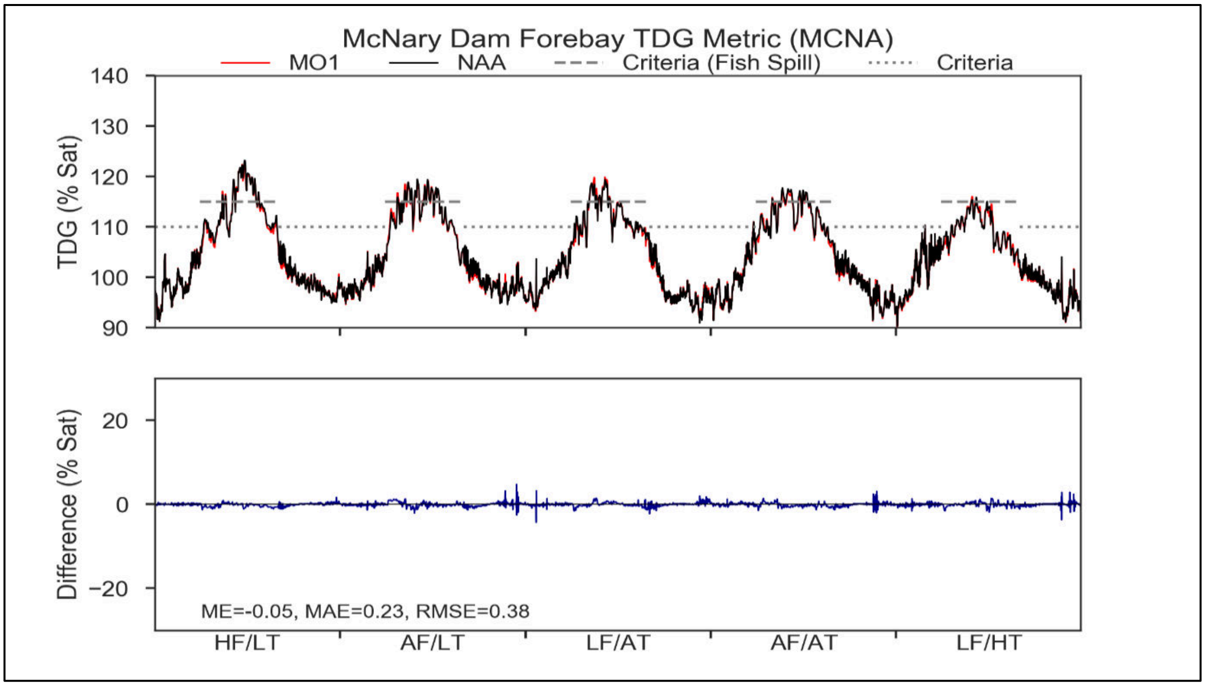


Figure 4-40. Modeled Forebay Total Dissolved Gas for Multiple Objective Alternative 1 at McNary Dam Under a 5-Year Range of River and Meteorological Conditions

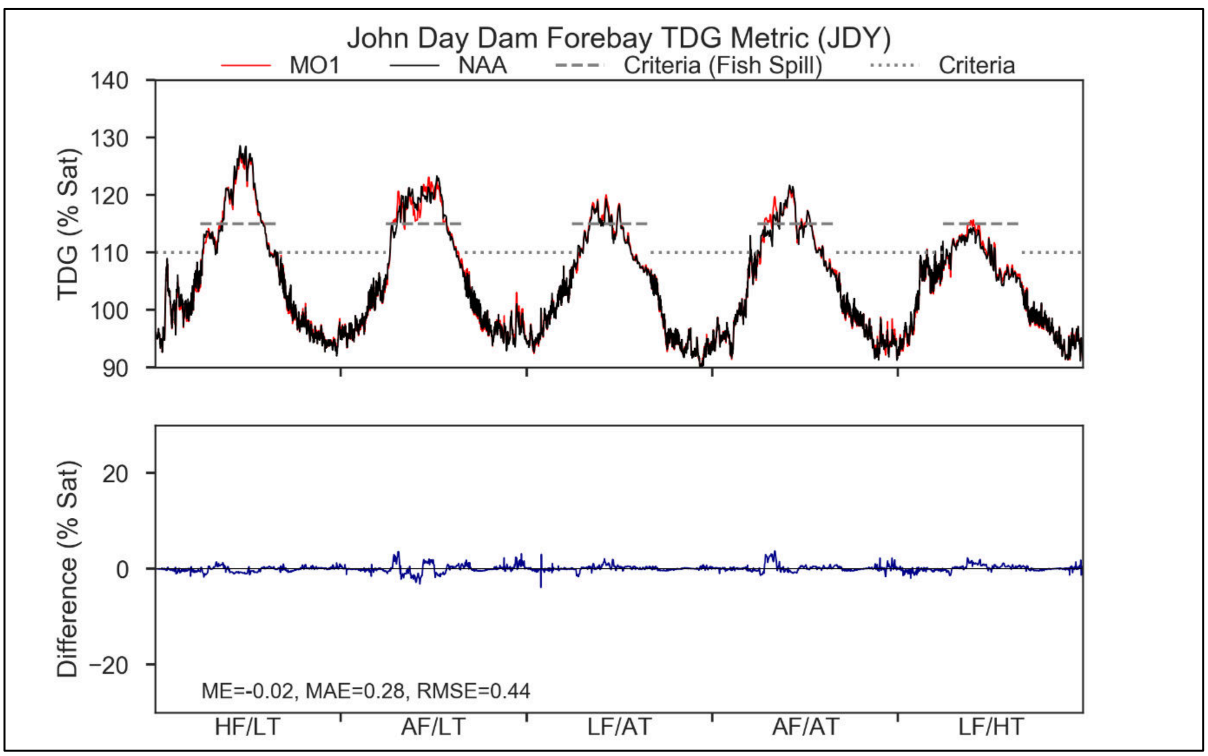


Figure 4-41. Modeled Forebay Total Dissolved Gas for Multiple Objective Alternative 1 at John Day Dam Under a 5-Year Range of River and Meteorological Conditions

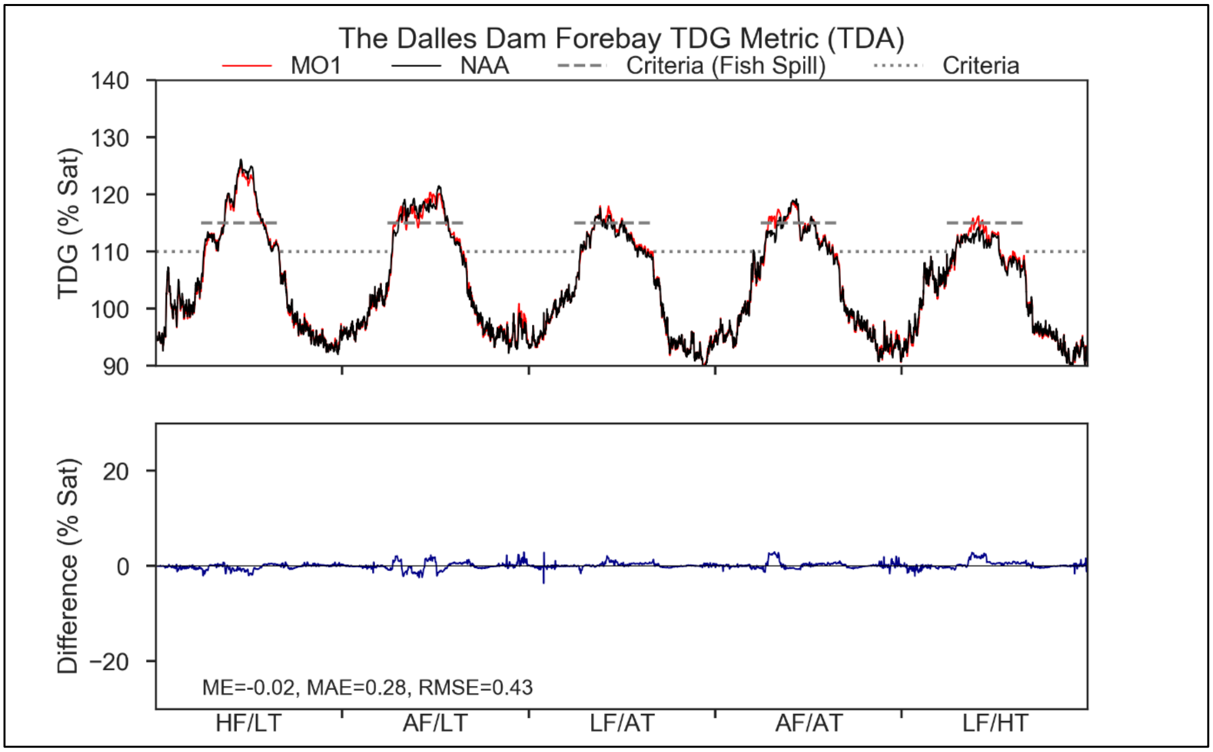


Figure 4-42. Modeled Forebay Total Dissolved Gas for Multiple Objective Alternative 1 at The Dalles Dam Under a 5-Year Range of River and Meteorological Conditions

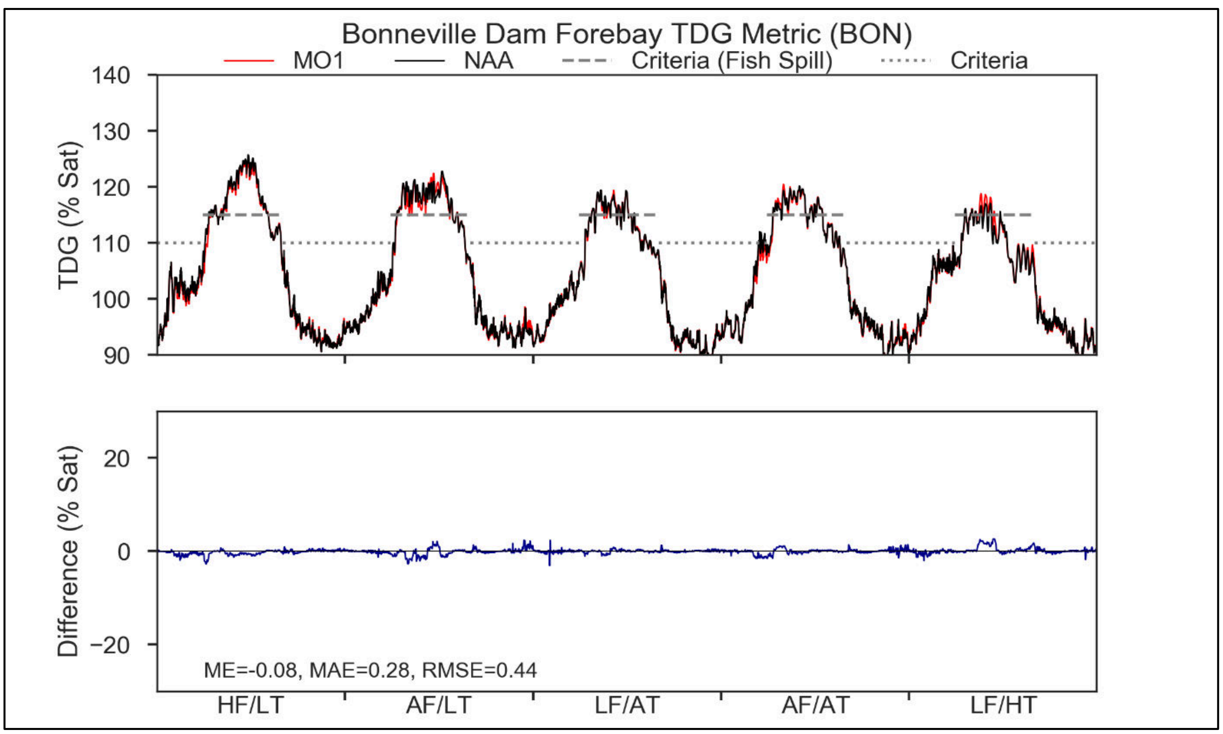


Figure 4-43. Modeled Forebay Total Dissolved Gas for Multiple Objective Alternative 1 at Bonneville Dam Under a 5-Year Range of River and Meteorological Conditions

Table 4-9. Difference in the Frequency of Modeled Forebay Total Dissolved Range for the Multiple Objective Alternative 1 relative to the No Action Alternative at McNary, John Day, The Dalles, and Bonneville Dams Under a 5-Year Range of River and Meteorological Conditions

SITE	TDG Range (% Sat)	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary Forebay	<=110	3.29%	-1.09%	1.92%	1.11%	0.00%
McNary Forebay	>110,<=115	-3.29%	1.37%	-3.01%	-0.01%	-0.55%
McNary Forebay	>115,<=120	0.27%	-0.27%	1.10%	-1.10%	0.55%
McNary Forebay	>120,<=125	-0.27%	0.00%	0.00%	0.00%	0.00%
McNary Forebay	>125	0.00%	0.00%	0.00%	0.00%	0.00%
John Day Forebay	<=110	0.27%	-0.82%	0.55%	-0.11%	-0.29%
John Day Forebay	>110,<=115	-1.10%	-1.09%	-1.64%	-5.91%	-1.91%
John Day Forebay	>115,<=120	1.92%	-0.27%	0.82%	7.12%	2.20%
John Day Forebay	>120,<=125	0.82%	2.19%	0.27%	-1.10%	0.00%
John Day Forebay	>125	-1.92%	0.00%	0.00%	0.00%	0.00%
The Dalles Forebay	<=110	0.82%	-0.27%	-0.87%	-1.02%	-0.27%
The Dalles Forebay	>110,<=115	-1.10%	0.82%	-2.97%	-3.37%	-3.57%
The Dalles Forebay	>115,<=120	2.19%	0.00%	3.84%	4.38%	3.85%
The Dalles Forebay	>120,<=125	-1.64%	-0.55%	0.00%	0.00%	0.00%
The Dalles Forebay	>125	-0.27%	0.00%	0.00%	0.00%	0.00%
Bonneville Forebay	<=110	1.37%	0.55%	-0.27%	2.31%	-0.55%
Bonneville Forebay	>110,<=115	-1.37%	0.27%	0.82%	-2.31%	-2.47%
Bonneville Forebay	>115,<=120	3.01%	1.37%	-0.55%	0.00%	3.02%
Bonneville Forebay	>120,<=125	-2.47%	-2.19%	0.00%	0.00%	0.00%
Bonneville Forebay	>125	-0.55%	0.00%	0.00%	0.00%	0.00%

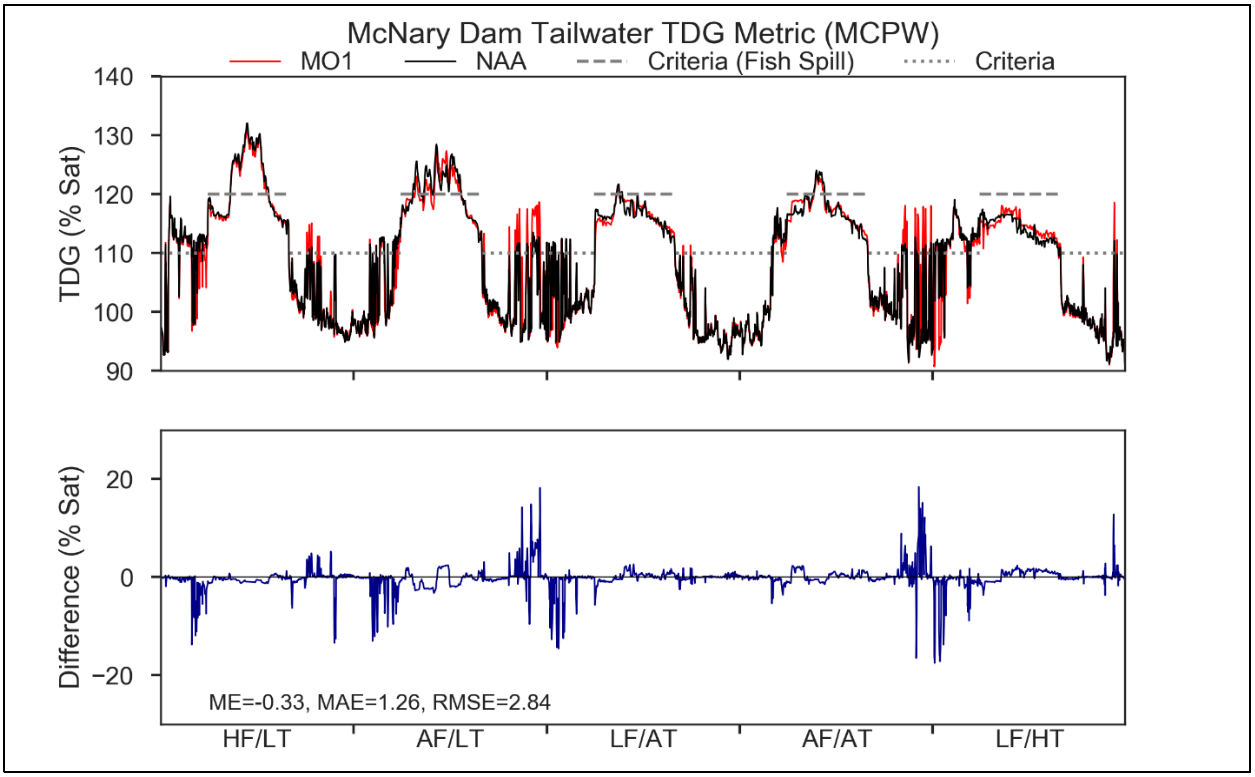


Figure 4-44. Modeled Tailwater Total Dissolved Gas for Multiple Objective Alternative 1 at McNary Dam Under a 5-Year Range of River and Meteorological Conditions

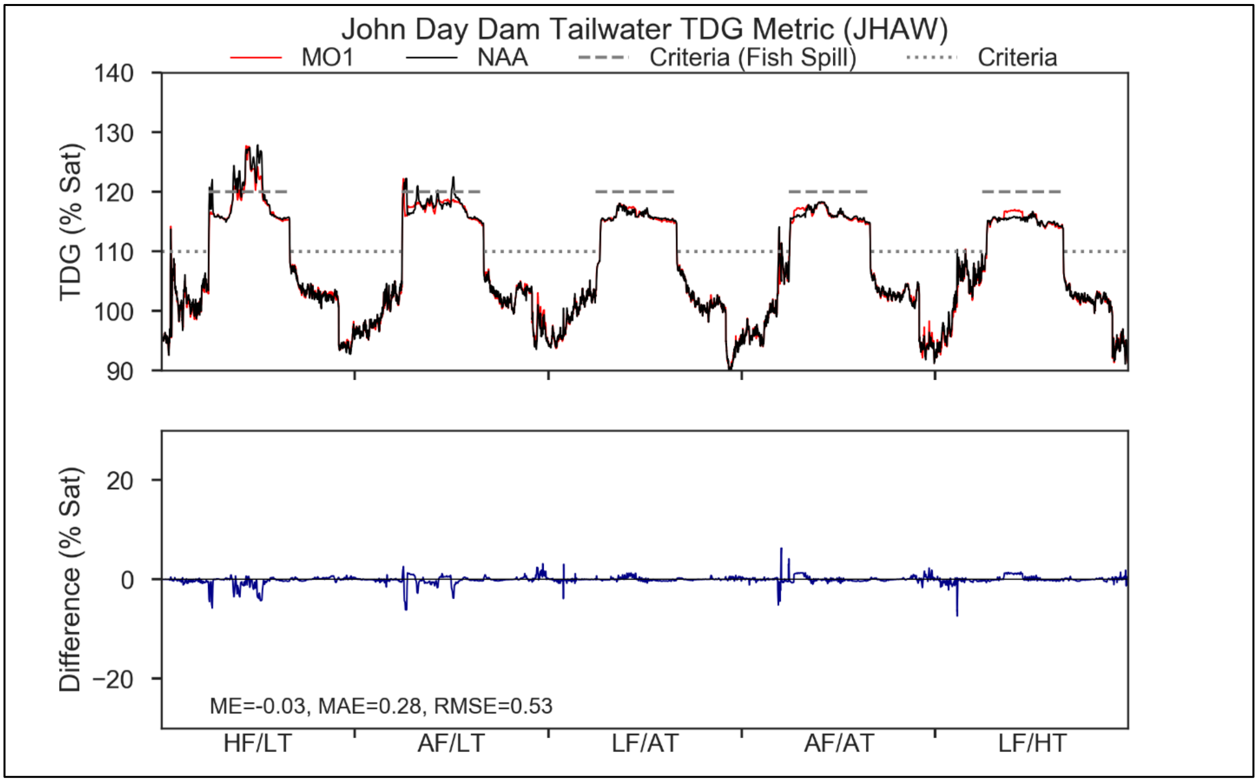


Figure 4-45. Modeled Tailwater Total Dissolved Gas for Multiple Objective Alternative 1 at John Day Dam Under a 5-Year Range of River and Meteorological Conditions

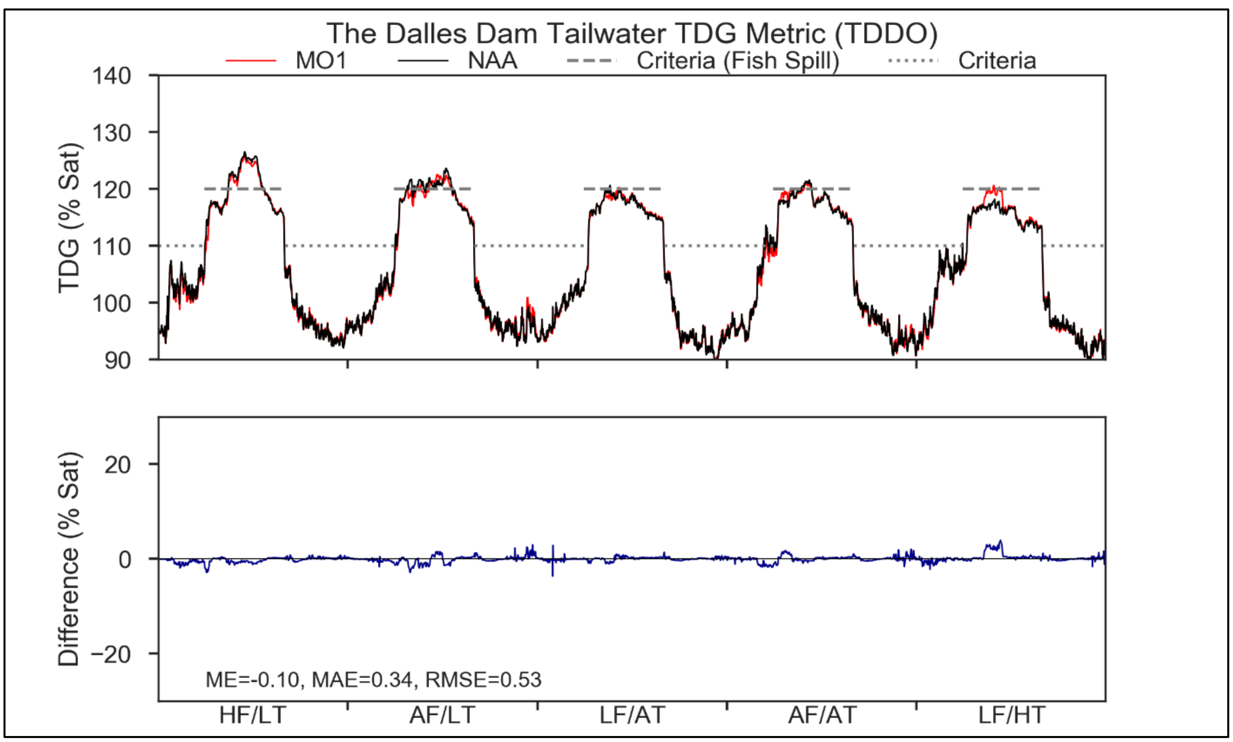


Figure 4-46. Modeled Tailwater Total Dissolved Gas for Multiple Objective Alternative 1 at The Dalles Dam Under a 5-Year Range of River and Meteorological Conditions

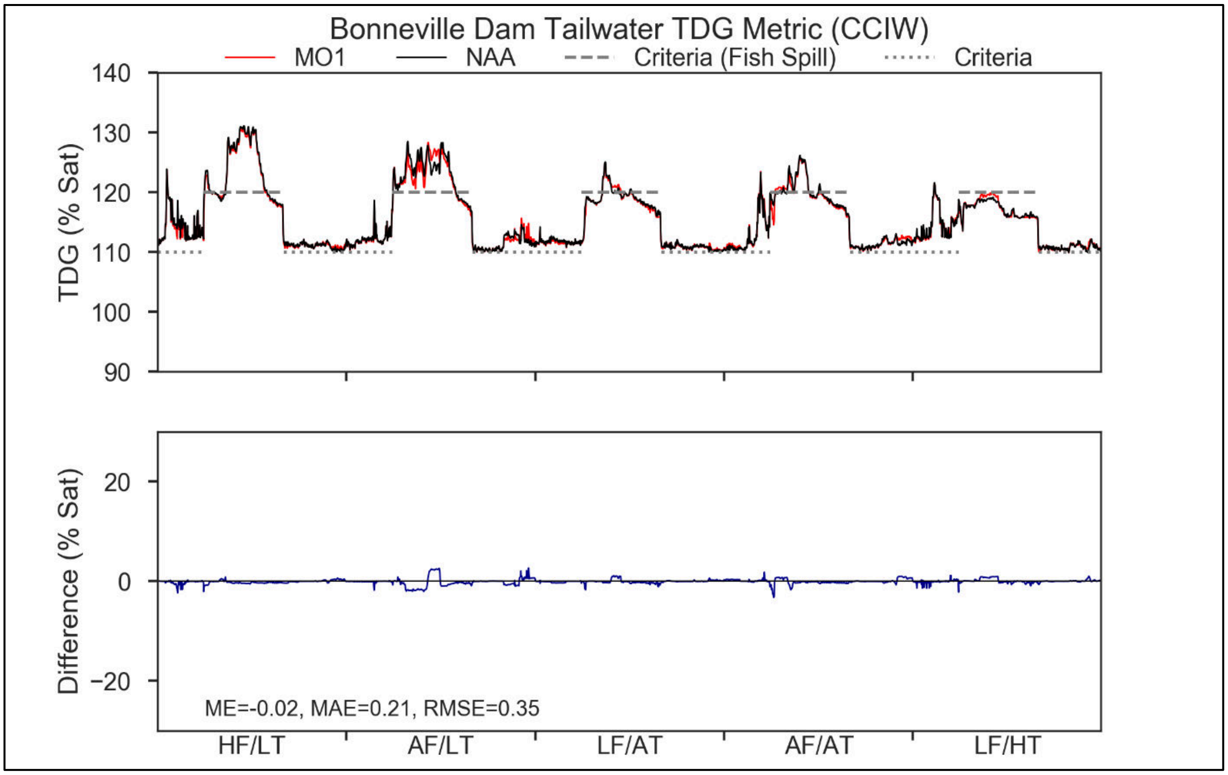


Figure 4-47. Modeled Tailwater Total Dissolved Gas for Multiple Objective Alternative 1 at Bonneville Dam Under a 5-Year Range of River and Meteorological Conditions

Table 4-10. Difference in the Frequency of Modeled Tailwater Total Dissolved Range for the Multiple Objective Alternative 1 relative to the No Action Alternative at McNary, John Day, The Dalles, and Bonneville Dams Under a 5-Year Range of River and Meteorological Conditions

SITE	TDG Range (% Sat)	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary Tailwater	<=110	1.47%	-0.20%	0.94%	-1.14%	1.92%
McNary Tailwater	>110,<=115	-0.39%	-2.98%	2.63%	-0.13%	3.00%
McNary Tailwater	>115,<=120	0.01%	7.29%	-2.47%	1.82%	-4.92%
McNary Tailwater	>120,<=125	1.10%	-3.83%	-1.10%	-0.55%	0.00%
McNary Tailwater	>125	-2.19%	-0.27%	0.00%	0.00%	0.00%
John Day Tailwater	<=110	-0.02%	0.00%	0.00%	-0.03%	0.01%
John Day Tailwater	>110,<=115	0.02%	1.09%	3.29%	2.23%	2.19%
John Day Tailwater	>115,<=120	2.47%	2.19%	-3.29%	-2.19%	-2.20%
John Day Tailwater	>120,<=125	1.10%	-3.28%	0.00%	0.00%	0.00%
John Day Tailwater	>125	-3.56%	0.00%	0.00%	0.00%	0.00%
The Dalles Tailwater	<=110	0.82%	0.00%	0.27%	3.89%	0.01%
The Dalles Tailwater	>110,<=115	-0.55%	-0.27%	-1.10%	-4.71%	-0.56%
The Dalles Tailwater	>115,<=120	0.82%	6.01%	0.55%	2.19%	-1.37%
The Dalles Tailwater	>120,<=125	4.66%	-5.74%	0.27%	-1.37%	1.92%

SITE	TDG Range (% Sat)	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
The Dalles Tailwater	>125	-5.75%	0.00%	0.00%	0.00%	0.00%
Bonneville Tailwater	<=110	-0.06%	0.06%	0.00%	0.00%	-0.41%
Bonneville Tailwater	>110,<=115	1.44%	-0.18%	0.00%	0.26%	0.08%
Bonneville Tailwater	>115,<=120	0.57%	0.40%	-2.19%	-3.31%	-0.17%
Bonneville Tailwater	>120,<=125	-1.95%	0.55%	2.47%	3.60%	0.50%
Bonneville Tailwater	>125	0.00%	-0.82%	-0.27%	-0.55%	0.00%

The operational changes for MO1 do cause a few minor total dissolved gas differences at both forebay and tailwater sites as can be seen in the figures above. In terms of the actual number of days of the criteria being exceeded, those changes can be seen in Table 4-11 and Table 4-12. The blue highlighted cells show when an increased number of exceedances occurs as compared to NAA. Only the months where the criteria is exceeded is shown in the table. If a month has all zeroes shown, it is only because that month has exceeded criteria under a different alternative. In general, the difference in the number of exceedances decreases in the forebay and increases at the tailwater sites as the water moves downstream.

Table 4-11. Difference in Number of Days the TDG Criteria is Exceeded at the Forebay Sites of McNary, John Day, The Dalles, and Bonneville for the Multiple Objective 1 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary	February	0	0	0	0	0
McNary	March	0	0	0	0	0
McNary	April	0	**2**	0	0	0
McNary	May	**2**	-4	**1**	0	**1**
McNary	June	0	**1**	**3**	-2	**1**
McNary	July	-2	0	0	-2	0
John Day	February	0	0	0	0	0
John Day	March	0	0	0	-1	0
John Day	April	0	**8**	0	**15**	0
John Day	May	**2**	-1	**3**	**3**	**8**
John Day	June	0	0	**1**	0	0
John Day	July	0	0	0	**4**	0
John Day	August	**1**	0	0	0	0
John Day	September	0	0	0	0	0
The Dalles	March	0	0	0	0	0
The Dalles	April	0	**5**	0	**12**	0
The Dalles	May	**2**	-6	**4**	**4**	**9**
The Dalles	June	0	0	**9**	0	**5**
The Dalles	July	-1	-1	**1**	0	0

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
The Dalles	August	0	0	0	0	0
The Dalles	September	0	0	0	0	0
Bonneville	March	0	0	0	-6	0
Bonneville	April	-1	0	0	**2**	-1
Bonneville	May	**1**	-2	-2	0	**8**
Bonneville	June	0	0	-1	-2	**4**
Bonneville	July	0	-1	**1**	0	0
Bonneville	August	0	0	0	0	0
Bonneville	September	0	0	0	0	0

Table 4-12. Difference in Number of Days the TDG Criteria is Exceeded at the Tailwater Sites of McNary, John Day, The Dalles, and Bonneville for the Multiple Objective 1 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary	January	0	0	-3	0	-6
McNary	February	0	-3	0	0	0
McNary	March	-11	-6	0	-4	-2
McNary	April	0	-3	0	0	0
McNary	May	0	-9	-3	-1	0
McNary	June	0	-1	-1	-1	0
McNary	July	-4	-2	0	0	0
McNary	August	0	0	0	0	0
McNary	September	0	1	**1**	0	0
McNary	October	**6**	**1**	0	0	0
McNary	November	0	**2**	0	**1**	0
McNary	December	0	**6**	0	**7**	**1**
John Day	January	0	0	0	0	0
John Day	February	0	0	0	0	0
John Day	March	0	0	0	0	0
John Day	April	-3	-5	0	0	0
John Day	May	-4	0	0	0	0
John Day	June	-1	-2	0	0	0
John Day	July	-1	-5	0	0	0
John Day	August	0	0	0	0	0
The Dalles	February	0	0	0	0	0
The Dalles	March	0	0	0	-11	0
The Dalles	April	0	-3	0	0	0
The Dalles	May	-1	-13	-1	-4	**4**

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
The Dalles	June	0	-4	**2**	-1	**3**
The Dalles	July	-3	-1	0	0	0
The Dalles	August	0	0	0	0	0
The Dalles	September	0	0	0	0	0
Bonneville	January	0	0	0	0	0
Bonneville	February	0	0	0	0	0
Bonneville	March	0	0	0	0	0
Bonneville	April	-6	0	0	**12**	0
Bonneville	May	**2**	0	**2**	**2**	0
Bonneville	June	0	0	**10**	-2	**2**
Bonneville	July	-3	-1	-4	-1	0
Bonneville	August	0	0	0	0	0
Bonneville	September	0	0	0	0	0
Bonneville	October	0	0	0	0	0
Bonneville	November	0	0	0	0	0
Bonneville	December	0	0	0	0	**2**

4.3.3 Other Physical, Chemical, and Biological Processes

4.3.3.1 McNary, John Day, The Dalles, and Bonneville Dams and Reservoirs

Under the MO1 *Predator Disruption Operations* measure, the John Day Reservoir elevation would be manipulated (raised and maintained) during April and May to disrupt juvenile salmonid predator reproduction success (Figure 4-48). Raising the water level could lead to a minor increase in total suspended solids (TSS) and associated impacts (turbidity, light attenuation, and/or chemicals that may be associated with TSS like nutrients, metals, and organics). However, the impact is expected to be negligible in the large John Day Reservoir.

Otherwise, the introduction of pollutants and excess nutrients from farming and industrial activities, as well as urban runoff, is expected to continue under MO1. As with the No Action Alternative, emerging contaminants such as pharmaceuticals and new pesticides will also likely become more prevalent. The lower Columbia River contains a variety of human-sourced compounds, including metals and organic contaminants. This condition is expected to remain generally unchanged, and it is expected that current water quality impairments would continue.

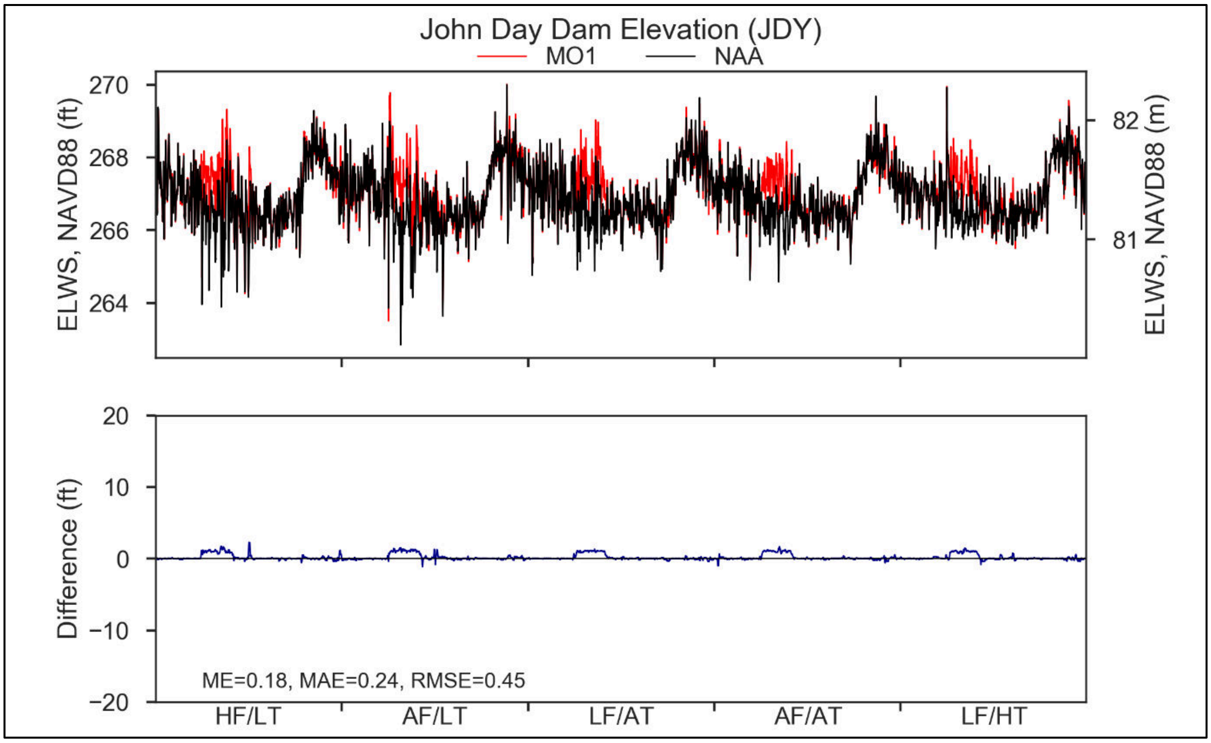


Figure 4-48. Modeled Forebay Elevation for Multiple Objective Alternative 1 at John Day Dam Under a 5-Year Range of River and Meteorological Conditions

4.4 SEDIMENT PROCESSES

4.4.1 Sediment Sources

Operational changes at Libby Dam under MO1 are not expected to affect sediment movement downstream in the Kootenai River when compared to existing conditions and the No Action Alternative; the same can be said for Hungry Horse Dam. MO1 does not impact Albeni Falls Dam operations and will not affect sediment sources or movement compared to existing conditions and the No Action Alternative. Some additional mobilization of sediment and shoreline erosion is expected within Lake Roosevelt Reservoir due to changes in elevations under MO1. However, it is not anticipated that additional sediment will pass the dam; expected impacts would occur within reservoir. MO1 flow changes at Chief Joseph Dam are minor, and no impacts to sediment sources or movement are expected.

MO1 includes structural changes aimed at improving fish passage in the lower Columbia River Basin; these proposed measures would not affect sediment sources or movement. The proposed operational changes generally have a goal of improving flexibility in operation and of improving in-stream (flow and temperature) conditions for fish; changing the timing of flows or the temperature characteristics does not affect sediment sources. MO1 is not expected to affect land use throughout the basin, including upland recreation, flood management, agricultural, timber, or mining activities, and it is not expected to change population growth patterns in the area of any of the affected reservoirs. Overall, MO1 is not expected to affect sediment movement within the system.

4.4.2 Chemicals of Concern

No change is predicted to the list of sediment chemicals of concern throughout the basin, compared to the existing conditions and No Action Alternative. The contaminants of concern would remain metals, polycyclic aromatic hydrocarbons, volatile organic compounds, pesticides and pesticide degradation products, PCBs, dioxins, and nutrients (ammonia—the form of nitrogen typically found in anoxic or anaerobic sediment). Due to changes in reservoir operation, changes to water levels could affect the mobility and bioavailability of some pollutants such as mercury (Willacker et al. 2016).

4.5 CONCEPTUAL SITE MODEL

MO1 is not expected to affect sediment movement patterns, so the conceptual site model for sediment/dredging is the same as the conceptual site model(s) for the existing conditions and No Action Alternative. Portions of the basin that are currently not dredged (Chief Joseph Reservoir) would not be dredged in the future. Areas of the basin that are currently maintained by dredging (such as at the confluence of the Snake River and Clearwater River) would continue to require periodic dredging. Sediment characterization following the Sediment Evaluation Framework (RSET 2018) or other applicable guidance would continue to be required for dredging or sediment related projects.

4.6 WATER AND SEDIMENT QUALITY CONCLUSIONS

The most notable MO1 measures that affect water quality include:

- *Block Spill Test* measure: This spill test is to evaluate latent mortality hypothesis (flip-flop between base and test spring spill operations).
- *Summer Spill Stop Trigger* measure: This measure modifies summer juvenile fish passage spill operations (ends spill on lower Snake River early).
- *Modified Draft at Libby, December Libby Target Elevation, Update System FRM Calculation, Planned Draft Rate at Coulee, Grand Coulee Maintenance Operations, Winter System FRM Space & Sliding Scale at Libby and Hungry Horse* measures: These measures maximize operating flexibility and improve overall systems operations including winter FRM at Libby and Grand Coulee Dams.
- *Lake Roosevelt Additional Water Supply & Hungry Horse Additional Water Supply* measures: These measures modify operations to meet existing contractual water supply obligations.
- *Modified Dworshak Summer Draft* measure: This measure modifies the timing of Dworshak Dam releases to provide cold water earlier (June 21 to August 1) and later (September 1 to September 30).

4.6.1 Multiple Objective Alternative 1 Results–Water Temperature

In general, MO1 would result in little to no change in water temperature conditions at Hungry Horse, Albeni Falls, Grand Coulee, and Chief Joseph dams and reservoirs, as compared to the No Action Alternative. Due to higher winter reservoir elevations at Libby Dam, resulting from the *December Libby Target Elevation* measure, followed by higher outflows (aggressive drafting) in late winter/early spring from the *Modified Draft at Libby* measure, water temperatures could be warmer in the winter and colder in the early spring and summer as compared to the No Action Alternative. This could result in minor negative impacts to resident fish species. Overall impacts to water temperature in Regions A and B are negligible. For the five flow and meteorological conditions modeled for Grand Coulee and Chief Joseph Dams, the change in the number of days of WQS exceedances ranged from a reduction of 4 days to an increase of 4 days, depending on location and flow and meteorological condition (Figure 4-49).

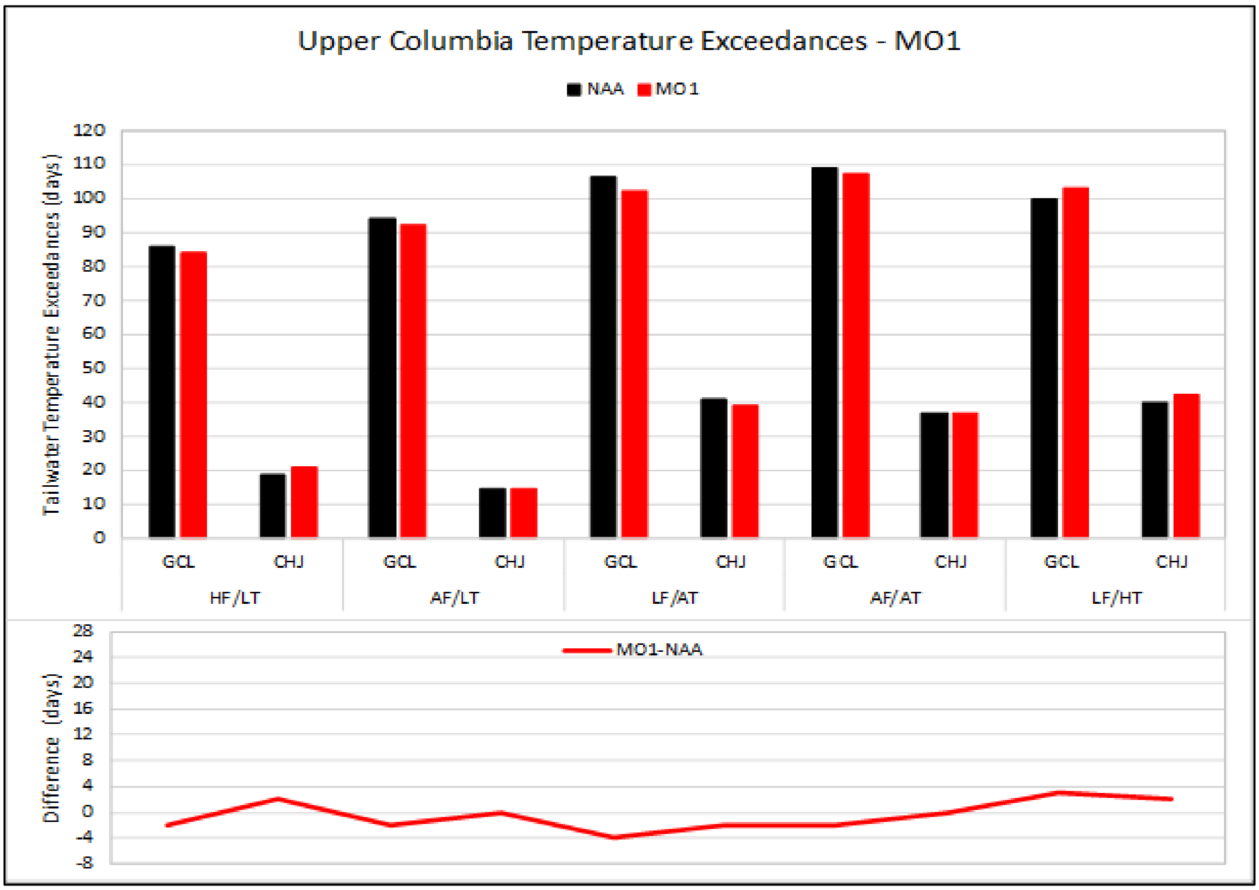


Figure 4-49. Modeled Tailwater Temperature Exceedances at Grand Coulee and Chief Joseph River Dams for Multiple Objective Alternative 1 Under a 5-Year Range of River and Meteorological Conditions

Under MO1, the *Modified Dworshak Summer Draft* measure, which calls for the modified timing of Dworshak Dam releases to provide cold water earlier (June 21 to August) and later (September 1 to September 30), would result in notable changes to Dworshak project outflows, but only slight changes in water temperature. Water temperature effects would be more pronounced downstream, with decreased water temperatures expected in the lower Snake River (Lower Granite – Ice Harbor Dams) in July and September, and warmer water temperatures and frequent exceedances to 68°F water temperature target set in the Lower Granite tailrace, expected in August (Figure 4-50). For the five flow and meteorological conditions modeled, the change in the number of days of WQS exceedances ranged from a reduction of 4 days to an increase of 22 days, depending on location and flow and meteorological condition, with the largest changes observed downstream of Lower Granite Dam. Average overall water temperature effects would be considered moderate in the lower Snake River, with major impacts expected downstream of Lower Granite Dam and negligible impacts downstream of Ice Harbor Dam (Section 2.6 and Chapter 9).

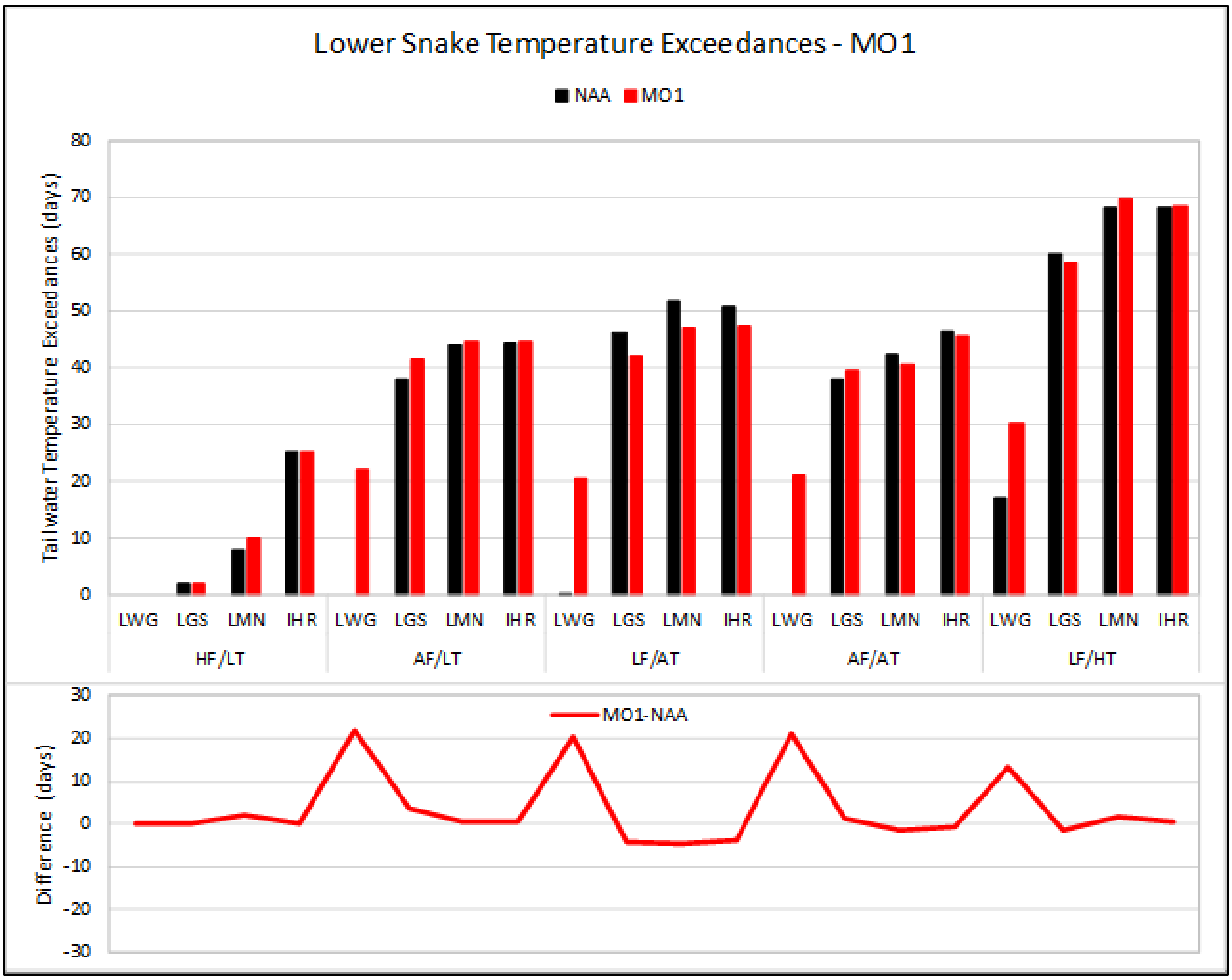


Figure 4-50. Modeled Tailwater Temperature Exceedances at the Lower Snake River Dams for Multiple Objective Alternative 1 Under a 5-Year Range of River and Meteorological Conditions

Little to no change in water temperatures would be expected in the lower Columbia River at McNary, John Day, The Dalles, and Bonneville dams and reservoirs under MO1 as compared to the No Action Alternative (Figure 4-51). For the five flow and meteorological conditions modeled, the change in the number of days of WQS exceedances ranged from a reduction of 4 days to an increase of 6 days, depending on location and flow and meteorological condition, with the largest changes observed downstream of McNary Dam.

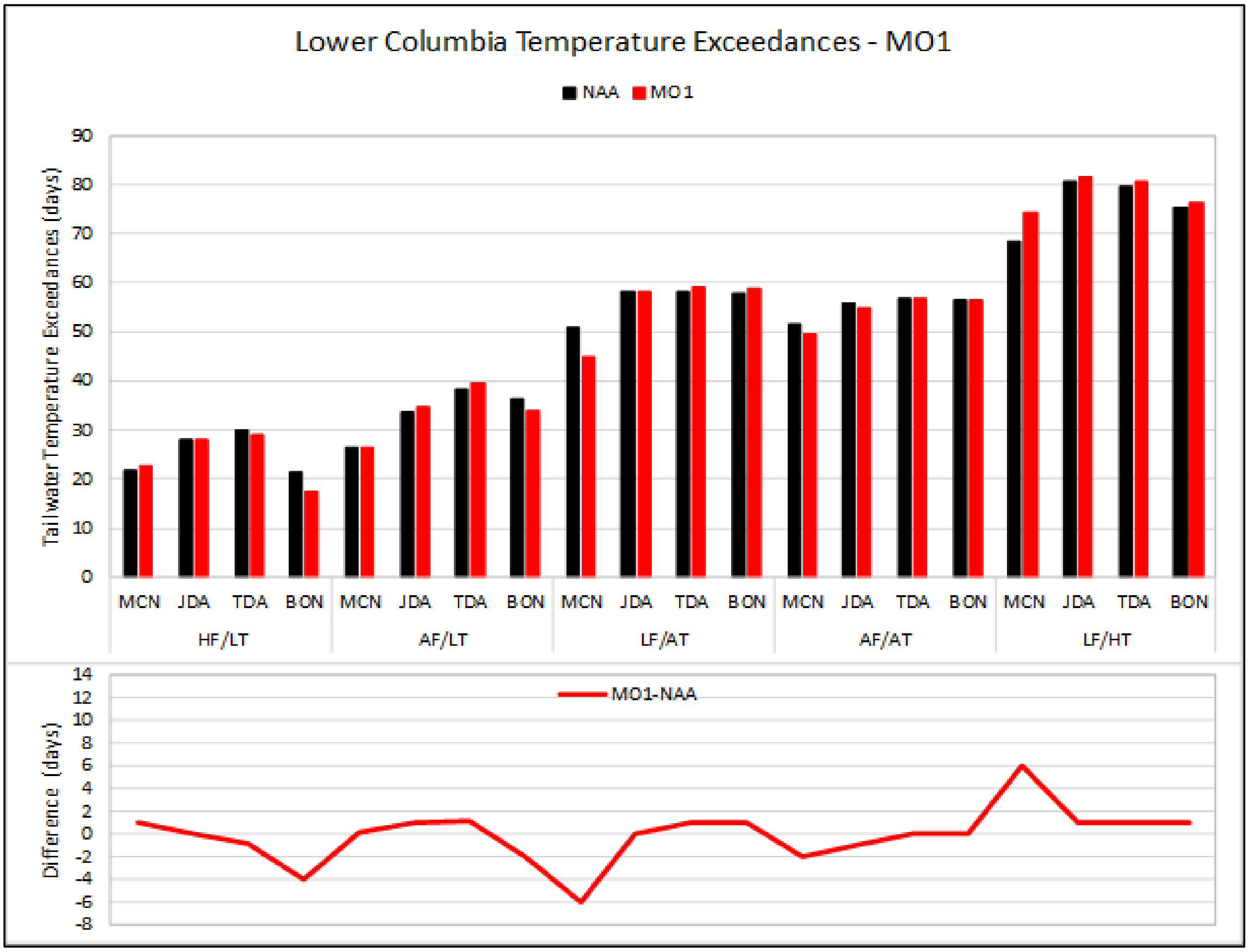


Figure 4-51. Modeled Tailwater Temperature Exceedances at the Lower Columbia River Dams for Multiple Objective Alternative 1 Under a 5-Year Range of River and Meteorological Conditions

4.6.2 Multiple Objective Alternative 1 Results–Total Dissolved Gas

In general, MO1 would have little to no impact on TDG conditions below Libby, Hungry Horse, and Albeni Falls as compared to the No Action Alternative. Downstream of Grand Coulee Dam, minor reductions in overall TDG may be possible in the spring/early summer due to the measures that call on more operational flexibility for FRM (*Update System FRM Calculation, Planned Draft Rate at Grand Coulee, Grand Coulee Maintenance Operations*, and *Winter System FRM Space* measures), and the water supply measure (*Lake Roosevelt Additional Water Supply*). The major maintenance measure (*Grand Coulee Maintenance Operations*), is expected to temporarily reduce the powerhouse capacity of Grand Coulee Dam and increase the magnitude of spill and TDG in some situations; but, when combined with other modifications to operations, effects seemed to balance and actually reduce TDG based on water quality results. During high flow events, TDG effects anticipated upstream and downstream of Grand Coulee would be carried downstream into Rufus Woods Lake. During high flow years, however, the spillway deflectors at Chief Joseph Dam would provide some degassing of elevated TDG generated from upstream Canadian dam and Grand Coulee Dam operations. TDG effects downstream of Chief Joseph Dam are negligible (Figure 4-52 and Figure 4-53).

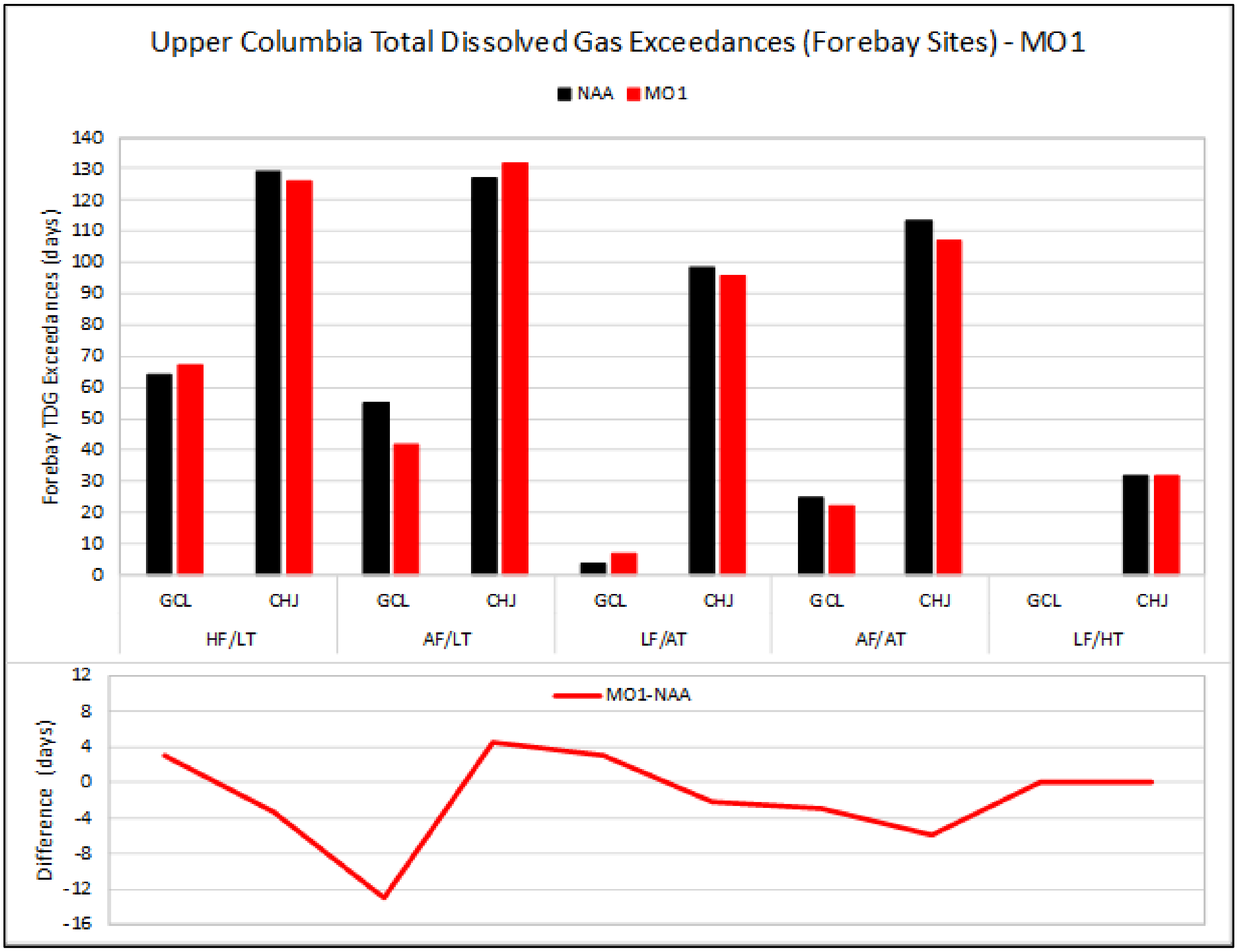


Figure 4-52. Modeled Forebay Total Dissolved Gas Exceedances at Grand Coulee and Chief Joseph River Dams for Multiple Objective Alternative 1 Under a 5-Year Range of River and Meteorological Conditions

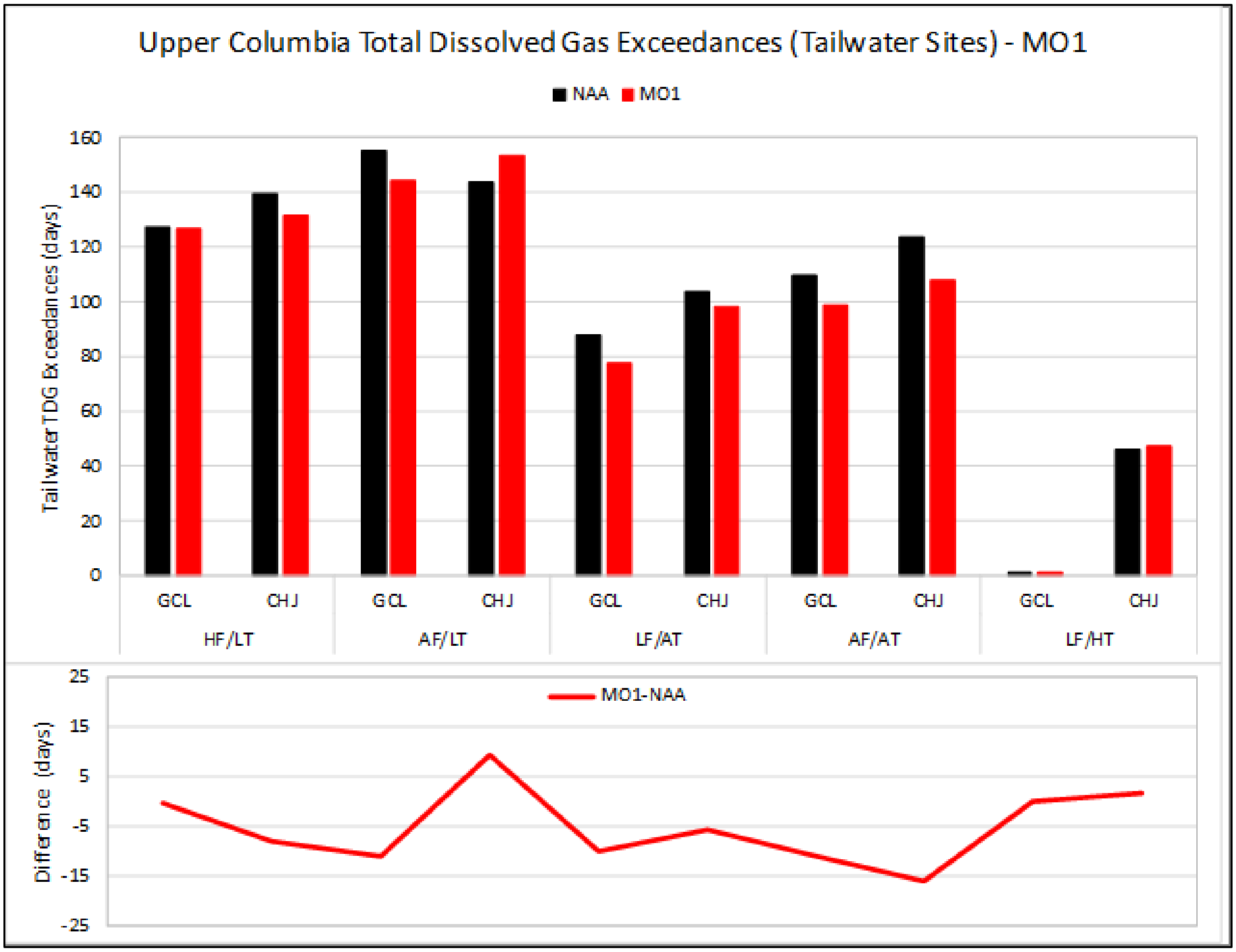


Figure 4-53. Modeled Tailwater Total Dissolved Gas Exceedances at Grand Coulee and Chief Joseph River Dams for Multiple Objective Alternative 1 Under a 5-Year Range of River and Meteorological Conditions

Slight differences to TDG could occur downstream of the lower Snake River projects due to the modification of spring and summer juvenile downstream fish passage spill as called for in the *Block Spill Test* and *Summer Spill Stop Trigger* measures, respectively; however, overall effects are expected to be negligible. No changes to lower Columbia River TDG are anticipated to occur under MO1 (Figure 4-54 through Figure 4-57).

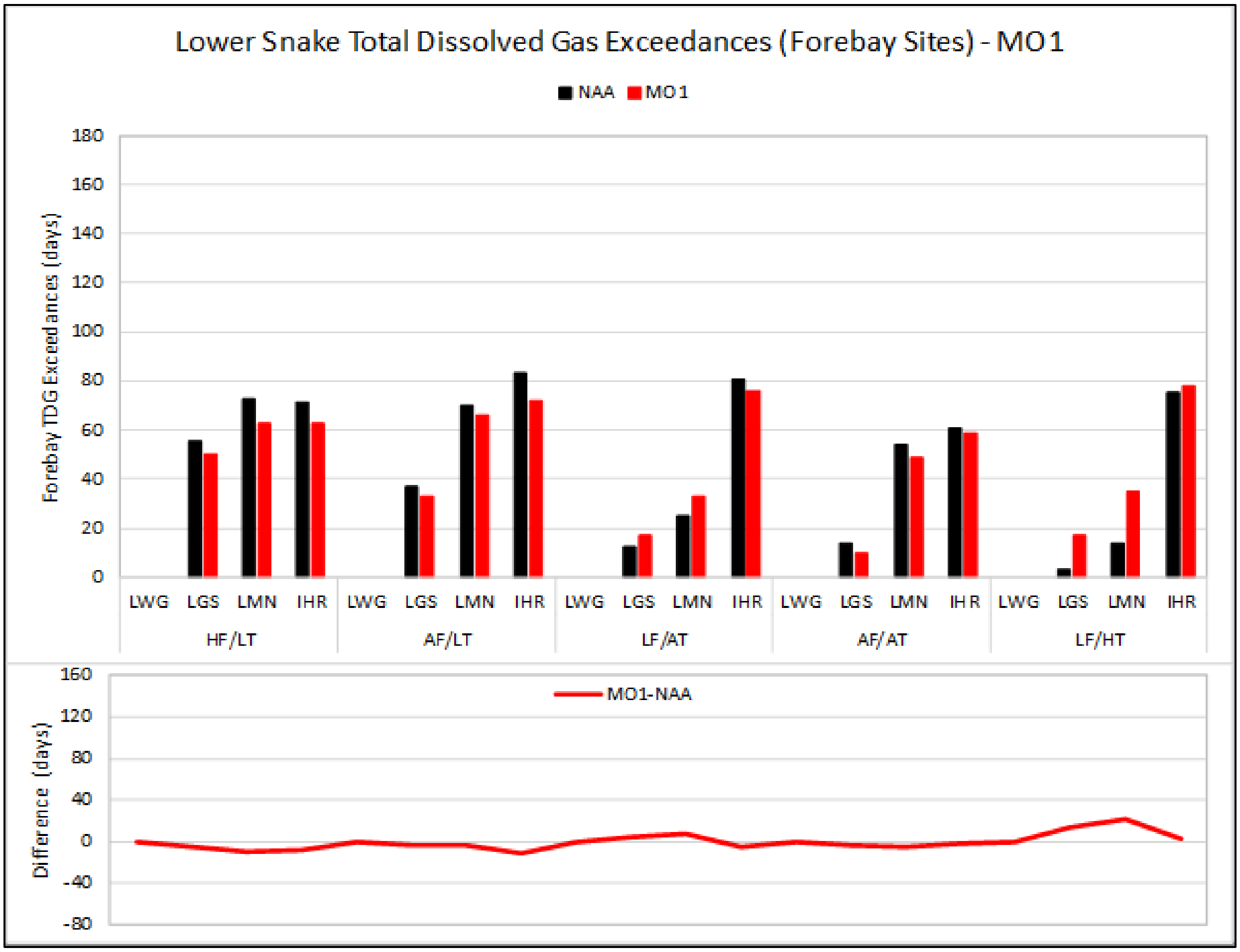


Figure 4-54. Modeled Forebay Total Dissolved Gas Exceedances at Lower Snake River Dams (Lower Granite, Little Goose, Lower Monumental, and Ice Harbor) for Multiple Objective Alternative 1 Under a 5-Year Range of River and Meteorological Conditions

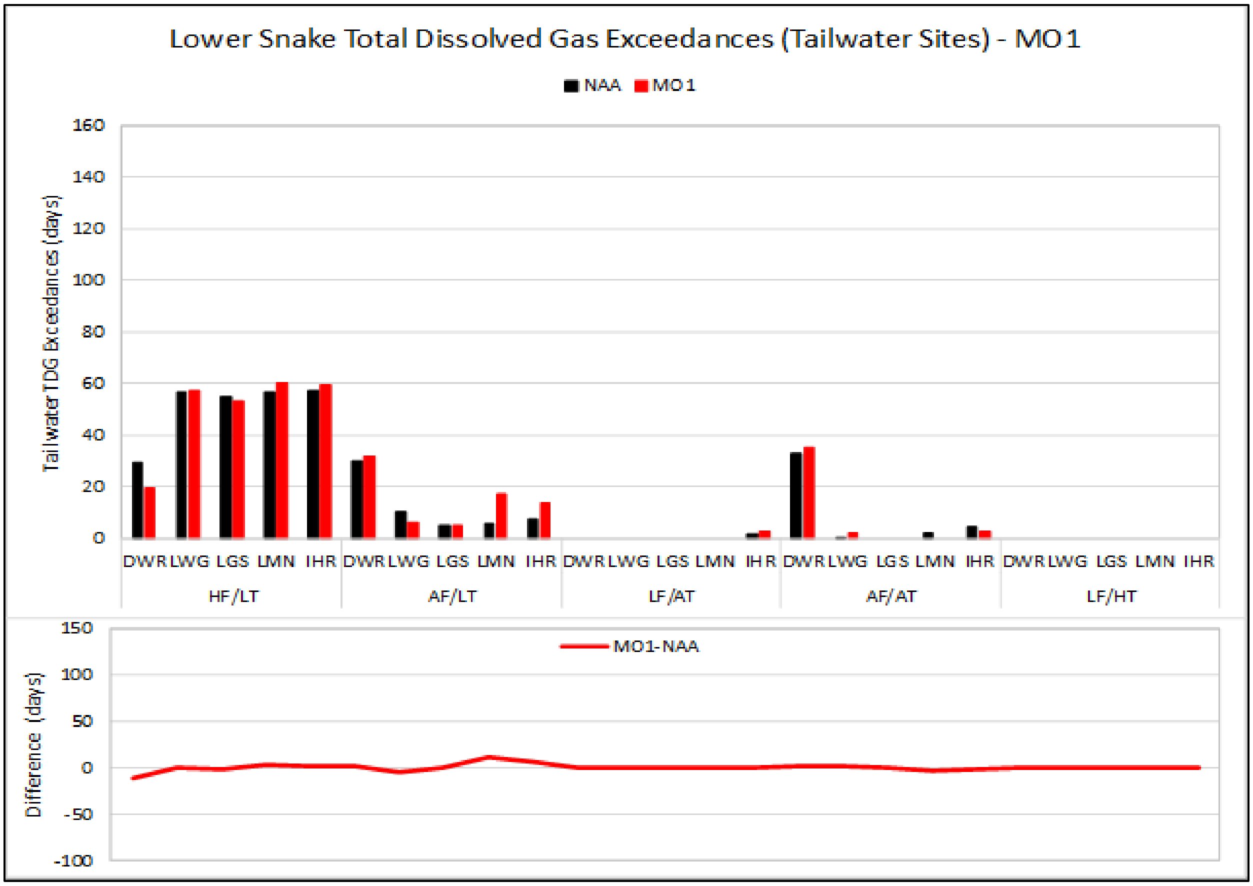


Figure 4-55. Modeled Tailwater Total Dissolved Gas Exceedances at Lower Snake River Dams (Lower Granite, Little Goose, Lower Monumental, and Ice Harbor) for Multiple Objective Alternative 1 Under a 5-Year Range of River and Meteorological Conditions

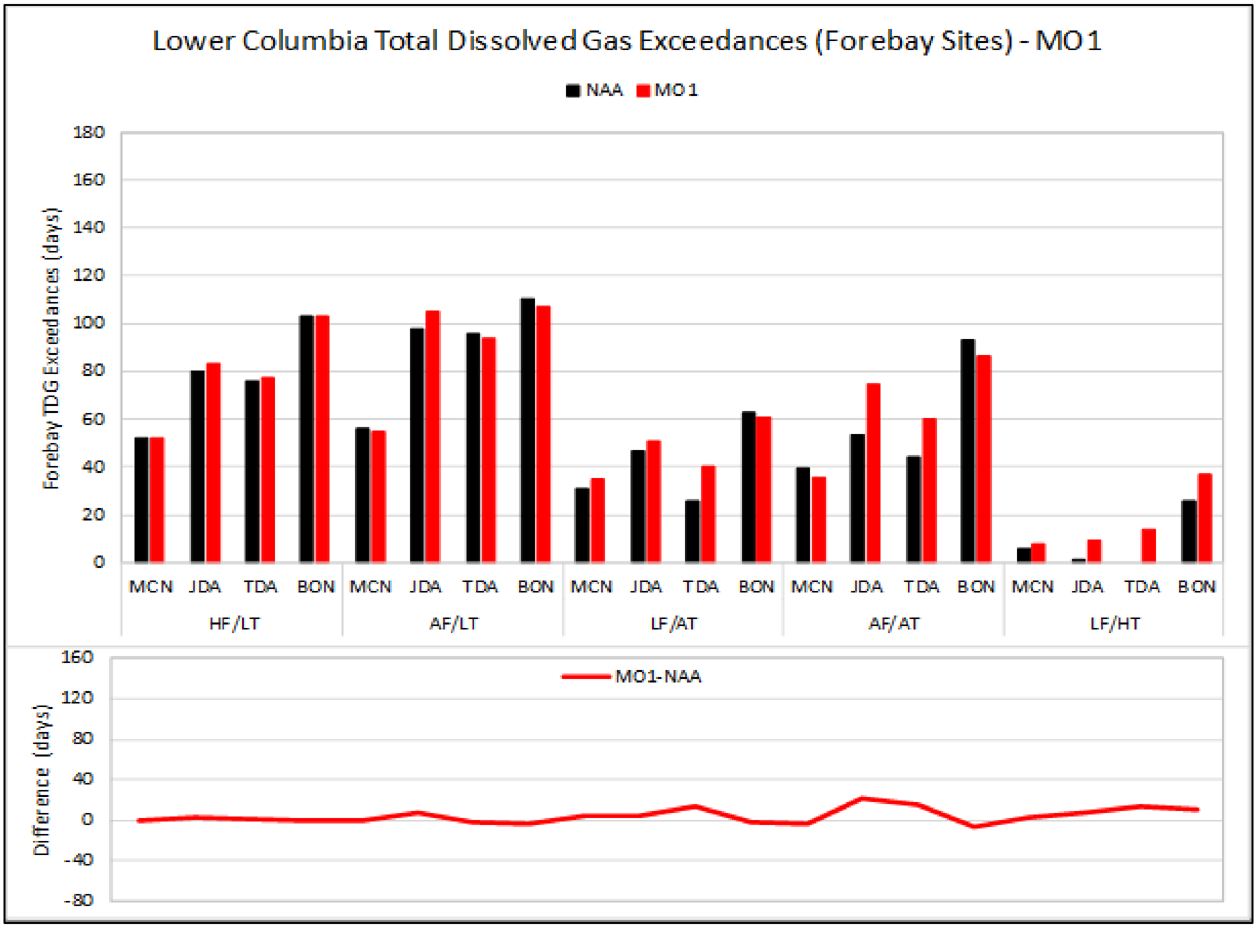


Figure 4-56. Modeled Forebay Total Dissolved Gas Exceedances at Lower Columbia River Dams (McNary, John Day, The Dalles, and Bonneville) for Multiple Objective Alternative 1 Under a 5-Year Range of River and Meteorological Conditions

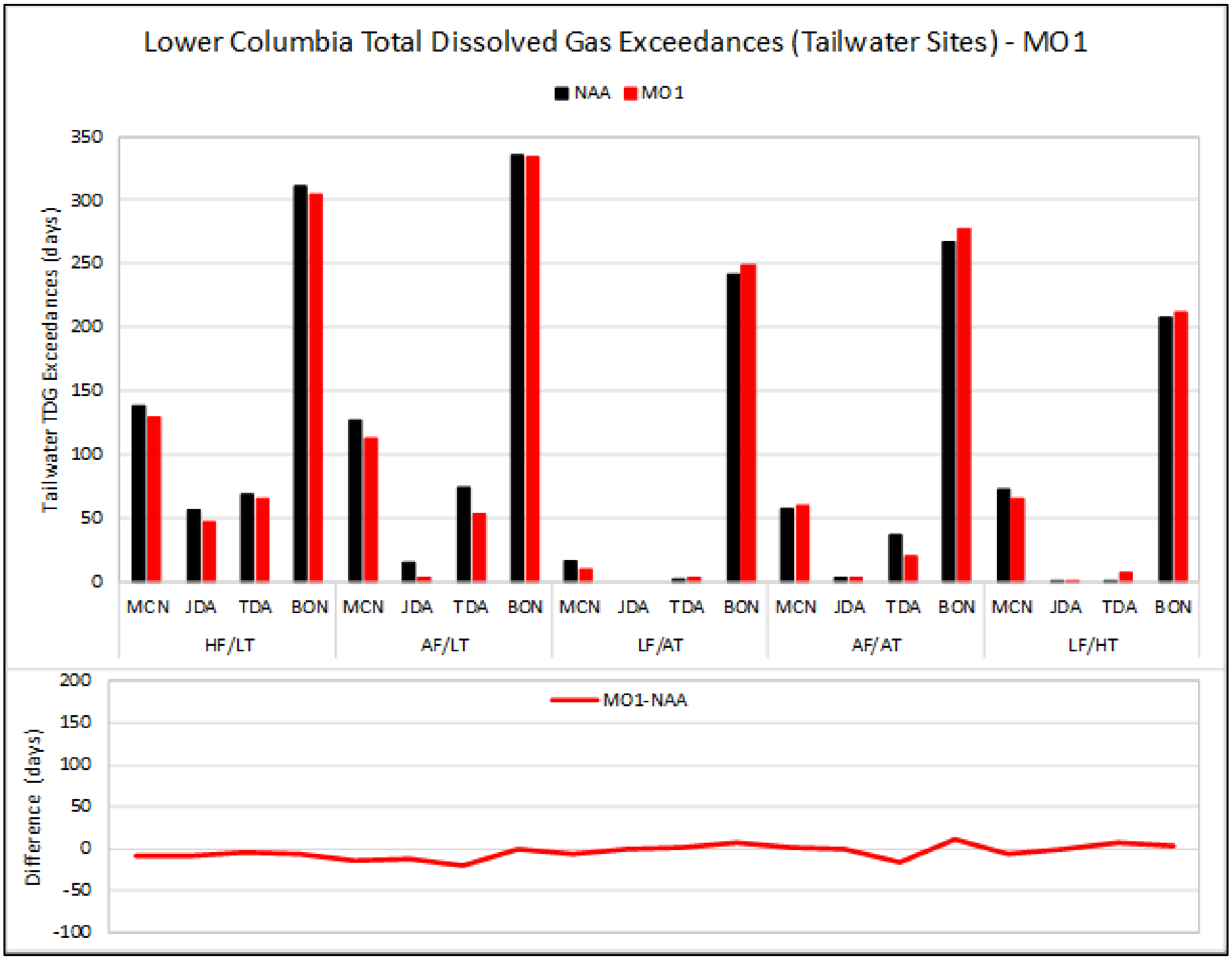


Figure 4-57. Modeled Tailwater Total Dissolved Gas Exceedances at Lower Columbia River Dams (McNary, John Day, The Dalles, and Bonneville) for Multiple Objective Alternative 1 Under a 5-Year Range of River and Meteorological Conditions

4.6.3 Multiple Objective Alternative 1 Results –Other Water Quality Impacts

In general, MO1 would result in little to no change in other water quality parameters at Libby Hungry Horse, Albeni Falls, and Chief Joseph dams and reservoirs, as compared to the No Action Alternative. At Grand Coulee, the increased reservoir elevation fluctuations, associated with FRM measures including the *Update System FRM Calculation, Winter System FRM Space,* and *Lake Roosevelt Additional Water Supply*, could lead to increased mercury methylation, while the measure *Planned Draft Rate At Grand Coulee*, which slows the reservoir draft rate to 0.8 feet per day, could result in a decrease in bank erosion, sloughing, and overall turbidity in the reservoir.

In the lower Snake River, anticipated warmer water temperatures in August, due to the *Modified Dworshak Summer Draft* measure, could result in increased cyanotoxin blooms and associated water quality issues such as increased epilimnetic dissolved oxygen, reduced hypolimnetic dissolved oxygen, etc. Little to no change in other water quality parameters would be expected in the lower Columbia River at McNary, John Day, The Dalles, and Bonneville dams and reservoirs as compared to No Action Alternative.

4.6.4 Multiple Objective Alternative 1 Results –Sediment Quality

MO1 is not expected to affect land use throughout the basin, including upland recreation, flood management, agricultural, timber, or mining activities, and it is not expected to change population growth patterns in the area of any of the affected reservoirs. Overall, MO1 is not expected to affect sediment movement within the system.

CHAPTER 5 - MULTIPLE OBJECTIVE ALTERNATIVE 2

Multiple Objective Alternative 2 (MO2) was developed with the goal to increase hydropower production and reduce regional greenhouse gas emissions while avoiding or minimizing negative impacts to other authorized project purposes. Refer to the complete alternative description located in Chapter 2 of the main EIS document.

5.1 UPPER COLUMBIA RIVER BASIN

5.1.1 Water Temperature

5.1.1.1 Libby and Hungry Horse Dams and Reservoirs

For Libby Dam, MO2 is similar to Multiple Objective Alternative (MO3) and includes operational changes that could result in changes to draft and refill operations when compared to the No Action Alternative, as shown in the summary hydrograph (Figure 5-1). For the majority of MO2 years, the end of November draft elevation target is 8 feet lower than the No Action Alternative to facilitate a lower end of December target elevation of 2,400 feet NGVD29, which is about 11 feet lower than the majority of No Action Alternative years. January and February draft elevations are typically deeper under MO2 largely because of the prolonged impacts of the deeper November and December drafts for hydropower operations as well as for adjusted draft targets (measures *Slightly Deeper Draft For Hydropower* and *Sliding Scale At Libby*, respectively). The final end-of-April draft elevation for the median and wettest quarter of years are similar to the No Action Alternative. However, for the driest 40 percent of years, the end-of-April draft is about 11 to 19 feet deeper than the No Action Alternative. Reservoir refill and summer pool elevations are improved over the No Action Alternative with the reservoir reaching the end of July full pool about 6 percent more often than under the No Action Alternative. August and September reservoir elevations under MO2 are about 1 to 4 feet higher than under the No Action Alternative. In general, the MO2 drafting changes would result in lower water elevations in Lake Koocanusa from November through April, with substantially lower end-of-April water elevations (11 to 19 feet) in the driest 40 percent of years. It should be noted that these changes do vary by water year, water forecast, and time of year. A summary hydrograph for Lake Koocanusa, representing the probability of the reservoir elevation on any given day under MO2 and the No Action Alternative is shown in Figure 5-1.

MO2 largely impacts Libby Dam outflows and Kootenai River flows from about November through April (Figure 5-2). When compared to the No Action Alternative, median average MO2 outflows are about 14 to 34 percent greater in November and December, 11 to 42 percent less from January through April, and about 5 to 9 percent less from May through September. Outflows are decreased in late April and May due to increased refill. For the median condition, sturgeon pulses remain the same. The increased outflow from Libby Dam in November and December results in an increase in median monthly river water elevations of 1.3 to 1.8 feet in the free-flowing reach below Libby Dam and about 1.6 feet at Bonners Ferry. Decreased January through May flows result in a decrease in median monthly Kootenai River water elevations below Libby Dam by as much as 2.1 feet.

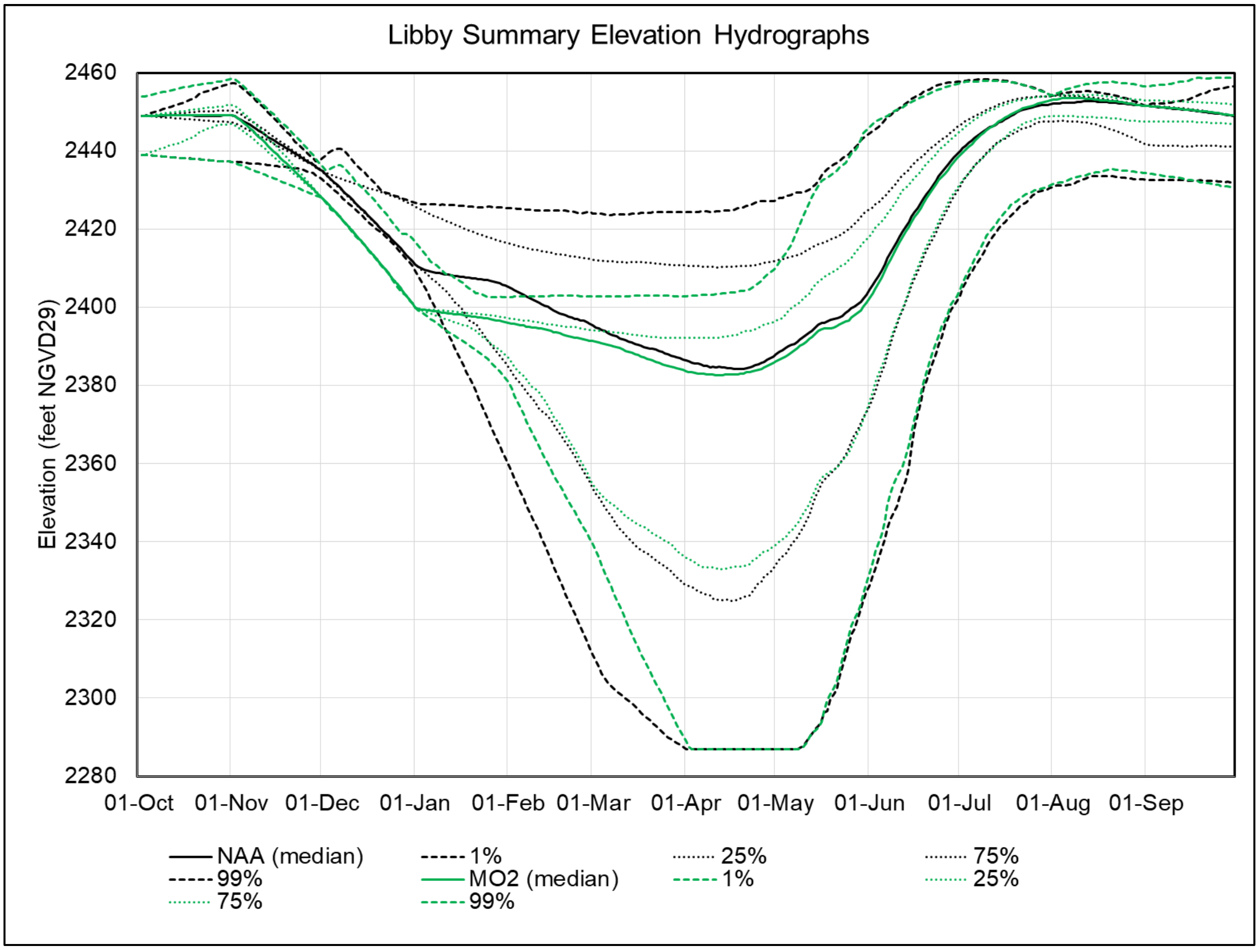


Figure 5-1. Libby Dam-Lake Koocanusa Summary Forebay Elevations for Multiple Objective Alternative 2 Versus the No Action Alternative

Similar to the No Action Alternative, Libby Dam's SWS provides some ability to adjust where in the water column water is drawn from. The range of the SWS bulkheads are from elevation 2,409 feet to 2,200 feet NGVD29. Because SWS protocol maintains at least 30 feet of submergence over the top row of the bulkheads for hydraulic stability, the SWS has the ability to perform under the full range of possible MO2 drawdown operations with a similar efficiency as under the No Action Alternative. Modeled forebay elevations under MO2 are predicted to be well within the operating range of the SWS and similar to the ranges observed in historical years.

The ability of the SWS to manage discharge temperatures under a variety of drawdown and inflow conditions would continue under MO2. However, thermal stratification must be present in the forebay for the SWS to achieve temperatures as close as possible to the temperature rule curve developed by the Corps and Montana Fish, Wildlife, and Parks and described in Section 3.1.1.1 of the No Action Alternative. The onset of thermal stratification is difficult to predict and can vary from year to year due to reasons such as inflow volumes, inflow temperatures, reservoir drawdown elevation, discharge volumes, and weather conditions. Historical temperature data suggests that holding the pool higher results in colder reservoir temperatures and difficulty for the SWS to achieve temperatures within the rule curve. When the pool is drafted deeper, the pool volume is less thereby allowing for greater warming in the spring and summer from warmer inflows and warming air temperatures.

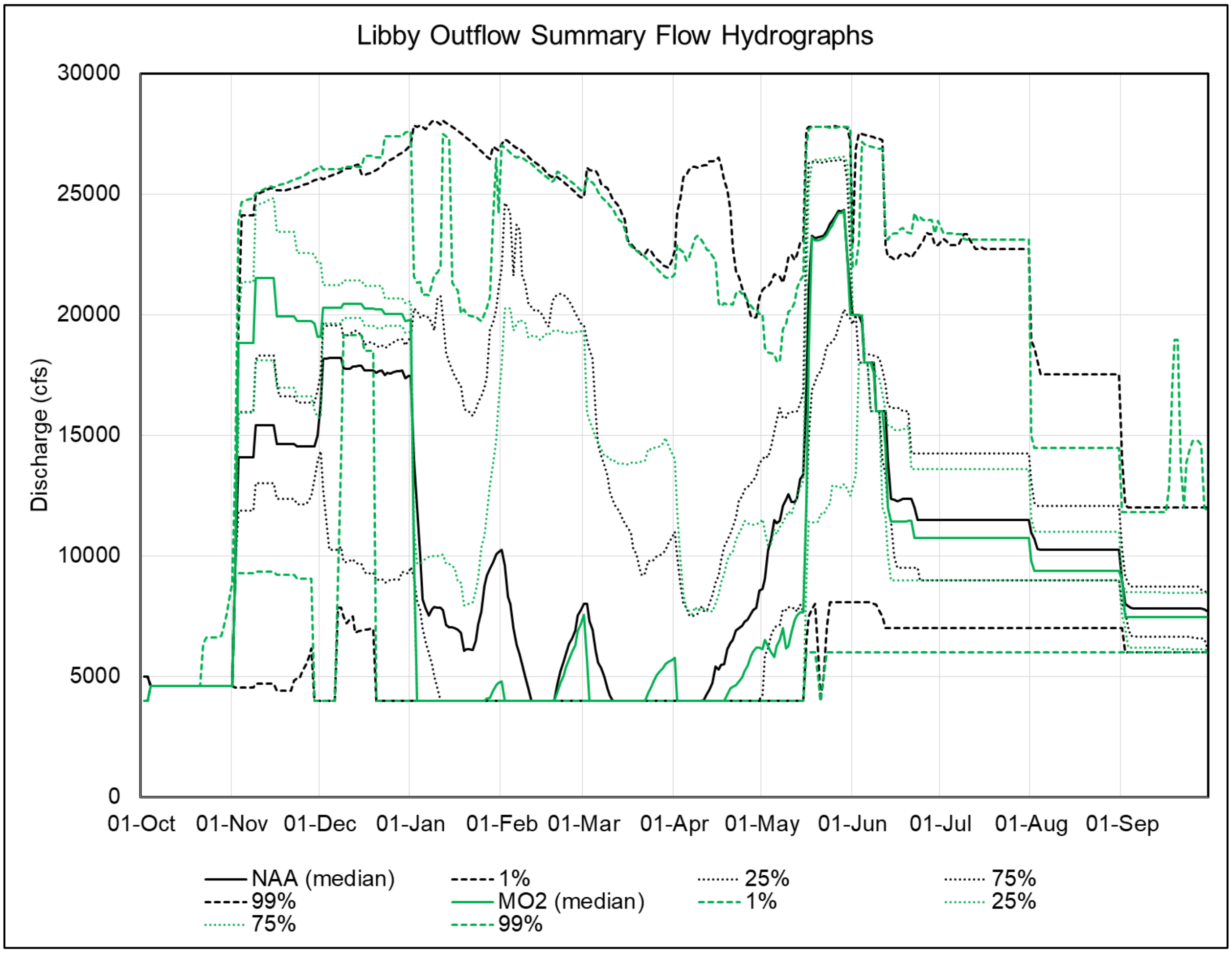


Figure 5-2. Libby Dam-Lake Koocanusa Summary Outflows for Multiple Objective Alternative 2 Versus the No Action Alternative

The lower reservoir elevations under MO2 for the driest 40 percent of years are likely substantial enough to result in a change in forebay temperatures and thermal stratification compared to the No Action Alternative. These lower reservoir elevations should result in slightly warmer reservoir temperatures and earlier thermal stratification during the spring and summer resulting in a greater ability for the SWS to achieve downstream temperatures within the rule curve when compared to the No Action Alternative. It should be noted that under the No Action Alternative, downstream river temperatures during the fall and winter are generally several degrees warmer than pre-dam Kootenai River conditions, while water released from the dam during the spring and summer is generally several degrees cooler than natural river conditions. The limitations of the SWS that exist for the No Action Alternative are expected to continue for MO2.

Changes in downstream temperatures from Libby Dam to Bonners Ferry may result from MO2 increasing the median average monthly flows in November and December and decreasing the median monthly flows in January through April. During the cold winter months, Kootenai River water can cool by several degrees between Libby Dam and Bonners Ferry if flows are held low. Therefore, by increasing November and December flows, downstream temperatures may increase during these months under MO2. Conversely, by decreasing flows from January through April, MO2 may decrease temperatures by allowing the natural cooling of the river as it moves downstream. It is uncertain how increasing early winter temperatures and then decreasing late winter temperatures in the Kootenai River would impact winter spawning fish species, such as burbot, which require near-freezing river temperatures (<35°F or <2°C) to spawn.

Under MO2, three operational measures apply to Hungry Horse:

- *Sliding Scale at Libby And Hungry Horse*
- *Ramping Rates for Safety*
- *Slightly Deeper Draft for Hydropower*

These operational measures lift all ramping rate limitations when restrictions are not for safety, partially lift pool elevation restrictions to allow use of storage for hydropower generation, and offer a sliding scale draft for summer flow augmentation. Implementing the operational measure *Slightly Deeper Draft for Hydropower* would result in lower reservoir elevations in winter and spring under MO2, which are likely substantial enough to result in a change in forebay temperatures and thermal stratification compared to the No Action Alternative (Figure 5-3). These lower reservoir elevations should result in slightly warmer reservoir temperatures and earlier thermal stratification during the spring and summer resulting in a greater ability for the SWS to achieve the best possible downstream temperatures when compared to the No Action Alternative.

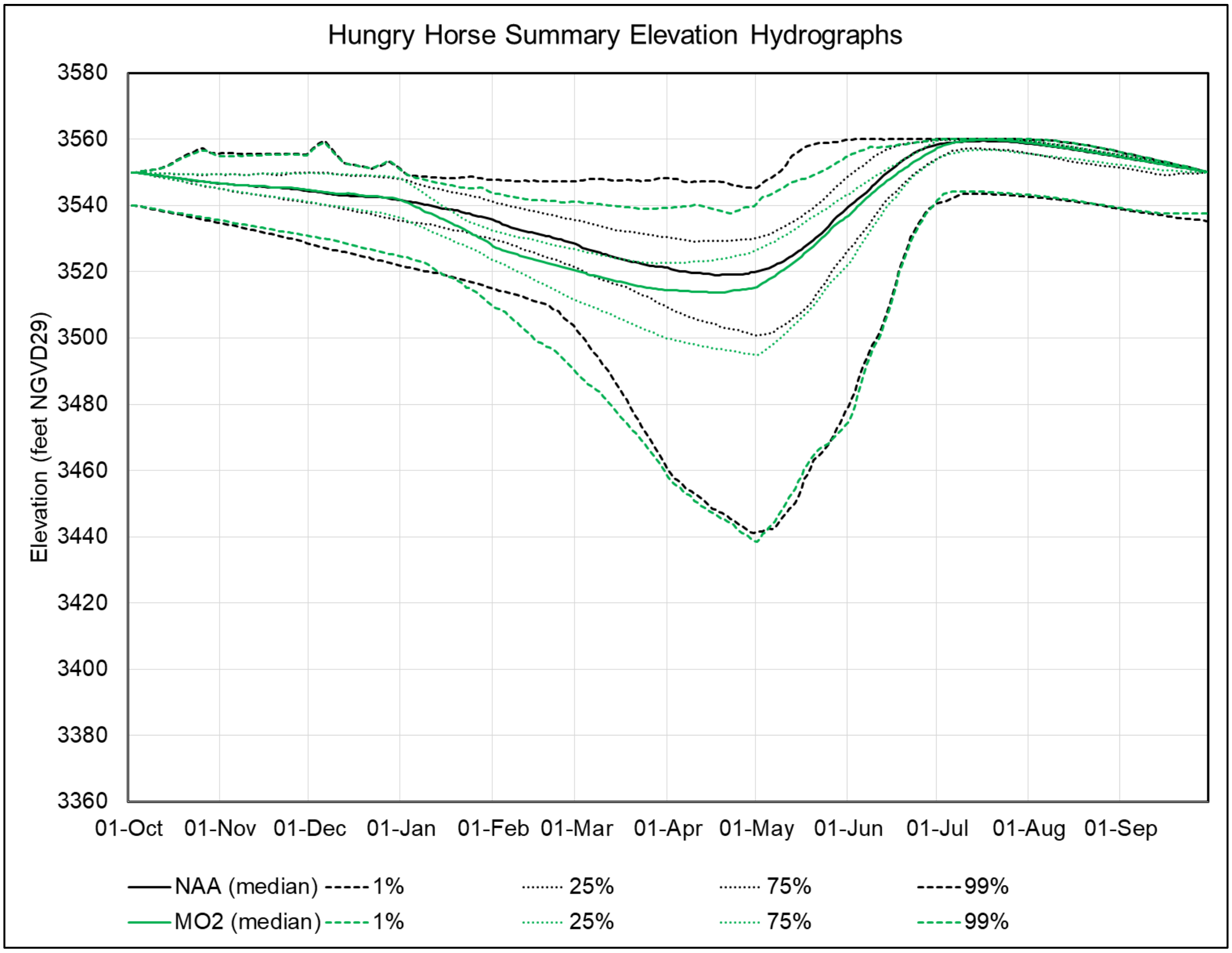


Figure 5-3. Hungry Horse Reservoir Summary Elevation Hydrograph for Multiple Objective Alternative 2 Versus the No Action Alternative

5.1.1.2 Albeni Falls Dam and Reservoir

Under MO2, Albeni Falls Dam operations will change little compared to the No Action Alternative. However, MO2 operational changes at Hungry Horse will result in flow changes in the Flathead River that will be evident downstream through Lake Pend Oreille and the Pend Oreille River. In particular, increases of 108 percent in the average January outflows out of Hungry Horse translates to an increase of about 20 percent in the Pend Oreille River at Albeni Falls Dam. Decreases of 8 to 37 percent in the average monthly March through June flows from Hungry Horse translate to about a 3 to 4 percent decrease in Pend Oreille River flows at Albeni Falls. Similar to other alternatives, flow reductions for Hungry Horse under MO2 can be seen through the Pend Oreille River Basin, but they are increasingly diluted moving downstream. As such, under MO2 Lake Pend Oreille and the Pend Oreille River will see only a small hydrological change compared to the No Action Alternative (Figure 5-4 and Figure 5-5).

Water temperatures in the Pend Oreille River upstream and downstream of Albeni Falls Dam were modeled using W2 for the period 2004 through 2006. W2 model results indicate little change in water temperatures upstream and downstream of Albeni Falls Dam. In general, temperature changes between

MO2 and the No Action Alternative are small, ranging from about 32.9°F to 34.7°F (-0.5 to 1.5°C). Temperature differences were greatest during the winter months (January and February) with MO2 slightly increasing river temperatures (up to 1.5 degrees Celsius) possibly due to the higher flows moving through the Pend Oreille River System from Hungry Horse operational changes (Figure 5-6 and Figure 5-7). Temperature differences between MO2 and No Action Alternative during the mid-June to mid-September summer period are minimal and range from about ± 32.9°F to 33.8°F (0.5 to 1.0°C).

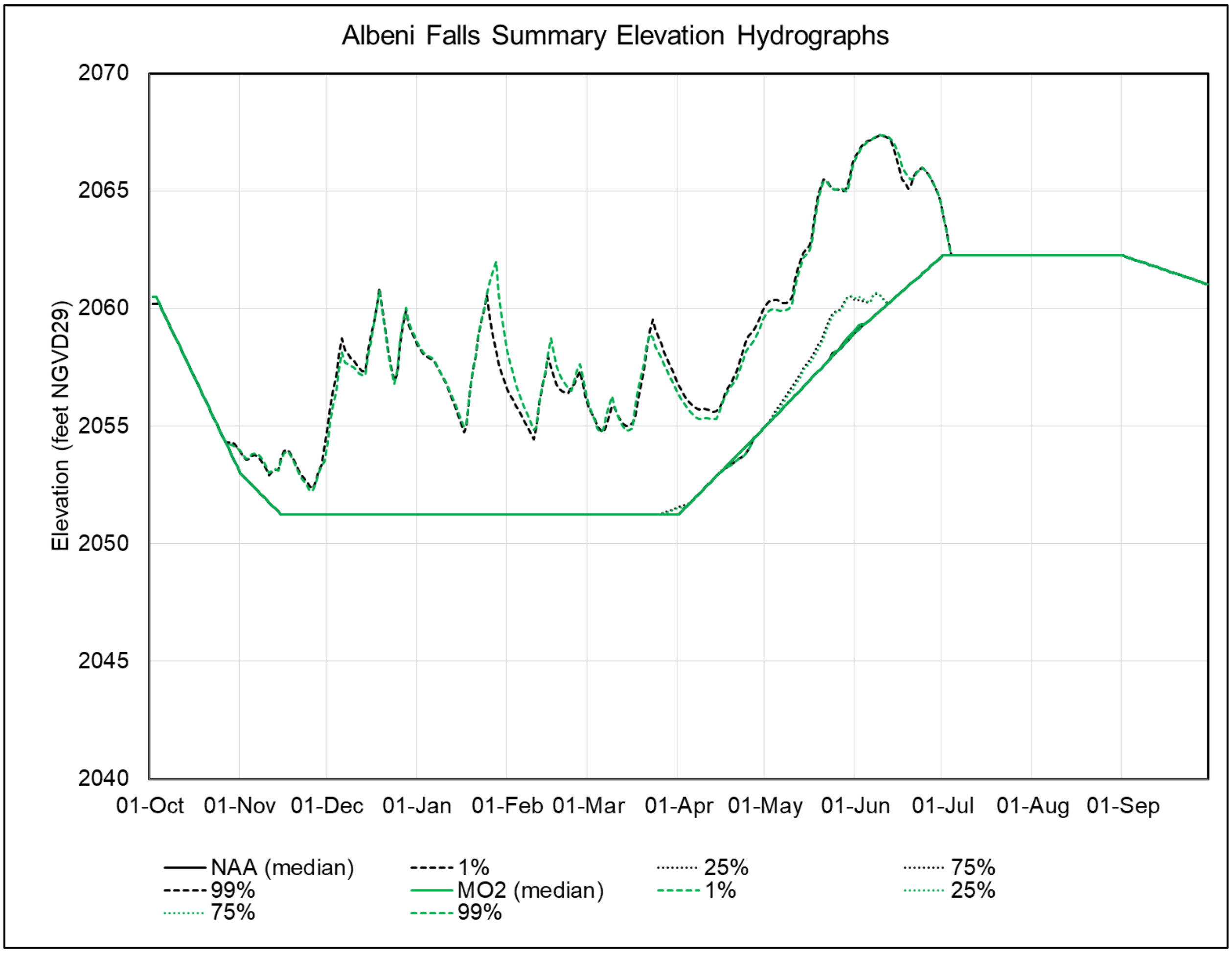


Figure 5-4. Albeni Falls Dam Summary Elevation Hydrograph for Multiple Objective Alternative 2 Versus the No Action Alternative

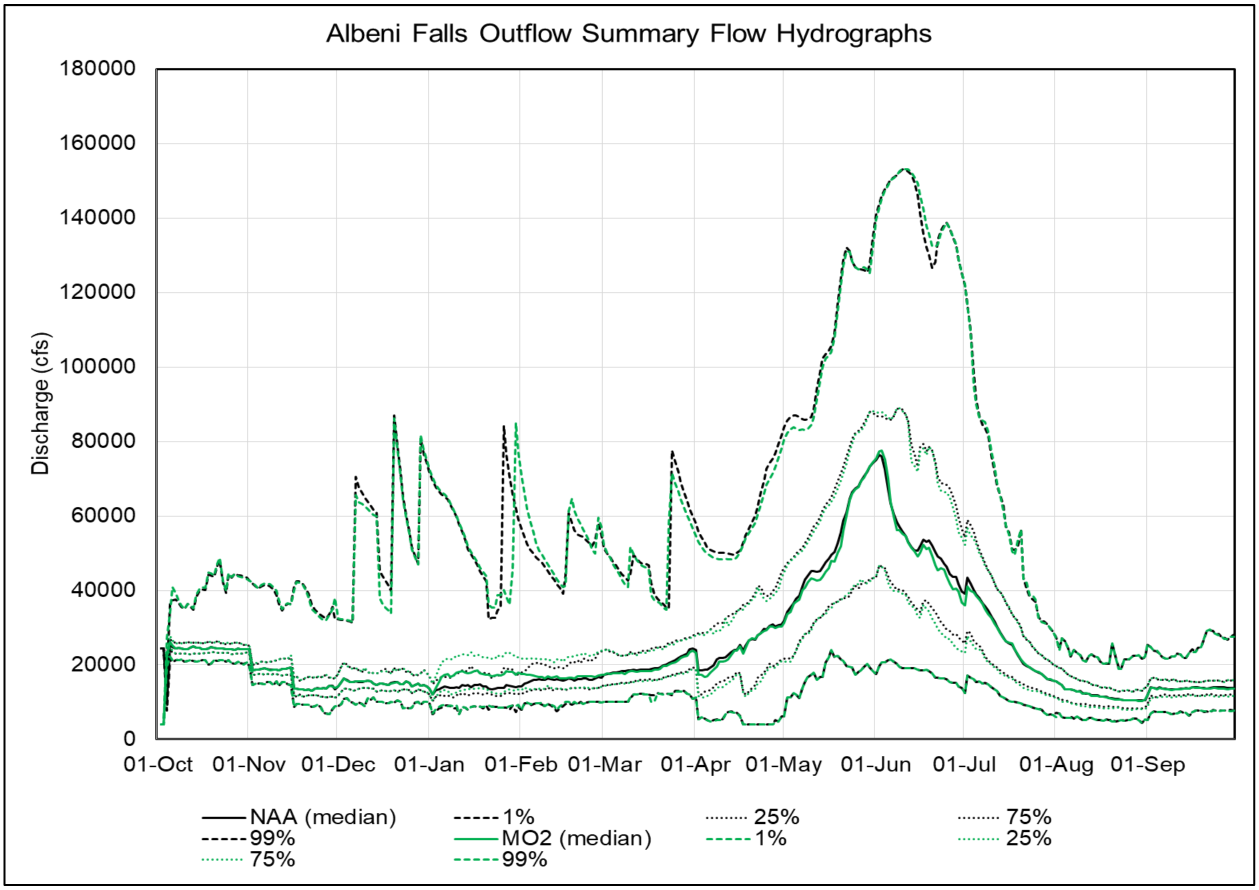


Figure 5-5. Albeni Falls Dam Summary Outflows for Multiple Objective Alternative 2 Versus the No Action Alternative

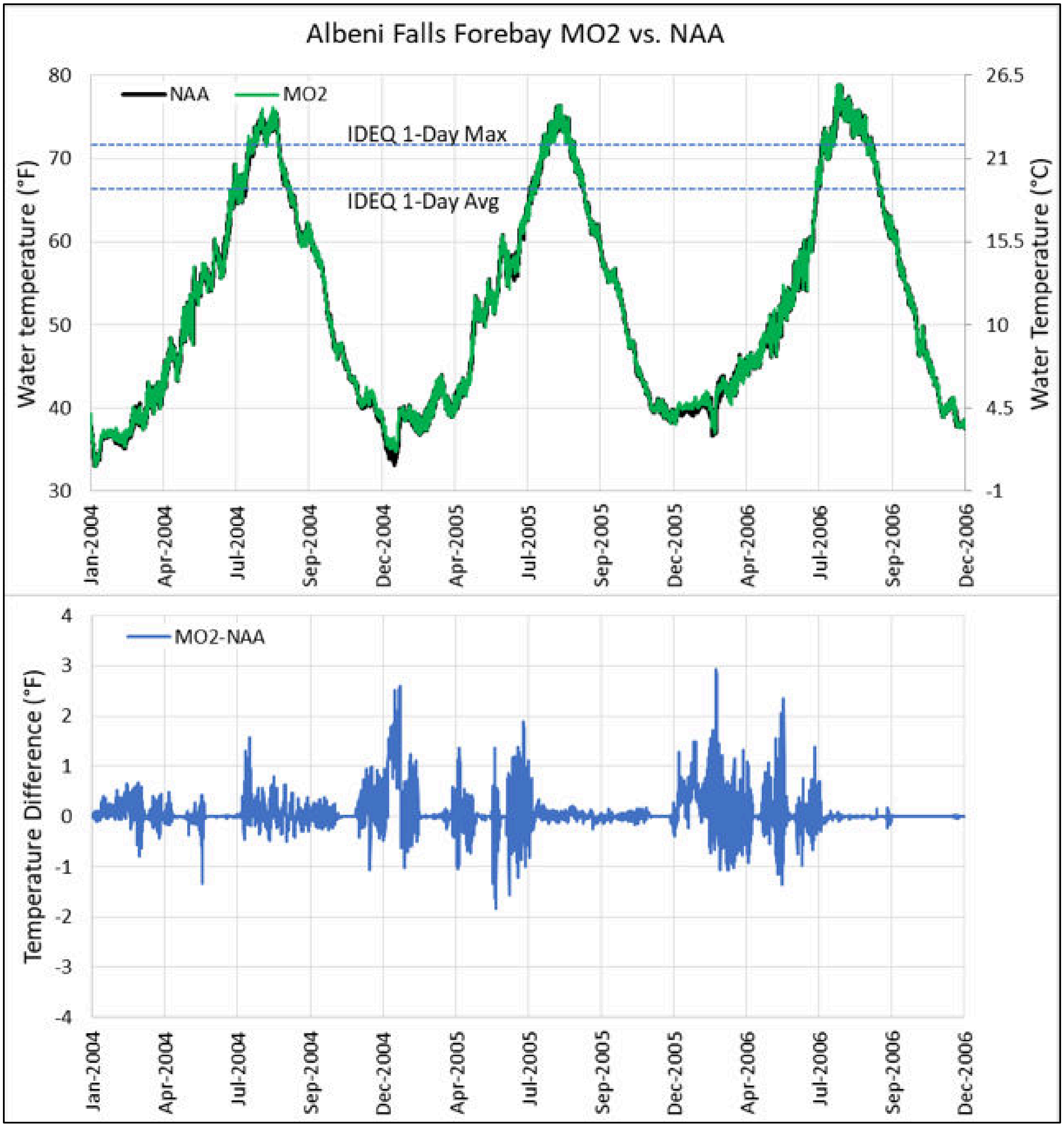


Figure 5-6. Modeled Forebay Temperatures for the No Action Alternative and Multiple Objective Alternative 2 at Albeni Falls from 2004 to 2006

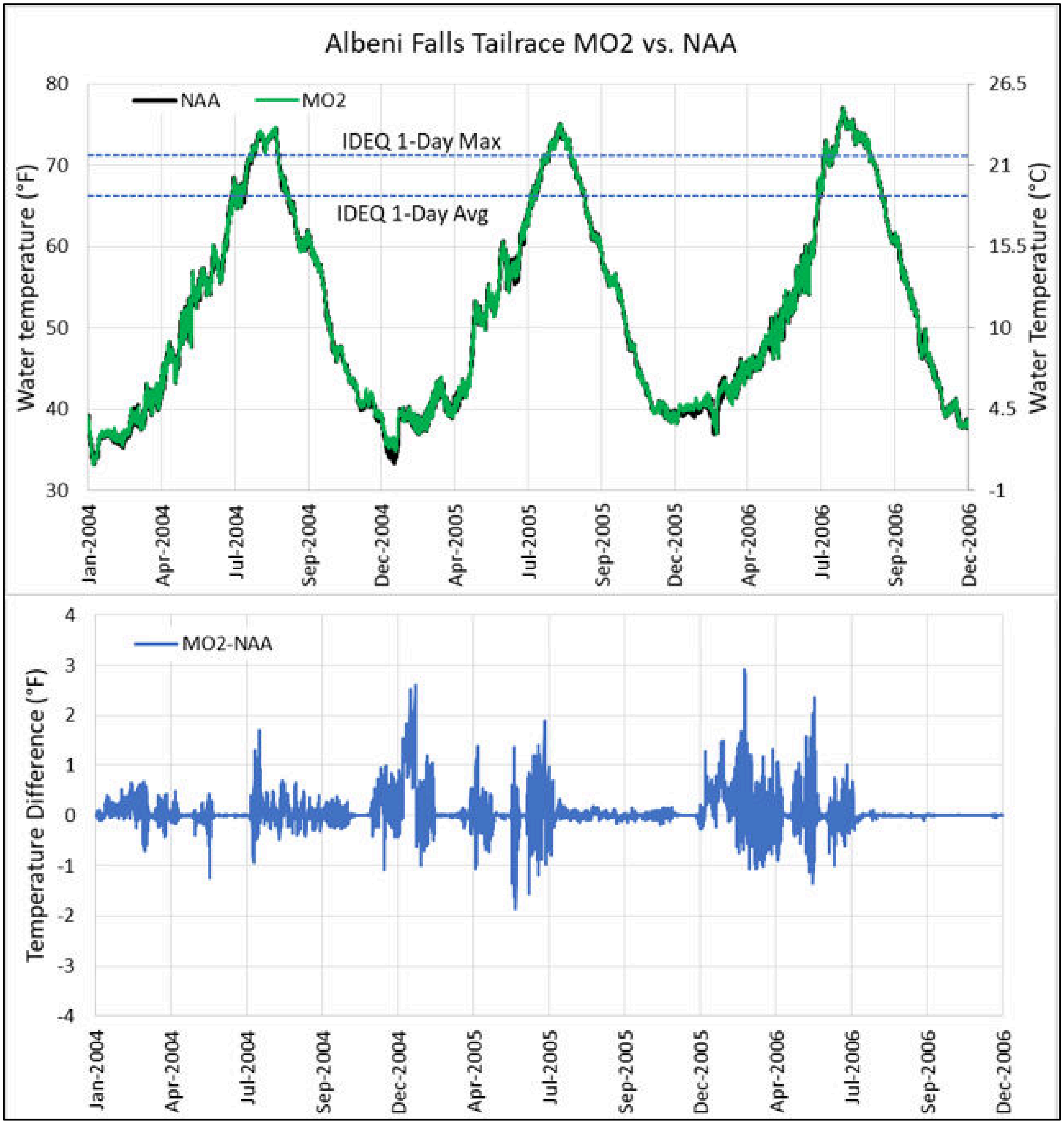


Figure 5-7. Modeled Tailwater Temperatures for the No Action Alternative and Multiple Objective Alternative 2 at Albeni Falls from 2004 to 2006

5.1.1.3 Chief Joseph Dams and Reservoirs

Under MO2, the operations of Grand Coulee Dam and Lake Roosevelt above the dam are altered by five operational measures:

- Update System FRM Calculation
- Grand Coulee Maintenance Operations

- Planned Draft Rate at Grand Coulee
- Winter System FRM Space
- *Slightly* Deeper Drafts for Hydropower

Lake Roosevelt water temperature could be impacted under MO2 through implementation of these multiple measures, and additionally by changes to inflows from measures targeting projects upstream. Many of these measures impact winter and spring storage and outflows; however, they are not expected to impact temperatures significantly.

The Grand Coulee Maintenance Operations would address operational constraints for the ongoing maintenance of the power plants. This measure would reduce the hydraulic capacity through the power plants and increase the likelihood of spill. This measure, however, is largely offset by the other measures that impact spring flows. Operational measure Winter System FRM Space increases the draft space available for winter operations starting in December, and in addition, measure Slightly Deeper Draft for Hydropower allows deeper draft, especially in the winter, for more power generation. A more in-depth discussion of these operational measures and their effects can be found in Appendix C, *Hydraulics and Hydrology*.

On average, MO2 water temperatures are nearly identical to conditions under the No Action Alternative in Lake Roosevelt and the Columbia River downstream. The changes that do occur are short in duration or low in magnitude. In general, impacts are greatest at Grand Coulee Dam and are reduced toward the U.S.-Canada border wherein the impacts from MO2 are almost unnoticeable at Hall Creek. Overall, an increase of temperature at depth in the fall, overall all years, is the most pronounced difference from the No Action Alternative in the lower reservoir. This is partially due to some modeling assumptions which warrants further investigation. An additional factor influencing spring and summer temperatures in some years may be winter and spring operations that decrease storage, which could potentially reduce the cold-water mass that influences the inflowing temperature signal from upstream.

The downstream temperatures vary slightly year to year from the No Action Alternative; generally they are very similar with changes well less than a degree on a monthly average. The modeled water temperatures below Grand Coulee Dam for MO2 result in a few more days above the 61˚F temperature criteria (Colville Tribe Class I Temperature TMDL) on average as compared to the No Action Alternative in all years except low flow years. Figure 5-8 shows predicted water temperatures below Grand Coulee Dam under MO2 compared to the No Action Alternative.

Under MO2, reservoir elevation changes and corresponding project outflow changes predicted at Grand Coulee Dam would carry downstream through Rufus Woods Lake and Chief Joseph Dam. In general, average monthly outflows out of Chief Joseph Dam would be greater in November and December (3 and 12 percent, respectively), and lower from about January through August (range of -1 to -6 percent). Changes in winter Columbia River flows below Grand Coulee Dam are largely due to MO2 operational measures at Grand Coulee Dam and from flow changes at Libby Dam (Figure 5-9). Since Chief Joseph Dam is a run-of-river project, little change to forebay elevations would occur for MO2 when compared to the No Action Alternative (Figure 5-10). Tailwater temperatures under both MO2 and the No Action Alternative are predicted to exceed the Washington State and tribal water quality standards regardless of water year type or meteorological condition.

Water temperatures under MO2 at Chief Joseph Dam tailwater are similar to or slightly cooler than the No Action Alternative with the majority of temperature differences in the ±1 to 2 degrees Fahrenheit range (Figure 5-11). In general, temperatures modeled for MO2 are similar to or slightly cooler than the No Action Alternative for most river and meteorological conditions. Exceptions are for the AF/AT and LF/HT scenarios where river temperatures in the spring and early summer are expected to be 1 to 2 degrees Fahrenheit warmer under MO2. Tailwater temperatures under both MO2 and the No Action Alternative are predicted to exceed the Washington State standard of 63.5°F (17.5°C) as measured by the 7-day average of the daily maximum temperature in August and September. Similar to the No Action Alternative, there is little difference between Grand Coulee Dam tailwater (Figure 5-8) and Chief Joseph Dam tailwater (Figure 5-11) temperatures under MO2, showing that water temperatures released from Lake Roosevelt are passed through Rufus Woods Lake unchanged.

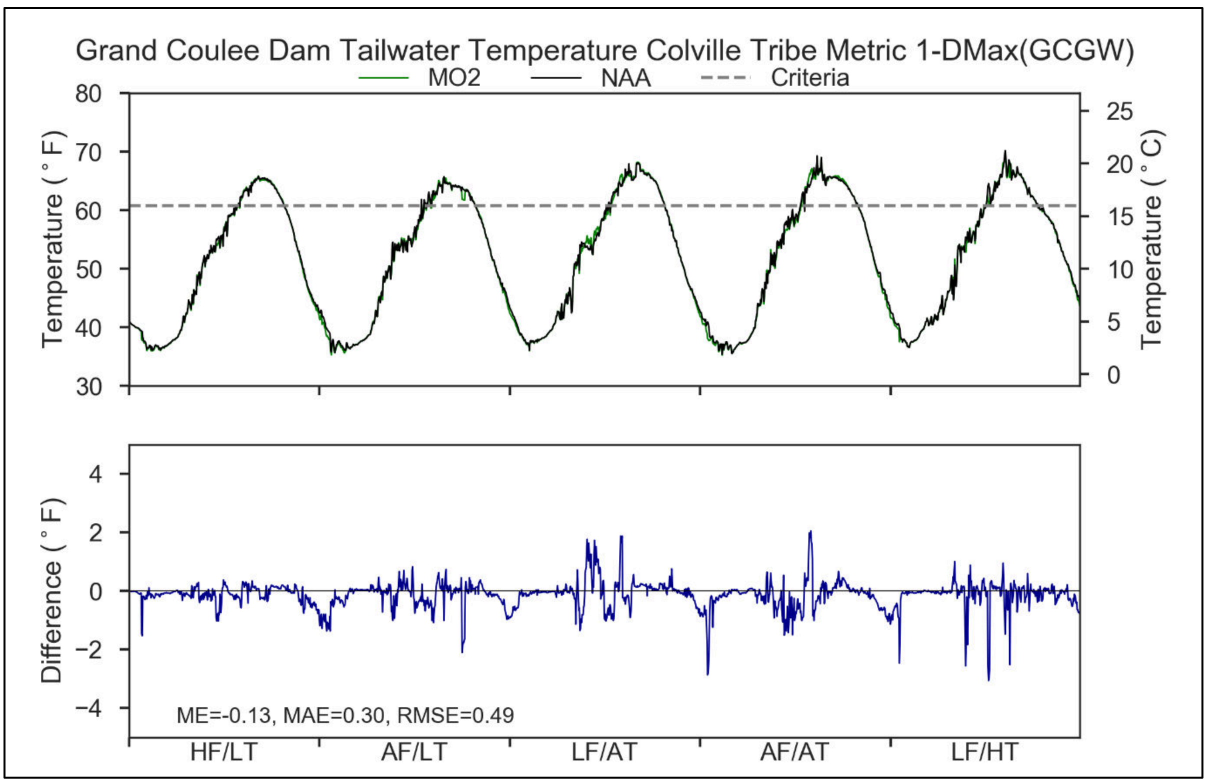


Figure 5-8. Modeled Tailwater Temperatures for the No Action Alternative and Multiple Objective Alternative 2 at Grand Coulee Dam Under a 5-Year Range of River and Meteorological Conditions Compared to the Confederated Colville Tribe 1-D Maximum Water Quality Standard

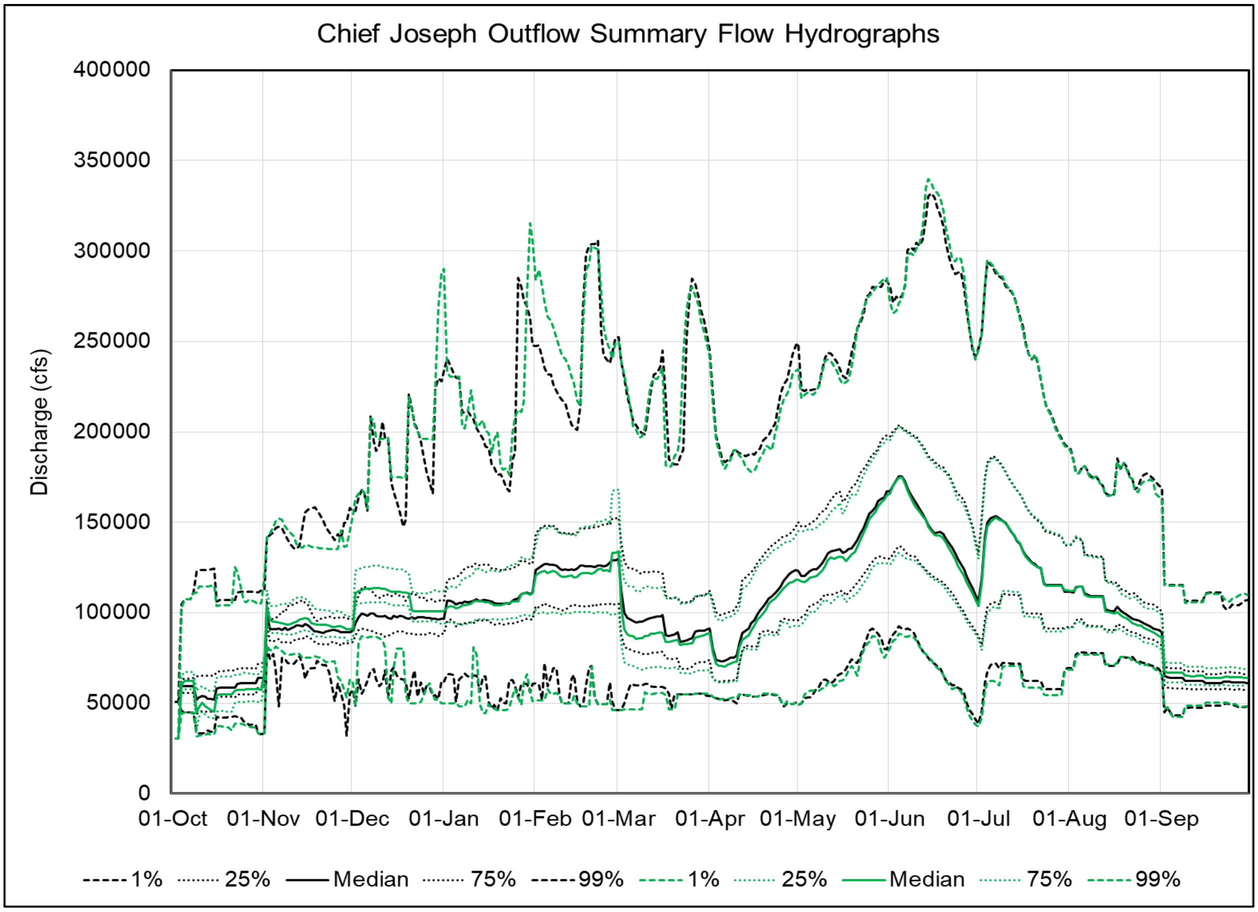


Figure 5-9. Chief Joseph Dam-Rufus Woods Lake Outflows for Multiple Objective Alternative 2 Versus the No Action Alternative

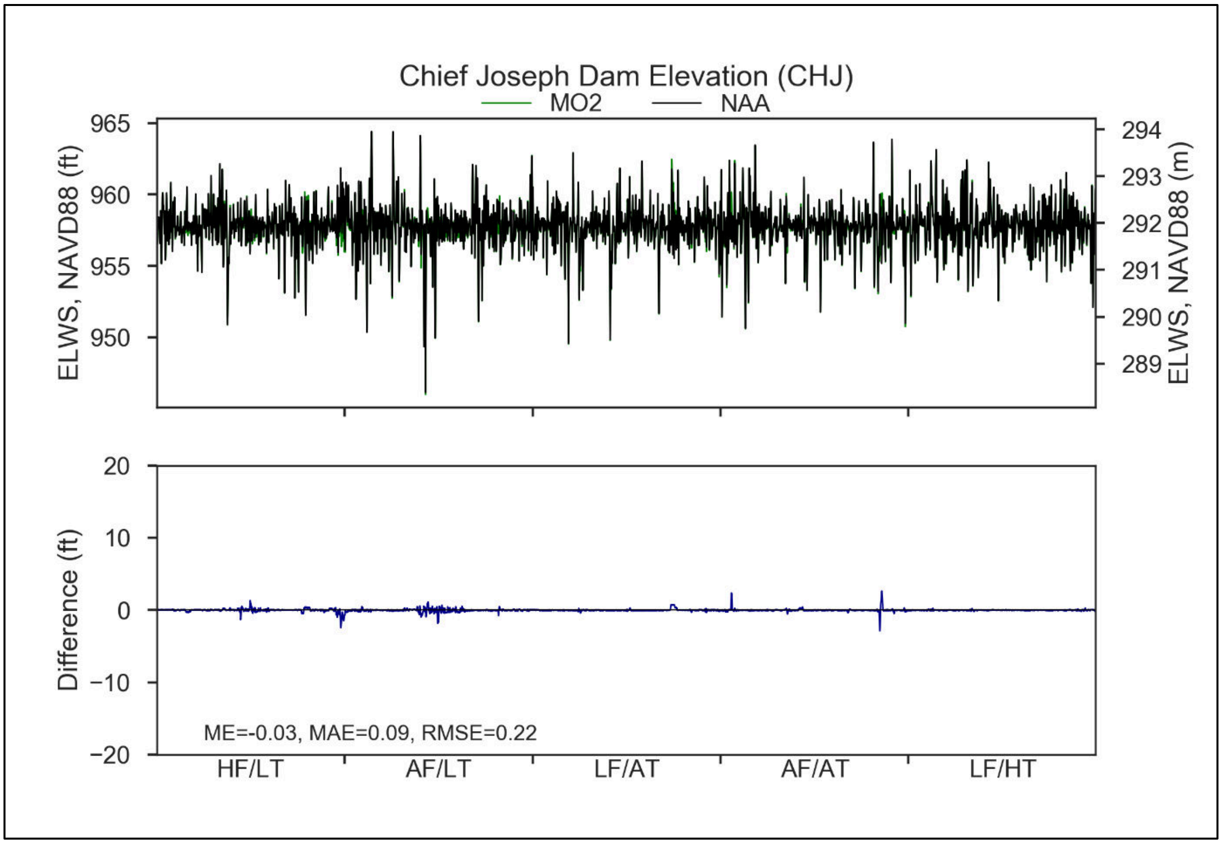


Figure 5-10. Chief Joseph Dam-Rufus Woods Lake Forebay Elevations for Multiple Objective Alternative 2 Versus the No Action Alternative

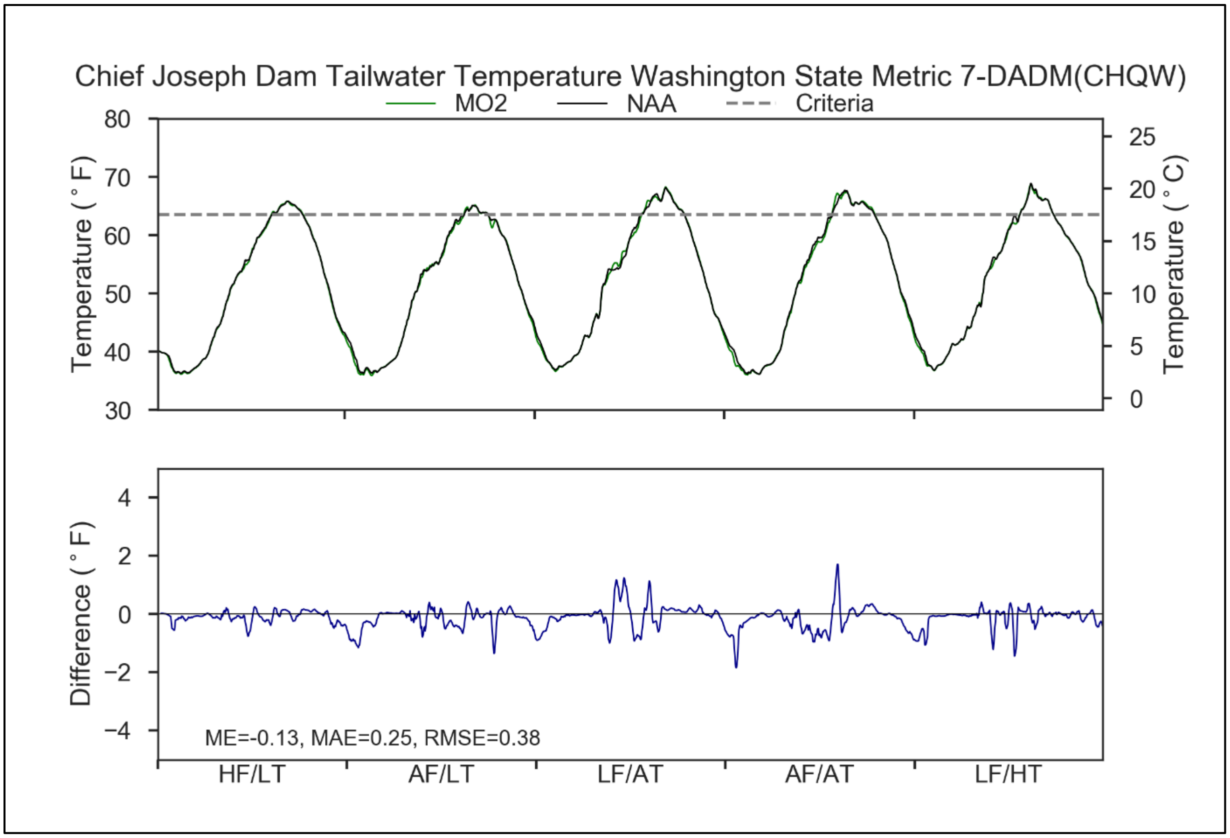


Figure 5-11. Modeled Tailwater Temperature for the No Action Alternative and Multiple Objective Alternative 2 at Chief Joseph Dam Under a 5-Year Range of River and Meteorological Conditions

The operational changes for MO2 do cause a few temperature differences as can be seen in the figures above. In terms of the actual number of days of the criteria being exceeded, those changes can be seen in Table 5-9. The blue highlighted cells show when an increased number of exceedances occurs as compared to NAA. Only the months where the criteria is exceeded is shown in the table. If a month has all zeroes shown, it is only because that month has exceeded criteria under a different alternative.

Table 5-1. Difference in Number of Days the Temperature Criteria is Exceeded at the Tailwater Sites of Grand Coulee and Chief Joseph for the Multiple Objective 2 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Grand Coulee	June	0	0	0	0	0
Grand Coulee	July	0	-3	-4	-2	-2
Grand Coulee	August	0	0	0	0	0
Grand Coulee	September	0	0	0	0	0
Grand Coulee	October	**1**	0	0	0	-1
Chief Joseph	July	0	0	-3	0	0
Chief Joseph	August	**1**	**1**	0	0	0
Chief Joseph	September	0	0	0	0	0
Chief Joseph	October	**1**	**1**	0	**1**	0

5.1.2 Total Dissolved Gas

5.1.2.1 Libby and Hungry Horse Dams and Reservoirs

Libby Dam is typically operated to minimize spill due to associated water quality concerns such as elevated TDG. Under MO2, Libby Dam's draft and refill operations will be modified resulting in an increase in the highest releases from the dam. This operational change is predicted to increase the chance of spill at Libby Dam. The 80-year period of record spill flows (1928 to 2008) were used to predict TDG, as presented in Figure 5-12. This shows that the number of years where spill could occur increases from three years under the No Action Alternative to 6 years under MO2. The number of days exceeding the State of Montana 110 percent criteria would increase as well, from 8 days for the No Action Alternative to 27 days for MO2. Although spill from Libby Dam for the 80-year model period is predicted to increase under MO2, the frequency of spill is still negligible.

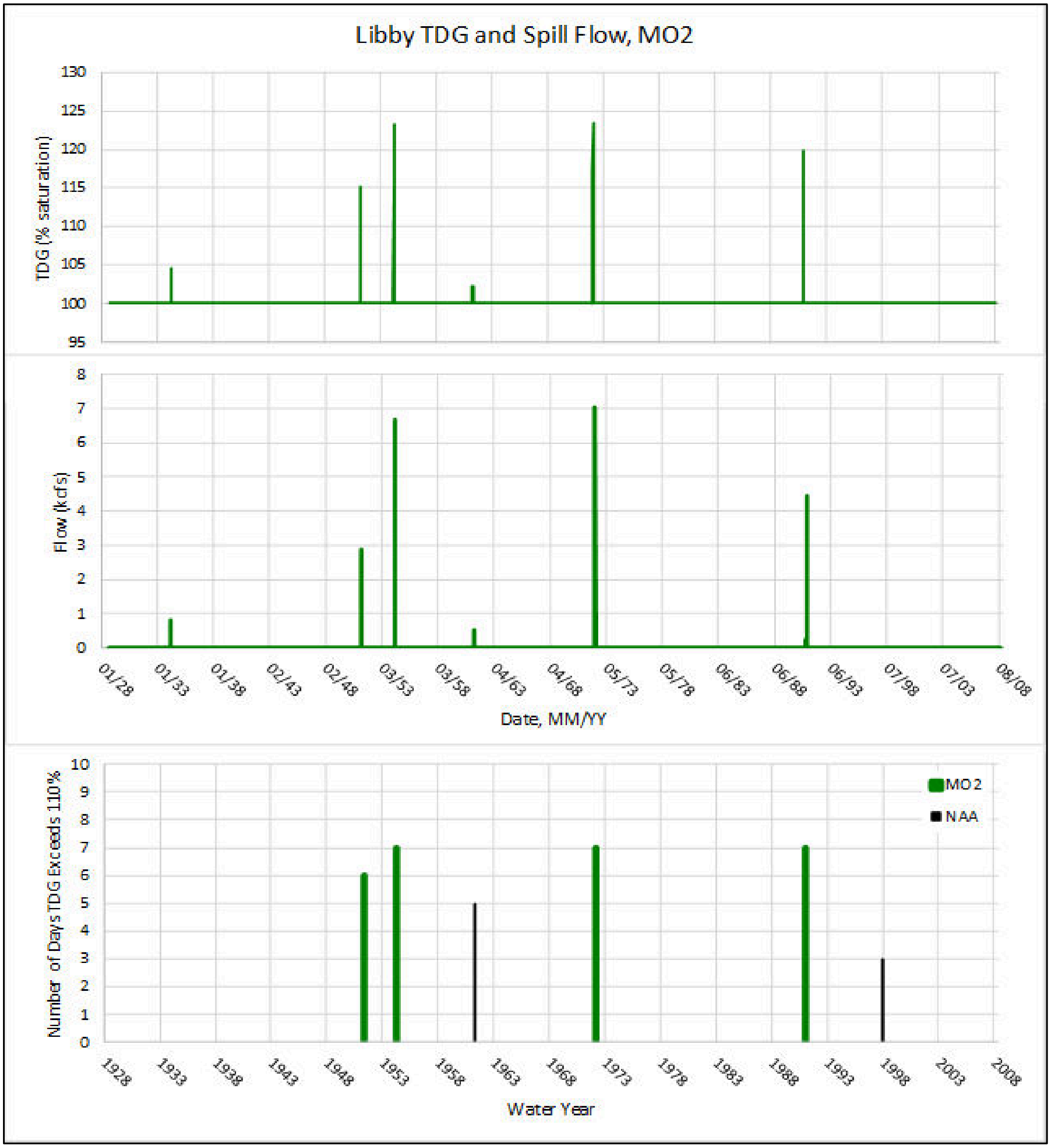


Figure 5-12. Modeled Tailwater Total Dissolved Gas and Spillway Flows for the Multiple Objective Alternative 2 and the Number of Exceedances for No Action Alternative and Multiple Objective Alternative 2 at Libby Dam over an 80Year Period

The Additional Draft for Hydropower measure results in additional winter outflows and a deeper draft (reservoir drawdown) in January. This reduces spring outflows and spill in some situations at Hungry Horse Dam, which could reduce the elevated TDG concentrations in the spring. The anticipated Hungry Horse Dam flow and spill changes under MO2 would reduce the number of days TDG is exceeded in most years. The Sliding Scale at Libby and Hungry Horse measure does not significantly change the summer storage in comparison to the No Action

Alternative and does not appear to affect spill and TDG at Hungry Horse Dam. Figure 5-13 shows the number of days that TDG is anticipated to exceed 110 percent below Hungry Horse Dam under the MO2 that was modeled from October 1928 through 2008. The number of days that the State water quality criterion is exceeded is notably less under MO2 as compared to the No Action Alternative: 309 days compared to 809 days under NAA.

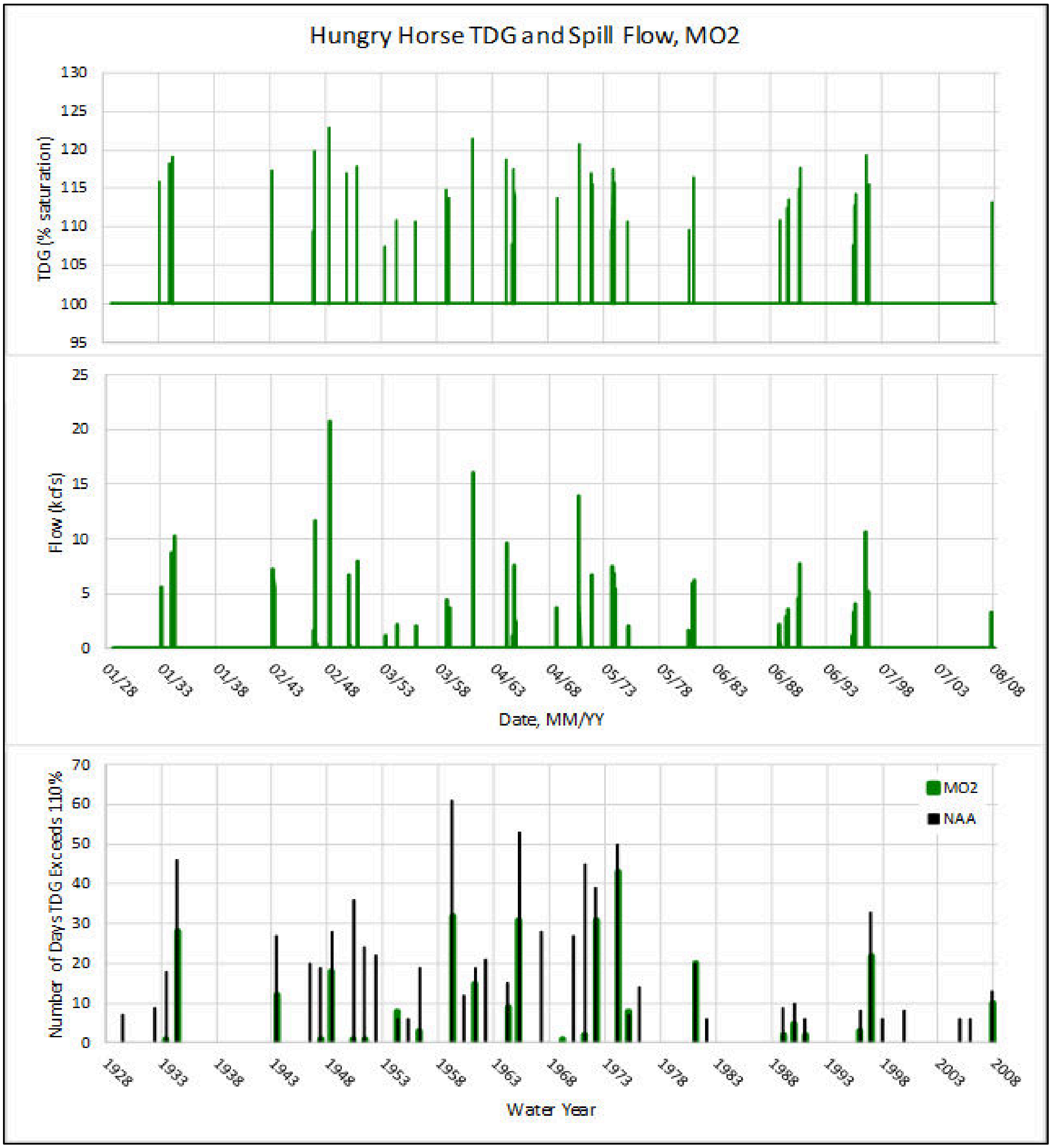


Figure 5-13. Modeled Tailwater Total Dissolved Gas and Spillway Flows for the Multiple Objective Alternative 2 and the Number of Exceedances for No Action Alternative and Multiple Objective Alternative 2 at Hungry Horse Dam over an 80Year Period

5.1.2.2 Albeni Falls Dam and Reservoir

TDG in the Pend Oreille River upstream of Albeni Falls Dam can be greater than the State of Montana 110 percent criteria largely because of spillway releases from Cabinet Gorge Dam, located on the Clark Fork River about 55 miles upstream of Albeni Falls Dam. During most years, Albeni Falls Dam spills during high flow spring runoff. In general, spillway discharges up to about 10 kcfs can increase TDG saturations over forebay levels by about 1 to 2 percent, while spill between 10 to 50 kcfs can increase TDG saturations downstream of Albeni Falls by about 5 to 9 percent. When Pend Oreille River flows exceed about 50 to 60 kcfs, Albeni Falls Dam powerhouse operations are suspended and the spillway gates are raised, allowing the river to flow relatively un-impounded across the dam. Under these high flow conditions, Albeni Falls Dam produces no TDG as the river is essentially free flowing. Spillway flows at Albeni Falls Dam were modeled under the MO2 and No Action Alternative for the 80-year period from 1928 to 2008 using the ResSim model (Figure 5-14). There was little difference in spillway flows between MO2 and the No Action Alternative. For both alternatives, spillway flows were predicted to range between 1 and 50 kcfs in nearly every year at Albeni Falls Dam, with many years having spill exceed about 60 kcfs, resulting in free-flowing conditions. These similar spillway flows under MO2 and the No Action Alternative are expected to result in no change in TDG saturations downstream of Albeni Falls Dam.

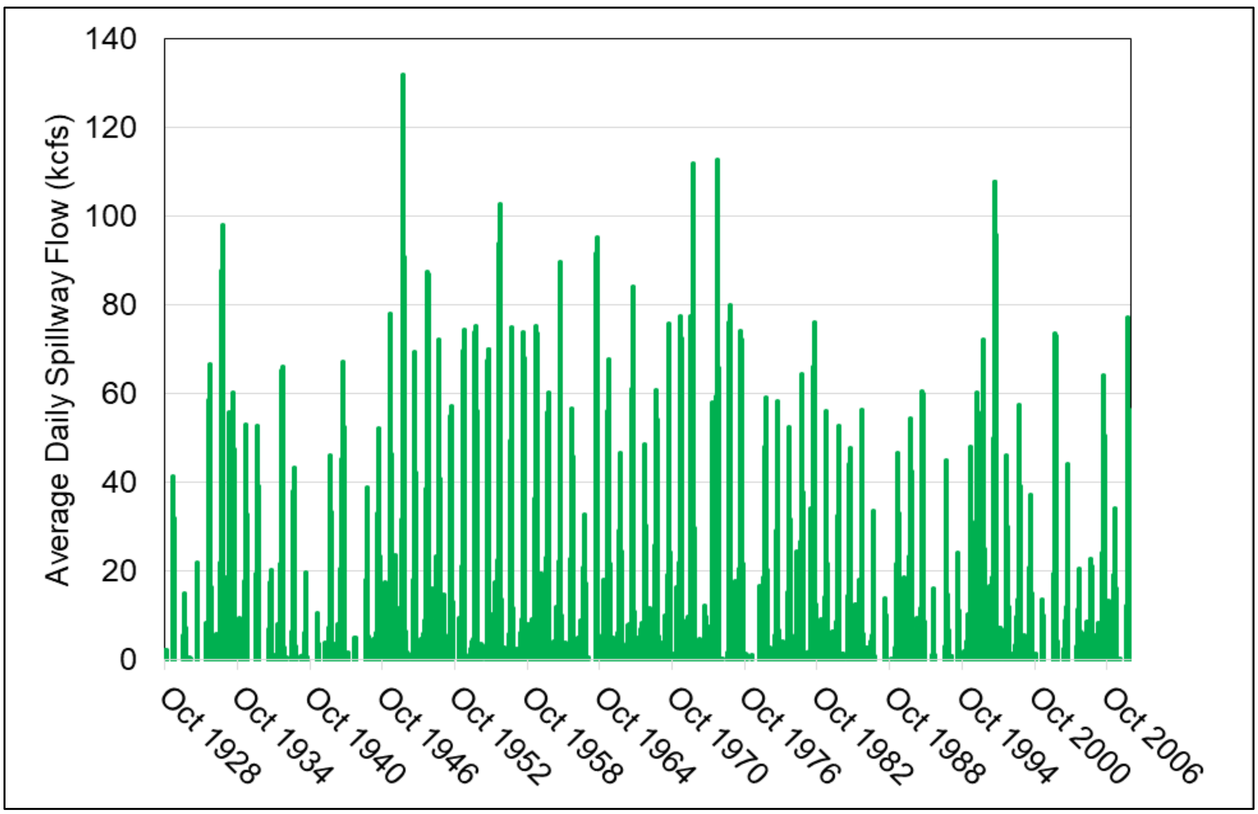


Figure 5-14. Modeled Tailwater Spillway Flows for the No Action Alternative and Multiple Objective Alternative 2 at Albeni Falls Dam over an 80-Year Period

5.1.2.3 Grand Coulee and Chief Joseph Dams and Reservoirs

There are five MO2 operational measures specific to Grand Coulee Dam that would impact TDG:

- *Deeper Drafts for Hydropower*
- *Update System FRM Calculation*
- *Planned Draft Rate at Grand Coulee*
- *Grand Coulee Maintenance Operations*
- *Winter System FRM Space*

A more in-depth discussion of these operational measures and their effects can be found in Appendix B, *Hydraulics and Hydrology*. None of these operational measures in MO2 would affect TDG levels within Lake Roosevelt, which are largely influenced by upstream dams that are outside the scope of this analysis. In addition to the measures listed above, changes in operations of upstream projects (from the *Deeper Drafts for Hydropower* measure and other modifications) could result in changes to inflows at Grand Coulee, which may have minor impacts on inflowing TDG but are not captured by the system modeling.

Increased outflows from Grand Coulee from November to January are a result of winter space requirements for rain-induced flooding (*Winter System FRM Space and Deeper Draft for Hydropower* measures). The *Grand Coulee Maintenance Operations* measure could increase spill by reducing the hydraulic capacity through the power plants during any period of the year when outflows exceed power plant capacity. Operational measure *Planned Draft Rate at Grand Coulee* would result in a slightly earlier draft in Lake Roosevelt in wetter years; while the *Update System FRM Calculation* measure determines the deepest draft point for Grand Coulee in the spring, and in some years this measure results in a deeper draft than in the No Action Alternative. Despite the increase in winter outflows, TDG is not anticipated to increase significantly as 98 percent of the time the project does not spill in December, and when spill does occur, it is likely that pool elevations during this time of year allow for spill over the drum gates. Overall, MO2 operational measures would result in higher Columbia River flows below the dam from December to February, when TDG is generally below the 110 percent Washington State and Colville Tribes criteria.

The increase in winter outflows and deeper pool elevations result in a decrease in outflow April through July. The reduced outflows, and spill in some cases, during the spring months result in decreased TDG. This is most pronounced in May and June. Under MO2, average TDG concentrations are slightly lower (0.3 percent), resulting in about 4 days less violations to Washington State water quality per year. Additionally, TDG might be reduced in May and June under MO2, but above the Washington State TDG criteria for about 90 hours more during high-flow years (Figure 5-15 and Figure 5-17).

As stated above, the operational measures for *Grand Coulee Maintenance Operations* have the potential to increase spill through the reduction in the hydraulic capacity of the powerhouse at Grand Coulee. The Grand Coulee Maintenance Operations in isolation could result in significant increases in spill and TDG, in some cases producing TDG in excess of 130 percent for limited duration; however, this effect is largely offset in the spring and early-summer by the other measures. An additional impact expected from *Grand Coulee Maintenance Operations* is the potential for slightly deeper spill over the drum gates (when the forebay elevation is greater than 1,267 feet, NGVD29). Information to assess the magnitude of water quality impacts directly related to Grand Coulee Maintenance Operations is unavailable but would likely result in small increases in TDG. In wet conditions, it is anticipated that potential maintenance activities could be delayed in advance of spill to allow spill over more gates. Another factor not considered in the analysis is that as maintenance occurs, there would be an increase to hydraulic capacity as more units become available. This would result in reduced spill and TDG in some cases; however, the other actions have a larger impact on outflows and associated spill.

As shown in Figure 5-16 and Figure 5-18, the combination of these particular operational measures tend to offset each other in the analysis of the overall alternative and, in some cases, result in a reduction in TDG. The shaded area in the figure shows the entire range of TDG predicted by the MO2 and No Action Alternative models. The models indicate significant reductions in the early months compared to the No Action Alternative in high water years. Therefore, compared to the No Action Alternative, MO2 could somewhat reduce TDG but the number of daily Washington State water quality violations in the Columbia River below the dam will mostly remain the same.

TDG at the forebay of Chief Joseph Dam is largely a function of the TDG released upstream from Lake Roosevelt and Grand Coulee Dam because little degassing occurs in Rufus Woods Lake. High inflow TDG saturations to Lake Roosevelt from Canada, as well as spill from Grand Coulee Dam via the outlet tubes, can increase TDG saturations in Rufus Woods Lake at the Chief Joseph Dam forebay to over 130 percent for a limited time. During periods when incoming TDG levels are above approximately 120 percent, spilling at Chief Joseph Dam over the spillway deflectors can degas the water and reduce downstream system TDG loading. Therefore, Chief Joseph Dam is often used to help manage overall system TDG production in the mainstem Columbia River. In addition, to avoid spilling through the outlet tubes at Grand Coulee Dam, spill is often shifted from Grand Coulee Dam to Chief Joseph Dam to take advantage of the lower TDG produced by spilling over the deflectors. These operational strategies are expected to continue under MO2.

Chief Joseph Dam TDG saturations at the forebay and tailwater modeled under MO2 were compared to the No Action Alternative (Figure 5-19). In general, MO2 forebay TDG saturations are predicted to be similar to or slightly less than the No Action Alternative under a wide range of flow and air temperature conditions. Tailwater TDG saturations under MO2 are predicted to be both lower and higher than the No Action Alternative depending on flow and meteorological conditions. The number of days the tailwater exceeds the 110 percent TDG criteria is predicted to be slightly lower under MO2 for all flow and meteorological conditions (Table 5-3). Decreased TDG saturations between the forebay and tailwater during higher spill years such as

2011 (HF/LT) and 2012 (AF/LT) modeled under the No Action Alternative would continue under MO2. It is expected that under MO2, Chief Joseph Dam would continue to decrease TDG during high spill years when TDG saturations greater than about 120 percent occur in the forebay.

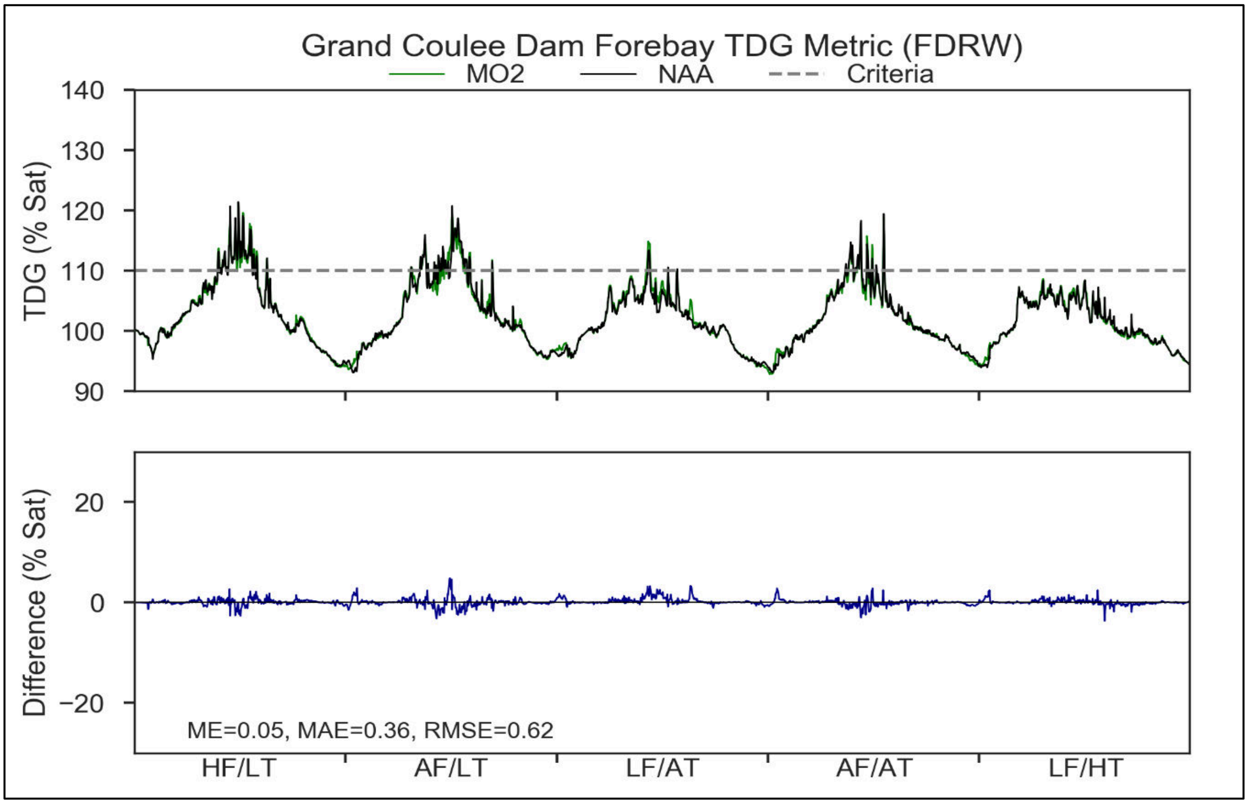


Figure 5-15. Modeled Forebay Total Dissolved Gas for the No Action Alternative and Multiple Objective Alternative 2 at Grand Coulee Dam Under a 5-Year Range of River and Meteorological Conditions

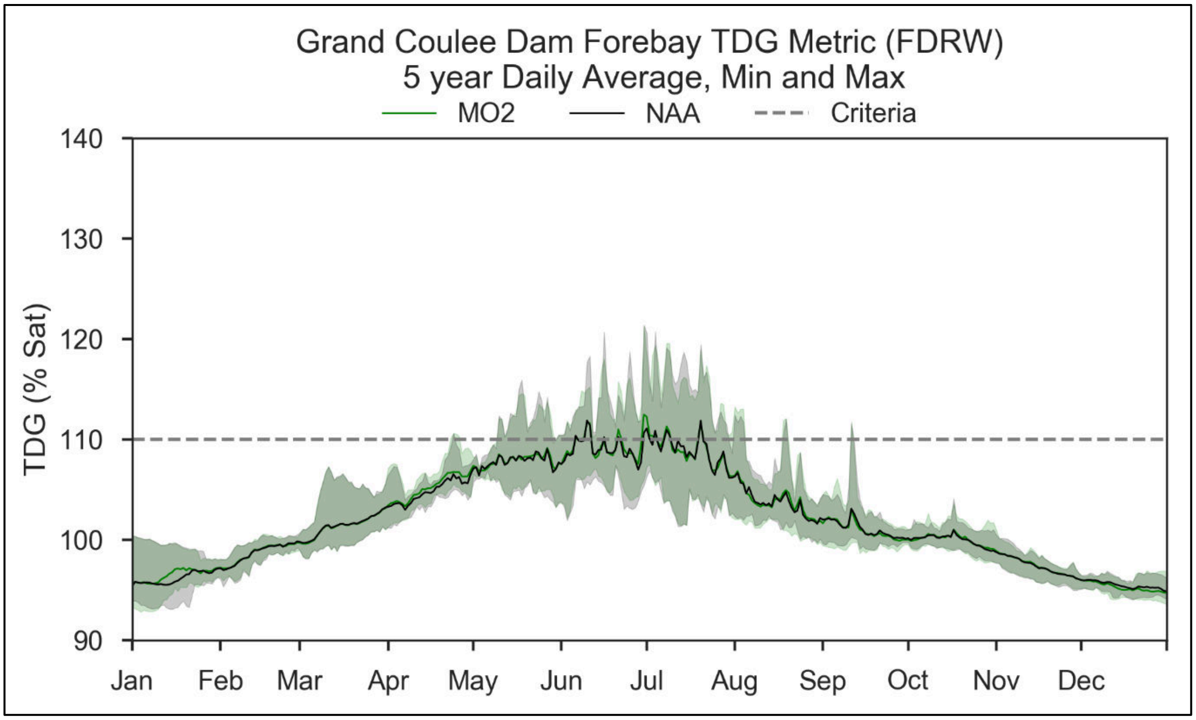


Figure 5-16. Modeled Range of Forebay Total Dissolved Gas for the No Action Alternative and Multiple Objective Alternative 2 at Grand Coulee Dam Under a 5-Year Range of River and Meteorological Conditions

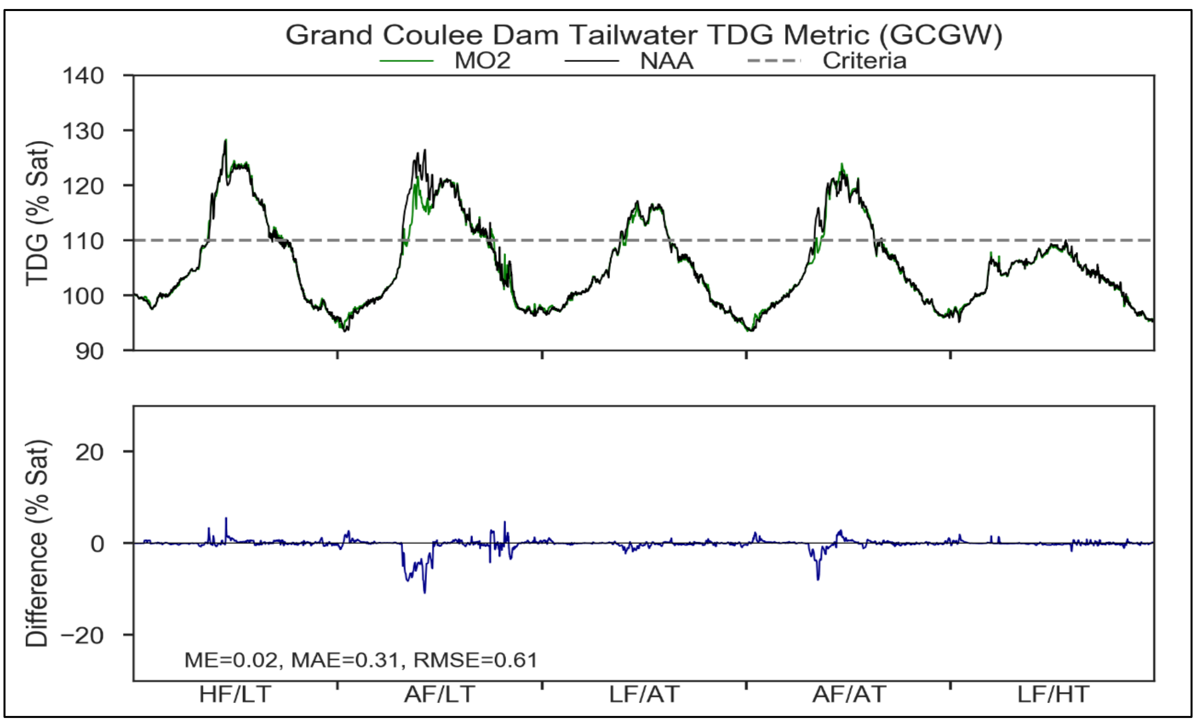


Figure 5-17. Modeled Tailwater Total Dissolved Gas for the No Action Alternative and Multiple Objective Alternative 2 at Grand Coulee Dam Under a 5-Year Range of River and Meteorological Conditions

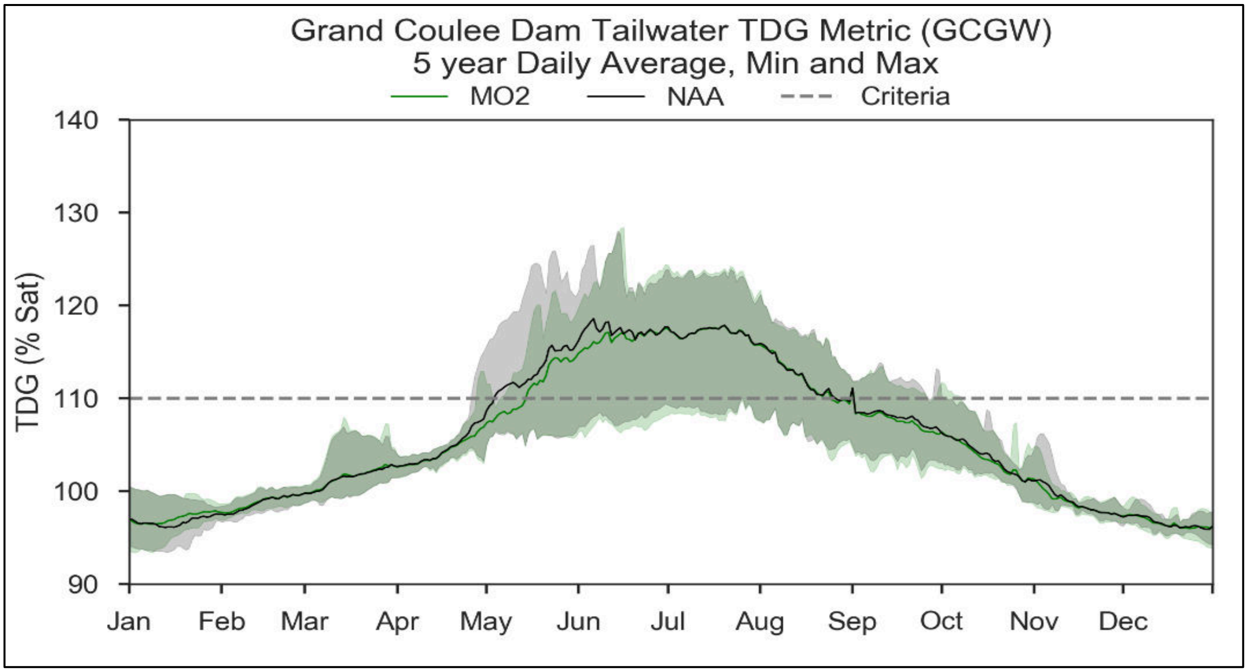


Figure 5-18. Modeled Range of Tailwater Total Dissolved Gas for the No Action Alternative and Multiple Objective Alternative 2 at Grand Coulee Dam Under a 5-Year Range of River and Meteorological Conditions

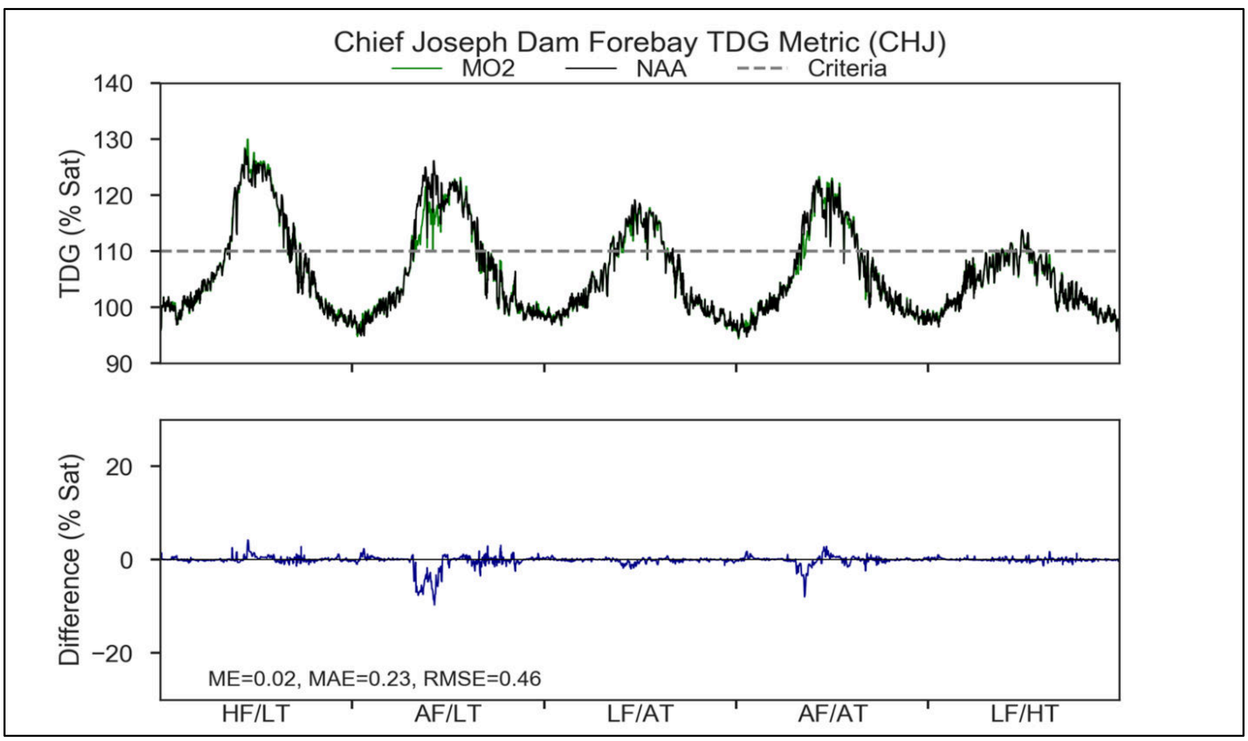


Figure 5-19. Modeled Forebay and Tailwater Total Dissolved Gas Saturations for the No Action Alternative and Multiple Objective Alternative 2 at Chief Joseph Dam Under a 5-Year Range of River and Meteorological Conditions

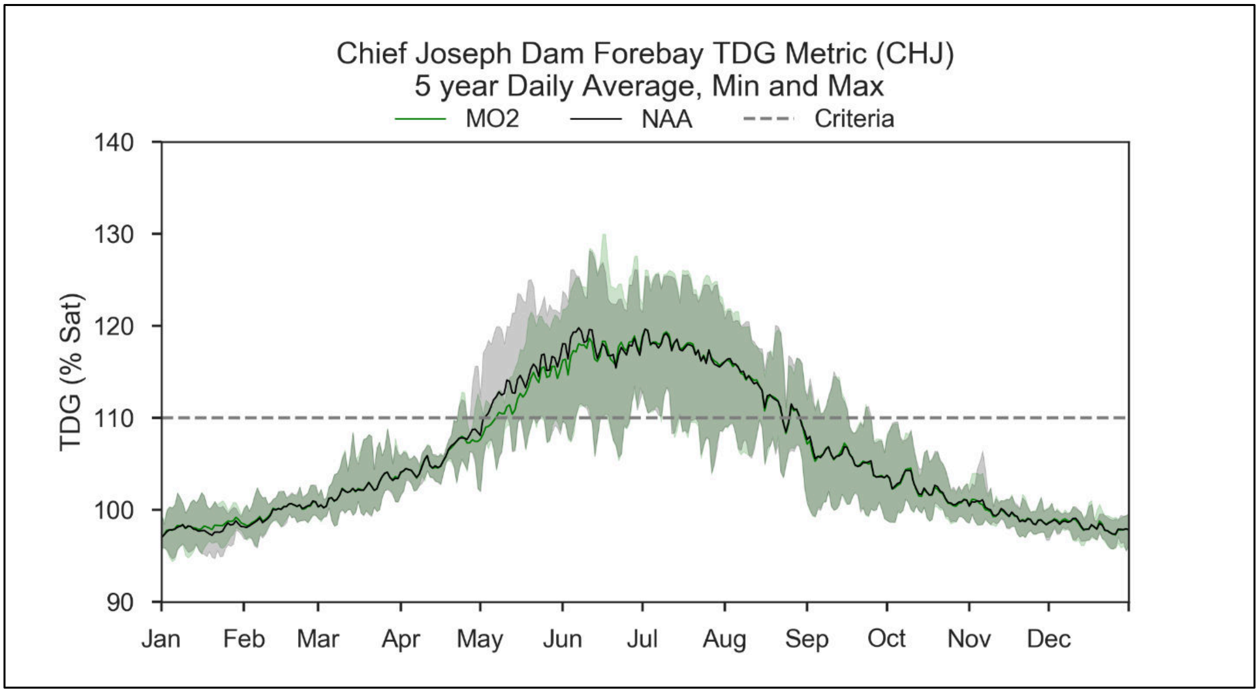


Figure 5-20. Modeled Range of Forebay and Tailwater Total Dissolved Gas for the No Action Alternative and Multiple Objective Alternative 2 at Chief Joseph Dam Under a 5-Year Range of River and Meteorological Conditions

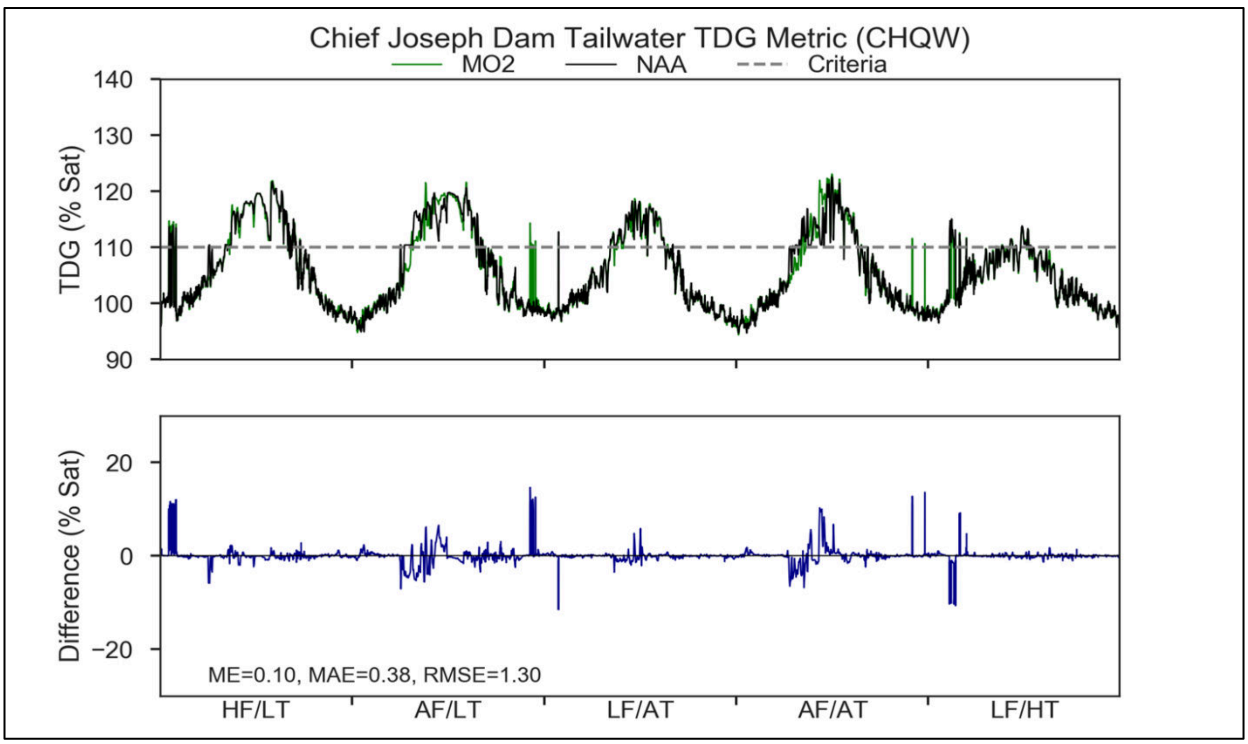


Figure 5-21. Modeled Tailwater Total Dissolved Gas Saturations for the No Action Alternative and Multiple Objective Alternative 2 at Chief Joseph Dam Under a 5-Year Range of River and Meteorological Conditions

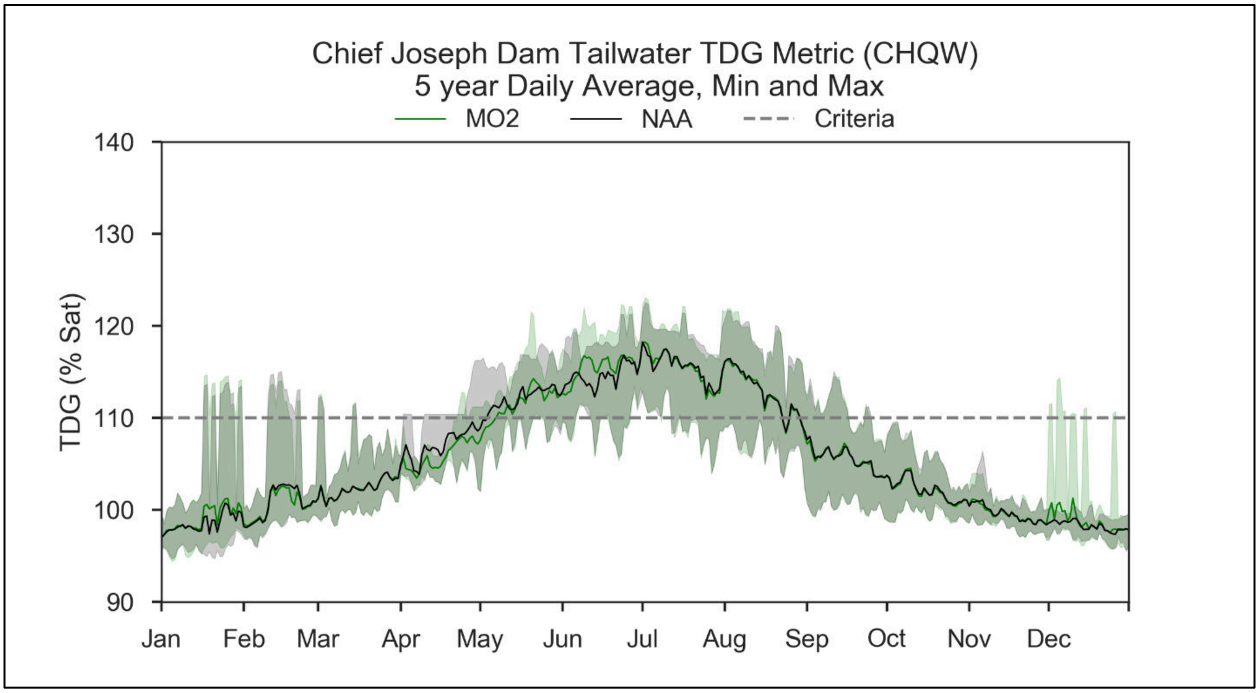


Figure 5-22. Modeled Range of Forebay and Tailwater Total Dissolved Gas for the No Action Alternative and Multiple Objective Alternative 2 at Chief Joseph Dam Under a 5-Year Range of River and Meteorological Conditions

The operational changes for MO2 do cause a few TDG differences as can be seen in the figures above. In terms of the actual number of days of the criteria being exceeded, those changes can be seen in Table 5-2 and Table 5-3. The blue highlighted cells show when an increased number of exceedances occurs as compared to NAA. Only the months where the criteria is exceeded is shown in the table. If a month has all zeroes shown, it is only because that month has exceeded the criteria under a different alternative.

Table 5-2. Difference in Number of Days the TDG Criteria is Exceeded at the Forebay Sites of Grand Coulee and Chief Joseph for the Multiple Objective 2 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Grand Coulee	April	0	**4**	0	0	0
Grand Coulee	May	**3**	**1**	0	-2	0
Grand Coulee	June	0	**1**	**2**	-2	0
Grand Coulee	July	0	-3	0	**6**	0
Grand Coulee	August	**2**	**3**	0	0	0
Grand Coulee	September	0	0	0	0	0
Chief Joseph	April	0	-1	0	-1	0
Chief Joseph	May	0	0	-5	-6	-2
Chief Joseph	June	0	0	0	0	-3

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Chief Joseph	July	0	0	0	0	-1
Chief Joseph	August	0	-1	**2**	0	0
Chief Joseph	September	-1	0	0	0	0
Chief Joseph	October	0	0	0	0	0

Table 5-3. Difference in Number of Days the TDG Criteria is Exceeded at the Tailwater Sites of Grand Coulee and Chief Joseph for the Multiple Objective 2 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Grand Coulee	April	0	-3	0	0	0
Grand Coulee	May	**1**	-6	-5	-10	0
Grand Coulee	June	0	0	0	0	0
Grand Coulee	July	0	0	0	0	-1
Grand Coulee	August	0	0	0	-1	0
Grand Coulee	September	**3**	-2	0	0	0
Grand Coulee	October	-1	**6**	0	0	0
Chief Joseph	January	**2**	0	0	0	0
Chief Joseph	February	0	0	0	0	-4
Chief Joseph	March	0	0	0	0	0
Chief Joseph	April	-3	-16	0	-11	0
Chief Joseph	May	-1	0	-9	-7	-2
Chief Joseph	June	0	0	0	0	-3
Chief Joseph	July	0	0	0	0	-1

5.1.3 Other Physical, Chemical, and Biological Processes

5.1.3.1 Libby and Hungry Horse Dams and Reservoirs

MO2 would modify operations at Libby Dam resulting in changes in the drafting depth and water elevations of Lake Koocanusa that may impact physical, chemical, and biological water quality parameters when compared to existing conditions and the No Action Alternative. In general, MO2 results in lower water elevations in Lake Koocanusa from November through April, with substantially lower end-of-April water elevations (11 to 19 feet) in the driest 40 percent of years. Reservoir refill and summer pool elevations are improved over the No Action Alternative with the reservoir reaching full pool by the end of July and maintaining higher elevations, of about 1 to 4 feet in August and September. For water quality concerns, of particular interest are the 11- to 19-foot lower end-of-April water elevations because they equate to less volume of water in Lake Koocanusa during the spring runoff and a shorter water retention time in Lake Koocanusa.

Water quality chemical and biological parameters of concern in Lake Koocanusa that may be impacted by changes in the reservoir elevation and retention times, under MO2, include suspended sediments, nutrients such as phosphorus and nitrogen, metals such as selenium, and phytoplankton such as cyanobacteria and diatoms. For a long, narrow, deep waterbody like Lake Koocanusa, shorter retention times may allow certain chemical constituents in inflowing waters to move farther down-reservoir toward the forebay and outflow before settling out or transforming.

It is likely that the end-of-April drawdown elevation and the corresponding reservoir volume, as well as spring runoff volume and the corresponding phosphorus and sediment concentrations, are all factors in determining how far down-reservoir total phosphorus and suspended sediments reach. Historical data show that Lake Koocanusa is a sink for phosphorus and sediments, with little inflow concentrations moving down-reservoir past Libby Dam. A recent study by Yassien and Ward (2018) concluded that from 2014 through 2017, the total phosphorus retention in the reservoir ranged from 80 to 93 percent. Under MO2, the lower reservoir elevations for the driest 40 percent of years would likely allow sediments and total phosphorus from the inflow to move farther down-reservoir before settling out.

Lake Koocanusa does not appear to be a sink for nitrogen and most of the inflow nitrate passes down-reservoir to the forebay and Kootenai River regardless of reservoir elevations and retention times. Increased nitrate loadings to Lake Koocanusa, largely due to coal mining operations in British Columbia and together with low phosphorus concentrations, have created a large imbalance in the nitrogen-to-phosphorus ratio, with the ratio often exceeding 100:1 at the forebay, resulting in strong phosphorus limitation. Despite rising nitrate concentrations in Lake Koocanusa, algal blooms appear to have been kept in check by the strong phosphorus limitation under existing conditions and the No Action Alternative. However, it is possible that the operational changes proposed for MO2 may increase total phosphorus concentrations in Lake Koocanusa, which could result in changes in phytoplankton densities and functional types.

Increasing selenium concentrations in Lake Koocanusa from coal mining operations in British Columbia are a concern and were previously discussed for MO1 and the No Action Alternative. Over the next 25 years, it is expected that coal production in the Kootenai River watershed will continue. Although there does not yet appear to be an increasing trend in water column selenium concentrations in the reservoir, there is concern that without water quality treatment, the continued selenium loadings to Lake Koocanusa may lead to additional selenium contamination. It is possible that the lower end-of-April reservoir elevations for the driest 40 percent of years under MO2 may alter the movement, cycling, and transformation of selenium in the reservoir and downstream in the Kootenai River, possibly resulting in water and sediment quality impacts.

Median reservoir elevations under MO2 would be lower during the spring, potentially flushing some early food sources from Libby Reservoir; however, during the growing season, mid-June through September, reservoir elevations would be similar as compared to the No Action Alternative. As such, Lake Koocanusa should not experience major changes to the physical, chemical, or biological processes compared to the No Action Alternative. Additionally, changes in the median average monthly outflows from Libby Dam during the mid-June through September time frame are relatively minor (reduction of 5 to 9 percent when compared to the No Action Alternative), which result in only a 0.3-foot decrease in median monthly elevation in the Kootenai River downstream of Libby Dam, and should not greatly impact the variability of (periodically wetted) zone productivity.

Hungry Horse median reservoir elevations are expected to be lower under MO2 as compared to the No Action Alternative, particularly in early spring and summer (Figure 5-3). These elevations combined with higher outflows (Figure 5-23) in late spring/early summer could reduce in-lake productivity and food availability for resident fish species (ISAB 1997, Fraley et. al 1989).

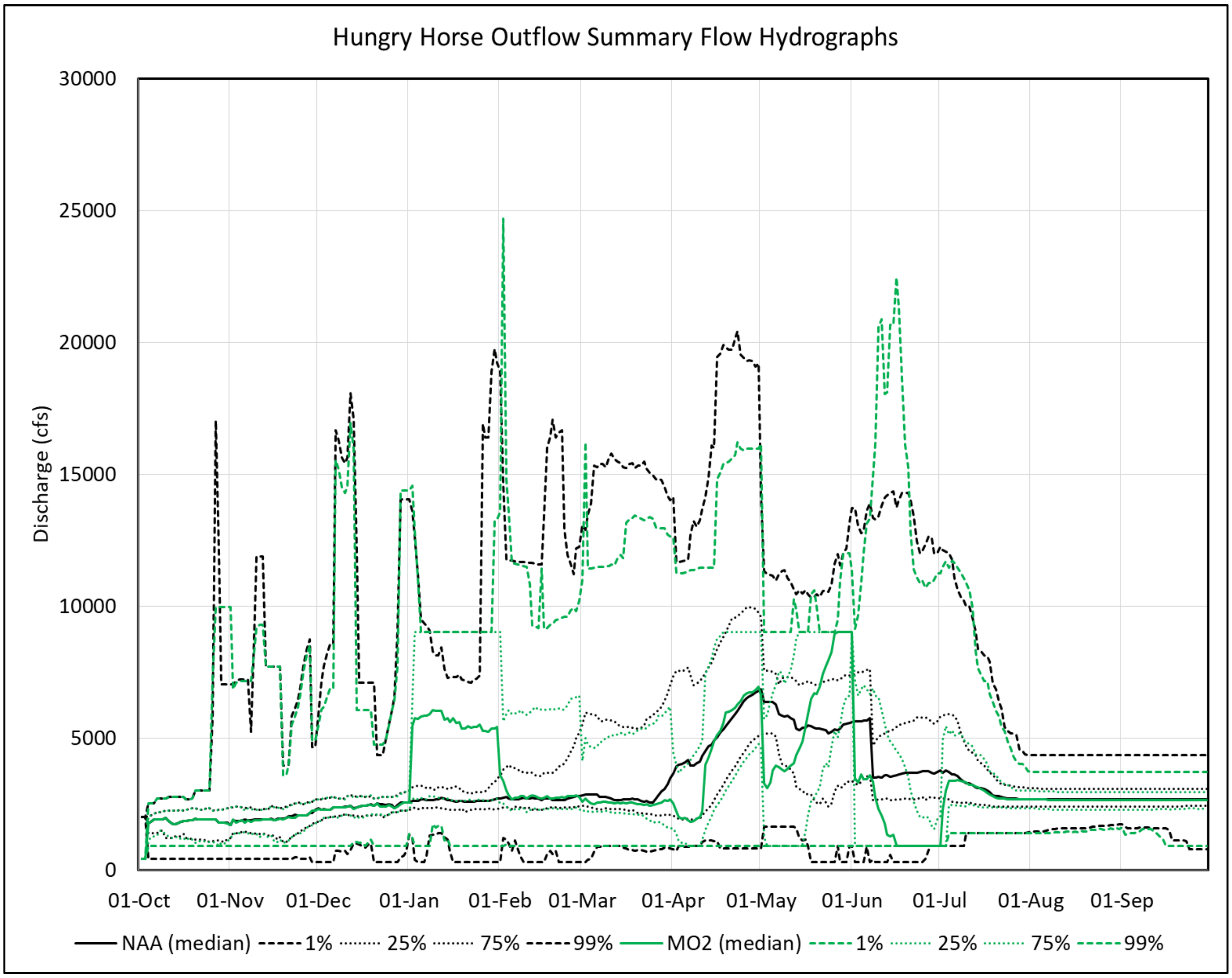


Figure 5-23. Hungry Horse Dam Outflows for Multiple Objective Alternative 2 Versus the No Action Alternative

Water level fluctuations in reservoirs may increase methyl-mercury concentrations in the waterbody as seasonally inundated areas of a reservoir have higher rates of methylation activity when compared to permanently inundated areas of a reservoir (Willacker et al. 2016). Studies suggest that methyl-mercury has a greater probability of entering the food web during the spring and summer growing seasons (January through July) (Willacker et al. 2016). Under MO2, the measures don't change the cyclic occurrence of inundation and exposure but do result in earlier and longer exposure of sediments that may have some impact on mercury methylation in Hungry Horse Reservoir. However, unlike other downstream locations such as Lake Roosevelt, mercury has not been recorded as a concern at Hungry Horse Reservoir as the only likely mercury input at this location is through airborne pollution. Additionally, even this input is likely minor due to the relatively high air quality in the region.

5.1.3.2 Albeni Falls Dam and Reservoir

Under MO2, there are minor changes to operations at Albeni Falls Dam. The physical, chemical, and biological water quality of Lake Pend Oreille and the Pend Oreille River described under the No Action Alternative are expected to remain unchanged.

5.1.3.3 Grand Coulee and Chief Joseph Dams and Reservoirs

Under MO2, retention time of water in the reservoir could decrease slightly from March through May; however, retention time would largely remain unchanged during the rest of the year, as compared to the No Action Alternative (Figure 5-24). Lake Roosevelt tends to display relatively low primary productivity throughout the year. However, with slightly longer water retention times, some locations of the reservoir may experience primary productivity blooms. These blooms have the potential to increase pH and decrease dissolved oxygen when they decay. In the part of Lake Roosevelt where the Spokane River enters, in the LF/HT year, there is a greater portion of the water column that is anoxic; this may be related to water retention time and temperature conditions in this year.

The *Planned Draft Rate at Grand Coulee* measure changes the planning drawdown rate (as depicted in the SRD) from 1.0 foot per day to a target of 0.8 feet per day. Mass wasting, such as small local landslides within Lake Roosevelt, has been related to the rate of drawdown at Grand Coulee Dam. Decreases in these mass wasting events that introduce sediment in pulses to the reservoir should result in decreases in turbidity under MO2.

Water level fluctuations in reservoirs may increase methyl-mercury concentrations in the waterbody as seasonally inundated areas of a reservoir have higher rates of methylation activity when compared to permanently inundated areas of a reservoir (Willacker et al. 2016). Studies suggest that methyl-mercury has a greater probability of entering the food web during the spring and summer growing seasons (January to July) (Willacker et al. 2016). Under MO2, the measures don't change the cyclic occurrence of inundation and exposure but do result in earlier and longer exposure of sediments that may have some impact on mercury methylation in Lake Roosevelt. The lower panel of Figure 5-24 shows the difference in Lake Roosevelt water elevation throughout the year between MO2 and the No Action Alternative. Modeling indicates that the average draft is expected to remain about 7 feet lower under this alternative. MO2 may very slightly increase the rate of mercury cycling within Lake Roosevelt.

MO2 includes modified operations at Grand Coulee Dam that result in some changes in monthly outflows to Rufus Woods Lake and Chief Joseph Dam. However, only minor changes to operational conditions at Chief Joseph Dam are expected. As such, the physical, chemical, and biological water quality of Rufus Woods Lake and the Columbia River downstream of Chief Joseph Dam under MO2 are expected to remain relatively unchanged from the No Action Alternative.

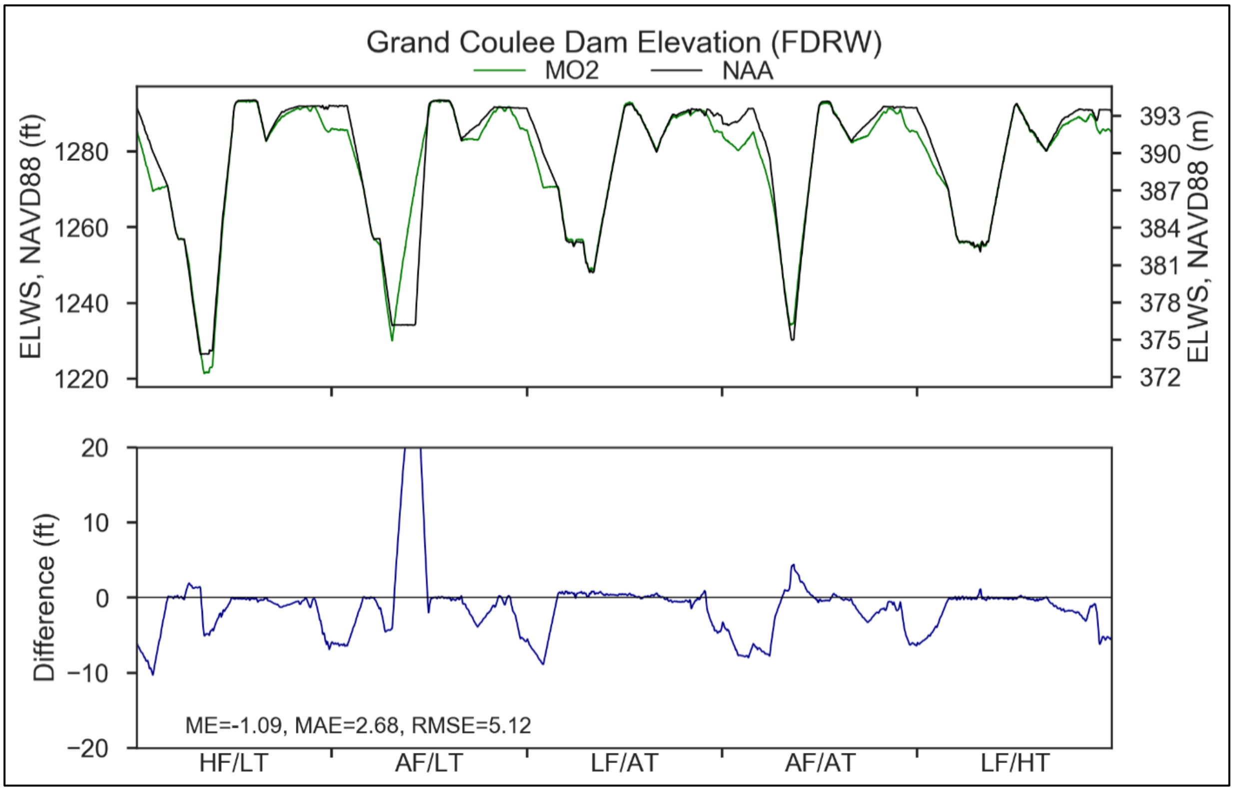


Figure 5-24. Modeled Forebay Elevations for the No Action Alternative and Multiple Objective Alternative 2 at Grand Coulee Dam Under a 5-Year Range of River and Meteorological Conditions

5.2 LOWER SNAKE RIVER BASIN

The two operational measures included as part of MO2 that would have the largest impact on water quality in the lower Snake River Basin are operational measures *Spill to 110% TDG* and *Slightly Deeper Draft for Hydropower*. The *Spill to 110% TDG* measure would limit juvenile fish passage spill at the four lower Snake River projects to 110 percent in the tailraces and downstream forebays. Exceptions would include times when spill is needed for the powerhouse surface passage routes, for the spillway weirs, adult attraction, and during high flow or flood events. Juvenile fish passage spill would begin annually on April 3 and end at midnight on July 31.

The *Slightly Deeper Draft for Hydropower* measure would result in deeper drafts and slower refill of Dworshak Reservoir during most of the five flow and meteorological conditions modeled (Figure 5-25). This measure would use current forecasts in the winter to draft

Dworshak 10 feet below its April draft target. If the forecast continued to become drier, it's possible that draft target could be missed by more than 10 feet. Due to time constraints ResSim logic was not able to capture all of the desired logic in the modeling of the measure, which caused Dworshak to miss refill by more than expected. However, some reduction in refill seems probable due to the nature of forecast error in reservoir operations.

For the model rule set evaluated, the two deepest drafts would occur during HF/LT and AF/AT conditions when the pool elevation would be less than 1,450 feet, NGVD29 during April. The anticipated MO2 minimum pool elevation during HF/LT conditions is, at most, 6 feet lower than it would be under the No Action Alternative (Figure 5-26). During AF/AT conditions, the late-April MO2 elevation would be up to 36 feet lower than during the No Action Alternative. Additional drafting would also occur under MO2 between January and March during each flow and meteorological condition. The largest differences between MO2 and the No Action Alternative during this part of the year would occur during LF/AT and AF/LT conditions when the pool elevation would be approximately 30 feet and 35 feet lower, respectively. Refill would also occur later in the year during average and low-flow years and not reach full pool of 1,600 feet, NGVD29 during AF/AT and LF/HT conditions.

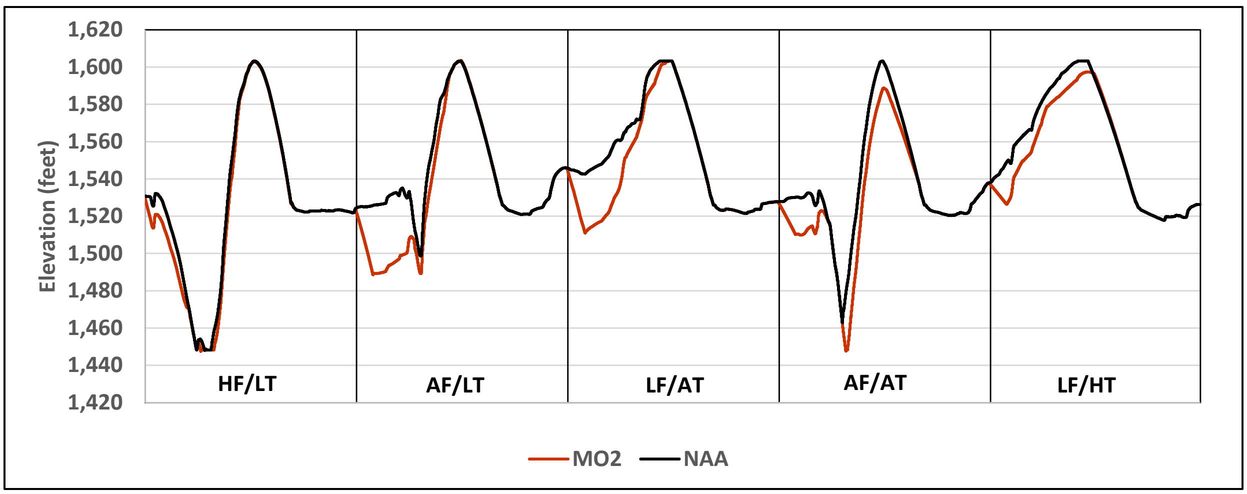


Figure 5-25. Dworshak Reservoir Pool Elevations for Multiple Objective Alternative 2 and No Action Alternative for the 5-Year Range of Flow and Meteorological Conditions Modeled

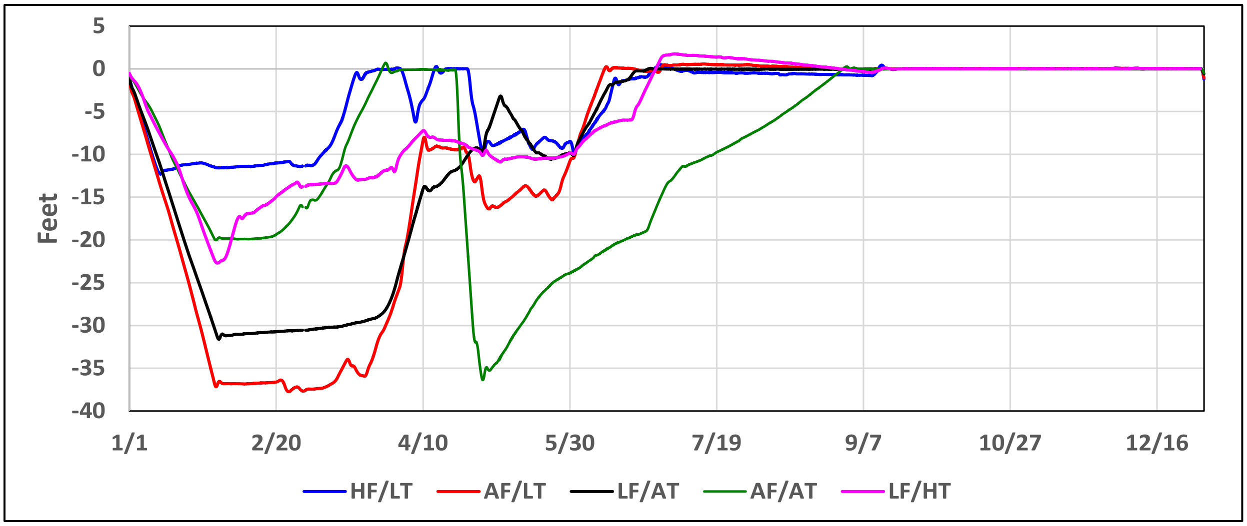


Figure 5-26. Differences Between Dworshak Reservoir Pool Elevations for Multiple Objective Alternative 2 and the No Action Alternative for the 5-Year Range of Flow and Meteorological Conditions Modeled

5.2.1 Water Temperature

5.2.1.1 Dworshak Dam and Reservoir

Dworshak MO2 outflow temperatures would be very similar to No Action Alternative conditions and remain less than 52°F throughout the year (Figure 5-27). The primary differences between the two alternatives occur during May, June, and July during AF/AT conditions (Table 5-4 and Table 5-5). The largest average temperature increases during July would be higher by 1.6 degrees Fahrenheit but still only reach a daily maximum of 48.7°F. The average difference between MO2 and the No Action Alternative for June during the same conditions would be 1.2 degrees Fahrenheit, with a maximum daily temperature of 44.9°F. Average temperature decreases of -0.5 degrees Fahrenheit could also occur during September with low-flow conditions, but these differences are small and within the margin of modeling error.

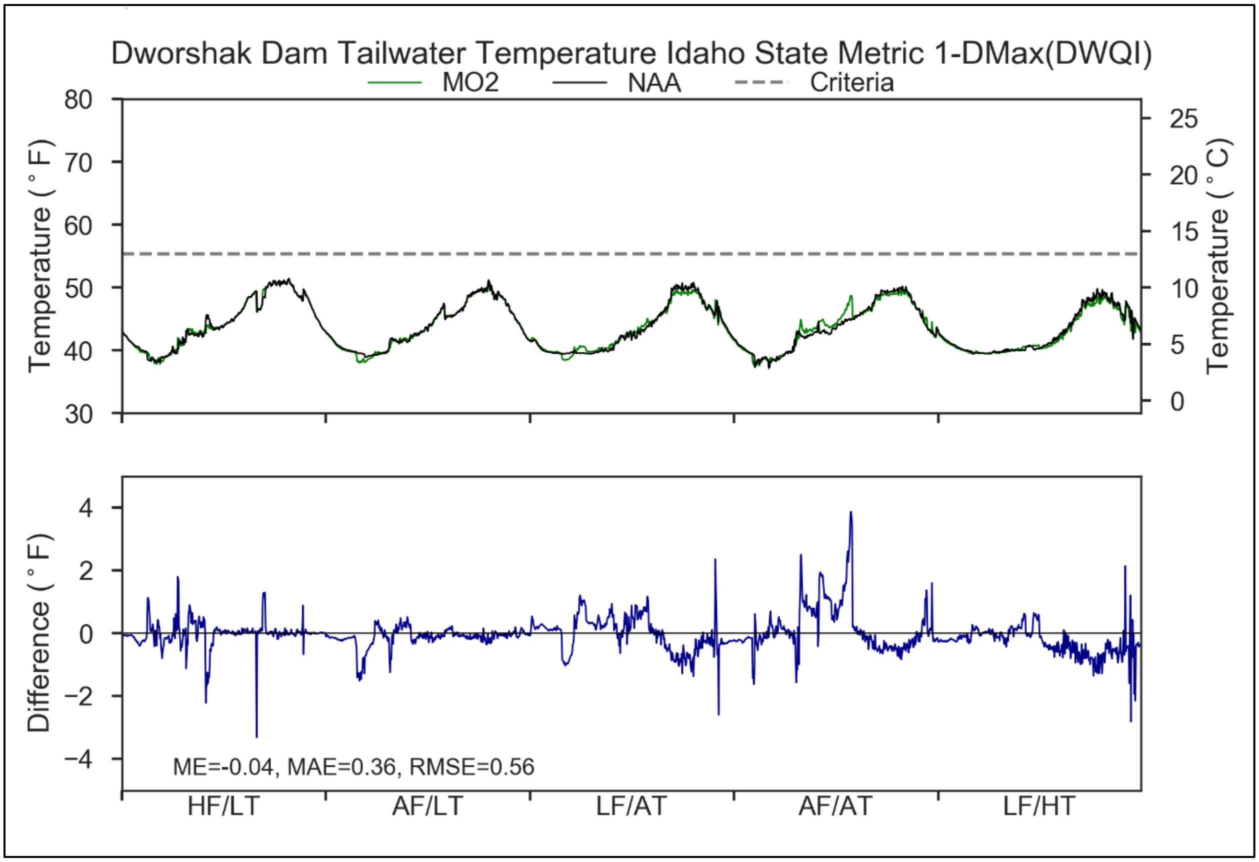


Figure 5-27. Modeled Tailwater Temperature for the No Action Alternative and Multiple Objective Alternative 2 at Dworshak Dam Under a 5-Year Range of River and Meteorological Conditions

Table 5-4. Monthly Average Temperature Differences Between Multiple Objective Alternative 2 and the No Action Alternative Model Results at Dworshak Dam Outflow for Five Flow and Meteorological Conditions

MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
April	0.0	-0.1	0.5	-0.1	-0.1
May	0.3	0.2	0.4	0.8	0.0
June	-0.3	-0.1	0.2	1.2	0.4
July	0.0	-0.1	0.6	1.6	-0.3
August	-0.1	0.0	0.0	0.0	-0.4
September	0.2	-0.1	-0.5	-0.4	-0.5

Table 5-5. Difference in Number of Days the Total Dissolved Gas Criteria is Exceeded at the Tailwater Site of Dworshak for the Multiple Objective 3 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
April	0	-7	0	**7**	0
May	**2**	**8**	0	**2**	0

MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
June	0	**17**	0	-4	0
July	0	**1**	0	0	0
August	**1**	0	0	0	0

5.2.1.2 Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams and Reservoirs

As modeled, water temperatures in the lower Snake River under MO2 showed some differences as compared the No Action Alternative for most of the year (Figure 5-28 through Figure 5-31). However, the modeling assumptions resulted in misleading conclusions, in the lower Snake River. ResSim modeling assumptions did not represent the intended operations and instead showed the reservoir would have a decreased refill probability, refilling to within 0.5 feet of the normal full reservoir elevation in about 48 percent of years (Chapter 3, Section 3.2, *Hydraulics & Hydrology*). It is likely that in real-time operations, the refill probability for Dworshak Reservoir under MO2 would be higher than shown in modeled results, and more closely aligned to the No Action Alternative. Therefore, effects to water temperatures are considered negligible (Table 5-4).

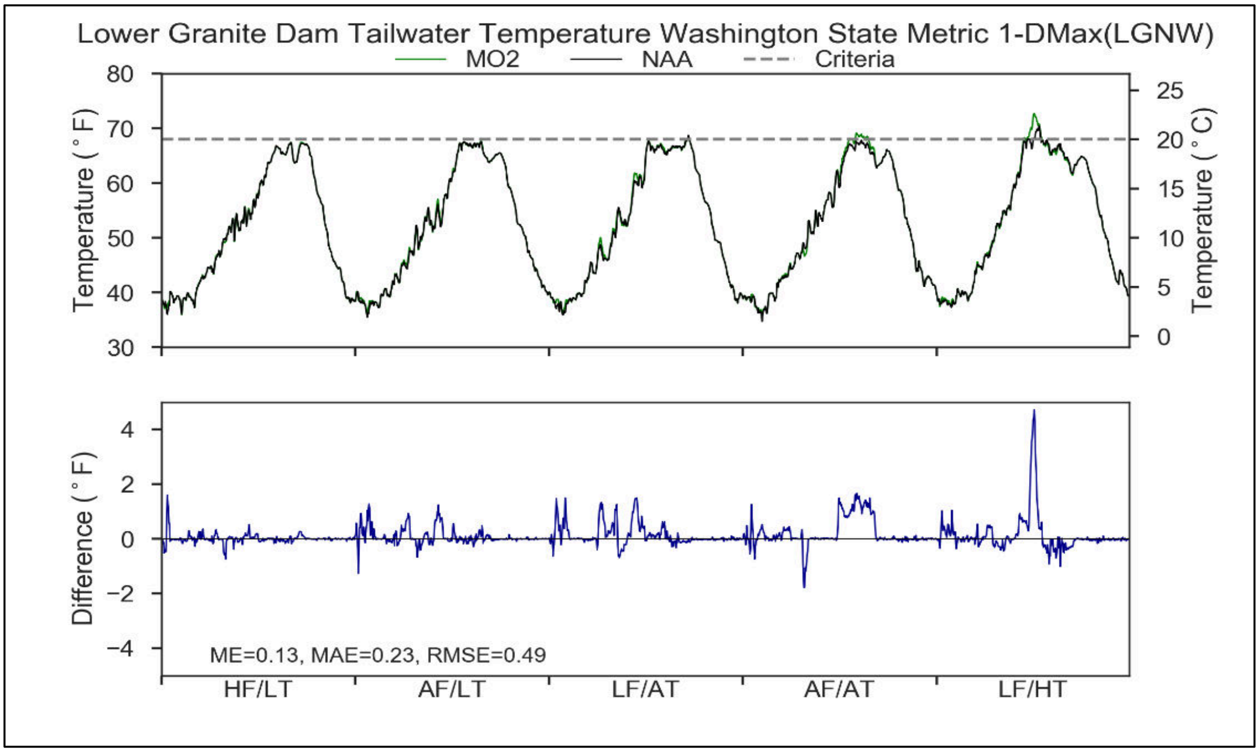


Figure 5-28. Modeled Tailwater Temperatures for the No Action Alternative and Multiple Objective Alternative 2 at Lower Granite Dam Under a 5-Year Range of River and Meteorological Conditions

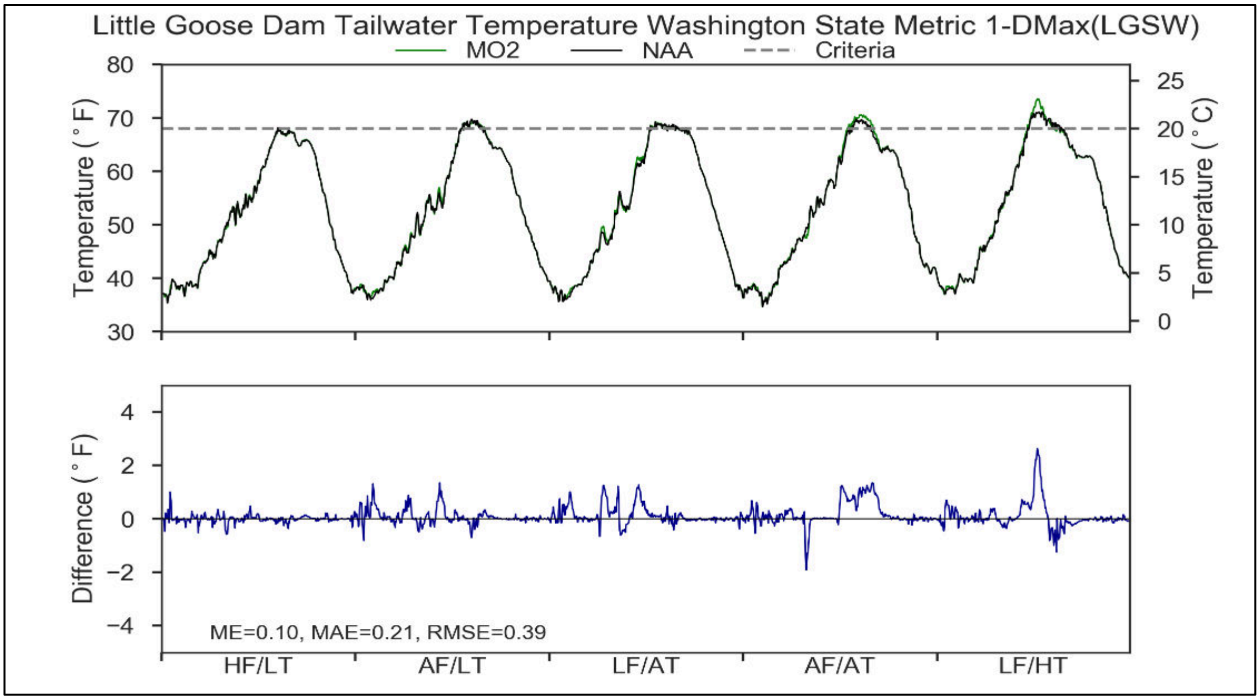


Figure 5-29. Modeled Tailwater Temperatures for the No Action Alternative and Multiple Objective Alternative 2 at Little Goose Dam Under a 5-Year Range of River and Meteorological Conditions

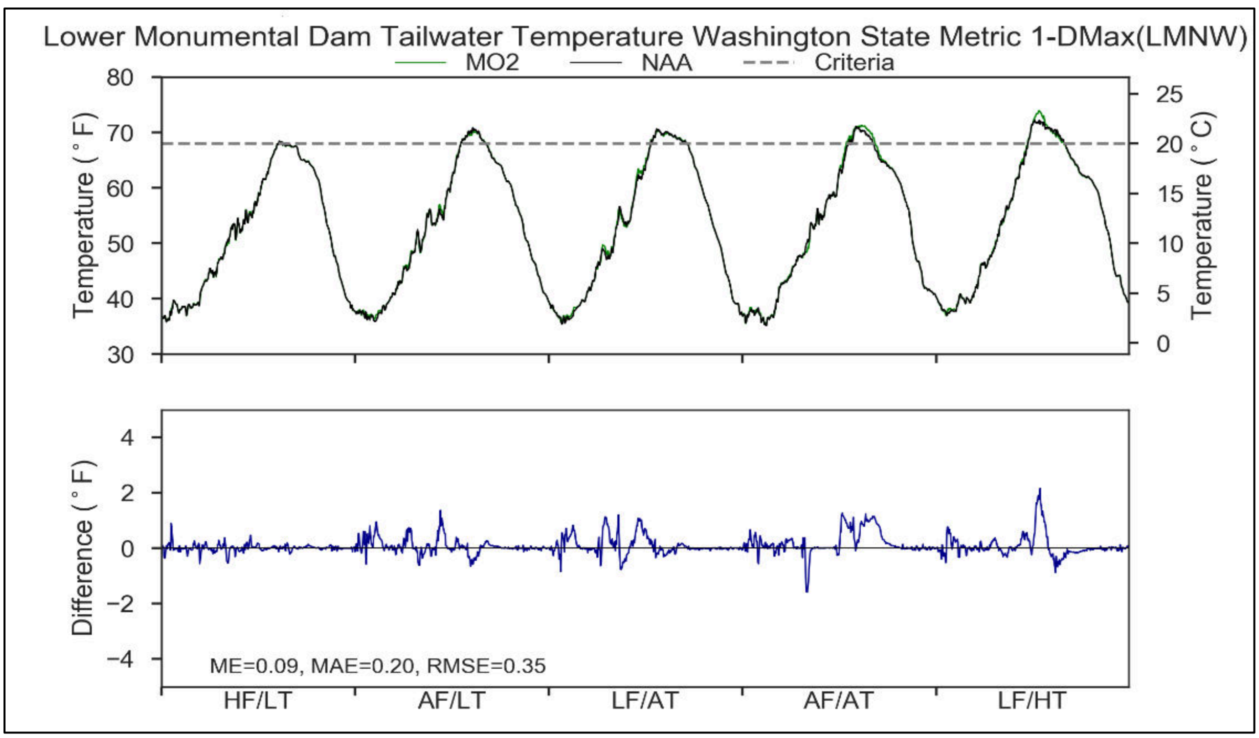


Figure 5-30. Modeled Tailwater Temperatures for the No Action Alternative and Multiple Objective Alternative 2 at Lower Monumental Dam Under a 5-Year Range of River and Meteorological Conditions

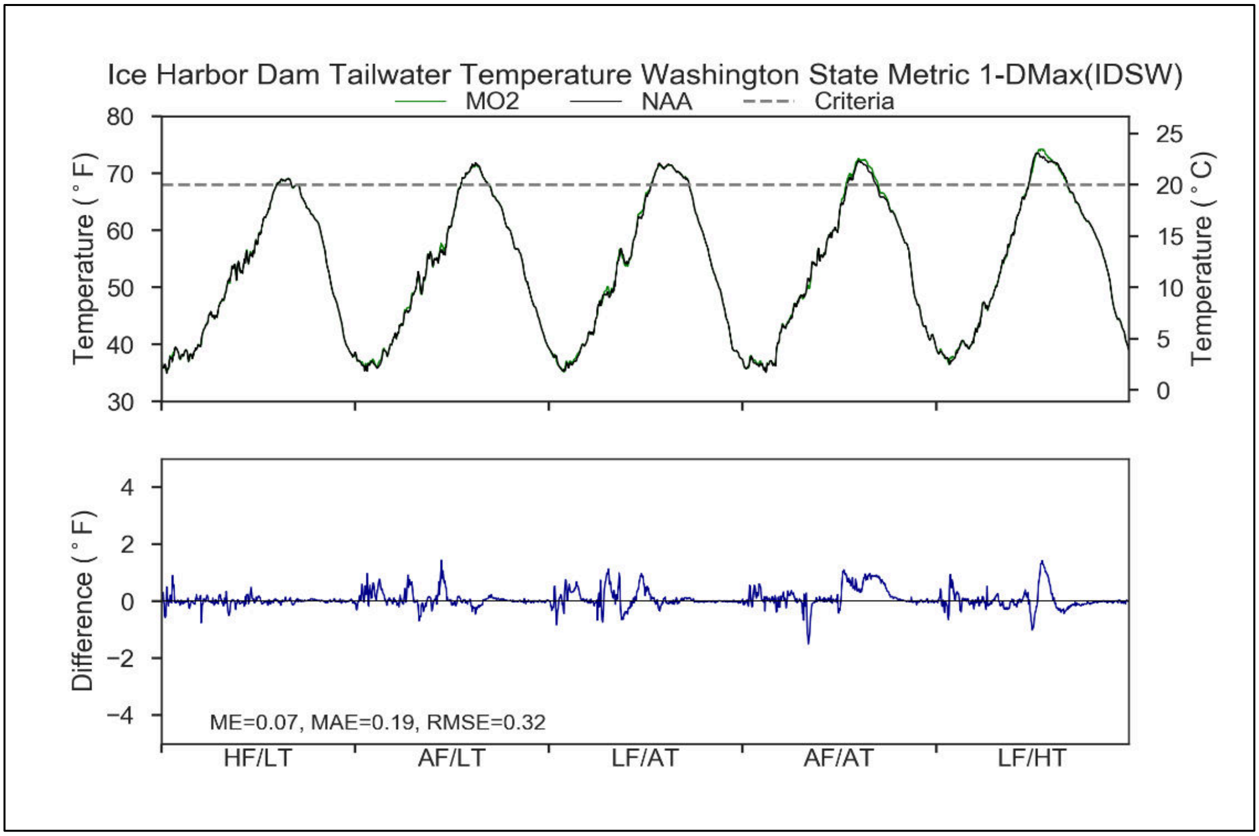


Figure 5-31. Modeled Tailwater Temperatures for the No Action Alternative and Multiple Objective Alternative 2 at Ice Harbor Dam Under a 5-Year Range of River and Meteorological Conditions

Table 5-6. Difference in Number of Days the Temperature Criteria is Exceeded at the Tailwater Sites of Lower Granite, Little Goose, Lower Monumental, and Ice Harbor for the Multiple Objective 2 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Lower Granite	June	0	0	0	0	**12**
Lower Granite	July	0	0	0	**2**	**3**
Lower Granite	August	0	0	0	**23**	0
Lower Granite	September	0	0	-2	0	0
Little Goose	June	0	0	0	0	**3**
Little Goose	July	0	0	**2**	**5**	0
Little Goose	August	-1	**2**	**1**	**2**	-7
Little Goose	September	0	0	**2**	**2**	0
Lower Monumental	June	0	0	0	0	0
Lower Monumental	July	0	0	0	**5**	0
Lower Monumental	August	-1	0	0	0	0

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Lower Monumental	September	0	**4**	0	**4**	-1
Ice Harbor	June	0	0	0	0	0
Ice Harbor	July	0	0	0	**1**	0
Ice Harbor	August	**1**	0	0	0	0
Ice Harbor	September	**1**	**1**	0	**4**	0

5.2.2 Total Dissolved Gas

5.2.2.1 Dworshak Dam and Reservoir

Total gas saturation downstream from Dworshak Dam in the North Fork Clearwater River could increase during some months if MO2 was implemented (Figure 5-32), however during realtime implementation of this measure, this would be avoided so as not to violate water quality TDG criteria. Model results show that the operational rule set modeled for MO2 would create the largest increase in TDG during June during AF/LT conditions. Notable increases would also occur under MO2 (as modeled) in May during AF/LT conditions and during April under AF/AT conditions (Table 5-7).

There are also a few instances when the TDG saturation would decrease if MO2 was implemented. Two of these instances would occur during March. During HF/LT conditions, the 110 percent criterion would be exceeded 15 percent of the time if MO2 was implemented compared to 35 percent for the time for the No Action Alternative. About 4 percent of the data would be greater than 120 percent for both alternatives. A similar reduction would occur during March with AF/AT conditions when the 110 percent criterion would be exceeded about 10 percent of the time under MO2 compared to 22 percent of the time under the No Action Alternative. Finally, during April of AF/LT conditions, the 110 percent criteria would be exceeded 48 percent of the time under MO2, down from 72 percent under the No Action Alternative. The percentage of time that the gas saturation would be greater than 120 percent would decrease from 63 percent for the No Action Alternative to 42 percent for MO2.

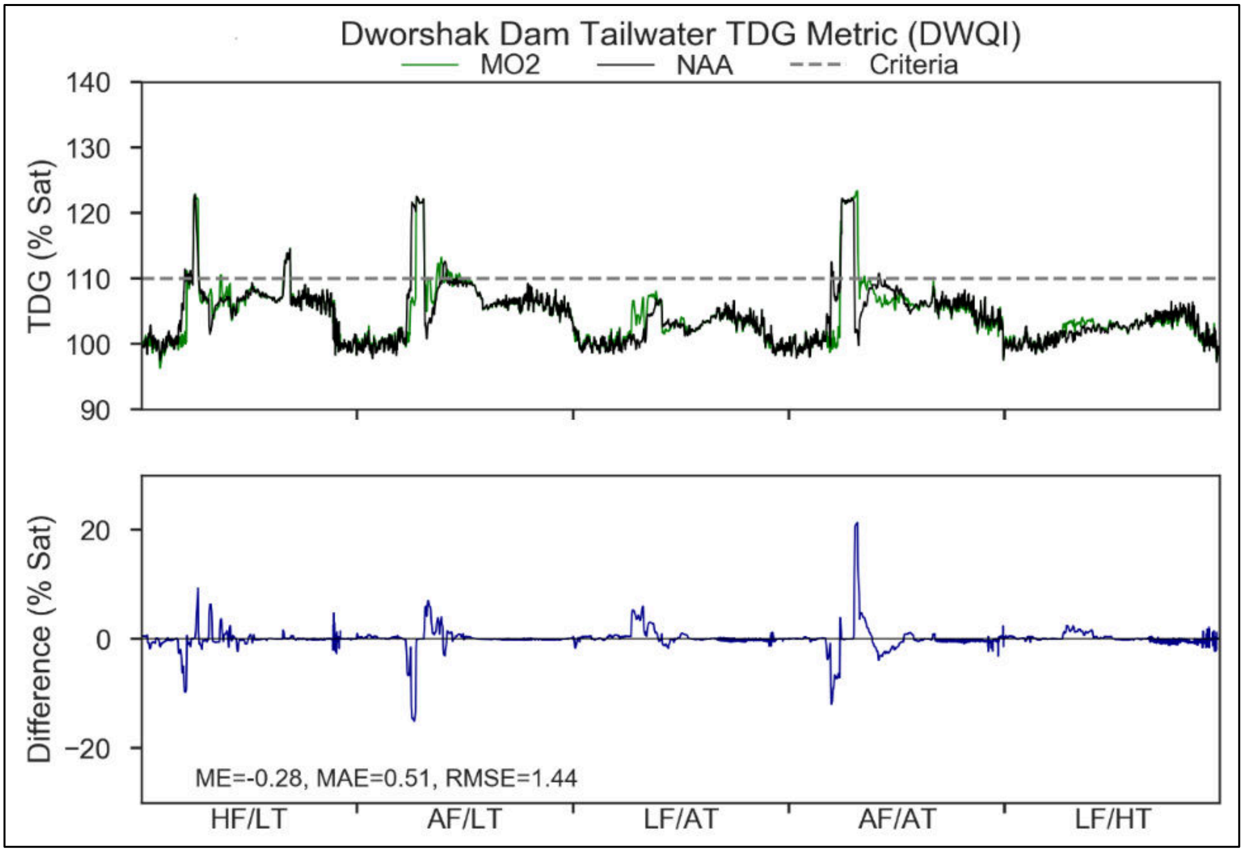


Figure 5-32. Modeled Tailwater Total Dissolved Gas for the No Action Alternative and Multiple Objective Alternative 2 at Dworshak Dam Under a 5-Year Range of River and Meteorological Conditions

Table 5-7. Difference in Number of Days the TDG Criteria is Exceeded at Dworshak Dam Tailwater for the Multiple Objective 1 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
April	0	-7	0	**7**	0
May	**2**	**8**	0	**2**	0
June	0	**17**	0	-4	0
July	0	**1**	0	0	0
August	**1**	0	0	0	0

5.2.2.2 Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams and Reservoirs

One of the operational measures within MO2 is to only spill for juvenile fish passage from April through July while keeping the TDG saturation in the river at less than 110 percent (Figure 5-34. and Figure 5-36.). Juvenile fish spill would not occur in August, but data for that month is included here to make comparisons with No Action Alternative model output. The combined April through August model data for each project tailwater location shows a shift toward a greater incidence of TDG saturation less than 110 percent at all projects (Table 5-8). Overall increases in the less than 110 percent category would range from about 12 percent at Little Goose Dam during LF/HT conditions to greater than 40 percent at both Little Goose and Lower Monumental projects during LF/AT and AF/AT conditions. Along with the greater amount of time that TDG would be less than 110 percent, there would be corresponding reductions in the higher TDG categories—typically the 110 to 115 percent and 115 to 120 percent ranges.

If implemented, maximum tailwater TDG saturation would exceed the 110 percent criteria at each of the four lower Snake River projects (Figure 5-37) due to minimum spill requirements, lack of market conditions and involuntary spill. Maximum levels would remain below 120 percent during most months and flow/meteorological conditions. The exceptions would occur during May, June, and July of HF/LT conditions when concentrations would exceed 125 percent at all four dams, and during April of AF/LT conditions when maximum gas saturations would range from 122 percent at Ice Harbor Dam to 125 percent at Lower Granite Dam. Maximum TDG levels during August would be less than 110 percent for almost all flow/meteorological conditions, the exceptions being Lower Monumental and Ice Harbor tailwaters during HF/LT conditions when gas saturation could reach 112 percent.

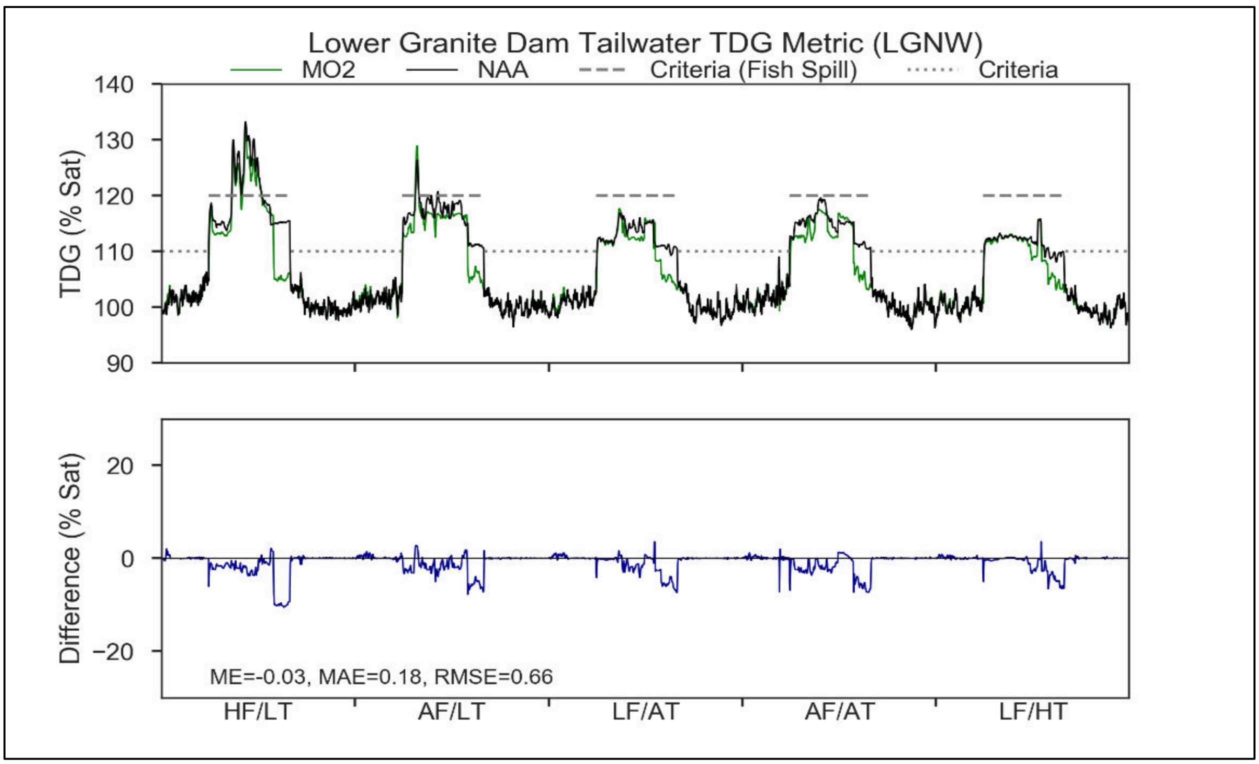


Figure 5-33. Modeled Tailwater Total Dissolved Gas for the No Action Alternative and Multiple Objective Alternative 2 at Lower Granite Dam Under a 5-Year Range of River and Meteorological Conditions

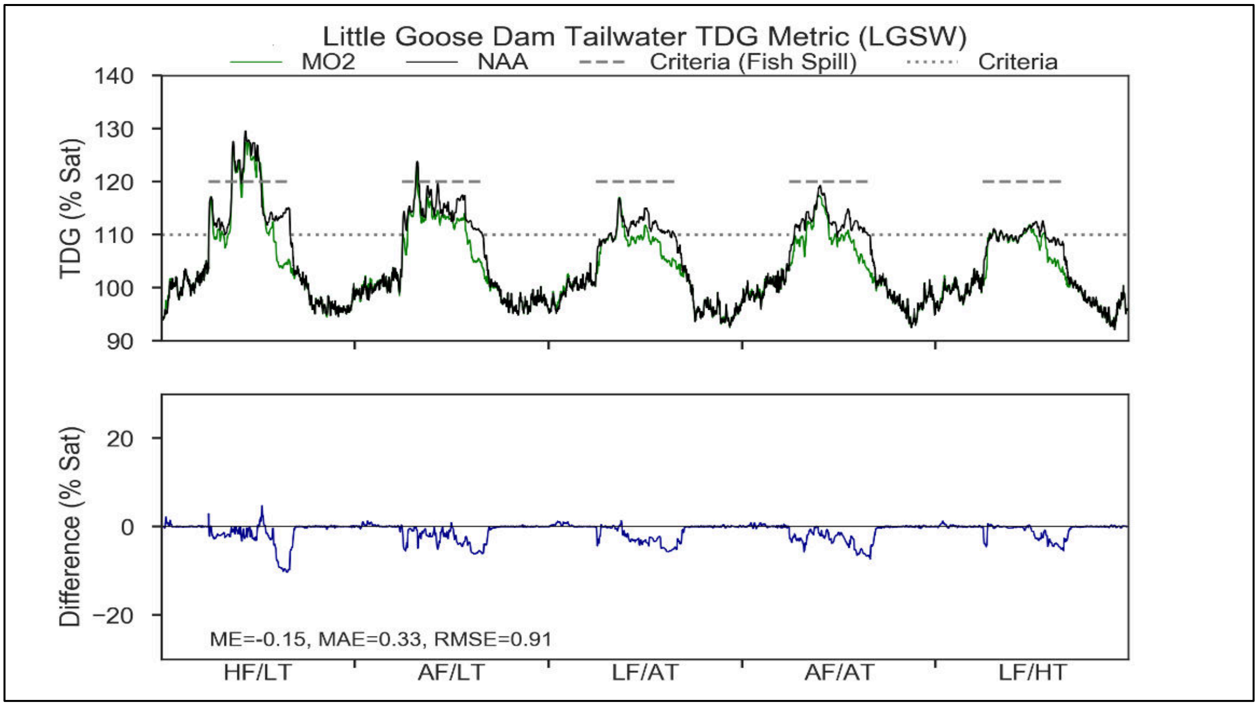


Figure 5-34. Modeled Tailwater Total Dissolved Gas for the No Action Alternative and Multiple Objective Alternative 2 at Little Goose Dam Under a 5-Year Range of River and Meteorological Conditions

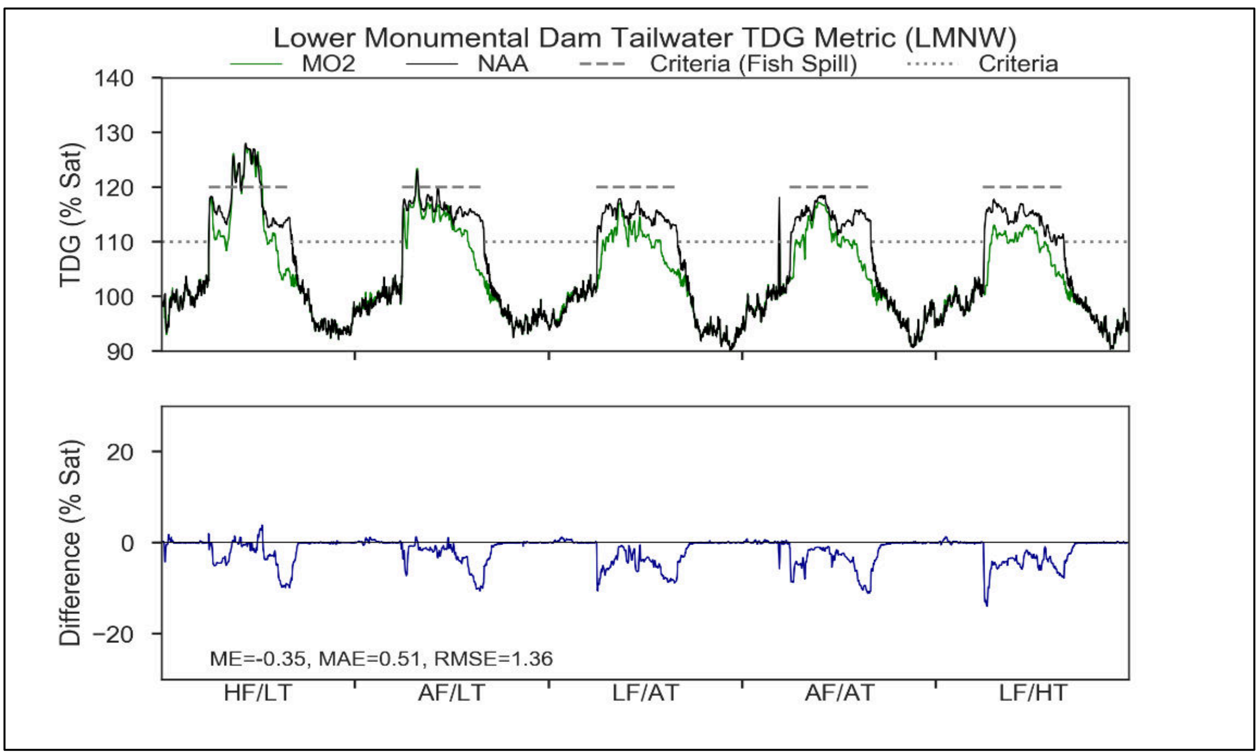


Figure 5-35. Modeled Tailwater Total Dissolved Gas for the No Action Alternative and Multiple Objective Alternative 2 at Lower Monumental Dam Under a 5-year Range of River and Meteorological Conditions

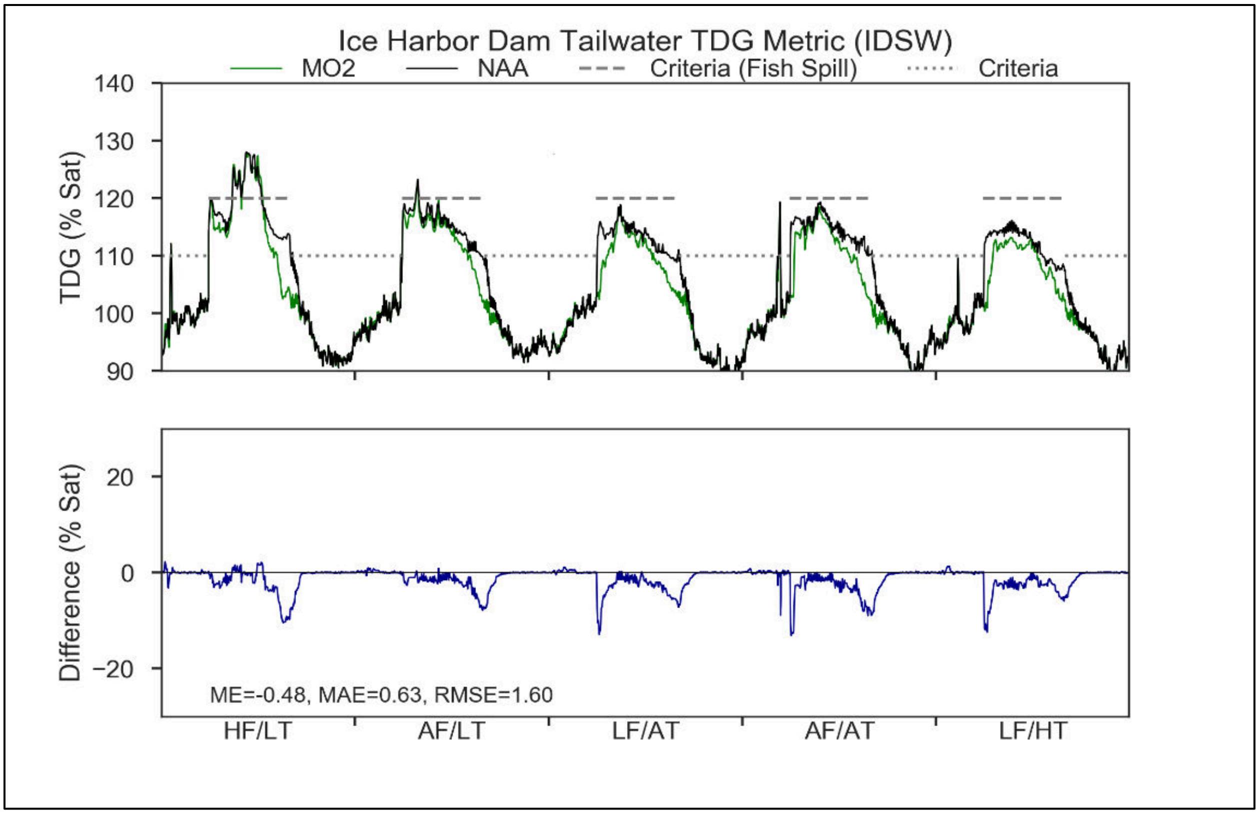


Figure 5-36. Modeled Tailwater Total Dissolved Gas for the No Action Alternative and Multiple Objective Alternative 2 at Ice Harbor Dam Under a 5-year Range of River and Meteorological Conditions

Table 5-8. Differences of the Frequency of the Total Dissolved Gas that Would Occur Within Selected Ranges During Juvenile Spill Season (April-August) if Multiple Objective Alternative 2 is Implemented when Compared to the No Action Alternative at the Four Lower Snake River Dam Tailwater Locations Under a 5-Year Range of River and Meteorological Conditions

SITE	TDG Range (% Sat)	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Lower Granite Tailwater	<=110	20.65%	20.00%	26.45%	23.23%	14.84%
Lower Granite Tailwater	>110,<=115	3.87%	-5.81%	-16.13%	-0.65%	-15.48%
Lower Granite Tailwater	>115,<=120	-23.23%	-10.97%	-10.32%	-22.58%	0.65%
Lower Granite Tailwater	>120,<=125	9.03%	-1.29%	0.00%	0.00%	0.00%
Lower Granite Tailwater	>125	-10.32%	-1.94%	0.00%	0.00%	0.00%
Little Goose Tailwater	<=110	30.32%	24.52%	55.48%	56.77%	10.97%
Little Goose Tailwater	>110,<=115	-29.03%	4.52%	-53.55%	-54.84%	-10.97%
Little Goose Tailwater	>115,<=120	0.00%	-27.74%	-1.94%	-1.94%	0.00%
Little Goose Tailwater	>120,<=125	4.52%	-1.29%	0.00%	0.00%	0.00%
Little Goose Tailwater	>125	-5.81%	0.00%	0.00%	0.00%	0.00%
Lower Monumental Tailwater	<=110	22.58%	21.29%	39.35%	45.16%	39.35%

SITE	TDG Range (% Sat)	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Lower Monumental Tailwater	>110,<=115	-7.10%	22.58%	-0.65%	-18.71%	6.45%
Lower Monumental Tailwater	>115,<=120	-16.77%	-43.87%	-38.71%	-26.45%	-45.81%
Lower Monumental Tailwater	>120,<=125	2.58%	0.00%	0.00%	0.00%	0.00%
Lower Monumental Tailwater	>125	-1.29%	0.00%	0.00%	0.00%	0.00%
Ice Harbor Tailwater	<=110	16.77%	14.19%	32.90%	30.32%	16.77%
Ice Harbor Tailwater	>110,<=115	4.52%	0.65%	-20.65%	-1.94%	-9.68%
Ice Harbor Tailwater	>115,<=120	-22.58%	-14.19%	-12.26%	-28.39%	-7.10%
Ice Harbor Tailwater	>120,<=125	0.65%	-0.65%	0.00%	0.00%	0.00%
Ice Harbor Tailwater	>125	0.65%	0.00%	0.00%	0.00%	0.00%

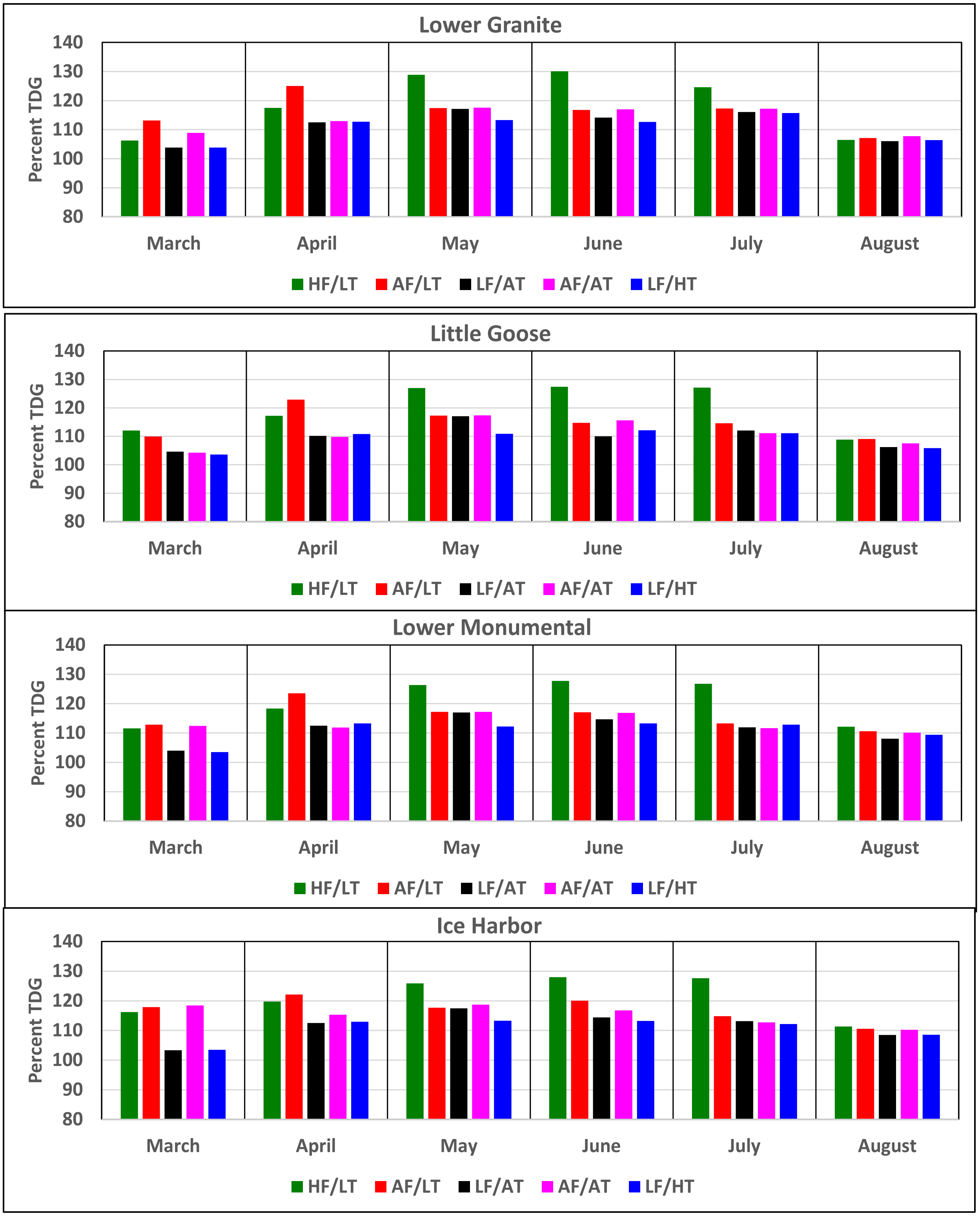


Figure 5-37. Maximum Total Dissolved Gas that Would be Expected at the Four Lower Snake River Dam Tailwater Locations During the Fish Passage Season if Multiple Objective Alternative 2 is Implemented Under a 5-Year Range of River and Meteorological Conditions

The MO2 model results for the lower Snake River dam forebay locations show that TDG would often be greater than 110 percent (Figure 5-38 through Figure 5-41). Maximum concentrations greater than 120 percent would occur during June and July during HF/LT conditions at the three lower projects. Gas saturation would range from 110 to 120 percent from April through August during AF/LT, LF/AT, and LF/HT conditions, as well as May through August of HF/LT and AF/AT conditions (Figure 5-42). The exception to this pattern would be at Lower Granite forebay where the maximum gas saturation would only reach 112 percent during HF/LT June conditions and remain less than 110 percent the rest of the time.

Comparisons of MO2 to No Action Alternative changes in the percent of time that forebay TDG saturation would occur within specific ranges for each month from April through August at each of the four lower Snake River projects are shown in Table 5-9. No differences were identified for Lower Granite Dam forebay. However, the trends at the three lower projects from April through August is for an increase in the proportion of values in the less than 110 percent category ranging from 7 to 41 percent, and corresponding decreases in the 110 to 115 percent and 115 to 120 percent categories.

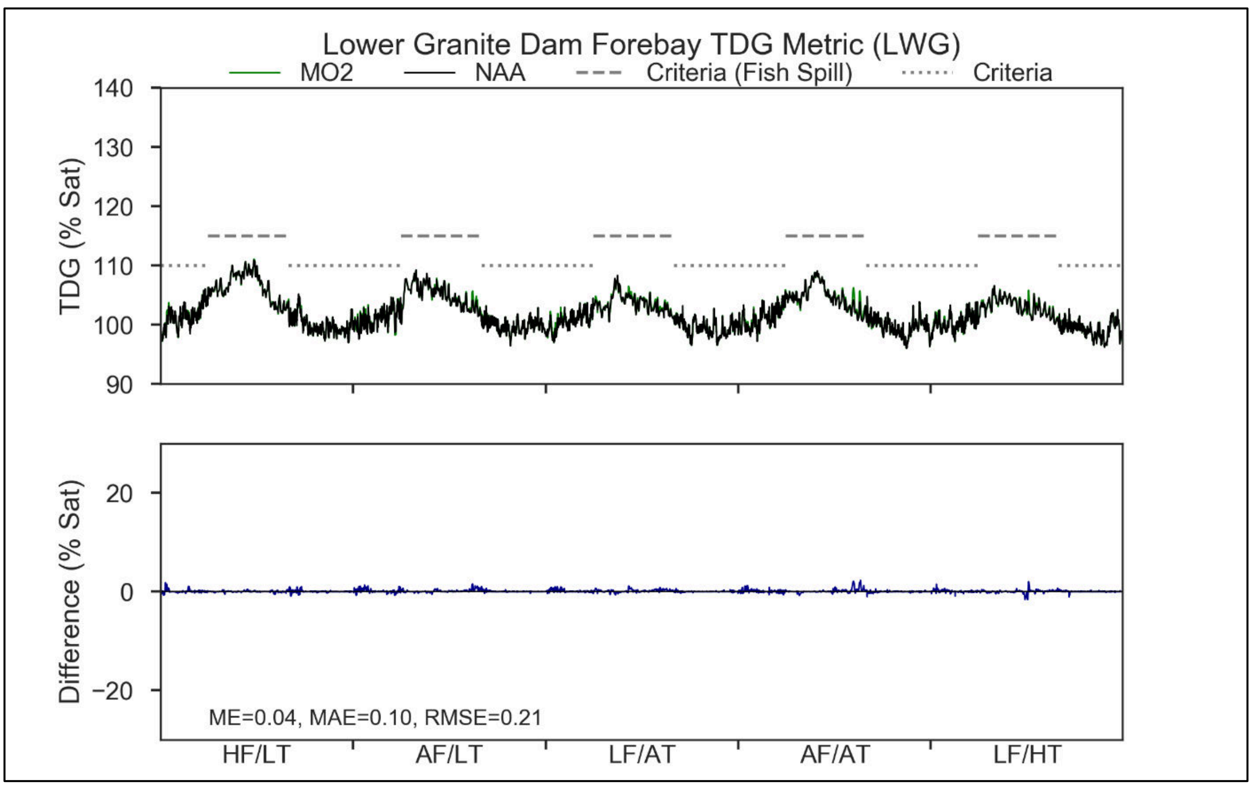


Figure 5-38. Modeled Forebay Total Dissolved Gas for the No Action Alternative and Multiple Objective Alternative 2 at Lower Granite Dam Under a 5-Year Range of River and Meteorological Conditions

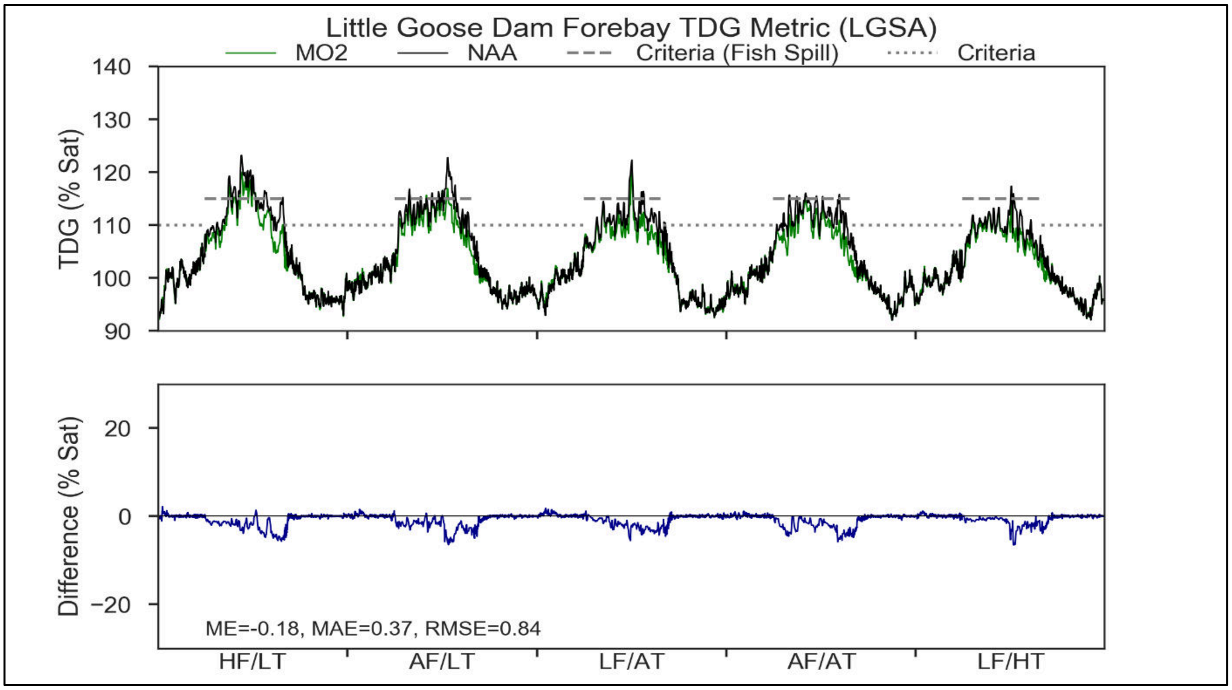


Figure 5-39. Modeled Forebay Total Dissolved Gas for the No Action Alternative and Multiple Objective Alternative 2 at Little Goose Dam Under a 5-Year Range of River and Meteorological Conditions

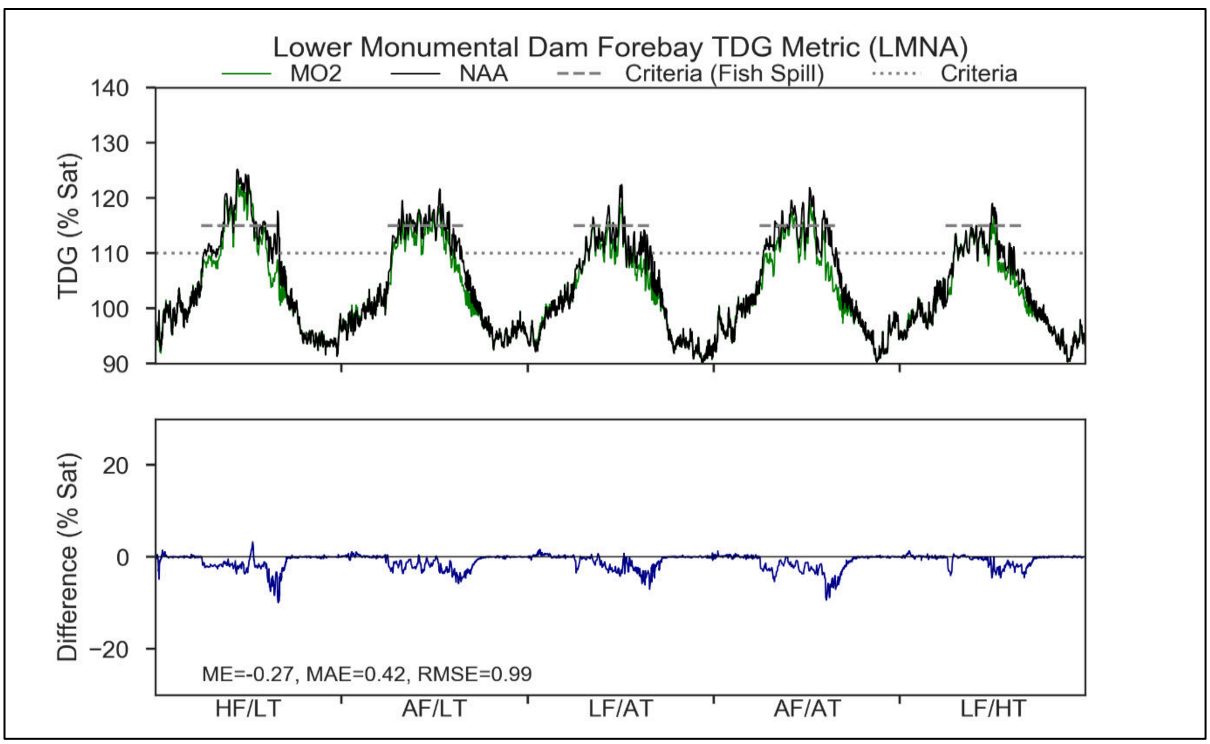


Figure 5-40. Modeled Forebay Total Dissolved Gas for the No Action Alternative and Multiple Objective Alternative 2 at Lower Monumental Dam Under a 5-Year Range of River and Meteorological Conditions

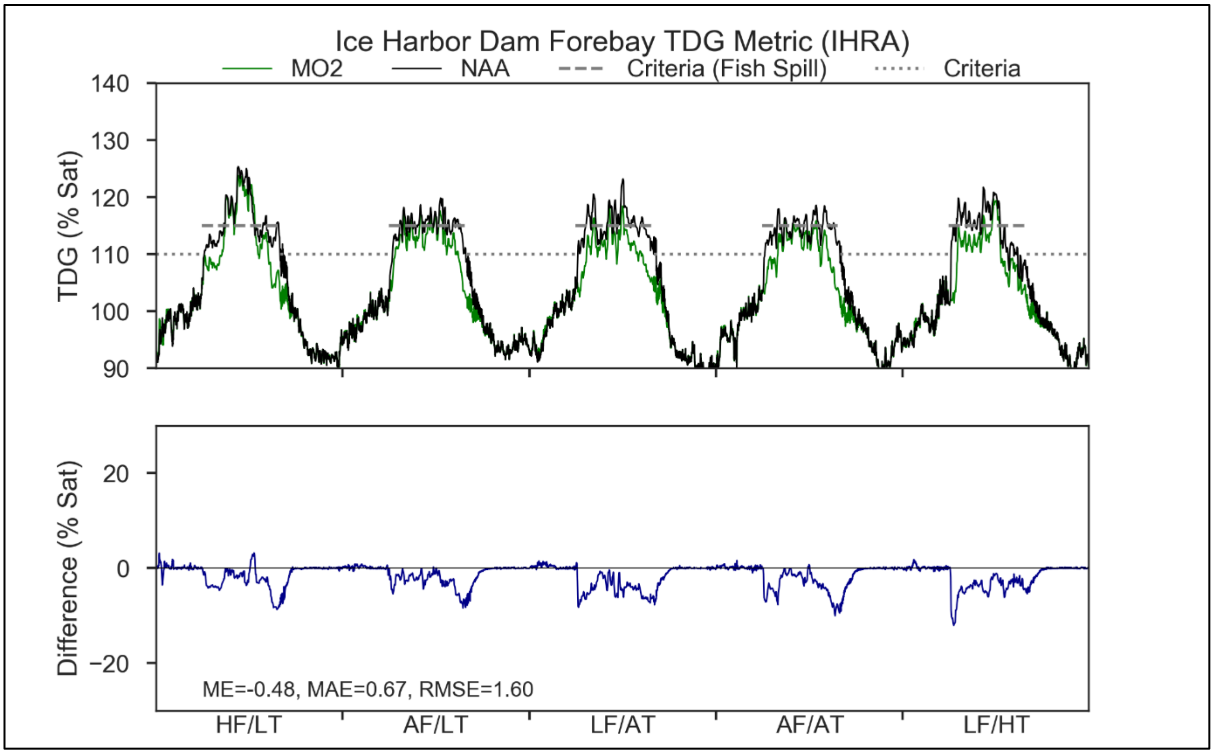


Figure 5-41. Modeled Forebay Total Dissolved Gas for the No Action Alternative and Multiple Objective Alternative 2 at Ice Harbor Dam Under a 5-Year Range of River and Meteorological Conditions

Table 5-9. Differences of the Frequency of the Total Dissolved Gas that Would Occur Within Selected Ranges During Juvenile Spill Season (April-August) if Multiple Objective Alternative 2 is Implemented when Compared to the No Action Alternative at the Four Lower Snake River Dam Forebay Locations Under a 5-Year Range of River and Meteorological Conditions

SITE	TDG Range (% Sat)	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Lower Granite Forebay	<=110	0.65%	0.00%	0.00%	0.00%	0.00%
Lower Granite Forebay	>110,<=115	-0.65%	0.00%	0.00%	0.00%	0.00%
Lower Granite Forebay	>115,<=120	0.00%	0.00%	0.00%	0.00%	0.00%
Lower Granite Forebay	>120,<=125	0.00%	0.00%	0.00%	0.00%	0.00%
Lower Granite Forebay	>125	0.00%	0.00%	0.00%	0.00%	0.00%
Little Goose Forebay	<=110	21.57%	23.53%	37.91%	33.33%	22.88%
Little Goose Forebay	>110,<=115	-9.80%	-3.92%	-32.68%	-24.18%	-20.92%
Little Goose Forebay	>115,<=120	-6.54%	-16.34%	-3.92%	-9.15%	-1.96%
Little Goose Forebay	>120,<=125	-5.23%	-3.27%	-1.31%	0.00%	0.00%
Little Goose Forebay	>125	0.00%	0.00%	0.00%	0.00%	0.00%

SITE	TDG Range (% Sat)	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Lower Monumental Forebay	<=110	30.07%	13.73%	24.84%	33.33%	9.80%
Lower Monumental Forebay	>110,<=115	-18.30%	9.80%	-16.99%	-16.99%	-3.92%
Lower Monumental Forebay	>115,<=120	-5.23%	-21.57%	-4.58%	-13.07%	-5.88%
Lower Monumental Forebay	>120,<=125	-5.23%	-1.96%	-3.27%	-3.27%	0.00%
Lower Monumental Forebay	>125	-1.31%	0.00%	0.00%	0.00%	0.00%
Ice Harbor Forebay	<=110	39.87%	15.69%	32.03%	33.99%	27.45%
Ice Harbor Forebay	>110,<=115	-31.37%	18.95%	7.19%	-0.65%	9.80%
Ice Harbor Forebay	>115,<=120	-5.23%	-34.64%	-34.64%	-33.33%	-30.07%
Ice Harbor Forebay	>120,<=125	-0.65%	0.00%	-4.58%	0.00%	-7.19%
Ice Harbor Forebay	>125	-2.61%	0.00%	0.00%	0.00%	0.00%

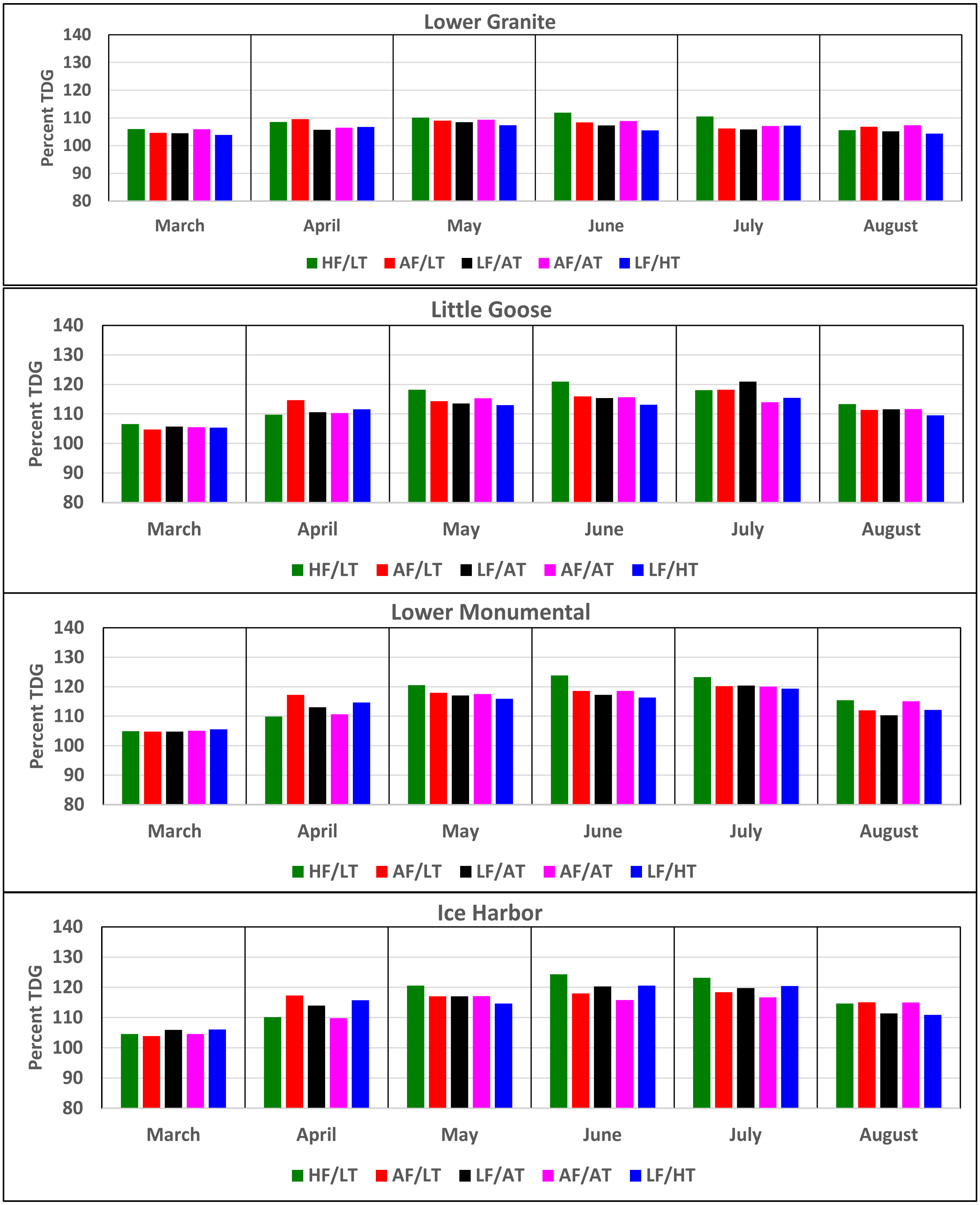


Figure 5-42. Maximum Total Dissolved Gas that Would be Expected at the Four Lower Snake River Dam Forebay Locations During the Fish Passage Season if Multiple Objective Alternative 2 is Implemented Under a 5-Year Range of River and Meteorological Conditions

The operational changes for MO2 do cause a few TDG differences as can be seen in the figures above. In terms of the actual number of days of the criteria being exceeded, those changes can be seen in Table 5-10 and Table 5-11. In general, MO2 results in fewer exceedances throughout the forebay sites and negligible at the tailwater sites.

Table 5-10. Difference in Number of Days the TDG Criteria is Exceeded at the Forebay Sites of Little Goose, Lower Monumental, and Ice Harbor for the Multiple Objective 2 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Little Goose	March	0	0	0	0	0
Little Goose	April	0	-2	0	0	0
Little Goose	May	-4	-3	0	-4	0
Little Goose	June	-4	-6	-3	-6	0
Little Goose	July	-8	-19	-5	-2	-3
Little Goose	August	-2	0	0	-2	0
Little Goose	September	0	0	-1	0	0
Lower Monumental	March	0	0	0	0	0
Lower Monumental	April	0	-4	0	0	0
Lower Monumental	May	-3	-13	-3	-5	-1
Lower Monumental	June	-2	-9	-8	-6	-2
Lower Monumental	July	-6	-10	-1	-5	-6
Lower Monumental	August	-7	0	0	-9	0
Lower Monumental	September	0	0	0	0	0
Ice Harbor	March	0	0	0	0	0
Ice Harbor	April	0	-4	-10	0	-15
Ice Harbor	May	-2	-15	-5	-7	-24
Ice Harbor	June	-2	-13	-17	-17	-17
Ice Harbor	July	0	-8	-22	-13	-1
Ice Harbor	August	-9	-13	-6	-14	0
Ice Harbor	September	-1	0	-5	-1	0

Table 5-11. Difference in Number of Days the TDG Criteria is Exceeded at the Tailwater Sites of Lower Granite, Little Goose, Lower Monumental, and Ice Harbor for the Multiple Objective 2 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Lower Granite	February	0	0	0	0	0
Lower Granite	March	0	0	0	0	0
Lower Granite	April	0	-1	0	0	0
Lower Granite	May	-1	-2	0	0	0
Lower Granite	June	-2	-2	0	0	0

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Lower Granite	July	**1**	0	0	0	0
Little Goose	March	0	0	0	0	0
Little Goose	April	0	-2	0	0	0
Little Goose	May	-2	0	0	0	0
Little Goose	June	-1	0	0	0	0
Little Goose	July	**1**	0	0	0	0
Little Goose	September	0	0	0	0	0
Lower Monumental	February	0	0	0	0	0
Lower Monumental	March	0	0	0	-1	0
Lower Monumental	April	0	0	0	0	0
Lower Monumental	May	**1**	0	0	0	0
Lower Monumental	June	-1	0	0	0	0
Lower Monumental	July	**2**	0	0	0	0
Lower Monumental	September	-3	0	0	0	0
Ice Harbor	January	0	0	0	0	0
Ice Harbor	February	0	0	0	0	0
Ice Harbor	March	0	0	0	0	0
Ice Harbor	April	0	-1	0	0	0
Ice Harbor	May	0	0	0	0	0
Ice Harbor	June	-1	0	0	0	0
Ice Harbor	July	**3**	0	0	0	0
Ice Harbor	September	-1	0	-2	-1	0

5.2.3 Other Physical, Chemical and Biological Processes

5.2.3.1 Dworshak Dam and Reservoir

The lower water elevation of Dworshak Reservoir from April through June would result in a smaller surface area and consequently slower warming by solar radiation. Additionally, shallower water depths at the upper end of the reservoir where the North Fork Clearwater River, Little North Fork River, and Breakfast Creek enter would lead to higher flow velocities and delay in primary production.

5.2.3.2 Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams and Reservoirs

No changes are expected to occur with respect to the other physicochemical and biological parameters in the lower Snake River if MO2 is implemented.

5.3 LOWER COLUMBIA RIVER

5.3.1 Water Temperature

There are no specific structural or operational measures in MO2 that are expected to influence water temperatures in the lower Columbia River. Details are provided below.

5.3.1.1 McNary, John Day, The Dalles, and Bonneville Dams and Reservoirs

The tailwater temperatures for MO2 at McNary, John Day, The Dalles, and Bonneville Dams were modeled under a 5-year range of river and meteorological conditions, and compared to the modeled results for the No Action Alternative (Figure 5-43 through Figure 5-46). Just as with the No Action Alternative model results, the MO2 model results show that tailwater temperatures can exceed 68°F at all four dams during any of the years and conditions presented, and maximum water temperatures and the frequency of water temperature violations of state water quality criteria would be higher during a year when river flows were lower than normal and summer ambient air temperatures were higher (as in LF/HT). The average frequency of water temperature violations of the State water quality criteria would be nearly identical for the No Action Alternative and MO2 for all four lower Columbia River dams (Figure 5-47 and Table 5-12). Generally, there would not be a significant difference in tailwater temperatures under the No Action Alternative and MO2.

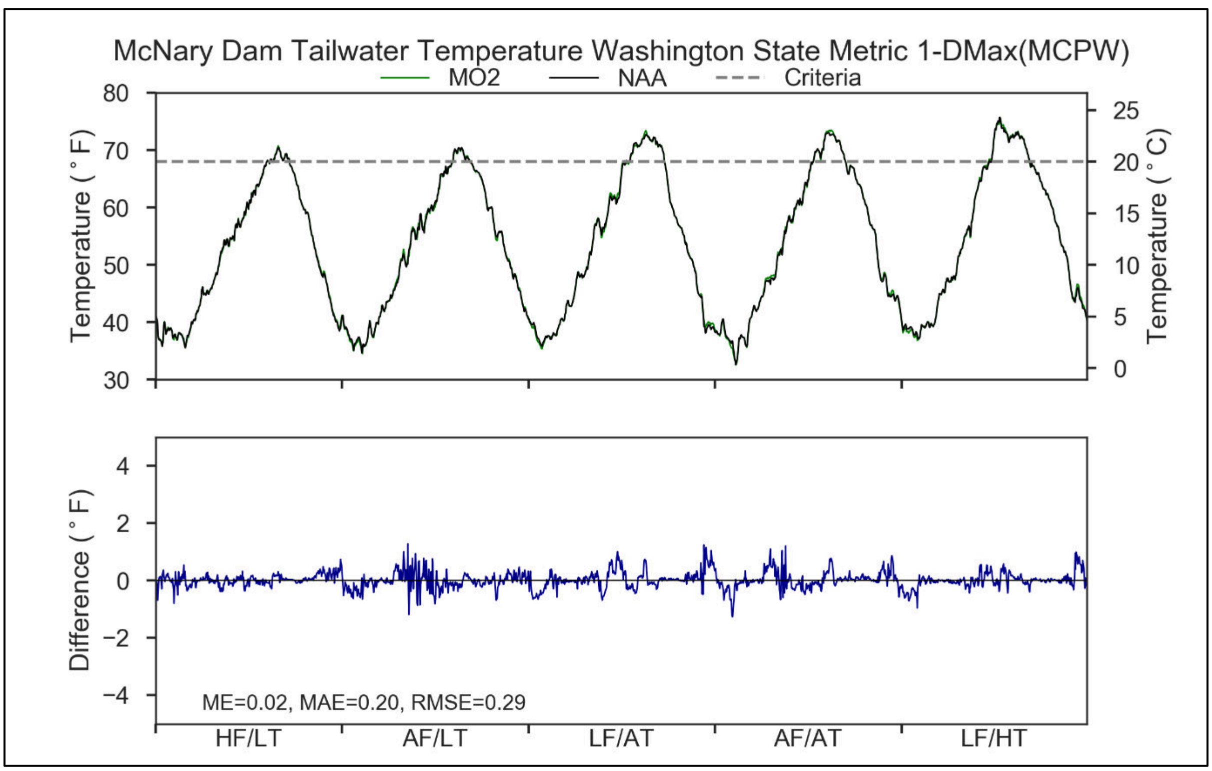


Figure 5-43. Modeled Tailwater Temperature for Multiple Objective Alternative 2 at McNary Dam Under a 5-Year Range of River and Meteorological Conditions

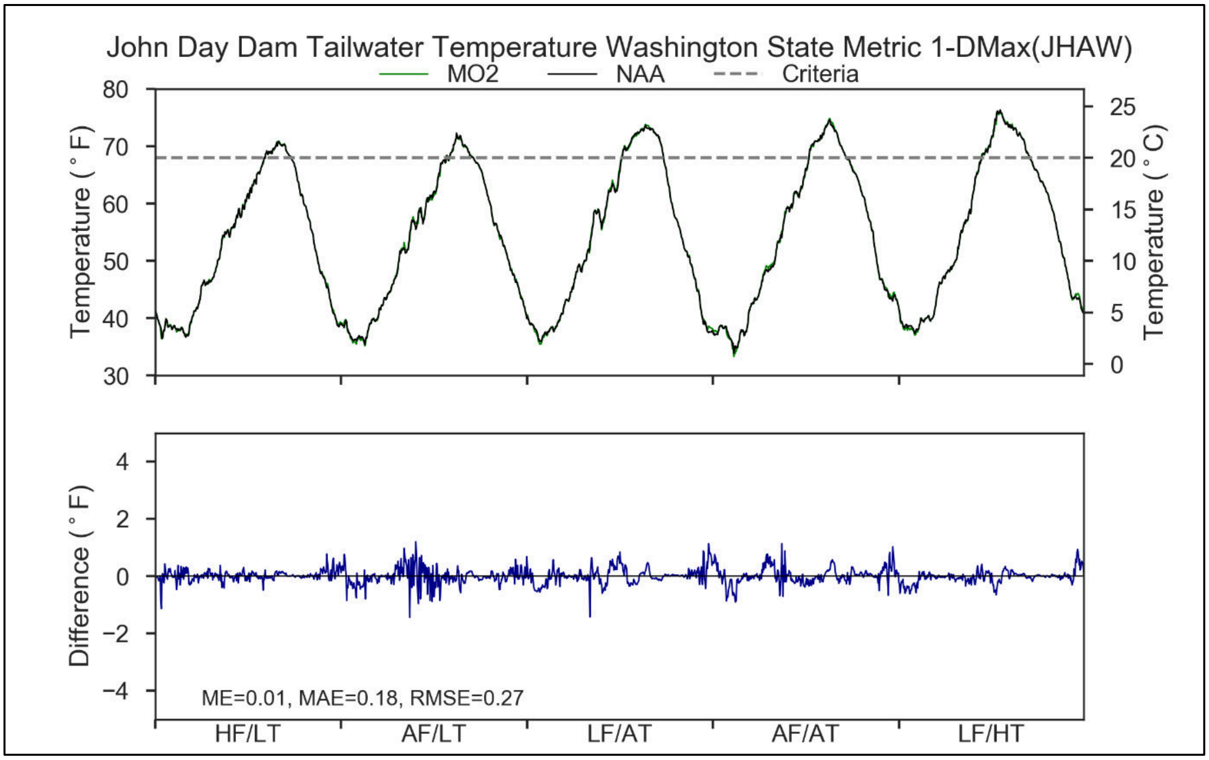


Figure 5-44. Modeled Tailwater Temperature for Multiple Objective Alternative 2 at John Day Dam Under a 5-Year Range of River and Meteorological Conditions

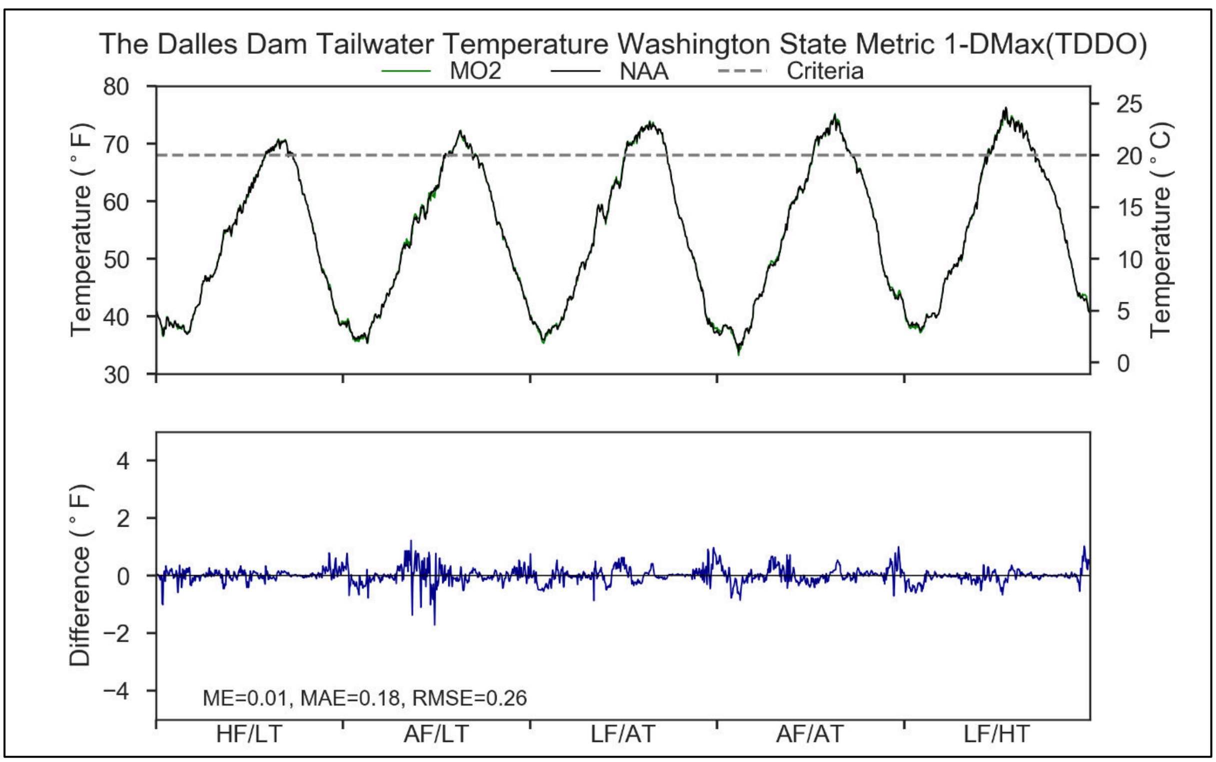


Figure 5-45. Modeled Tailwater Temperature for Multiple Objective Alternative 2 at The Dalles Dam Under a 5-Year Range of River and Meteorological Conditions

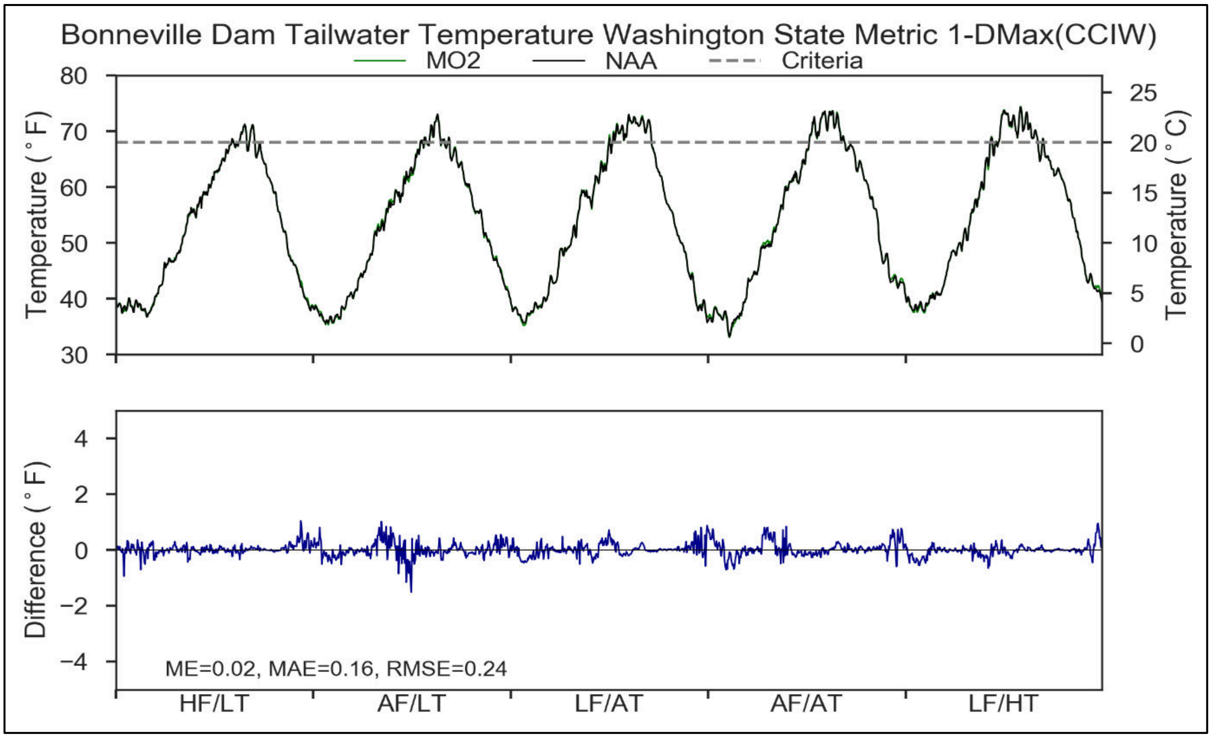


Figure 5-46. Modeled Tailwater Temperature for Multiple Objective Alternative 2 at Bonneville Dam Under a 5-Year Range of River and Meteorological Conditions

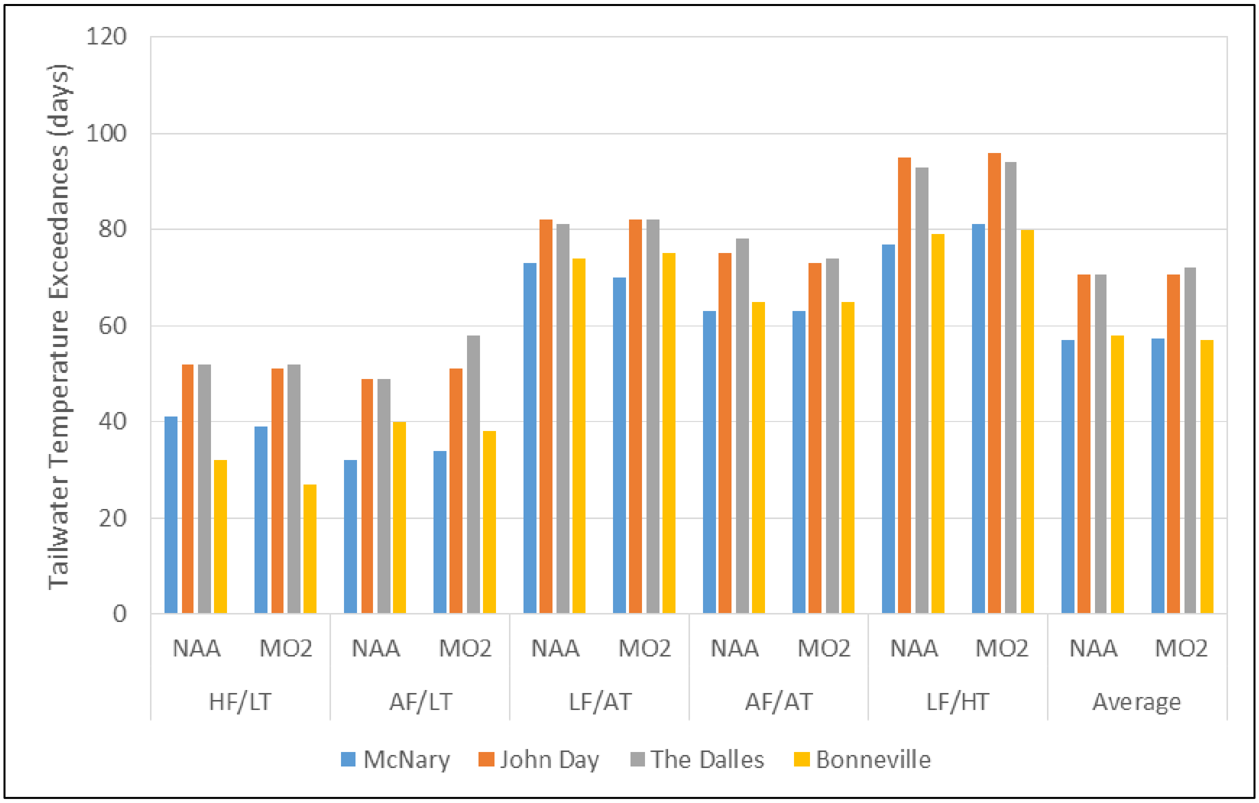


Figure 5-47. Frequency of Modeled Tailwater Temperature Violations to State Water Quality Criteria for the No Action Alternative and Multiple Objective Alternative 2 at McNary, John Day, The Dalles, and Bonneville Dams Under a 5-Year Range of River and Meteorological Conditions

Table 5-12. Difference in Number of Days the Temperature Criteria is Exceeded at the Tailwater Sites of McNary, John Day, The Dalles, and Bonneville for the Multiple Objective 2 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary	June	0	0	0	0	**3**
McNary	July	0	0	-4	-1	0
McNary	August	-3	0	0	0	0
McNary	September	0	**2**	0	**1**	-1
John Day	June	0	0	0	0	0
John Day	July	0	**1**	**1**	-1	0
John Day	August	**1**	0	0	0	0
John Day	September	0	**1**	0	-2	0
The Dalles	June	0	0	0	0	0

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
The Dalles	July	0	**1**	**1**	0	0
The Dalles	August	0	0	0	0	0
The Dalles	September	0	**2**	0	-3	0
Bonneville	June	0	0	0	0	**1**
Bonneville	July	0	0	**1**	0	0
Bonneville	August	-3	-2	0	0	0
Bonneville	September	-1	-1	0	0	**1**

5.3.2 Total Dissolved Gas

Under MO2, the *Spill to 110% TDG*, which is the state TDG criterion, limits juvenile fish passage spill to 110 percent TDG as measured in-river, including tailraces and downstream forebays except when minimum spill levels are higher including spill needed for powerhouse surface passage routes, for spillway weirs, and/or for adult attraction. Additionally, spill during high-flow and flood events would not be restricted to a cap of 110 percent TDG, but rather set to levels necessary for safety. Lack-of-market spill would also continue and would follow on the spill priority list. This limitation would begin April 10 and end at midnight July 31. Because of the TDG limitation and the earlier end of fish passage spill, MO2 model results generally show notable decreases in forebay and tailwater TDG saturations and in the frequency of violations of current State TDG criteria as compared to the No Action Alternative. Details are described below.

5.3.2.1 McNary, John Day, The Dalles, and Bonneville Dams and Reservoirs

Forebay TDG saturations for MO2 at McNary, John Day, The Dalles, and Bonneville Dams were modeled under a 5-year range of river and meteorological conditions, and compared to the modeled results for the No Action Alternative (Figure 5-48- Figure 5-51). The MO2 model results show that forebay TDG saturations can exceed the current 115 percent spill season TDG criterion at all four dams during most of the years and conditions presented (the exceptions being John Day and The Dalles during low flow/high water temperature conditions). Maximum forebay TDG saturation would be higher during a year when river flows were higher than normal and summer ambient air temperatures were lower (as in 2011). Maximum forebay TDG saturations during spill season would be lower in MO2 as compared to the No Action Alternative for all four dams. In general, forebay TDG saturations would be lower during spill season at John Day, The Dalles, and Bonneville. Outside of the current juvenile fish spill season, the frequency of 110% TDG exceedances would be similar for MO2 and No Action at all four dams (Table 5-13). At McNary, the frequency of 110% TDG exceedances during the current juvenile fish spill season would be slightly less for MO2 than No Action, but the frequencies of 115% TDG exceedances would be similar for the two alternatives. During juvenile spill season, at John Day, The Dalles, and Bonneville, the frequency of 110% and 115% TDG exceedances would be lower for MO2 than the No Action Alternative (Table 5-14).

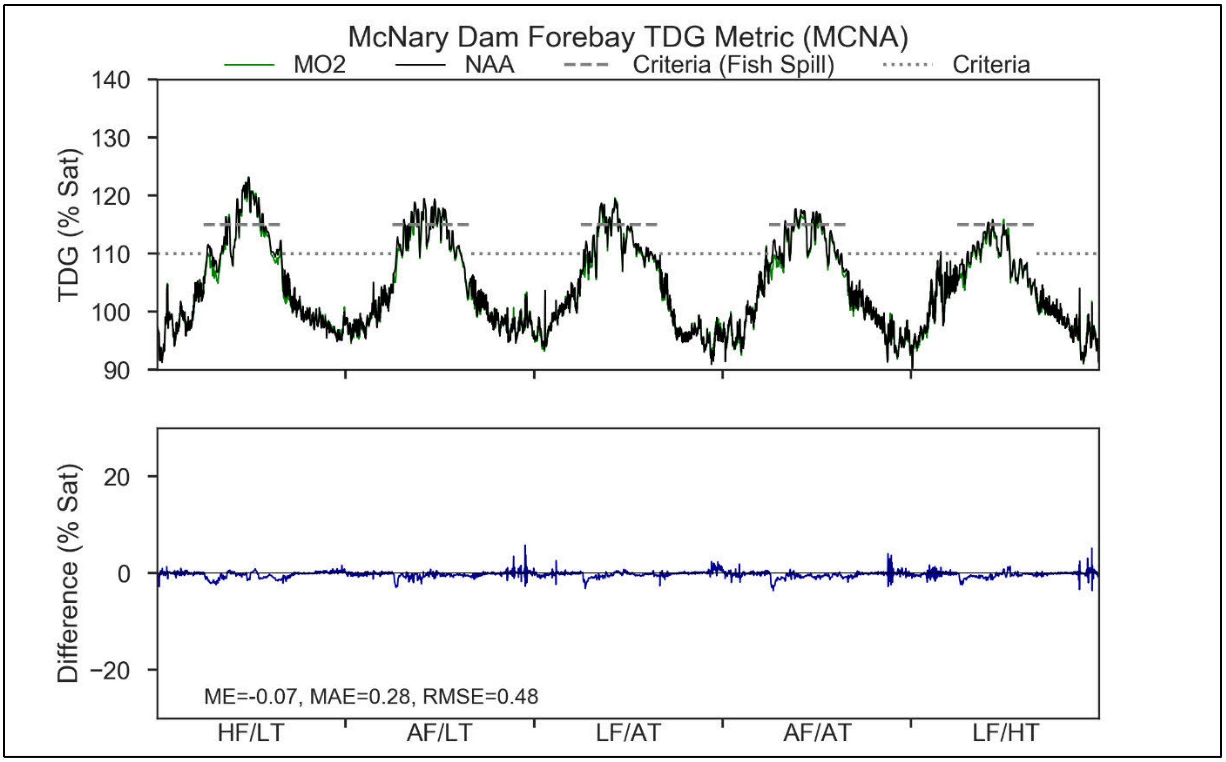


Figure 5-48. Modeled Forebay Total Dissolved Gas for Multiple Objective Alternative 2 at McNary Dam Under a 5-Year Range of River and Meteorological Conditions

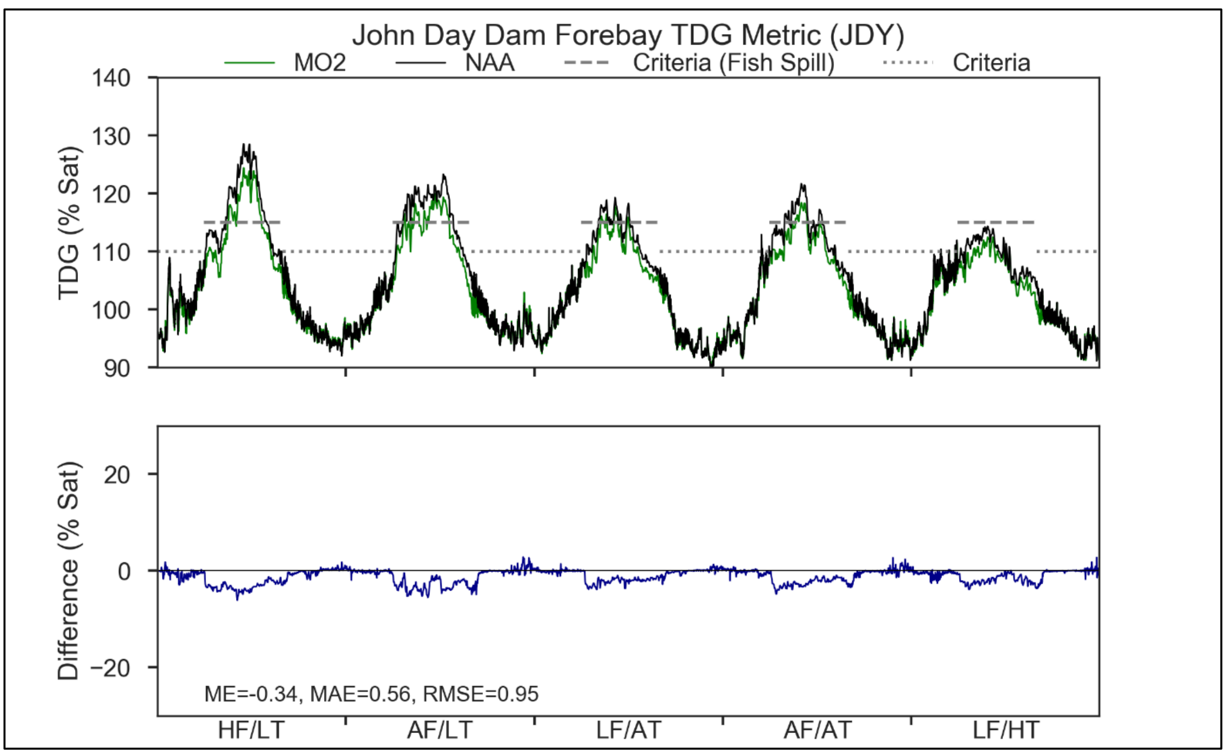


Figure 5-49. Modeled Forebay Total Dissolved Gas for Multiple Objective Alternative 2 at John Day Dam Under a 5-Year Range of River and Meteorological Conditions

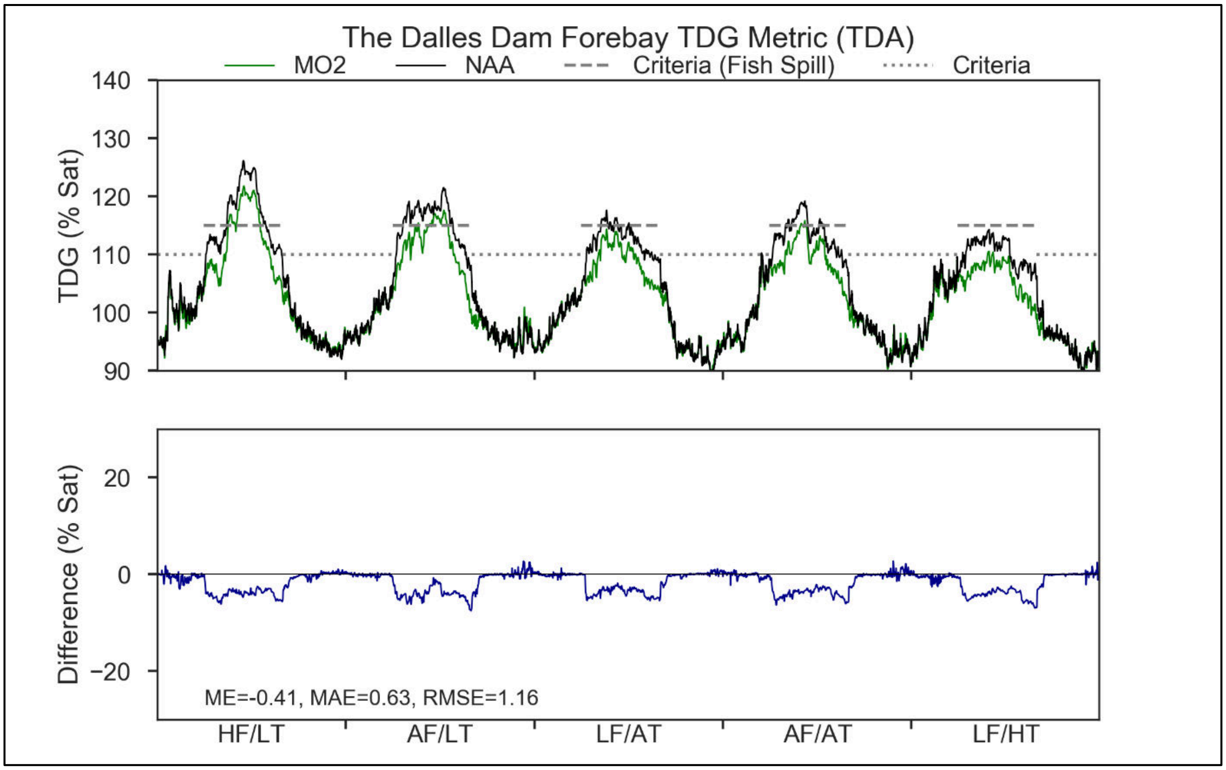


Figure 5-50. Modeled Forebay Total Dissolved Gas for Multiple Objective Alternative 2 at The Dalles Dam Under a 5-Year Range of River and Meteorological Conditions

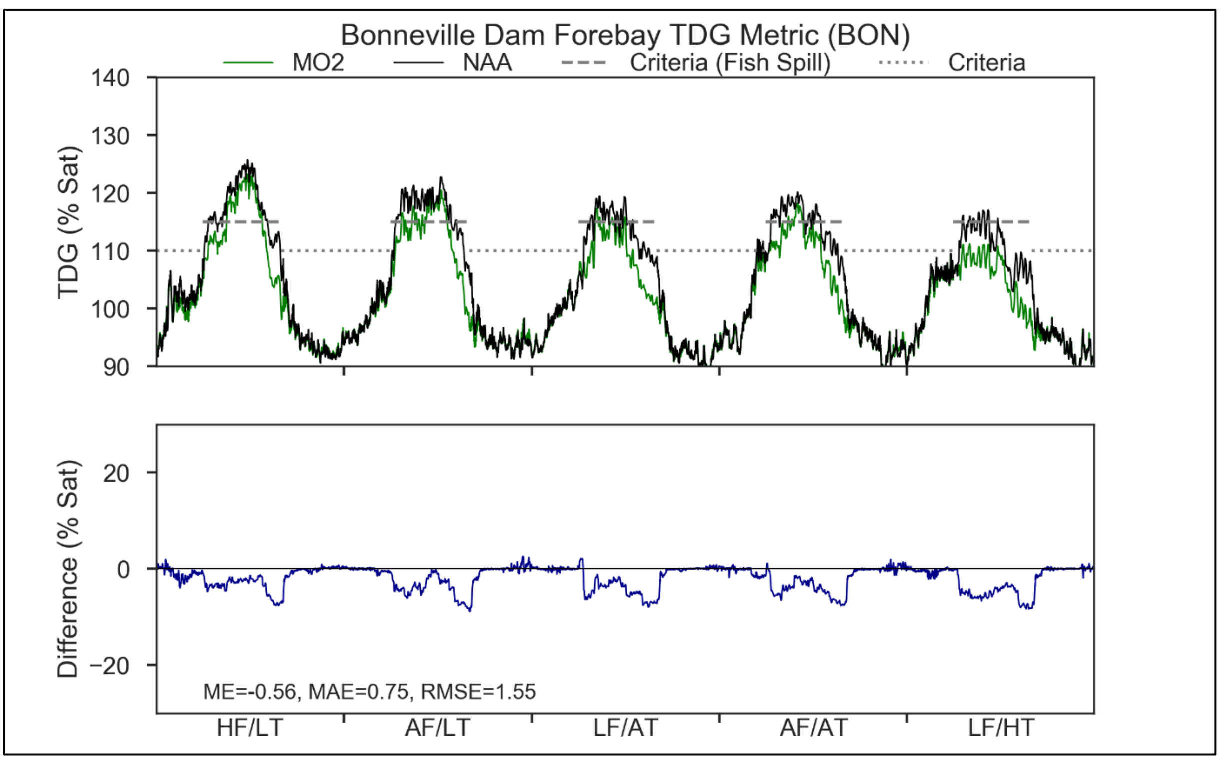


Figure 5-51. Modeled Forebay Total Dissolved Gas for Multiple Objective Alternative 2 at Bonneville Dam Under a 5-Year Range of River and Meteorological Conditions

Table 5-13. Differences of the Frequency of the Total Dissolved Gas that Would Occur Within Selected Ranges Outside of Juvenile Spill Season if Multiple Objective Alternative 2 is Implemented when Compared to the No Action Alternative at the Four Lower Columbia River Dam Forebay Locations Under a 5-Year Range of River and Meteorological Conditions

SITE	TDG Range (% Sat)	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary Forebay	<=110	0.00%	0.00%	0.00%	-0.02%	0.00%
McNary Forebay	>110,<=115	0.00%	0.00%	0.00%	0.02%	0.00%
McNary Forebay	>115,<=120	0.00%	0.00%	0.00%	0.00%	0.00%
McNary Forebay	>120,<=125	0.00%	0.00%	0.00%	0.00%	0.00%
McNary Forebay	>125	0.00%	0.00%	0.00%	0.00%	0.00%
John Day Forebay	<=110	0.00%	0.00%	0.00%	0.69%	0.20%
John Day Forebay	>110,<=115	0.00%	0.00%	0.00%	-0.69%	-0.20%
John Day Forebay	>115,<=120	0.00%	0.00%	0.00%	0.00%	0.00%
John Day Forebay	>120,<=125	0.00%	0.00%	0.00%	0.00%	0.00%
John Day Forebay	>125	0.00%	0.00%	0.00%	0.00%	0.00%
The Dalles Forebay	<=110	0.00%	0.00%	0.00%	0.18%	0.00%
The Dalles Forebay	>110,<=115	0.00%	0.00%	0.00%	-0.18%	0.00%
The Dalles Forebay	>115,<=120	0.00%	0.00%	0.00%	0.00%	0.00%
The Dalles Forebay	>120,<=125	0.00%	0.00%	0.00%	0.00%	0.00%
The Dalles Forebay	>125	0.00%	0.00%	0.00%	0.00%	0.00%
Bonneville Forebay	<=110	0.00%	0.00%	0.00%	3.58%	0.00%
Bonneville Forebay	>110,<=115	0.00%	0.00%	0.00%	-3.58%	0.00%
Bonneville Forebay	>115,<=120	0.00%	0.00%	0.00%	0.00%	0.00%
Bonneville Forebay	>120,<=125	0.00%	0.00%	0.00%	0.00%	0.00%
Bonneville Forebay	>125	0.00%	0.00%	0.00%	0.00%	0.00%

Table 5-14. Differences of the Frequency of the Total Dissolved Gas that Would Occur Within Selected Ranges During Juvenile Spill Season (April-August) if Multiple Objective Alternative 2 is Implemented when Compared to the No Action Alternative at the Four Lower Columbia River Dam Forebay Locations Under a 5-Year Range of River and Meteorological Conditions

SITE	TDG Range (% Sat)	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary Forebay	<=110	15.69%	1.96%	8.50%	13.73%	7.84%
McNary Forebay	>110,<=115	-15.03%	2.61%	-7.19%	-7.19%	-5.23%
McNary Forebay	>115,<=120	-1.96%	-4.58%	-1.31%	-6.54%	-2.61%
McNary Forebay	>120,<=125	1.31%	0.00%	0.00%	0.00%	0.00%
McNary Forebay	>125	0.00%	0.00%	0.00%	0.00%	0.00%
John Day Forebay	<=110	20.26%	8.50%	17.65%	19.61%	24.84%
John Day Forebay	>110,<=115	-9.15%	13.73%	0.00%	-3.27%	-24.84%

SITE	TDG Range (% Sat)	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
John Day Forebay	>115,<=120	3.92%	-1.96%	-17.65%	-9.15%	0.00%
John Day Forebay	>120,<=125	3.92%	-20.26%	0.00%	-7.19%	0.00%
John Day Forebay	>125	-18.95%	0.00%	0.00%	0.00%	0.00%
The Dalles Forebay	<=110	39.87%	24.18%	41.83%	39.22%	52.94%
The Dalles Forebay	>110,<=115	-29.41%	14.38%	-24.84%	-15.69%	-52.94%
The Dalles Forebay	>115,<=120	5.23%	-32.68%	-16.99%	-23.53%	0.00%
The Dalles Forebay	>120,<=125	-13.73%	-5.88%	0.00%	0.00%	0.00%
The Dalles Forebay	>125	-1.96%	0.00%	0.00%	0.00%	0.00%
Bonneville Forebay	<=110	22.22%	16.99%	32.03%	20.26%	43.14%
Bonneville Forebay	>110,<=115	-0.65%	13.07%	-1.31%	21.57%	-26.14%
Bonneville Forebay	>115,<=120	-5.88%	-9.80%	-30.72%	-40.52%	-16.99%
Bonneville Forebay	>120,<=125	-13.07%	-20.26%	0.00%	-1.31%	0.00%
Bonneville Forebay	>125	-2.61%	0.00%	0.00%	0.00%	0.00%

Tailwater TDG saturations for MO2 at McNary, John Day, The Dalles, and Bonneville Dams were modeled under a 5-year range of river and meteorological conditions, and compared to the modeled results for the No Action Alternative (Figure 5-52 through Figure 5-55). The MO2 model results show that tailwater TDG saturations can exceed the current 120 percent spill season TDG criterion at all four dams, but it depends on the river and meteorological conditions present. For example, tailwater TDG at Bonneville would be expected to exceed the 120 percent spill season criterion under all conditions, while the criterion would be exceeded at John Day and The Dalles only under low air temperature conditions and at McNary only under average flow and low air temperature conditions. Maximum tailwater TDG saturation would be higher during a year when river flows were higher than normal and summer ambient air temperatures were lower (as in 2011). Tailwater TDG saturations would generally be lower in MO2 as compared to No Action Alternative for all four dams during spill season, and particularly in August because of the earlier end to juvenile fish spill. At all four dams, the frequency of 110% TDG exceedances outside of current juvenile fish spill would be lower than or remain about the same under MO2 as compared the No Action Alternative under all modeled river and meteorological conditions (Table 5-15). At McNary, The Dalles, and Bonneville, the frequency of 120% TDG exceedances during the current fish spill season would be lower (or otherwise remain at zero) under MO2 than the No Action Alternative under all modeled river and meteorological conditions; at John Day, the frequency of 120% TDG exceedances would be similar for both MO2 and the No Action Alternative, though the frequency of 115% TDG exceedances would be significantly reduced (Table 5-16).

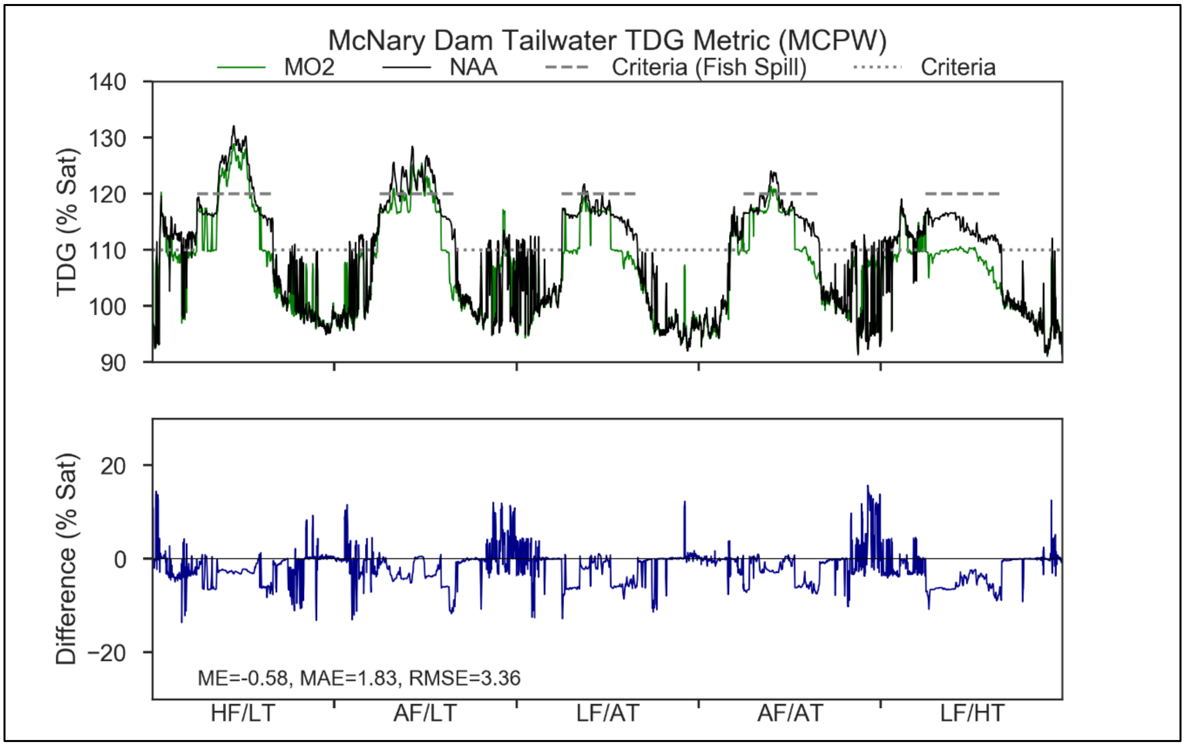


Figure 5-52. Modeled Tailwater Total Dissolved Gas for Multiple Objective Alternative 2 at McNary Dam Under a 5-Year Range of River and Meteorological Conditions

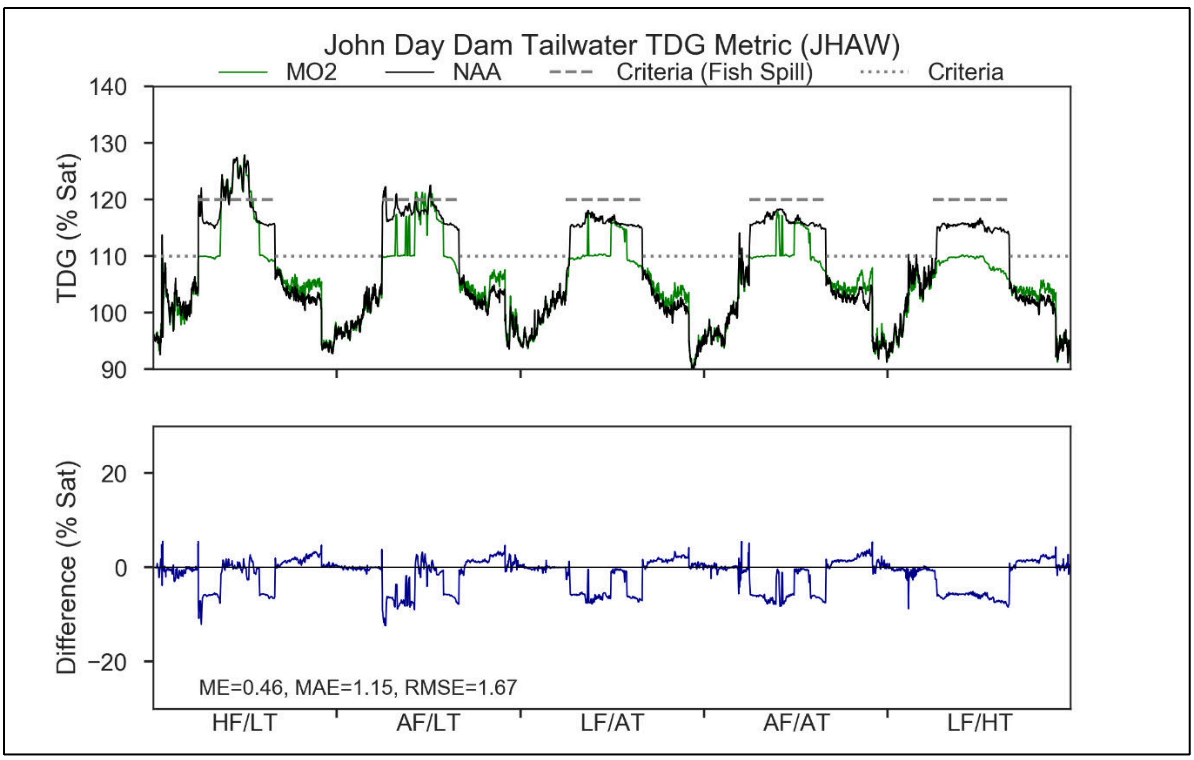


Figure 5-53. Modeled Tailwater Total Dissolved Gas for Multiple Objective Alternative 2 at John Day Dam Under a 5-Year Range of River and Meteorological Conditions

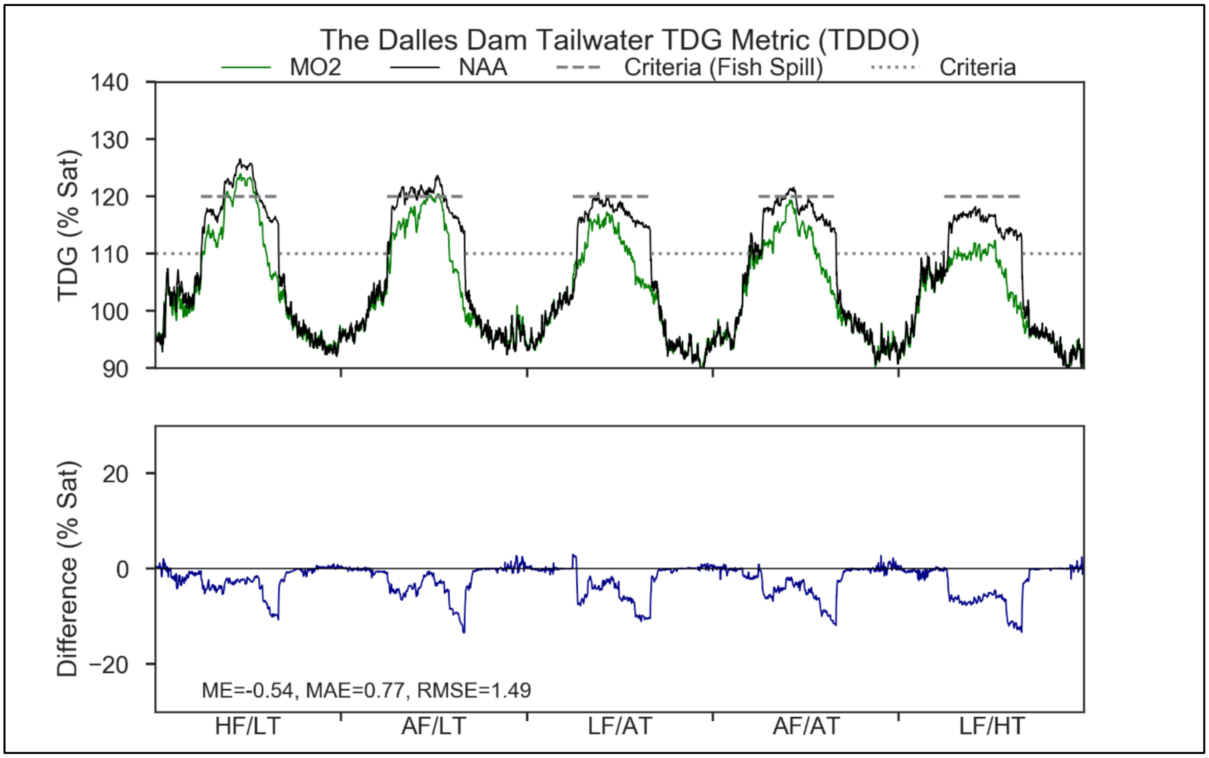


Figure 5-54. Modeled Tailwater Total Dissolved Gas for Multiple Objective Alternative 2 at The Dalles Dam Under a 5-Year Range of River and Meteorological Conditions

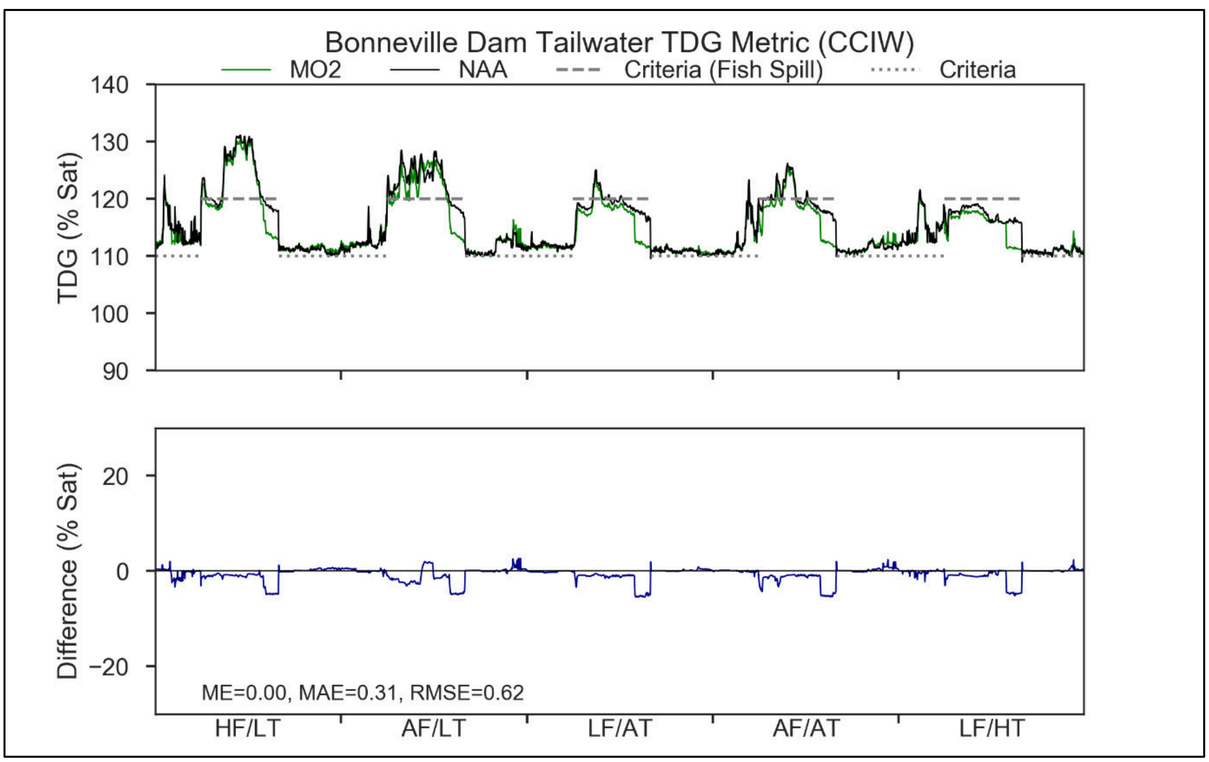


Figure 5-55. Modeled Tailwater Total Dissolved Gas for Multiple Objective Alternative 2 at Bonneville Dam Under a 5-Year Range of River and Meteorological Conditions

Table 5-15. Differences of the Frequency of the Total Dissolved Gas that Would Occur Outside Juvenile Spill Season if Multiple Objective Alternative 2 is Implemented when Compared to the No Action Alternative at the Four Lower Columbia River Dam Tailwater Locations Under a 5-Year Range of River and Meteorological Conditions

SITE	TDG Range (% Sat)	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary Tailwater	<=110	22.74%	15.84%	3.47%	9.38%	22.37%
McNary Tailwater	>110,<=115	-22.68%	-17.56%	-3.47%	-9.17%	-21.59%
McNary Tailwater	>115,<=120	-0.16%	1.72%	0.00%	-0.22%	-0.78%
McNary Tailwater	>120,<=125	0.10%	0.00%	0.00%	0.00%	0.00%
McNary Tailwater	>125	0.00%	0.00%	0.00%	0.00%	0.00%
John Day Tailwater	<=110	0.42%	0.00%	0.00%	1.25%	0.40%
John Day Tailwater	>110,<=115	-0.42%	0.00%	0.00%	-1.25%	-0.40%
John Day Tailwater	>115,<=120	0.00%	0.00%	0.00%	0.00%	0.00%
John Day Tailwater	>120,<=125	0.00%	0.00%	0.00%	0.00%	0.00%
John Day Tailwater	>125	0.00%	0.00%	0.00%	0.00%	0.00%
The Dalles Tailwater	<=110	0.00%	0.00%	0.00%	5.75%	0.10%
The Dalles Tailwater	>110,<=115	0.00%	0.00%	0.00%	-5.75%	-0.10%
The Dalles Tailwater	>115,<=120	0.00%	0.00%	0.00%	0.00%	0.00%
The Dalles Tailwater	>120,<=125	0.00%	0.00%	0.00%	0.00%	0.00%
The Dalles Tailwater	>125	0.00%	0.00%	0.00%	0.00%	0.00%
Bonneville Tailwater	<=110	-0.10%	0.67%	0.00%	0.00%	-0.46%
Bonneville Tailwater	>110,<=115	2.76%	-2.21%	0.00%	0.14%	2.19%
Bonneville Tailwater	>115,<=120	-2.84%	1.54%	0.00%	-0.08%	-1.42%
Bonneville Tailwater	>120,<=125	0.18%	0.00%	0.00%	-0.06%	-0.32%
Bonneville Tailwater	>125	0.00%	0.00%	0.00%	0.00%	0.00%

Table 5-16. Differences of the Frequency of the Total Dissolved Gas that Would Occur Within Selected Ranges During Juvenile Spill Season (April-August) if Multiple Objective Alternative 2 is Implemented when Compared to the No Action Alternative at the Four Lower Columbia River Dam Tailwater Locations Under a 5-Year Range of River and Meteorological Conditions

SITE	TDG Range (% Sat)	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary Tailwater	<=110	27.74%	18.71%	50.32%	28.39%	72.26%
McNary Tailwater	>110,<=115	0.65%	-7.10%	-10.32%	-4.52%	-27.74%
McNary Tailwater	>115,<=120	-22.58%	13.55%	-34.19%	-18.06%	-44.52%
McNary Tailwater	>120,<=125	10.97%	-16.77%	-5.81%	-5.81%	0.00%
McNary Tailwater	>125	-16.77%	-8.39%	0.00%	0.00%	0.00%
John Day Tailwater	<=110	40.65%	31.61%	39.35%	42.58%	85.81%
John Day Tailwater	>110,<=115	7.74%	23.23%	36.77%	28.39%	-25.16%
John Day Tailwater	>115,<=120	-50.97%	-56.77%	-76.13%	-70.97%	-60.65%
John Day Tailwater	>120,<=125	5.16%	1.94%	0.00%	0.00%	0.00%
John Day Tailwater	>125	-2.58%	0.00%	0.00%	0.00%	0.00%
The Dalles Tailwater	<=110	18.71%	23.87%	35.48%	27.10%	64.52%
The Dalles Tailwater	>110,<=115	26.45%	10.97%	21.29%	31.61%	-7.10%
The Dalles Tailwater	>115,<=120	-30.97%	7.74%	-55.48%	-45.81%	-57.42%
The Dalles Tailwater	>120,<=125	4.52%	-42.58%	-1.29%	-12.90%	0.00%
The Dalles Tailwater	>125	-18.71%	0.00%	0.00%	0.00%	0.00%
Bonneville Tailwater	<=110	0.00%	0.00%	0.00%	0.00%	0.00%
Bonneville Tailwater	>110,<=115	16.77%	18.71%	21.29%	22.58%	22.58%
Bonneville Tailwater	>115,<=120	-4.52%	-7.10%	-12.90%	-5.81%	-22.58%
Bonneville Tailwater	>120,<=125	-10.97%	-1.94%	-7.74%	-10.32%	0.00%
Bonneville Tailwater	>125	-1.29%	-9.68%	-0.65%	-6.45%	0.00%

The operational changes for MO2 do cause a few minor total dissolved gas differences at both forebay and tailwater sites as can be seen in the figures above. In terms of the actual number of days of the criteria being exceeded, those changes can be seen in Table 5-17 and Table 5-18. In general, the differences seen under MO2 show an improvement to the number of exceedances over the NAA.

Table 5-17. Difference in Number of Days the TDG Criteria is Exceeded at the Forebay Sites of McNary, John Day, The Dalles, and Bonneville for the Multiple Objective 2 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary	February	0	0	0	0	0
McNary	March	0	0	0	0	0
McNary	April	0	0	0	0	0
McNary	May	**1**	-5	-2	-4	-2
McNary	June	0	-2	0	-2	-2
McNary	July	-2	0	0	-4	0
John Day	February	0	0	0	0	0
John Day	March	0	0	0	-1	0
John Day	April	0	-8	0	0	0
John Day	May	-4	-17	-15	-17	0
John Day	June	-2	-2	-11	-4	0
John Day	July	-10	-7	-1	-4	0
John Day	August	-1	0	0	0	0
John Day	September	0	0	0	0	0
The Dalles	March	0	0	0	0	0
The Dalles	April	0	-10	0	0	0
The Dalles	May	-2	-27	-17	-22	0
The Dalles	June	-3	-13	-7	-6	0
The Dalles	July	-11	-9	-2	-8	0
The Dalles	August	0	0	0	0	0
The Dalles	September	0	0	0	0	0
Bonneville	March	0	0	0	-8	0
Bonneville	April	-12	-12	-5	-17	-4
Bonneville	May	-11	-20	-19	-22	-15
Bonneville	June	0	-4	-18	-9	-7
Bonneville	July	-5	-7	-5	-16	0
Bonneville	August	-5	-3	0	0	0
Bonneville	September	0	0	0	0	0

Table 5-18. Difference in Number of Days the TDG Criteria is Exceeded at the Tailwater Sites of McNary, John Day, The Dalles, and Bonneville for the Multiple Objective 2 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary	January	-2	0	-5	0	-18
McNary	February	-24	-10	-2	0	-12
McNary	March	-21	-10	0	-11	-16
McNary	April	0	-6	0	0	0
McNary	May	-2	-20	-8	-5	0
McNary	June	0	-4	-1	-4	0
McNary	July	-7	-9	0	0	0
McNary	August	0	0	0	0	0
McNary	September	0	1	**1**	0	0
McNary	October	**6**	**1**	0	0	0
McNary	November	0	**2**	0	**1**	0
McNary	December	0	**6**	0	**7**	**1**
John Day	January	-1	0	0	0	0
John Day	February	0	0	0	0	-1
John Day	March	0	-1	0	-3	0
John Day	April	-3	-8	0	0	0
John Day	May	**2**	0	0	0	0
John Day	June	**1**	**8**	0	0	0
John Day	July	**4**	**3**	0	0	0
John Day	August	0	0	0	0	0
The Dalles	February	0	0	0	0	0
The Dalles	March	0	0	0	-13	0
The Dalles	April	0	-5	0	0	0
The Dalles	May	-11	-20	-2	-7	0
The Dalles	June	-5	-25	0	-13	0
The Dalles	July	-6	-16	0	0	0
The Dalles	August	0	0	0	0	0
The Dalles	September	0	0	0	0	0
Bonneville	January	0	0	0	0	0
Bonneville	February	0	0	0	0	0
Bonneville	March	0	0	0	0	0
Bonneville	April	-13	-11	0	-9	0
Bonneville	May	-1	-3	-2	-11	0
Bonneville	June	0	0	-5	-3	0

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Bonneville	July	-5	-4	-6	-3	0
Bonneville	August	0	0	0	0	0
Bonneville	September	0	0	0	0	0
Bonneville	October	0	0	0	0	0
Bonneville	November	0	0	0	0	0
Bonneville	December	0	0	0	0	**2**

5.3.3 Other Physical, Chemical, and Biological Processes

5.3.3.1 McNary, John Day, The Dalles, and Bonneville Dams and Reservoirs

Under the MO2 *John Day Full Pool* measure, the John Day pool would operate within the full reservoir operating range (262.5 to 266.5 feet, NGVD29) year-round except as needed for flood risk management. Currently, the John Day pool is restricted to operating within 1.5 feet above minimum irrigation pool during juvenile fish passage season (April through August). However, modeling suggests forebay elevations for MO2 will not be substantially different from forebay elevations for the No Action Alternative (Figure 5-56 through Figure 5-59).

The introduction of pollutants and excess nutrients from air deposition, farming and industrial activities, as well as urban runoff, is expected to continue under MO2. As with the No Action, emerging contaminants such as pharmaceuticals and new pesticides will also likely become more prevalent. The lower Columbia River contains a variety of human-sourced compounds, including metals and organic compounds. This condition is expected to remain generally unchanged, and it is expected that current water quality impairments would continue.

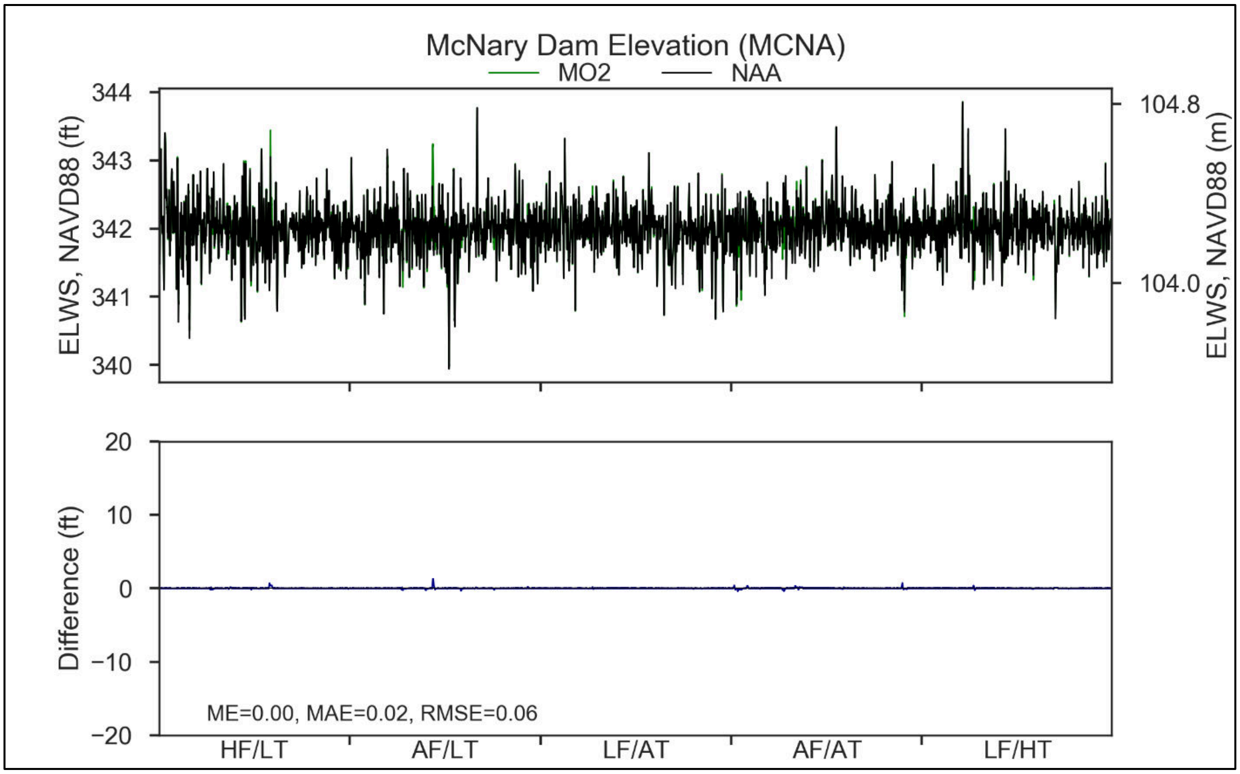


Figure 5-56. Modeled Forebay Elevation for Multiple Objective Alternative 2 at McNary Dam Under a 5-Year Range of River and Meteorological Conditions

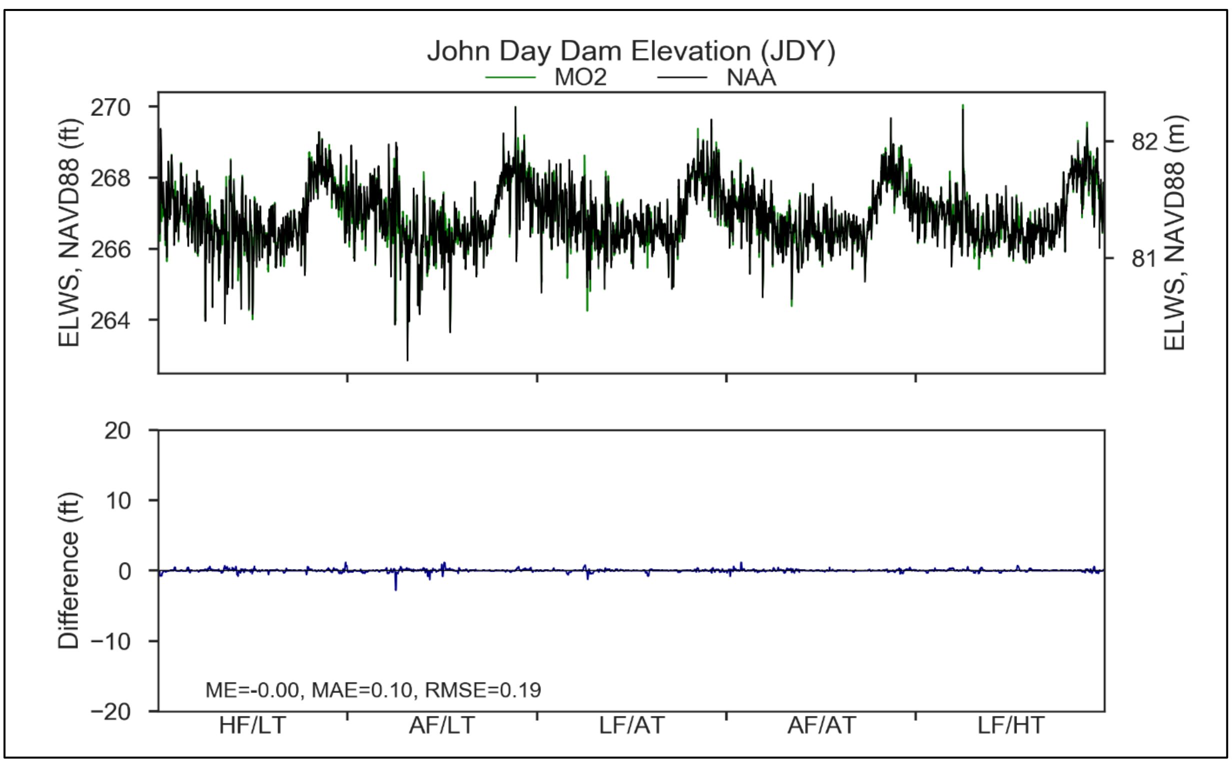


Figure 5-57. Modeled Forebay Elevation for Multiple Objective Alternative 2 at John Day Dam Under a 5-Year Range of River and Meteorological Conditions

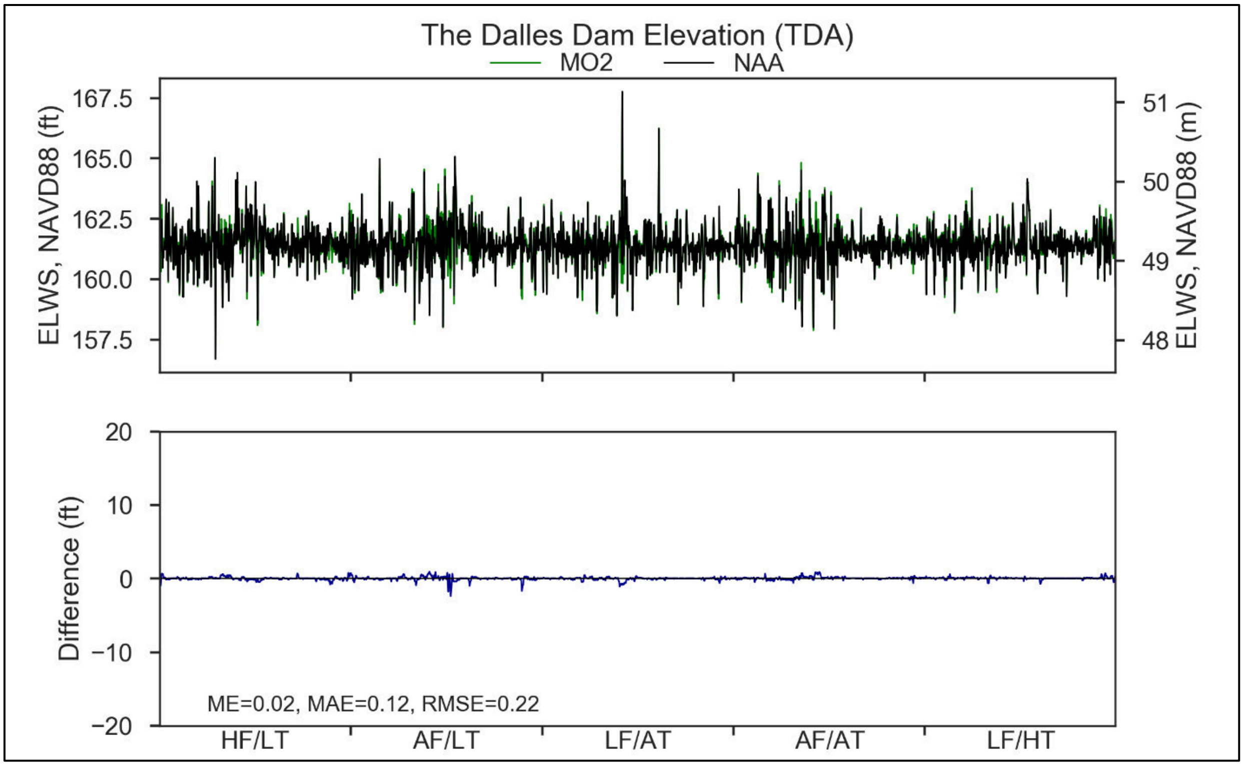


Figure 5-58. Modeled Forebay Elevation for Multiple Objective Alternative 2 at The Dalles Dam Under a 5-Year Range of River and Meteorological Conditions

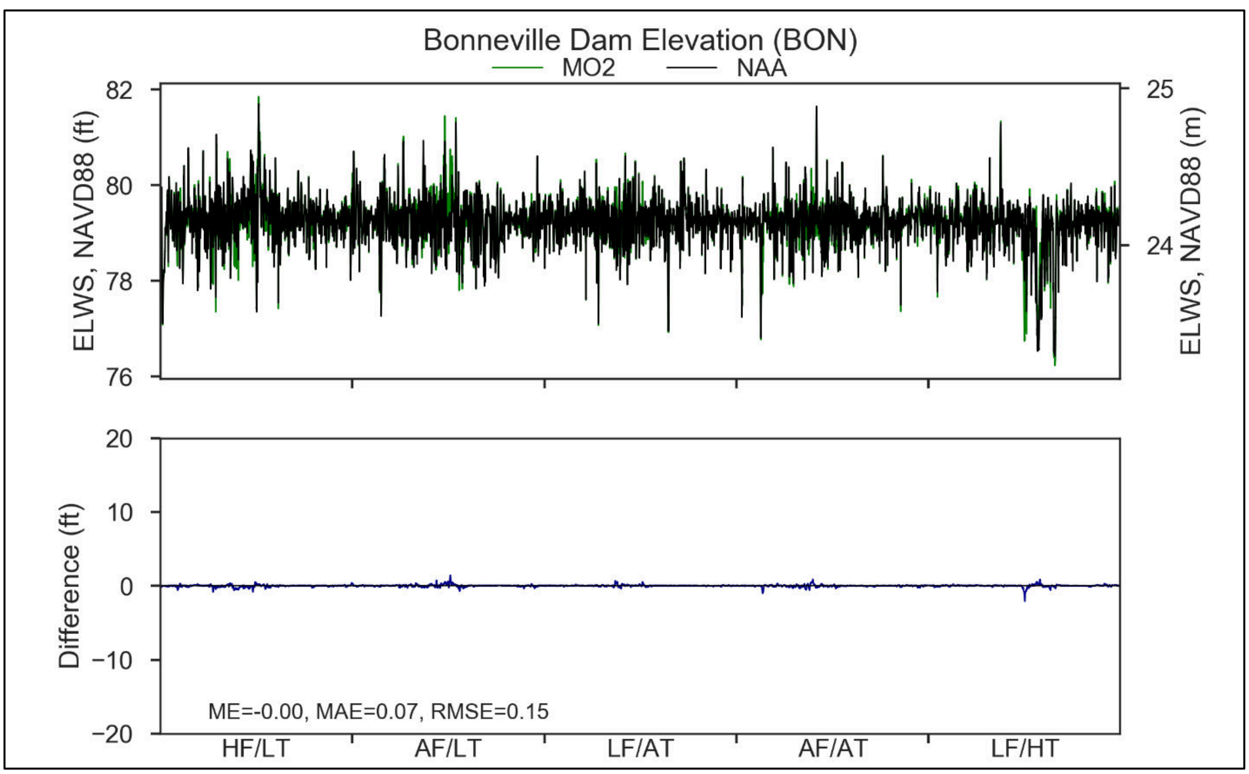


Figure 5-59. Modeled Forebay Elevation for Multiple Objective Alternative 2 at Bonneville Dam Under a 5-Year Range of River and Meteorological Conditions

5.4 SEDIMENT PROCESSES

5.4.1 Sediment Sources

MO2 includes structural changes aimed at improving juvenile fish passage; these proposed measures would not affect sediment sources or movement. The proposed operational changes generally have a goal of improving flexibility in operation and of improving in-stream (flow and temperature) conditions for fish; changing the timing of flows or the temperature characteristics does not affect sediment sources although changing reservoir water levels could have an impact on the bioavailability of some sediment pollutants (Willacker et al. 2016). MO2 is not expected to affect land use throughout the basin, including upland recreation, flood management, agricultural, timber, or mining activities, and is not expected to change population growth patterns in the area of any of the affected reservoirs. Overall, MO2 is not expected to affect sediment movement within the system.

5.4.2 Chemicals of Concern

No change is predicted to the list of sediment chemicals of concern throughout the basin, compared to the existing conditions and No Action Alternative. The contaminants of concern would remain metals, polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds, pesticides and pesticide degradation products, PCBs, dioxins, and nutrients (ammonia). Due to changes in reservoir operation, changes to water levels could affect the mobility and bioavailability of some pollutants such as mercury (Willacker et al. 2016).

5.5 CONCEPTUAL SITE MODEL

MO2 is not expected to affect sediment movement patterns, so the conceptual site model for sediment/dredging is the same as the conceptual site model(s) for the existing conditions and No Action Alternative. Portions of the Columbia Basin that are currently not dredged (Chief Joseph Reservoir) would not be dredged in the future. Areas of the basin that are currently maintained by dredging (such as at the confluence of the Snake River and Clearwater River) would continue to require periodic dredging. Sediment characterization following the Sediment Evaluation Framework (RSET 2018) or other applicable guidance would continue to be required for dredging or sediment-related projects.

5.6 WATER AND SEDIMENT QUALITY CONCLUSIONS

The most notable MO2 measures that affect water quality are as follows:

- Spill to 110 *percent* TDG: Limit fish passage spill to 110 percent TDG at the lower Snake and Columbia projects.
- Slightly Deeper Draft for Hydropower: Allow for a larger operating range at storage projects for hydropower flexibility.
- Full Range Turbine Operations: Operate turbines across their full range of capacity.

- Update System FRM Calculation, Winter System FRM Space, Planned Draft Rate at Grand Coulee, Sliding Scale at Libby and Hungry Horse, Modified Draft at Libby, December Libby Target Elevation*: Modify operations for FRM at Libby, Grand Coulee, and Hungry Horse Dams.*
- Grand Coulee Maintenance Operations: Plan for major maintenance at Grand Coulee Dam.

5.6.1 Multiple Objective Alternative 2 Results – Water Temperature

In general, MO2 would result in negligible impacts to water temperature throughout the CRS (Figure 5-60 through Figure 5-62). Deeper drawdowns of Dworshak Reservoir from the *Slightly Deeper Draft for Hydropower* measure could lead to slower warming of the surface waters because the smaller surface area would result in less warming by the sun in the early spring. Near-full pool would be reached by July, and thermal stratification for the remainder of the year would not change. Temperatures would remain less than 52 °F throughout the year, and overall water temperature effects downstream of Dworshak Dam under MO2 would be negligible using the logic presented in Section 3.4.3.2. Modeling assumptions may have resulted in misleading conclusions, in the lower Snake River. MO2 water temperatures in the lower Snake River would result in moderate to minor changes as modeled, compared to the No Action Alternative. However, ResSim modeling assumptions did not represent the intended operations and instead showed the reservoir would have a decreased refill probability, refilling to within 0.5 feet of the normal full reservoir elevation in about 48 percent of years. It is likely that in real-time operations, the refill probability for Dworshak Reservoir under MO2 would be higher than shown in modeled results, and more closely aligned to the No Action Alternative. Therefore, effects to water temperatures are considered negligible.

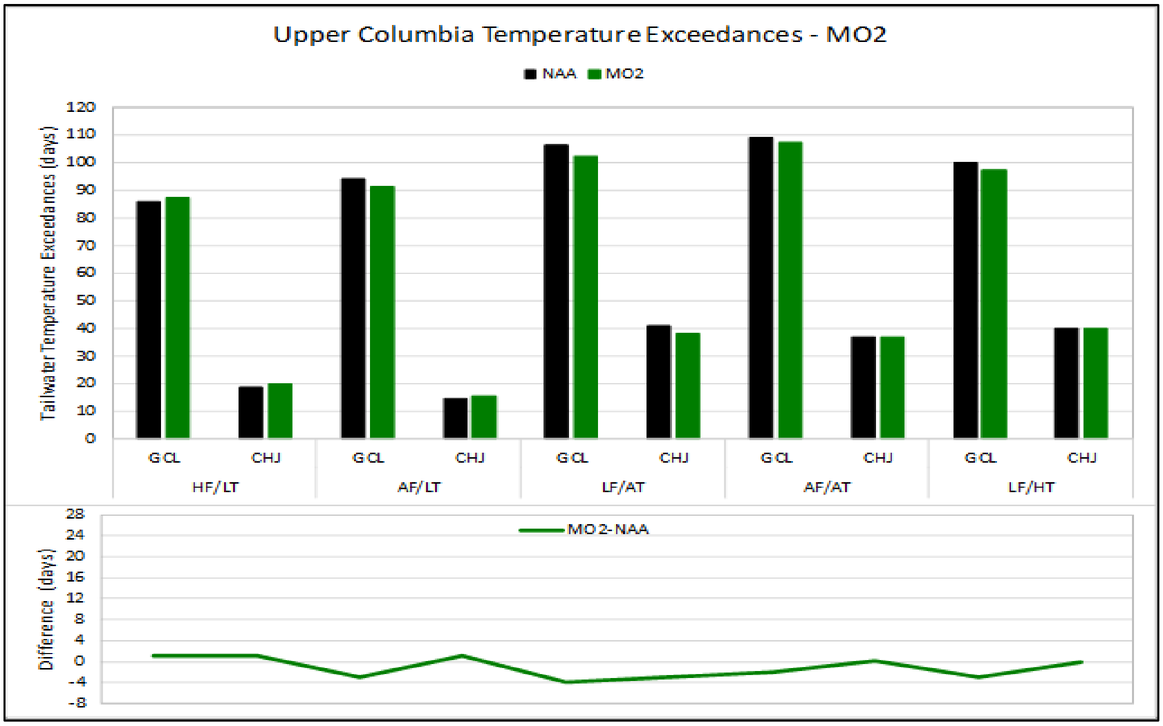


Figure 5-60. Modeled Tailwater Temperature Exceedances for the No Action Alternative and Multiple Objective Alternative 2 at Grand Coulee and Chief Joseph Dams Under a 5-Year Range of River and Meteorological Conditions

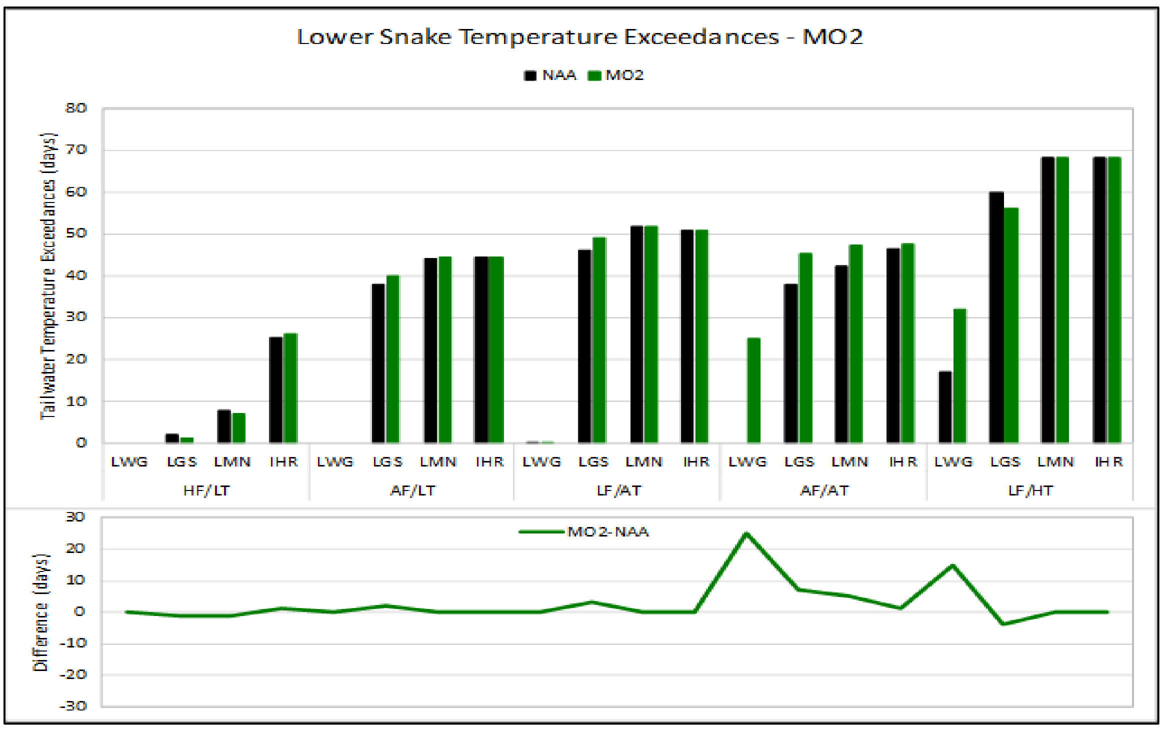


Figure 5-61. Modeled Tailwater Temperature Exceedances for the No Action Alternative and Multiple Objective Alternative 2 at Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams Under a 5-Year Range of River and Meteorological Conditions

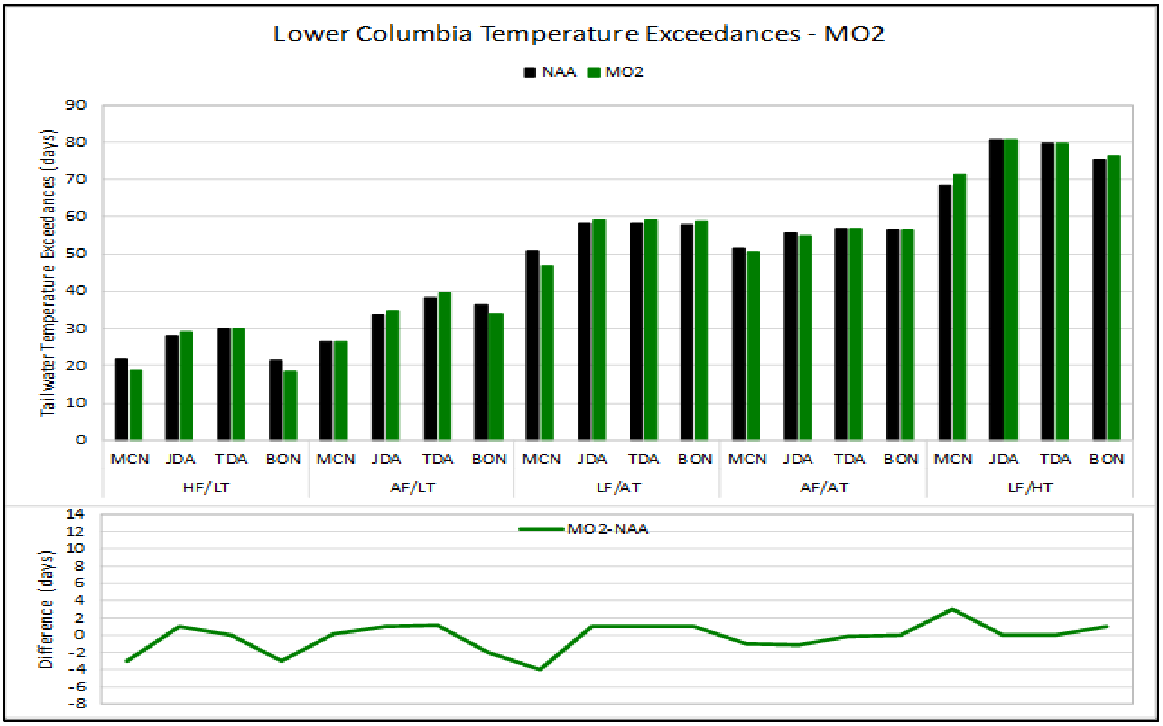


Figure 5-62. Modeled Tailwater Temperature Exceedances for the No Action Alternative and Multiple Objective Alternative 2 at McNary, John Day, The Dalles, and Bonneville Dams Under a 5-Year Range of River and Meteorological Conditions

5.6.2 Multiple Objective Alternative 2 Results –Total Dissolved Gas

In general, the MO2 alternative would have little to no impact on TDG conditions below Libby, Albeni Falls, Grand Coulee, and Chief Joseph dams as compared to No Action Alternative (Figure 5-63). TDG would likely be reduced downstream of Hungry Horse. The *Grand Coulee Maintenance Operations* measure, in isolation, could result in significant increases in spill and TDG, in some cases producing TDG in excess of 130 percent for a limited time; however, this effect is largely offset in the spring and early summer by the other measures.

Water quality model results indicate that some increases in TDG below Dworshak Dam would occur under MO2. However, during realtime implementation of this measure, this would be avoided so as not to violate water quality TDG criteria. Minor reductions in TDG would be expected in the lower Snake (Figure 5-64) and Columbia Rivers (Figure 5-65) due to the *Spill to 110% TDG* measure, which calls for a reduction in downstream juvenile fish passage spill to not exceed a TDG limit of 110 percent. Even though the 110 percent TDG limit would be hard to achieve due to minimum spill requirements, involuntary spill, and lack of market conditions, average TDG would still be lower as compared to the No Action Alternative.

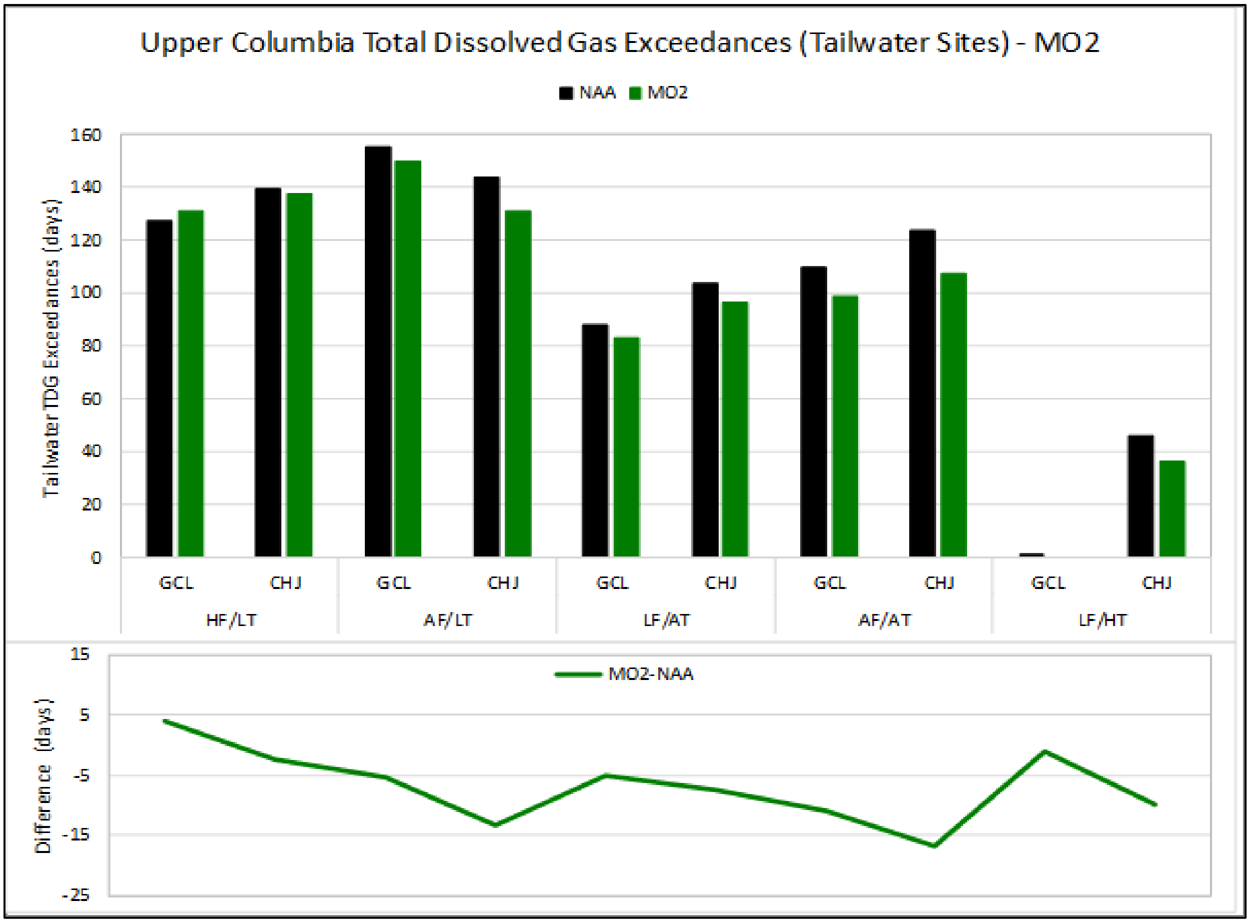


Figure 5-63. Modeled Tailwater Total Dissolved Gas Exceedances for the No Action Alternative and Multiple Objective Alternative 2 at Grand Coulee and Chief Joseph Under a 5-Year Range of River and Meteorological Conditions

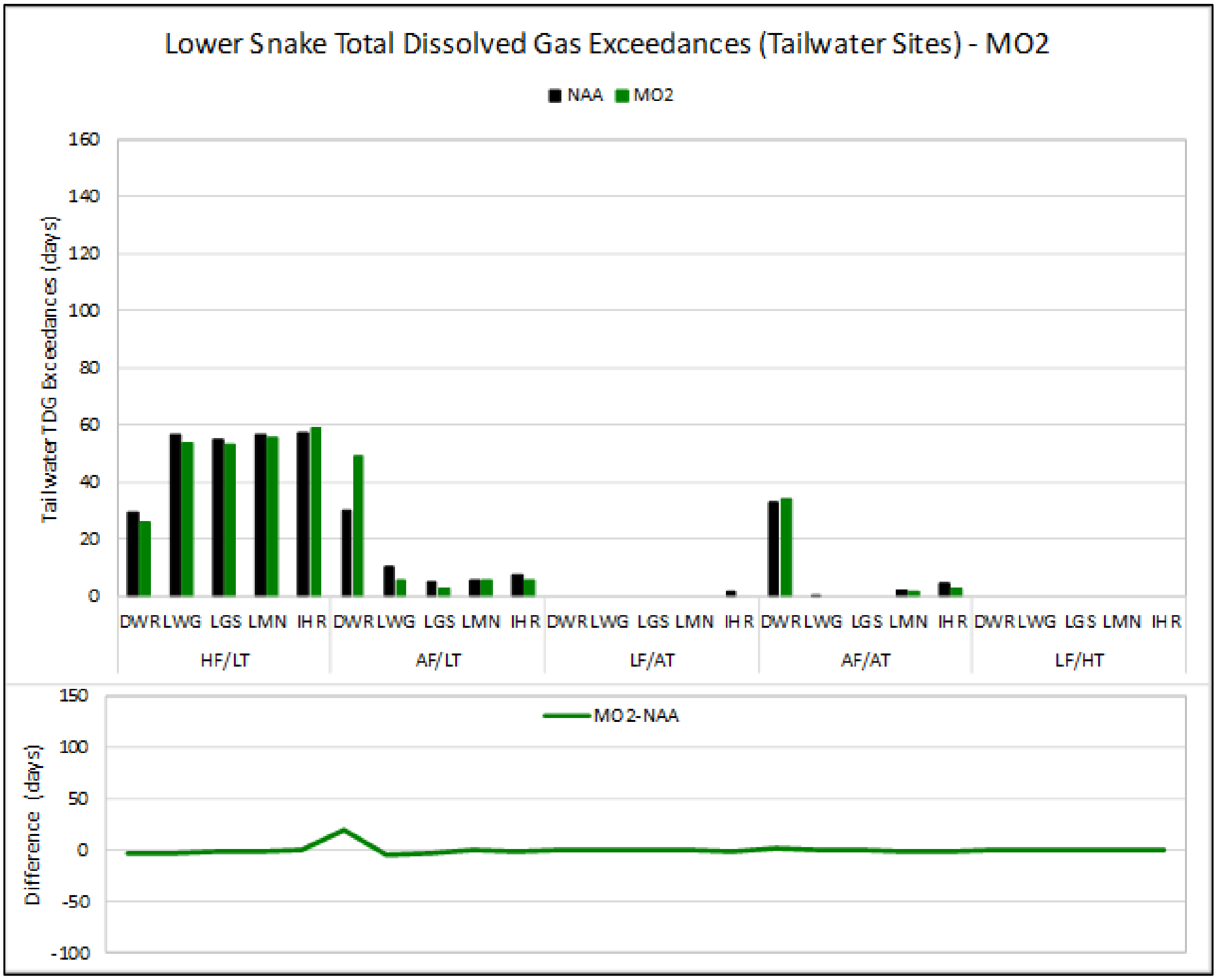


Figure 5-64. Modeled Tailwater Total Dissolved Gas Exceedances for the No Action Alternative and Multiple Objective Alternative 2 at Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams Under a 5-Year Range of River and Meteorological Conditions

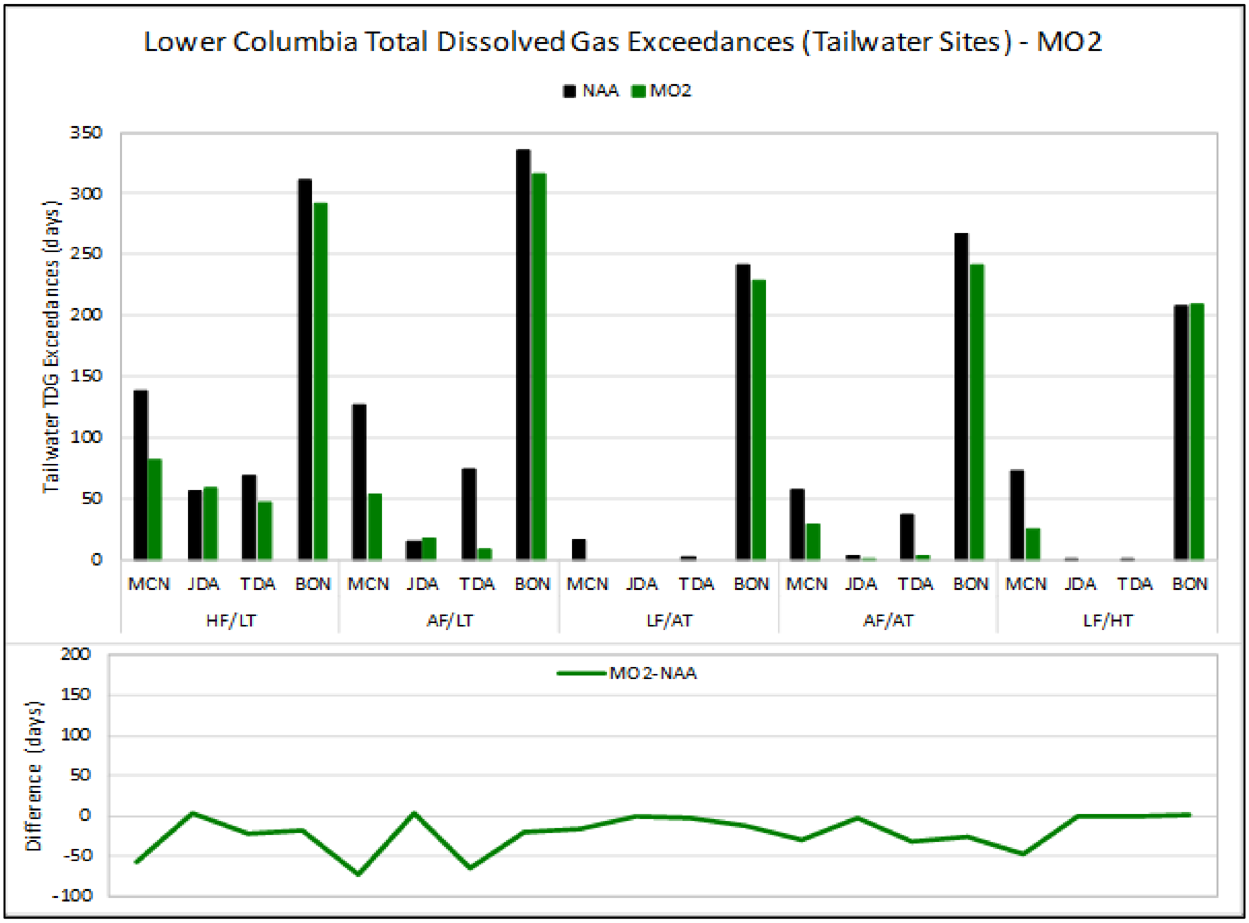


Figure 5-65. Modeled Tailwater Total Dissolved Gas Exceedances for the No Action Alternative and Multiple Objective Alternative 2 at McNary, John Day, The Dalles, and Bonneville Dams Under a 5-Year Range of River and Meteorological Conditions

5.6.3 Multiple Objective Alternative 2 Results –Other Water Quality Impacts

In general, MO2 would result in little to no change on other water quality parameters at Albeni Falls and Chief Joseph dams and reservoirs, as compared to the No Action Alternative. Due to lower winter reservoir elevations and increased outflows at Libby and Hungry Horse projects, resulting from the *Slightly Deeper Draft for Hydropower* measure, combined with the *Modified Draft at Libby* measure, a reduction in lake productivity may occur. This could result in lower growth rate in fish within and downstream of the reservoir. At Grand Coulee, the increased reservoir elevation fluctuations, associated with the *Slightly Deeper Draft for Hydropower* and FRM measures (*Winter System FRM Space*), could lead to increased mercury methylation, while the Planned Draft Rate at Grand Coulee measure, which decreases the planning draft rate of the reservoir to 0.8 feet per day could result in a decrease in bank erosion, sloughing, and overall turbidity in the reservoir.

The *Deeper Draft for Hydropower* measure could result in shallower water depths at the upper end of Dworshak Reservoir where the North Fork Clearwater River, Little North Fork River, and Breakfast Creek enter, leading to higher flow velocities and a delay in primary production. In general, MO2 would have little to no impact on other water quality parameters at, the lower Snake River and the lower Columbia River projects as compared to the No Action Alternative.

5.6.4 Multiple Objective Alternative 2 Results –Sediment Quality

MO2 is not expected to affect land use throughout the basin, including upland recreation, flood management, agricultural, timber, or mining activities, and is not expected to change population growth patterns in the area of any of the affected reservoirs. No change is predicted to the list of sediment chemicals of concern throughout the basin, compared to the existing conditions and No Action Alternative.

CHAPTER 6 - MULTIPLE OBJECTIVE ALTERNATIVE 3

Multiple Objective Alternative 3 (MO3 was developed with the goal to meet objectives to benefit ESA-listed fish while integrating actions for water management flexibility for flood risk management. MO3 also sought to adapt to changing environmental conditions as described in Chapter 2, hydropower production at the remaining CRS projects, and water supply. This alternative includes many measures similar to previous alternatives, but it also includes breaching the lower Snake River dams. See Chapter 2 in the main EIS report for a complete description of the dam breach plus alternative. However, it should be noted that the sediment study for MO3 did not include existing bridges and therefore does not consider bridge-related scour and deposition potential. Structural measures for this alternative include:

- Remove earthen embankments and adjacent structures, as required, at each dam to facilitate reservoir drawdown at the lower Snake River dams.
- Modify existing equipment and dam infrastructure at the lower Snake River dams to adjust to drawdown conditions (Existing equipment would not be used for hydropower generation but would be used as low-level outlets for drawdown below spillway elevations).
- Construction of additional powerhouse and/or spill surface passage routes at the McNary Project.

6.1 UPPER COLUMBIA RIVER BASIN

6.1.1 Water Temperature

6.1.1.1 Libby and Hungry Horse Dams and Reservoirs

For Libby Dam, MO3 is similar to Multiple Objective Alternative (MO2) and includes operational changes that could result in changes to draft and refill operations when compared to the No Action Alternative as shown in the summary hydrograph (Figure 6-1). For the majority of years under MO3, the end-of-November draft elevation target is 8 feet lower than the No Action Alternative to facilitate a lower end-of-December target elevation of 2,400 feet NGVD29, which is about 11 feet lower than the majority of No Action Alternative years. January and February draft elevations are typically deeper under MO3 largely due to the prolonged impacts of the deeper November and December drafts. Final end-of-April draft elevation for the median and wettest quarter of years are similar to the No Action Alternative. However, for the driest 40 percent of years, the end-of-April draft is about 11 to 19 feet deeper than the No Action Alternative. Reservoir refill and summer pool elevations are improved over the No Action Alternative with the reservoir reaching the end-of-July full pool about 6 percent more often than under the No Action Alternative. August and September reservoir elevations under MO3 are about 1 to 4 feet greater than under the No Action Alternative. In general, the MO3 drafting changes would result in lower water elevations in Lake Koocanusa from November through April, with substantially lower end-of-April water elevations (11 to 19 feet) in the driest 40 percent of years. It should be noted that these changes do vary by water year, water forecast, and time of year. A summary hydrograph for Lake Koocanusa, representing the probability of the reservoir elevation on any given day under MO3 and the No Action Alternative is shown in Figure 6-1.

MO3 largely impacts Libby Dam outflows and Kootenai River flows from about November through April (Figure 6-2). When compared to the No Action Alternative, median average MO3 outflows are about 14 to 34 percent greater in November and December, 11 to 42 percent less from January through April, and about 5 to 9 percent less from May through September. Outflows are decreased in late April and May due to increased refill. For the median condition, sturgeon pulses remain the same. The pattern and magnitude of flow changes from Libby Dam are clearly seen downstream in the Kootenai River at Bonners Ferry, Idaho, and in a much diluted condition as far downstream as the Columbia River and Lake Roosevelt. The increased outflow from Libby Dam in November and December results in an increase in median monthly river water elevations of 1.4 to 1.8 feet in the free-flowing reach below Libby Dam and about 1.6 feet at Bonners Ferry. Decreased January through April flows result in a decrease in median monthly Kootenai River water elevations by as much as 2 feet.

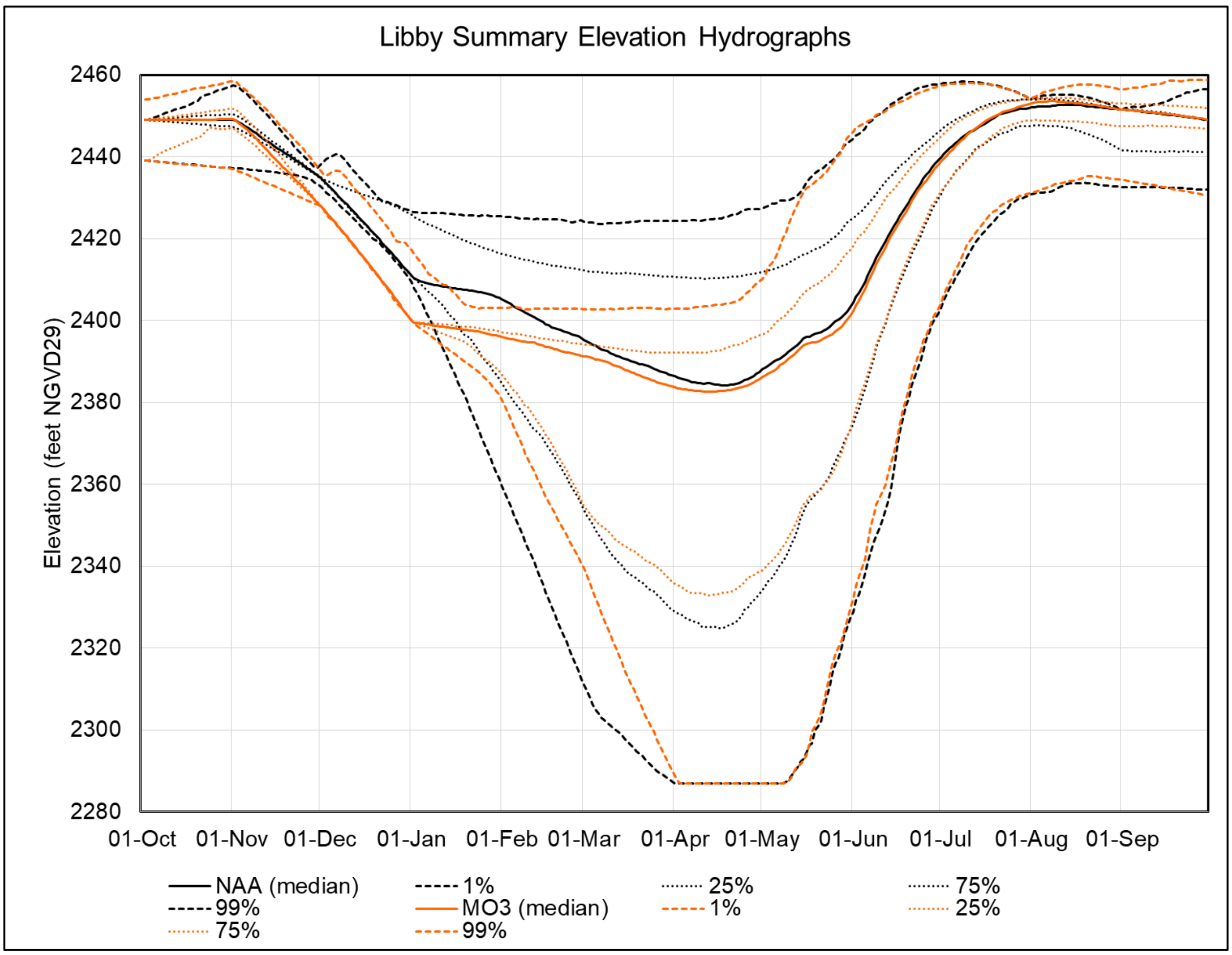


Figure 6-1. Libby Dam-Lake Koocanusa Summary Forebay Elevations for Multiple Objective Alternative 3 Versus the No Action Alternative

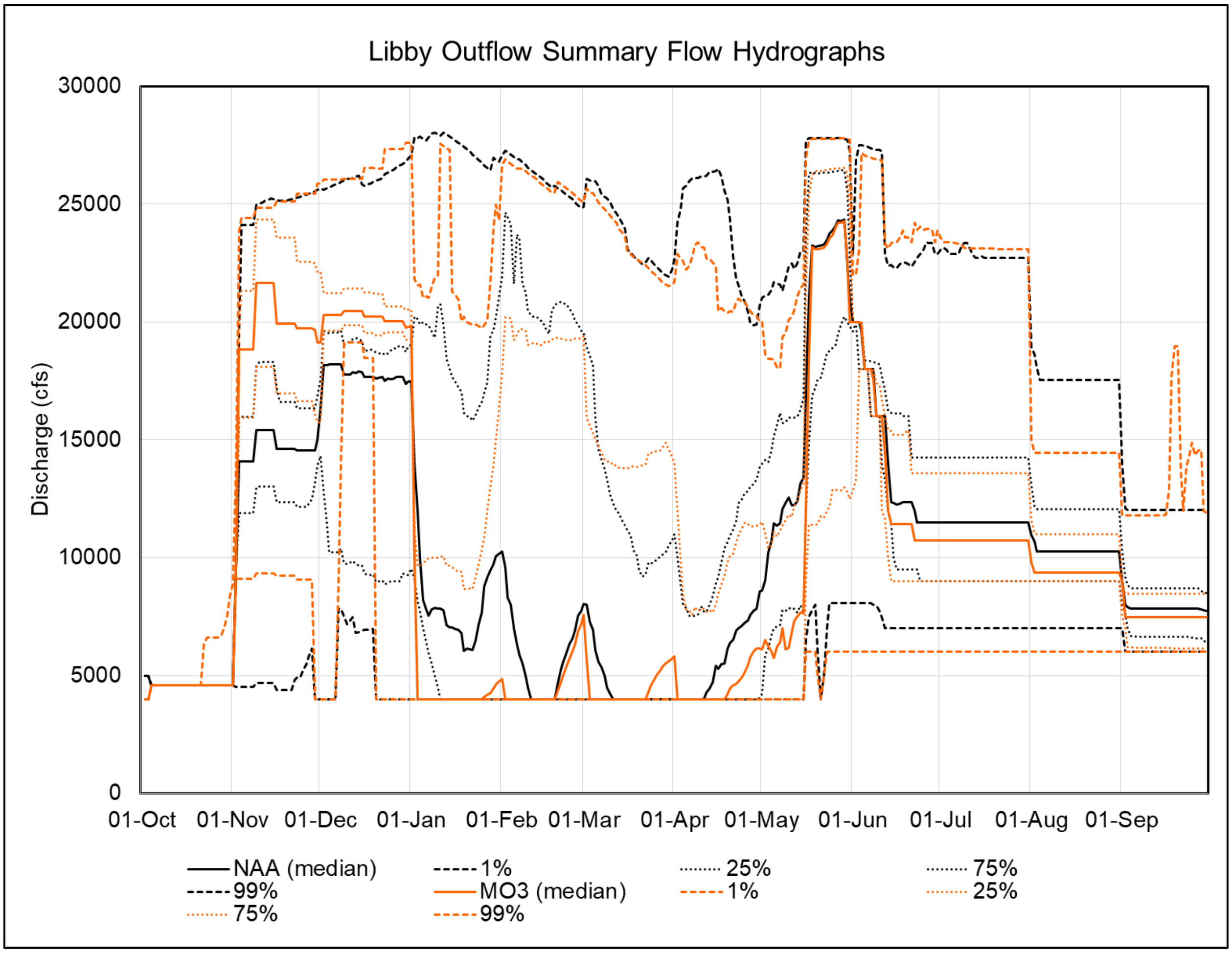


Figure 6-2. Libby Dam-Lake Koocanusa Summary Outflows for Multiple Objective Alternative 3 Versus No Action Alternative

Similar to the No Action Alternative, Libby Dam's SWS provides some ability to adjust where in the water column water is drawn from. The range of the SWS bulkheads is from elevation 2,409 feet to 2,200 feet NGVD29. Because SWS protocol maintains at least 30 feet of submergence over the top row of the bulkheads for hydraulic stability, the SWS has the ability to perform under the full range of possible MO3 drawdown operations with a similar efficiency as under the No Action Alternative. Modeled forebay elevations under MO3 are predicted to be well within the operating range of the SWS and similar to the ranges observed in historical years described in Section 3.1.1.1.

The ability of the SWS to manage discharge temperatures under a variety of drawdown and inflow conditions will continue under MO3. However, for the SWS to achieve the best possible downstream temperatures, thermal stratification must be present in the forebay. The onset of thermal stratification is difficult to predict and can vary from year to year due to reasons such as inflow volumes, inflow temperatures, reservoir drawdown elevation, discharge volumes, and weather conditions. Historical temperature data suggests that holding the pool higher results in colder reservoir temperatures and difficulty for the SWS to achieve the best possible downstream temperatures. When the pool is drafted deeper, the pool volume is less thereby allowing for greater warming in the spring and summer from warmer inflows and warming air temperatures.

The lower reservoir elevations under MO3 for the driest 40 percent of years are likely substantial enough to result in a change in forebay temperatures and thermal stratification compared to the No Action Alternative. These lower reservoir elevations should result in slightly warmer reservoir temperatures and earlier thermal stratification during the spring, resulting in a greater ability for the SWS to achieve downstream water temperature objectives when compared to the No Action Alternative. Under the No Action Alternative, downstream river temperatures during the fall and winter are generally several degrees warmer than pre-dam Kootenai River conditions, while water released from the dam during the spring and summer is generally several degrees cooler than natural river conditions. Overall, the limitations of the SWS that exist for the No Action Alternative are expected to continue for MO3.

Changes in downstream temperatures from Libby Dam to Bonners Ferry may result from MO3 increasing the median average monthly flows in November and December and decreasing the median monthly flows in January through April. During the cold winter months, Kootenai River water can cool by several degrees between Libby Dam and Bonners Ferry if flows are held low. Therefore, by increasing November and December flows, MO3 may increase downstream temperatures. However, by decreasing the flows from January through April, MO3 may decrease temperatures by allowing the natural cooling of the river as it moves downstream. These lower winter temperatures in the Kootenai River would benefit winter spawning fish species, such as burbot, which require near-freezing river temperatures (<35.6°F or <2°C) to spawn.

Under MO3, three operational measures apply to Hungry Horse Dam:

- Sliding Scale at Libby And Hungry Horse
- Hungry Horse Additional Water Supply
- Ramping Rates for Safety

The operational measure Hungry Horse Additional Water Supply would allow for the additional release of 90 kaf of stored water during the summer after the typical refill period for water supply; operational measure Sliding Scale *a*t Libby And Hungry Horse would implement a sliding scale draft based on a local forecast (rather than The Dalles forecast); and operational measure Ramping Rates *f*or Safety would lift all ramping rate limitations when restrictions are not for safety. None of these operational measures would likely have an impact on the ability to operate the SWS based on reservoir elevations expected under MO3 (Figure 6-3). The deeper draft associated with carryover impacts from *Hungry Horse Additional Water Supply* results in lower reservoir elevations in winter. Although selective withdrawal would continue to be operational, drawing the reservoirs down lower in the winter may allow for greater warming in the reservoir and downstream in the early spring.

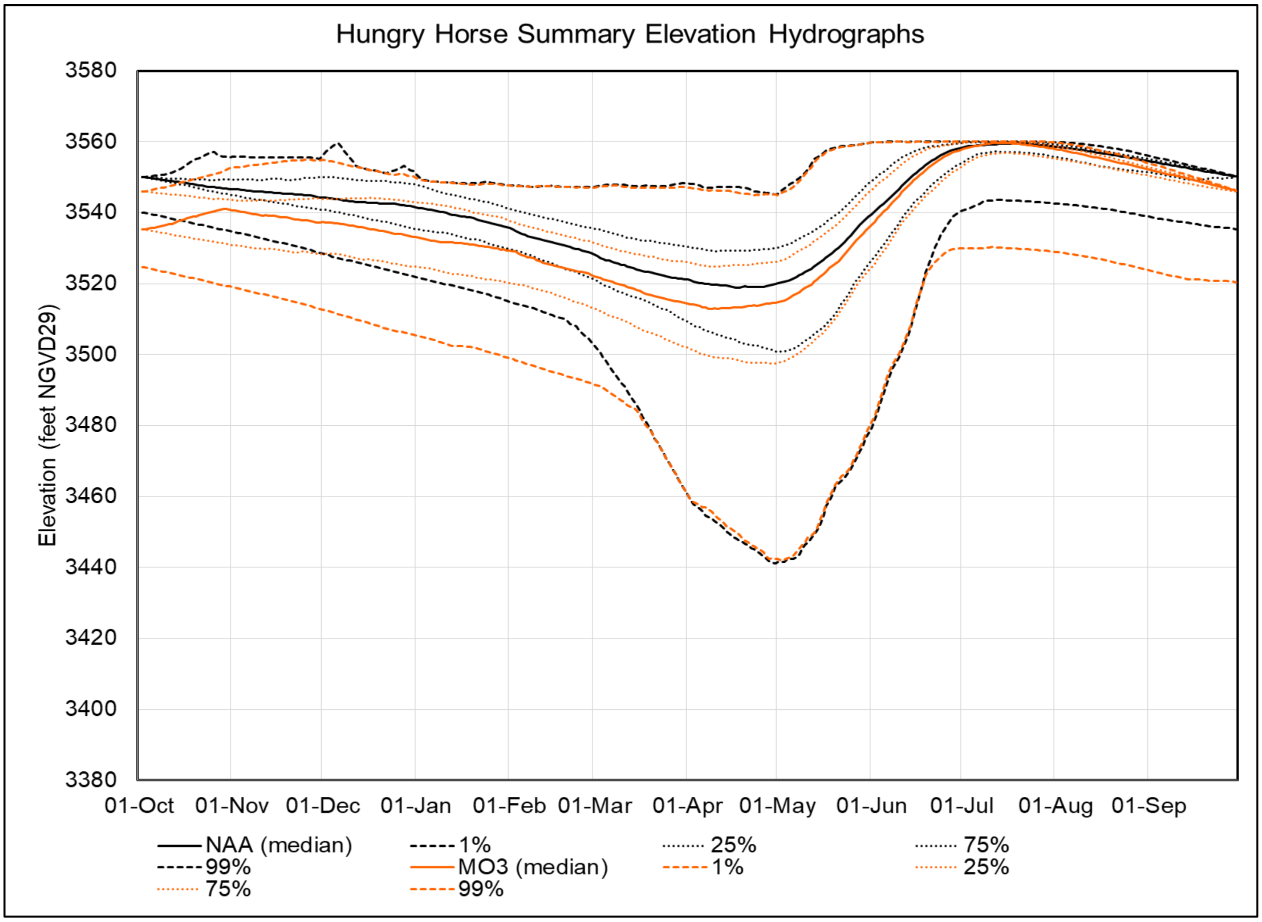


Figure 6-3. Hungry Horse Reservoir Summary Elevation Hydrograph for Multiple Objective Alternative 3 Versus No Action Alternative

6.1.1.2 Albeni Falls Dam and Reservoir

Under the MO3 Alternative, Lake Pend Oreille and the Pend Oreille River will experience little change in elevation and flow compared to the No Action Alternative. Although flow reductions for Hungry Horse under MO3 can be seen through the Pend Oreille River Basin, flow reductions are increasingly diluted moving downstream. As such, under MO3, Lake Pend Oreille and the Pend Oreille River will see very little hydrological change compared to the No Action Alternative (Figure 6-4).

Water temperatures in the Pend Oreille River upstream and downstream of Albeni Falls Dam were modeled using W2 for the period 2004 through 2006. The reason for using this time period is described in Section 2.2.3. W2 model results indicate little change in water temperatures upstream and downstream of Albeni Falls Dam. In general, temperature changes between MO3 and the No Action Alternative is about ± 0.2 to -1.4 degrees Fahrenheit (± 0.1 to 0.8 degree Celsius) with increases and decreases evenly distributed (Figure 6-5 and Figure 6-6).

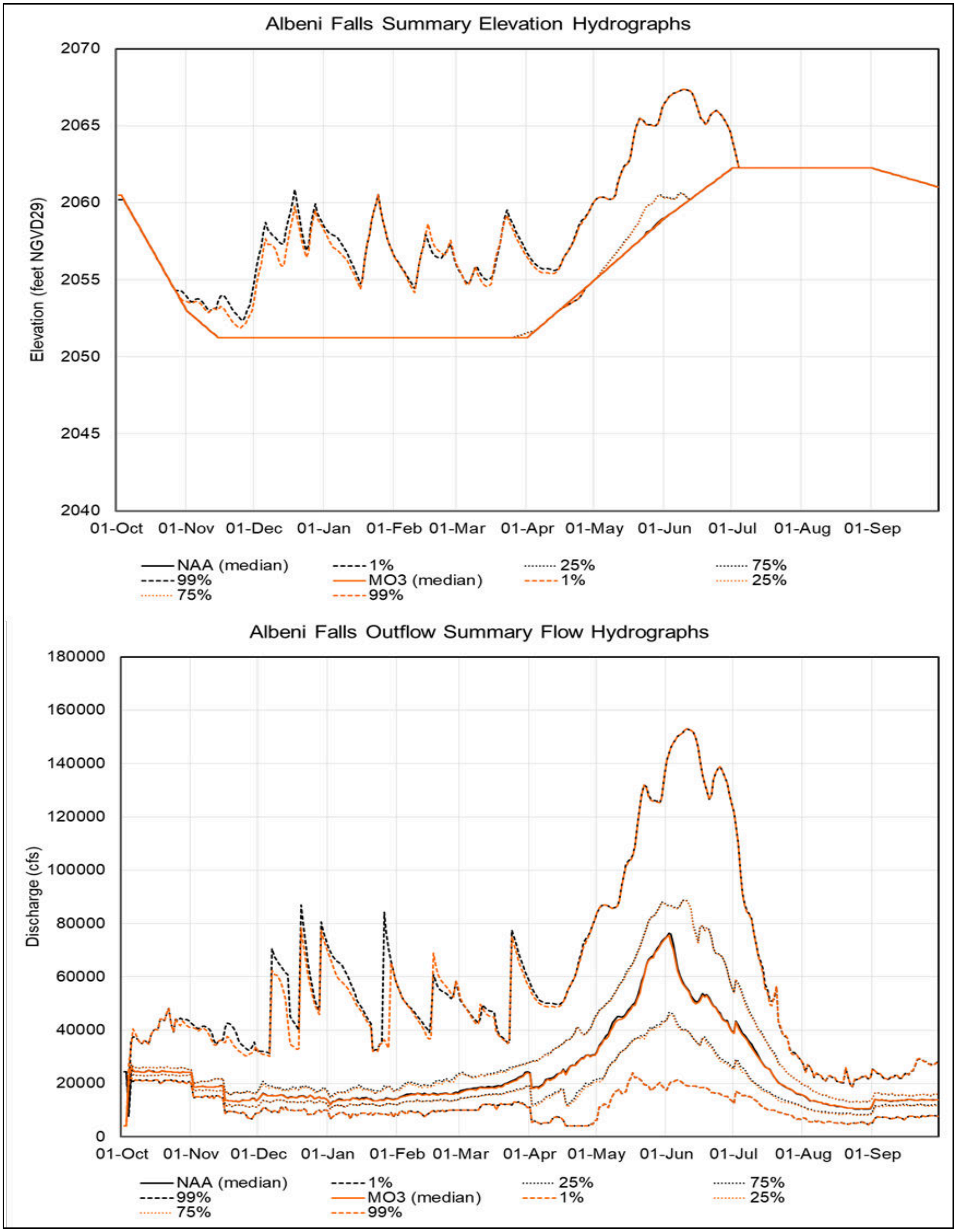


Figure 6-4. Albeni Falls Reservoir Summary Elevation Hydrographs and Outflows for Multiple Objective Alternative 3 Versus No Action Alternative

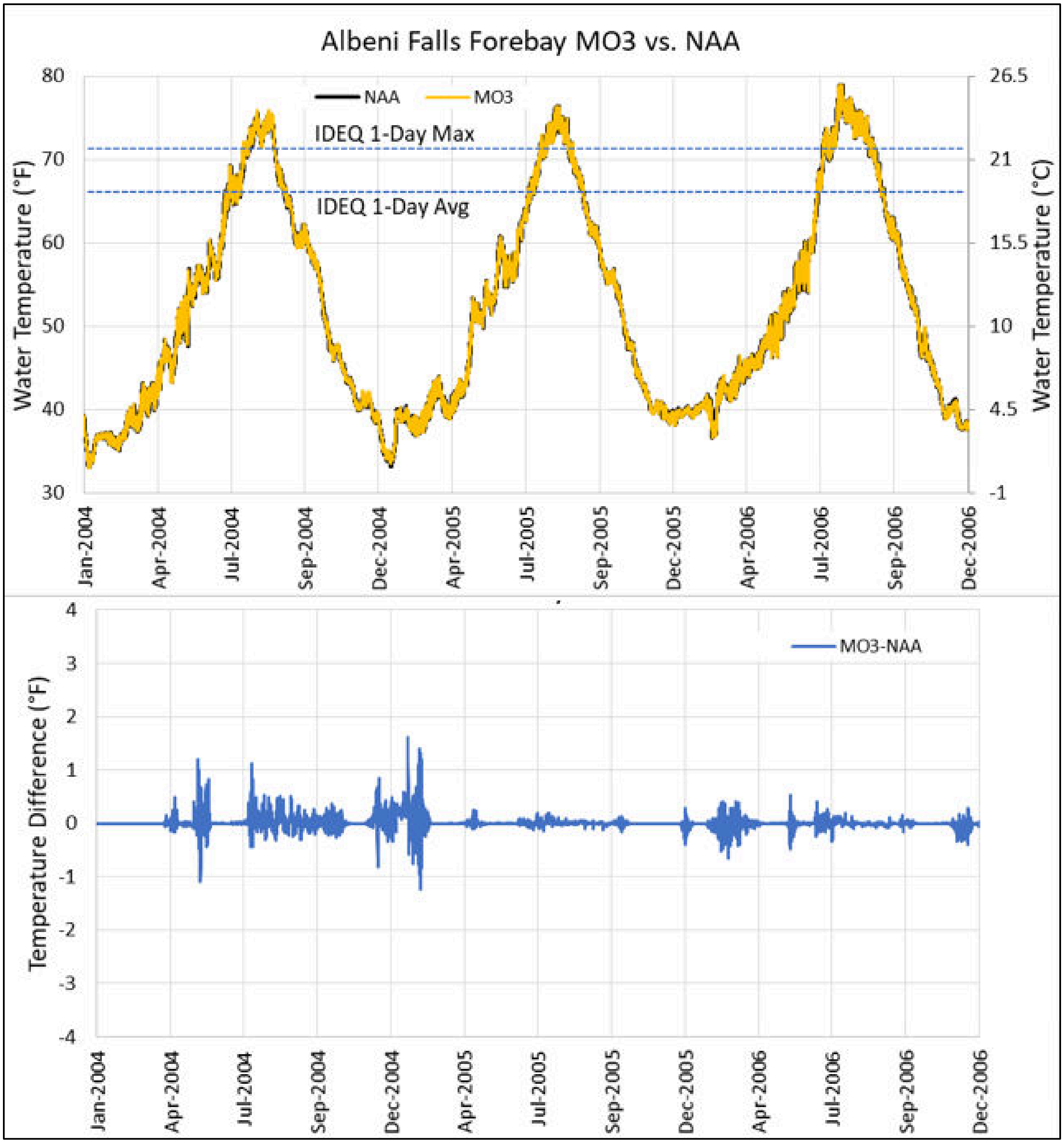


Figure 6-5. Modeled Forebay Temperatures for No Action Alternative and Multiple Objective Alternative 3 at Albeni Falls for 2004 to 2006

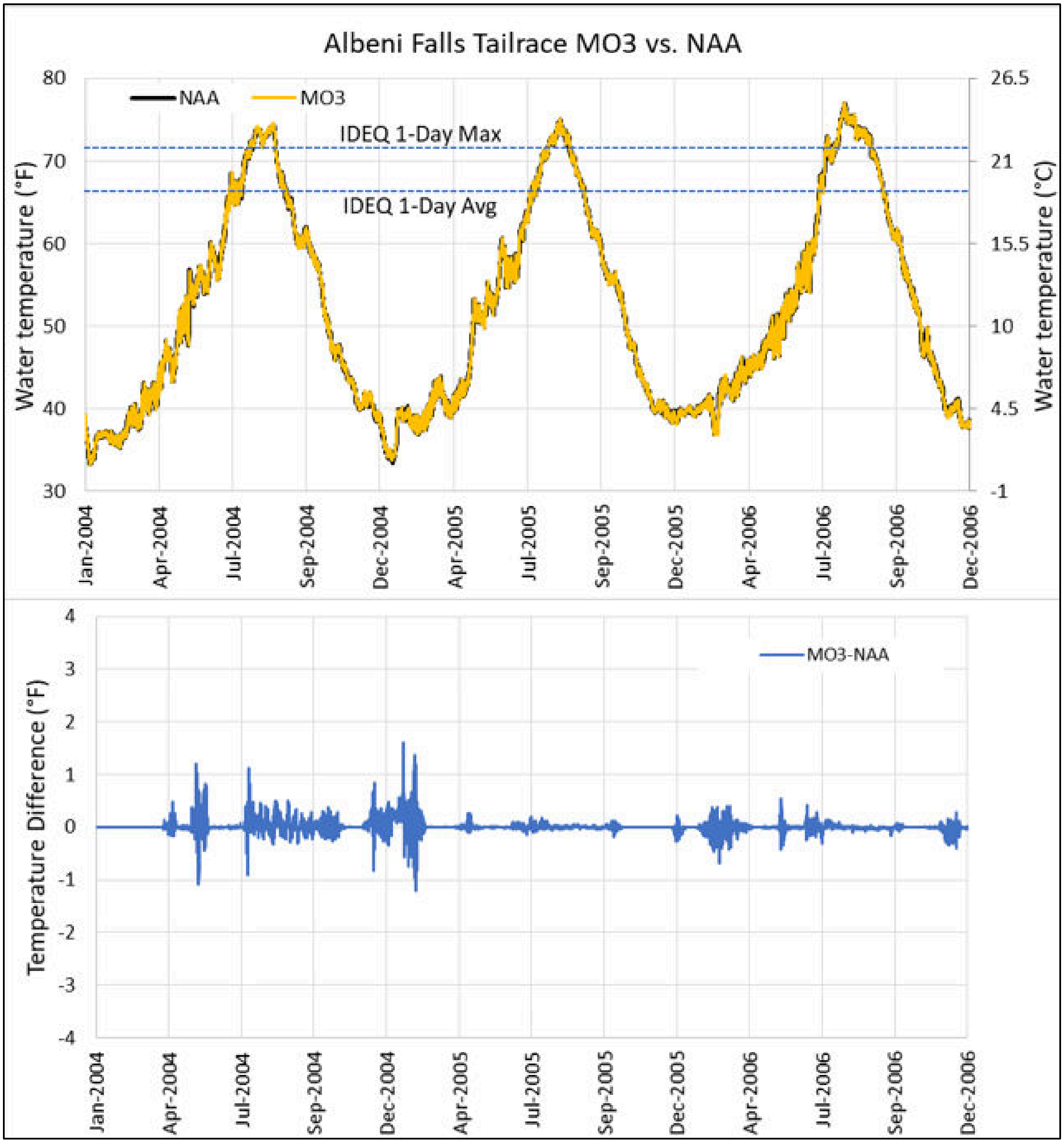


Figure 6-6. Modeled Tailwater Temperatures for No Action Alternative and Multiple Objective Alternative 3 at Albeni Falls for 2004 to 2006

6.1.1.3 Grand Coulee and Chief Joseph Dams and Reservoirs

Under MO3, the operations of Grand Coulee Dam and Lake Roosevelt above the dam are altered by four operational measures:

- *U*pdate *S*ystem FRM *C*alculation
- *Grand Coulee M*aintenance *O*perations
- *Planned Draft Rate a*t Grand Coulee
- *Lake Roosevelt A*dditional *W*ater *S*upply

Grand Coulee Maintenance Operations would address operational constraints for ongoing Grand Coulee maintenance of power plants and reduce the hydraulic capacity through the power plants, increasing the likelihood of spill, but this is largely offset by the impacts of other measures on spring flows. Operational measure *Lake Roosevelt Additional Water Supply* increases pumping for irrigation and municipal and industrial (M&I) purposes, directly reducing outflows. Increased withdrawal under this operational measure would begin in March (0.6 kcfs increase in pumping) and increase through the summer to a maximum additional withdrawal of 4.1 kcfs in July. A more in-depth discussion of these operational measures and their effects can be found in [Section H&H-MO3].

Many of the MO3 measures impact winter and spring storage and outflows; however, they are not expected to impact temperatures significantly. MO3 water temperatures are nearly identical to conditions under the No Action Alternative in Lake Roosevelt and the Columbia River downstream. In the reservoir, the impacts are greatest near Grand Coulee Dam and are reduced toward the U.S.-Canada border wherein the impacts from MO3 are almost unnoticeable at Hall Creek. These differences, on average, are very small in the reservoir for MO3.

For the LF/HT–type years, the modeled water temperature downstream of Grand Coulee during the spring and early summer months are approximately 0.3 degree Fahrenheit warmer, which is within the margin of error for the model, (for the period May through July) than the No Action Alternative. These differences are likely due to a combination of the water year type (extreme low flow year with high temperatures susceptible to changes in operations) and operational changes resulting in reduced outflows (FRM and Water Supply measures). An additional factor influencing spring and summer temperatures in some years may be winter and spring operations that decrease storage during that period, which would potentially reduce the cold water mass that would influence the inflowing temperature signal from upstream.

Additionally, based on the 5-year period presented in Figure 6-7 the Washington State water quality criteria of 61°F would be exceeded, on average, by an additional two days per year compared to the No Action Alternative. The small flow pattern change in Grand Coulee Dam outflows would be seen through Rufus Woods Lake and downstream in the tailwater of Chief Joseph Dam.

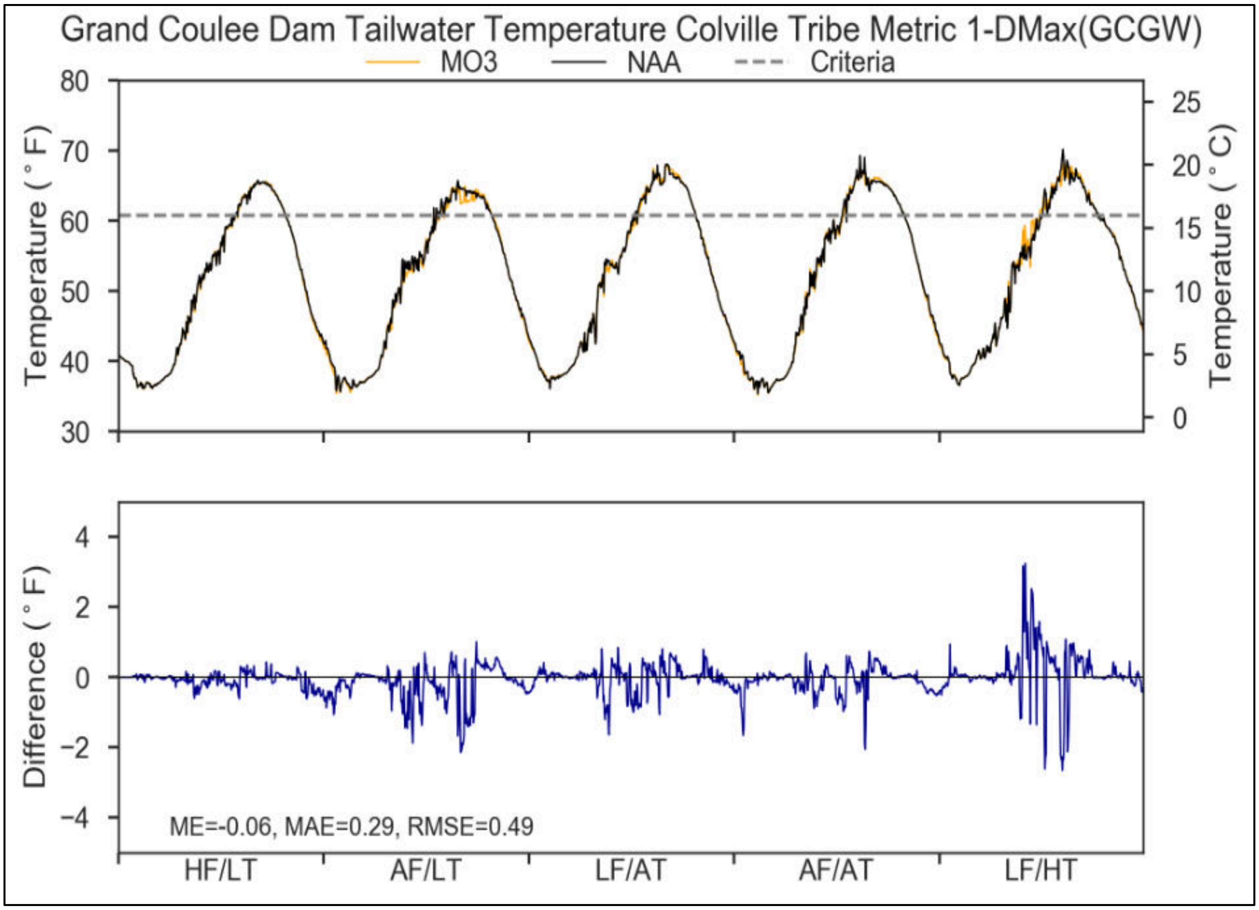


Figure 6-7. Modeled Tailwater Temperature for the No Action Alternative and Multiple Objective Alternative 3 at Grand Coulee Dam Under a 5-Year Range of River and Meteorological Conditions Compared to the Confederated Colville Tribe 1-D Maximum Water Quality Criterion

Under MO3, reservoir elevation changes and corresponding project outflow changes predicted at Grand Coulee Dam would carry downstream through Rufus Woods Lake to Chief Joseph Dam. In general, monthly average outflows out of Chief Joseph Dam would be similar to the No Action Alternative. Average monthly outflows would slightly increase in November and December by 2 to 4 percent, reflecting the increased outflow from Libby Dam during this time period. Average monthly outflows would slightly decrease by 1 to 5 percent from January through September, largely related to changes in Libby Dam operations, Grand Coulee operations and the *Lake Roosevelt Additional Water Supply* measure (Figure 6-8). Since Chief Joseph Dam is a run-of-river project, little change to forebay elevations would occur for MO3 when compared to the No Action Alternative (Figure 6-9).

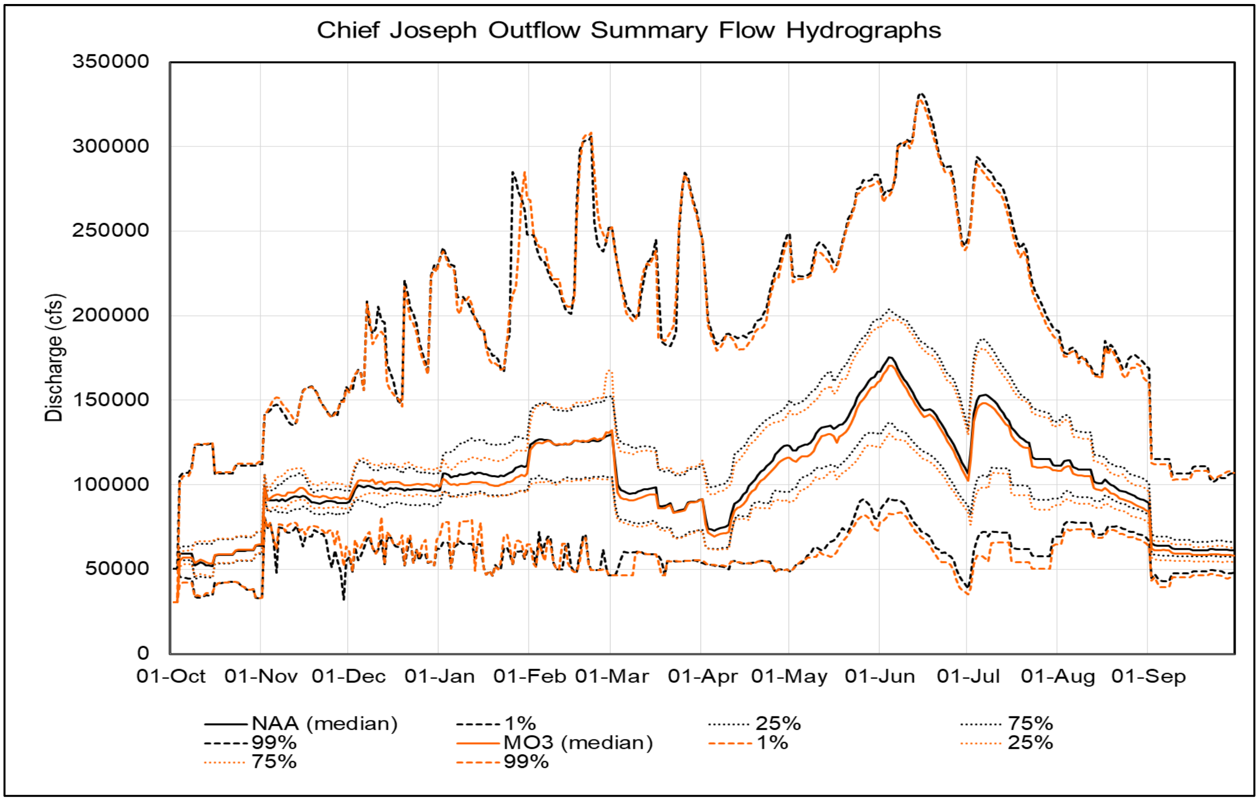


Figure 6-8. Chief Joseph Dam-Rufus Woods Lake Outflows for Multiple Objective Alternative 3 Versus No Action Alternative

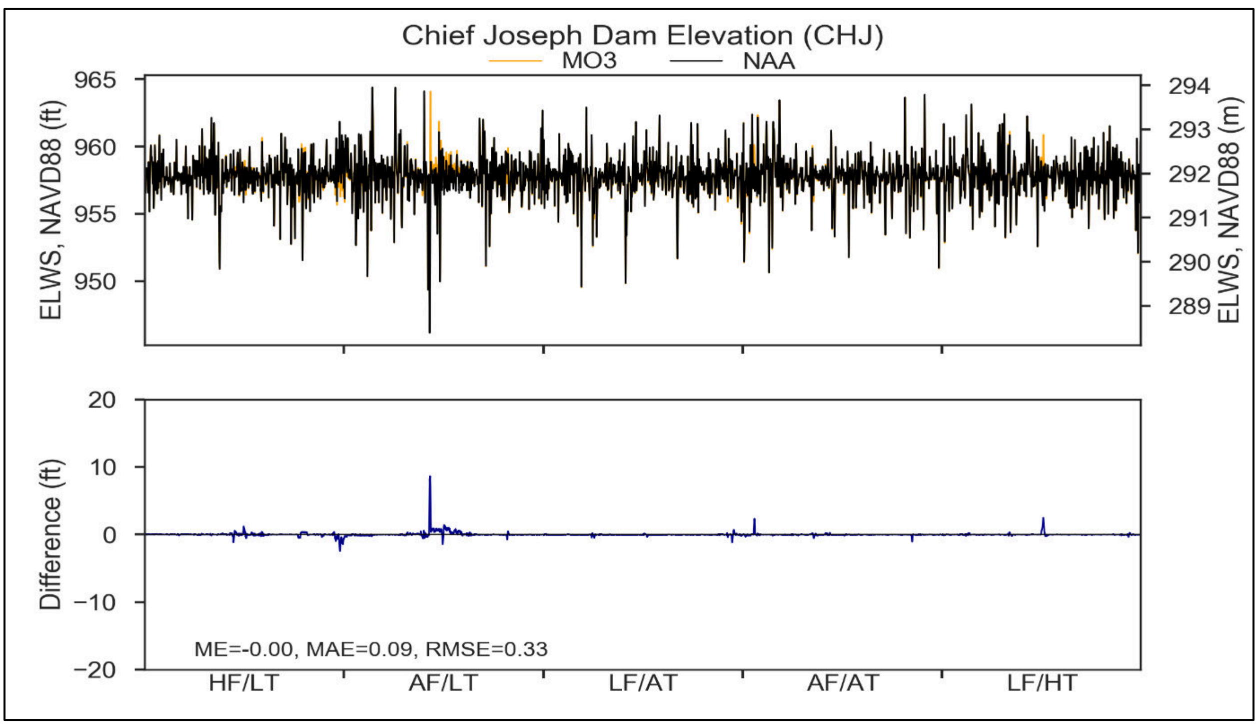


Figure 6-9. Chief Joseph Dam-Rufus Woods Lake Forebay Elevations Multiple Objective Alternative 3 Versus No Action Alternative

Water temperatures under MO3 at Chief Joseph Dam tailwater are similar to or slightly cooler than the No Action Alternative with the majority of temperature differences in the ±1 to 2 degrees Fahrenheit range (Figure 6-10). In general, temperatures modeled for MO3 are similar to or slightly cooler than the No Action Alternative for most river and meteorological conditions. In particular, maximum summer temperatures are typically 0.5 to 2 degrees Fahrenheit cooler for MO3 under the 5-year range of river flow and meteorological conditions. An exception is for the LF/HT scenario where river temperatures in the spring are expected to be up to 2 degrees Fahrenheit warmer under MO3. Tailwater temperatures under both MO3 and the No Action Alternative are predicted to exceed the tribal water temperatures criterion (1-day maximum of 18°F) as well as the Washington State criterion of 63.5°F (17.5°C) as measured by the 7-day average of the daily maximum temperature in August and September. Similar to the No Action Alternative, there is little difference in temperature between Grand Coulee Dam tailwater (Figure 6-7) and Chief Joseph Dam tailwater conditions (Figure 6-10) under MO3, showing that water temperatures released from Lake Roosevelt are passed through Rufus Woods Lake mainly unchanged.

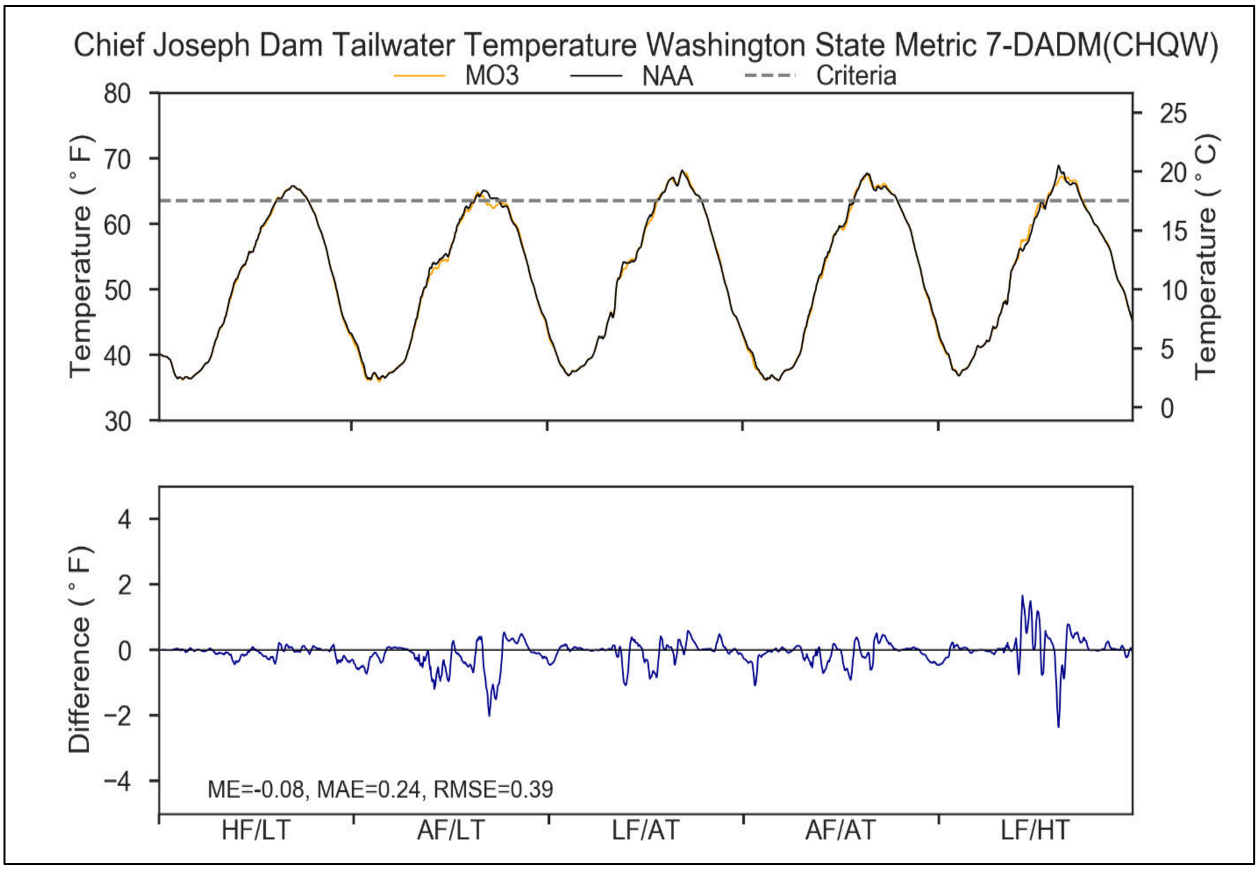


Figure 6-10. Modeled Tailwater Temperature for the No Action Alternative and Multiple Objective Alternative 3 at Chief Joseph Dam Under a 5-Year Range of River and Meteorological Conditions

The operational changes for MO3 do cause a few temperature differences as can be seen in the figures above. In terms of the actual number of days of the criteria being exceeded, those changes can be seen in Table 6-1. The blue highlighted cells show when an increased number of exceedances occurs as compared to NAA. Only the months where the criteria is exceeded is shown in the table. If a month has all zeroes shown, it is only because that month has exceeded criteria under a different alternative.

Table 6-1. Difference in Number of Days the Temperature Criteria is Exceeded at the Tailwater Sites of Grand Coulee and Chief Joseph for the Multiple Objective 3 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Grand Coulee	June	0	0	0	0	**1**
Grand Coulee	July	0	-3	-4	-2	**2**
Grand Coulee	August	0	0	0	0	0
Grand Coulee	September	0	0	0	0	0
Grand Coulee	October	0	**1**	0	0	0
Chief Joseph	July	0	0	-2	0	**2**
Chief Joseph	August	**1**	**1**	0	0	0
Chief Joseph	September	0	-22	0	0	**1**
Chief Joseph	October	0	-3	0	0	0

6.1.2 Total Dissolved Gas

6.1.2.1 Libby and Hungry Horse Dams and Reservoirs

Libby Dam is typically operated to minimize spill due to associated water quality concerns such as elevated TDG. Under MO3, Libby Dam's draft and refill operations will be modified resulting in an increase in the highest releases from the dam. This operational change is predicted to increase the chance of spill at Libby Dam. The 80-year period of record flows (1928 to 2008) were used to predict TDG, as presented in Figure 6-11. This shows that the number of years where spill could occur increases from 3 years under the No Action Alternative to 5 years under MO3. The number of days exceeding 110 percent would increase as well, from 8 days for the No Action Alternative to 27 days for MO3. Although spill from Libby Dam for the 80-year model period are predicted to increase under MO3, the frequency of spill is still small.

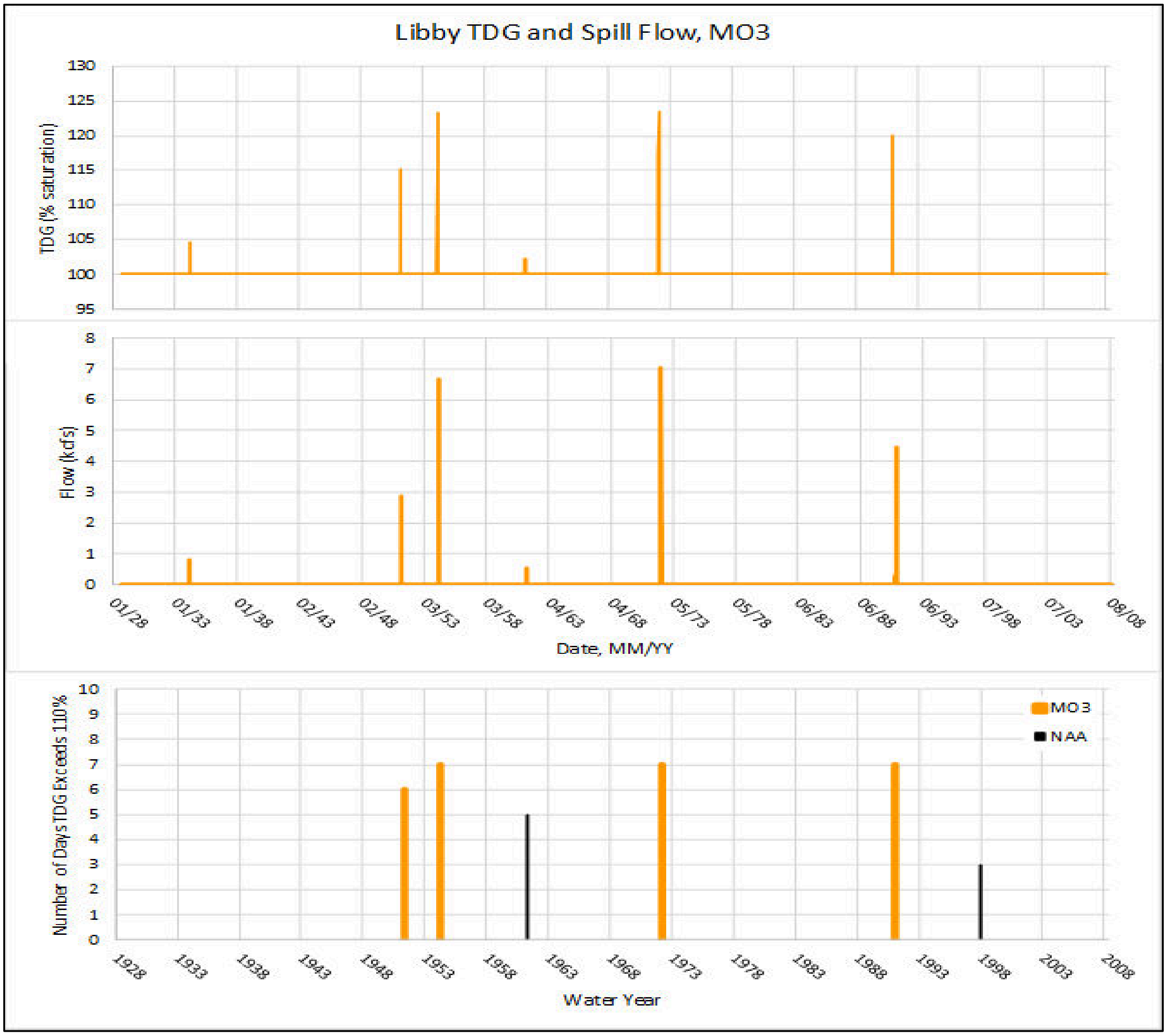


Figure 6-11. Modeled Tailwater Total Dissolved Gas and Spillway Flows for the No Action Alternative and Multiple Objective Alternative 3 at Libby Dam over an 80-Year Period

Under MO3, the operations of Hungry Horse Dam are altered by three operational measures:

- *Hungry Horse Additional Water Supply*
- *Sliding Scale at Libby And Hungry Horse*
- *Ramping Rates for Safety*

The additional draft provided in these measures, particularly the additional 90 kaf of draft in dry years under *Hungry Horse Additional Water Supply*, could reduce the likelihood of spill and associated elevated TDG concentrations in the following spring. These flow and spill impacts are small, therefore, TDG below the dam under MO3 is expected to be relatively similar to the No Action Alternative in most years.

Figure 6-12 shows the number of days that TDG is anticipated to exceed 110 percent below Hungry Horse Dam under MO3, for the period of record flows (1929 through 2008). The number of days that TDG goes above the State of Montana water quality criterion of 110 percent in MO3 is similar to the No Action Alternative. Some years would see more violations while others would see fewer. On average, TDG would exceed 110 percent in the river below the dam approximately 0.5 days more per year compared to the No Action Alternative (775 days compared to 809 under NAA). These are results of ResSim modeled operations, which do not consider spill when making releases for water supply (Hungry Horse Additional Water Supply), as would be done in real time. In application, it would be unlikely that spill would be required to meet water supply needs.

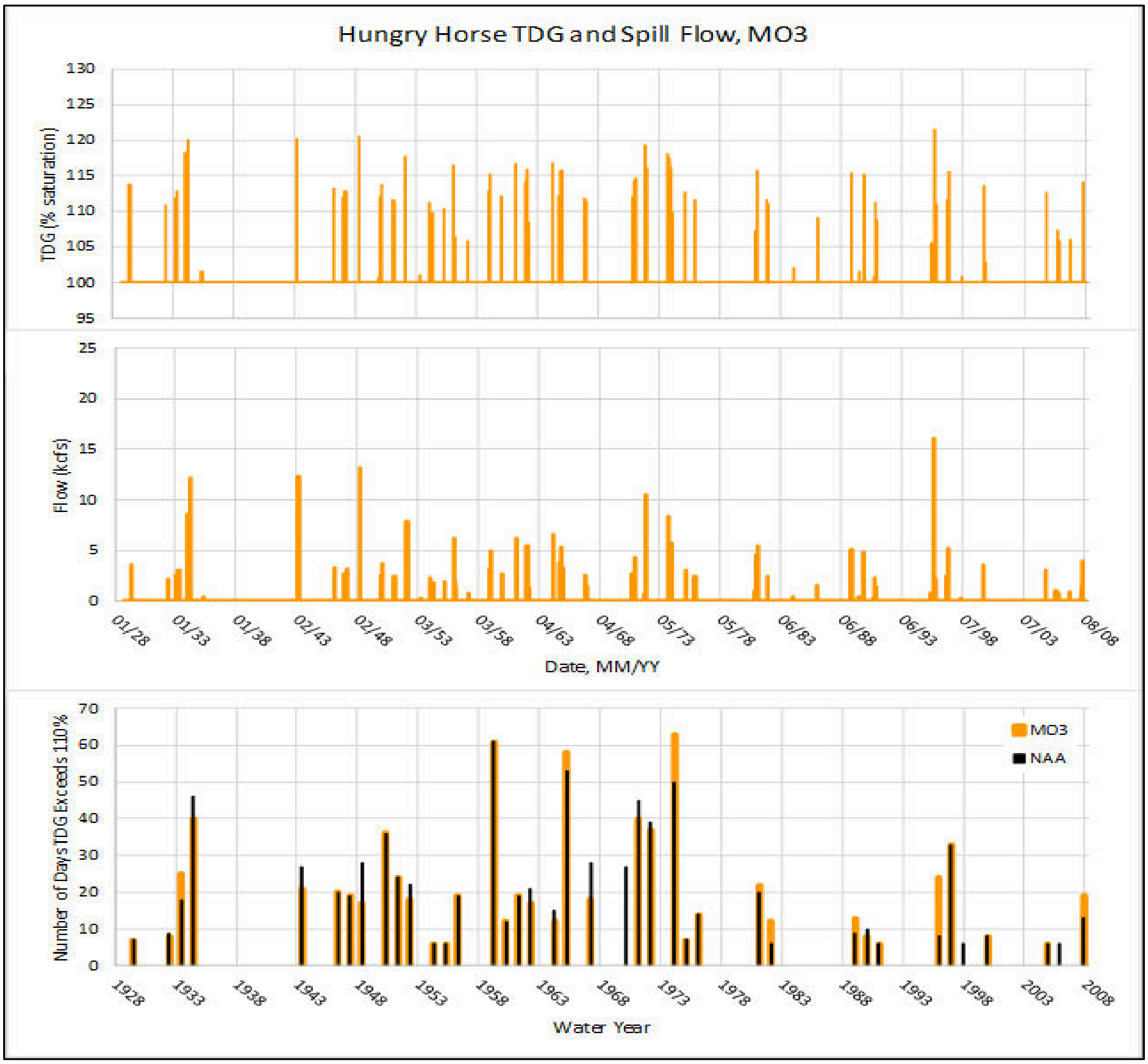


Figure 6-12. Number of Days that Total Dissolved Gas is Above the 110 percent State Water Quality Criterion Under the No Action Alternative and Multiple Objective Alternative 3 at Hungry Horse Dam

6.1.2.2 Albeni Falls Dam and Reservoir

TDG in the Pend Oreille River upstream of Albeni Falls Dam can be greater than 110 percent largely because of spillway releases from Cabinet Gorge Dam located on the Clark Fork River about 55 miles upstream of Albeni Falls Dam. During most years, Albeni Falls Dam spills during high flow spring runoff. In general, spillway discharges up to about 10 kcfs can increase TDG saturations over forebay levels by about 1 to 2 percent, while spill between 10 to 50 kcfs can increase TDG saturations downstream of Albeni Falls by about 5 to 9 percent. When Pend Oreille River flows exceed about 50 to 60 kcfs, Albeni Falls Dam powerhouse operations are suspended and the spillway gates are raised, allowing the river to flow relatively un-impounded across the dam. Under these high flow conditions, Albeni Falls Dam produces no TDG as the river is essentially free flowing. Spillway flows at Albeni Falls Dam were modeled under MO3 and the No Action Alternative for the 80-year period from 1928 to 2008 using the ResSim model (Figure 6-13). There would be little difference in spillway flows between MO3 and the No Action Alternative. For both alternatives, spillway flows are predicted to range between 1 and 50 kcfs in nearly every year at Albeni Falls Dam, with many years having spill exceed about 60 kcfs resulting in free-flowing conditions. These similar spillway flows under MO3 and the No Action Alternative are expected to result in no change in TDG saturations downstream of Albeni Falls Dam.

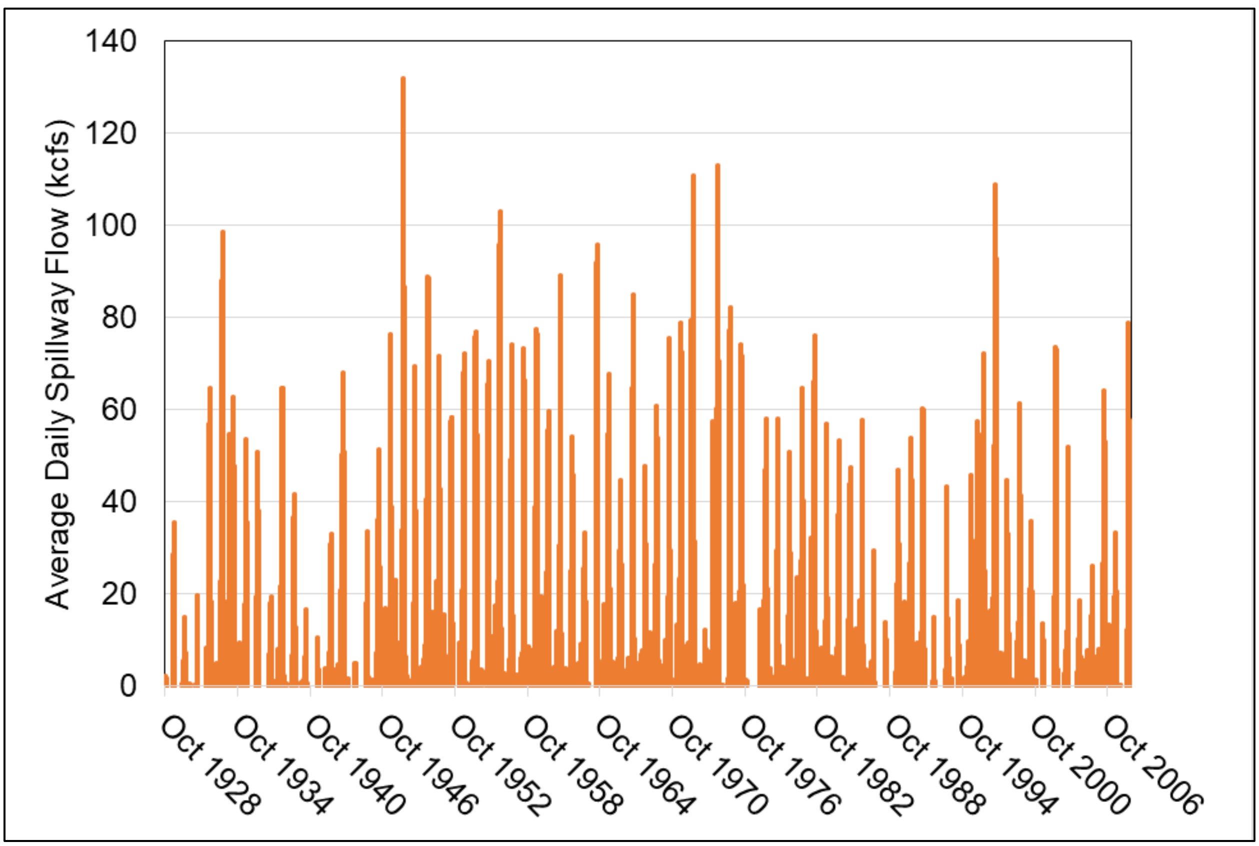


Figure 6-13. Modeled Tailwater Spillway Flows for the No Action Alternative and Multiple Objective Alternative 3 at Albeni Falls Dam over an 80-Year Period

6.1.2.3 Grand Coulee and Chief Joseph Dams and Reservoirs

None of the operational measures in MO3 would notably affect TDG levels within Lake Roosevelt, which are largely influenced by upstream dams that are outside the scope of this analysis. Changes in operations of upstream dams result in an increase in inflows in November and December at Grand Coulee, which may have minor impacts on inflowing TDG but are not captured by the system modeling.

The operational measure *Planned Draft Rate at Grand Coulee* would result in a slightly earlier draft in Lake Roosevelt in wetter years as early as January; Update System FRM Calculation determines the deepest draft point in the spring, and in some years is slightly deeper. These changes result in increased flows in the winter and decreased flows in April through July, which reduce spill in some situations (Figure 6-16).

Starting in March, the increase in water withdrawal (0.6 kcfs) from Lake Roosevelt under operational measure *Lake Roosevelt Additional Water Supply* also decreases outflows and spill from Grand Coulee; however, this influence is not significant until April (3.2 kcfs increase in pumping and decrease in outflows) and continues through the summer period. A more in-depth discussion of these operational measures and their effects can be found in [Section H&H-MO3].

Overall, MO3 operational measures would result in higher Columbia River flows below the dam from December to February, when TDG is generally below the 110 percent Washington State and Colville Tribes water quality criteria. On average, the decrease in outflow and spill associated with the operational measure Lake Roosevelt Additional Water Supply results in a decrease in the modeled TDG for May andJune by about 5 percent, typically when the highest seasonal TDG concentrations are observed below the dam.

The *Grand Coulee Maintenance Operations* measure has the potential to increase spill through the reduction in the hydraulic capacity of the powerhouse at Grand Coulee; however, the other actions have a larger impact on outflows and associated spill. The *Grand Coulee Maintenance Operations* measure in isolation could result in significant increases in spill and TDG, in some cases producing TDG in excess of 130 percent for a limited duration. An additional impact that is expected from Grand Coulee Maintenance Operations is the potential for slightly deeper spill over the drum gates (when the forebay elevation is greater than 1,267 feet, NGVD29). Information to assess the magnitude of water quality impacts is unavailable but would likely result in small increases in TDG. In wet conditions, it is anticipated that potential maintenance activities could be delayed in advance of spill to allow spill over more gates. Another factor not considered in the analysis is that as maintenance occurs, there would be an increase to hydraulic capacity as more units become available. This would result in reduced spill and TDG in some cases; however, the other actions have a larger impact on outflows and associated spill.

As shown in Figure 6-14 and Figure 6-15, the combination of the MO3 operational measures tend to offset each other in the analysis of the alternative, and in some cases, result in a reduction in TDG. Average TDG is slightly lower (0.2 percent) but results in about 0.5 days of more Washington State water quality violations per year. Additionally, in the highest flow years, TDG concentration may be reduced in May and June under MO3 due to the water supply measure (*Lake Roosevelt Additional Water Supply*) (Table 6-3). The shaded area in the figure shows the entire range of TDG predicted by the MO3 and No Action Alternative simulations. The model indicates reductions in TDG in the early months compared to the No Action Alternative in high water years. Therefore, compared to the No Action Alternative, MO3 could reduce TDG, but the number of daily Washington State water quality violations in the Columbia River below the dam would mostly remain the same.

TDG at the forebay of Chief Joseph Dam is largely a function of the TDG released upstream from Lake Roosevelt and Grand Coulee Dam because little degassing occurs in Rufus Woods Lake. High inflow TDG saturations to Lake Roosevelt from Canada, as well as spill from Grand Coulee Dam via the outlet tubes, can increase TDG saturations in Rufus Woods Lake at the Chief Joseph Dam forebay to over 130 percent for a limited time. During periods when incoming TDG levels are above approximately 120 percent, spilling at Chief Joseph Dam over the spillway deflectors can degas the water and reduce downstream system TDG loading. Therefore, Chief Joseph Dam is often used to help manage overall system TDG production in the mainstem Columbia River. In addition, to avoid spilling through the outlet tubes at Grand Coulee Dam, spill is often shifted from Grand Coulee to Chief Joseph Dam to take advantage of the lower TDG produced by spilling over the deflectors. These operational strategies are expected to continue under MO3.

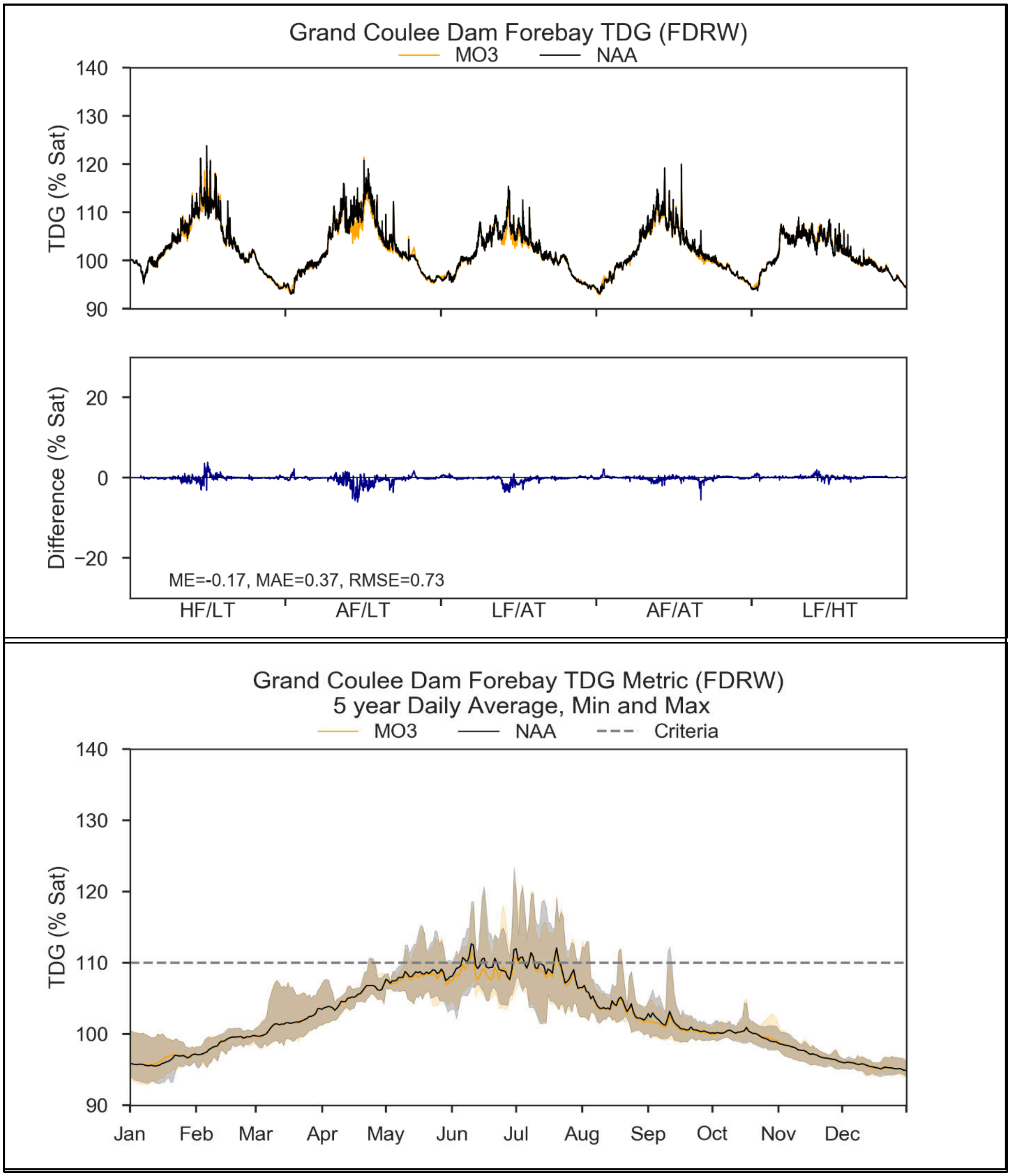


Figure 6-14. Modeled Forebay Total Dissolved Gas for the No Action Alternative and Multiple Objective Alternative 2 at Grand Coulee Dam Under a 5-Year Range of River and Meteorological Conditions and 5-Year Average Conditions

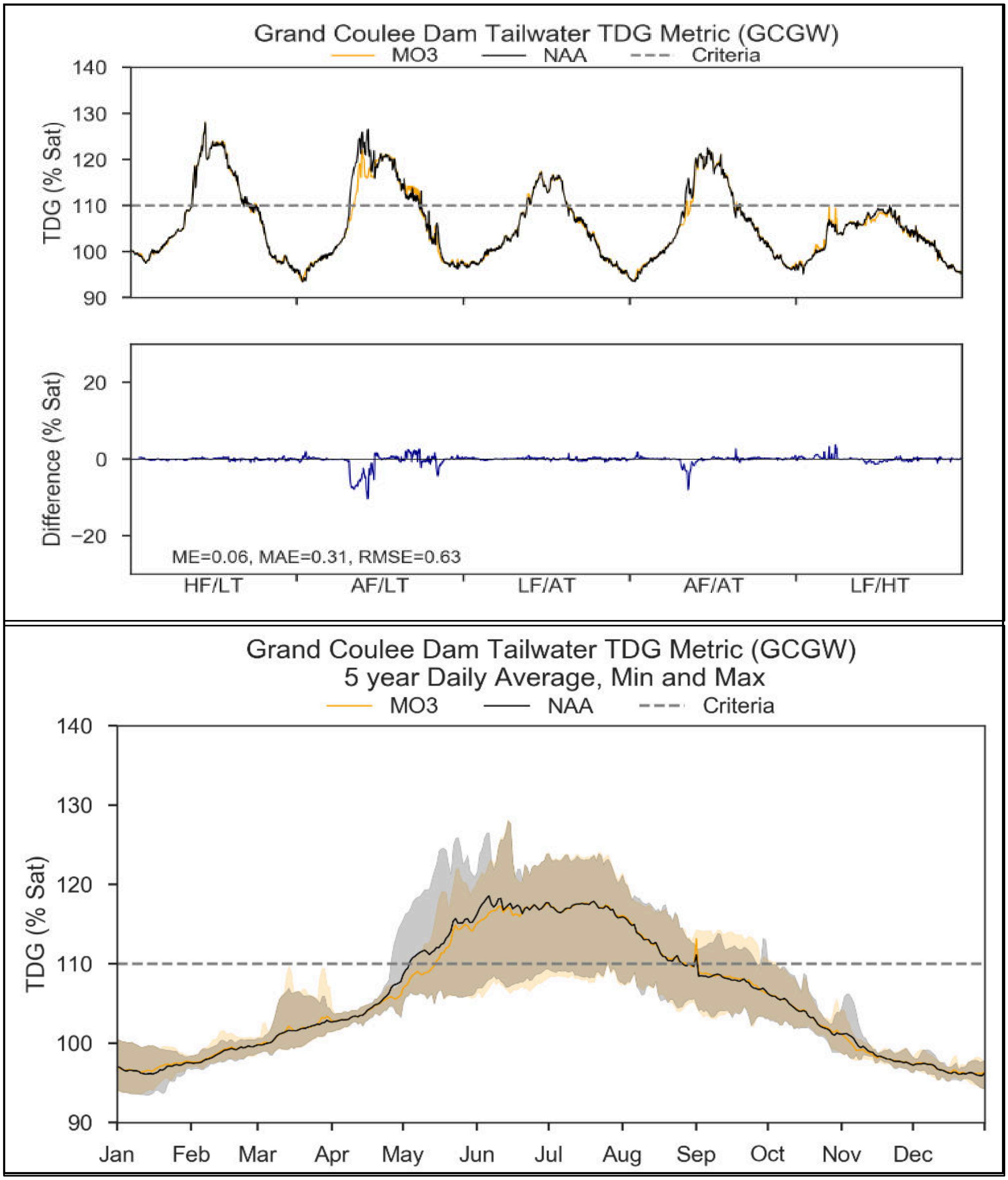


Figure 6-15. Modeled Tailwater Total Dissolved Gas for the No Action Alternative and Multiple Objective Alternative 3 at Grand Coulee Dam Under a 5-Year Range of River and Meteorological Conditions and 5-Year Average Conditions

Chief Joseph Dam TDG saturations at the forebay and tailwater modeled under MO3 were compared to the No Action Alternative (Figure 6-16 and Figure 6-17). In general, MO3 forebay TDG saturations are predicted to be similar to, or slightly lower than, the No Action Alternative under a wide range of flow and air temperature conditions. Tailwater TDG saturations under MO3 are predicted to be both lower and higher than the No Action Alternative depending on flow and meteorological conditions. The number of days the tailwater exceeds the 110 percent TDG criteria is predicted to be slightly lower under MO3 for all flow and meteorological conditions (Figure 6-18, Table 6-2, and Table 6-3), likely due to the FRM and water supply measures implemented at Grand Coulee Dam. Decreased TDG saturations between the forebay and tailwater during higher spill years such as 2011 (HF/LT) and 2012 (AF/LT) modeled under the No Action Alternative would continue under the MO3 Alternative. It is expected that under MO3, Chief Joseph Dam would continue to decrease TDG during high spill years when TDG saturations greater than about 120 percent occur in the forebay.

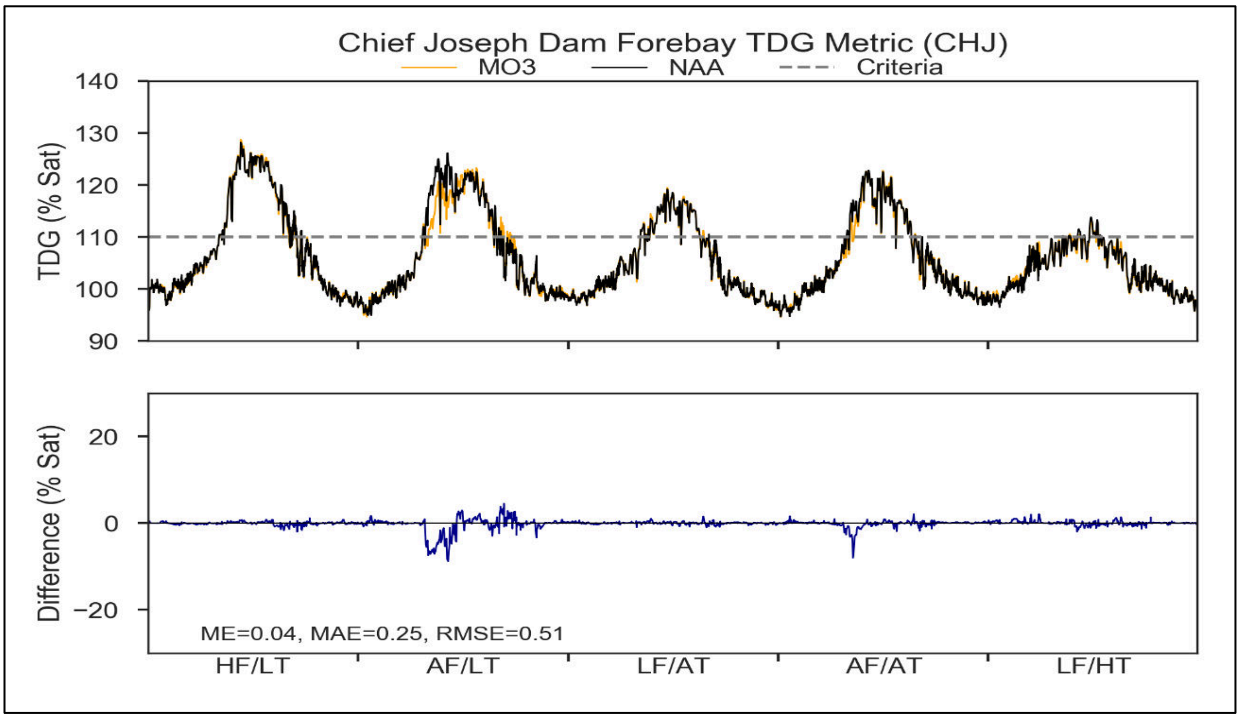


Figure 6-16. Modeled Forebay Total Dissolved Gas Saturations for the No Action Alternative and Multiple Objective Alternative 3 at Chief Joseph Dam Under a 5-Year Range of River and Meteorological Conditions

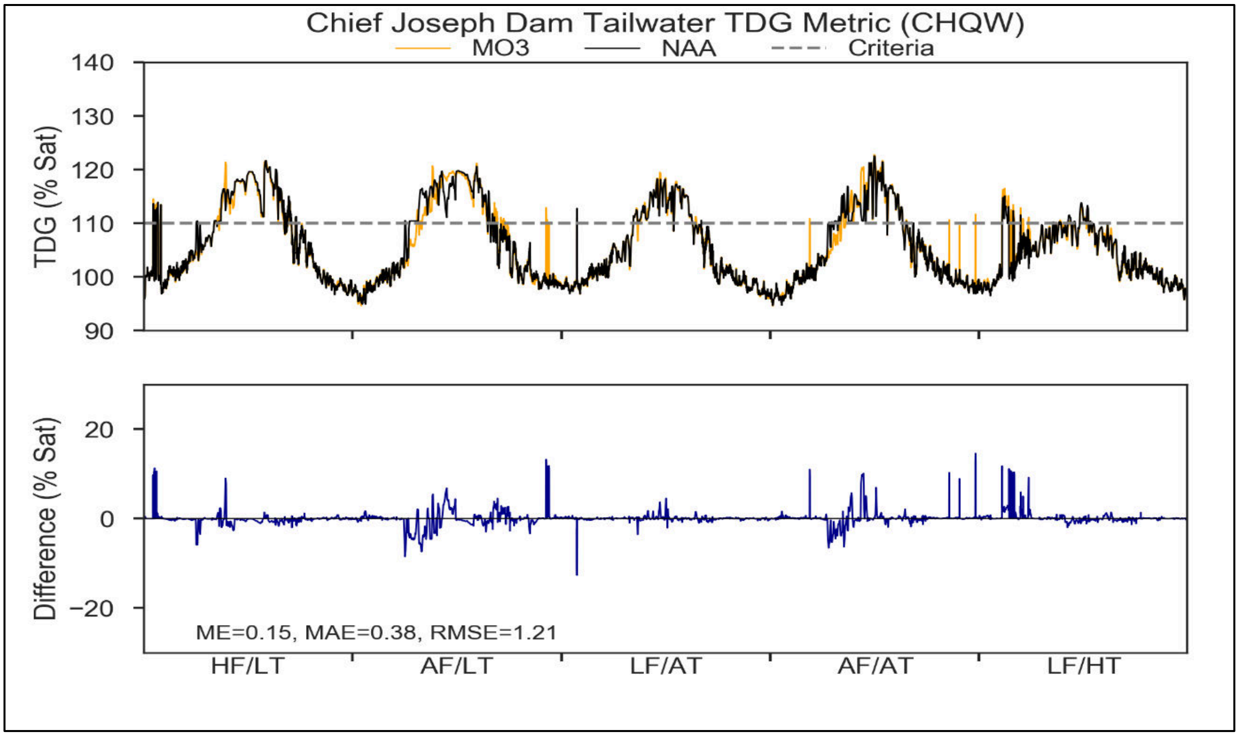


Figure 6-17. Modeled Tailwater Total Dissolved Gas Saturations for the No Action Alternative and Multiple Objective Alternative 3 at Chief Joseph Dam Under a 5-Year Range of River and Meteorological Conditions

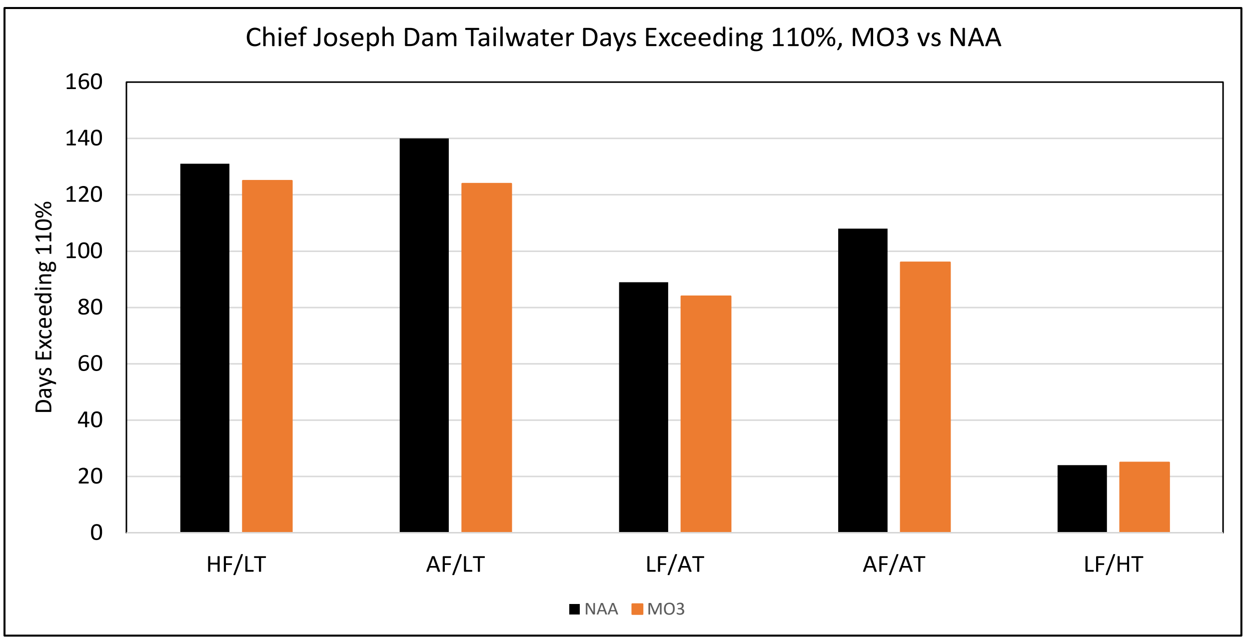


Figure 6-18. Days Exceeding the 110 percent TDG criteria for the No Action Alternative and Multiple Objective Alternative 3 at Chief Joseph Dam Tailwater Under a 5-Year Range of River and Meteorological Conditions

Table 6-2. Difference in Number of Days the TDG Criteria is Exceeded at the Forebay Sites of Grand Coulee and Chief Joseph for the Multiple Objective 3 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Grand Coulee	April	0	**4**	0	0	0
Grand Coulee	May	**4**	**1**	0	-2	0
Grand Coulee	June	-4	-11	**1**	-1	0
Grand Coulee	July	0	-5	**1**	**6**	0
Grand Coulee	August	**2**	**3**	0	0	0
Grand Coulee	September	0	0	0	0	0
Chief Joseph	April	0	-1	0	-1	0
Chief Joseph	May	0	-2	0	-5	**1**
Chief Joseph	June	0	0	0	0	-5
Chief Joseph	July	0	0	0	0	-1
Chief Joseph	August	-1	-1	**3**	0	0
Chief Joseph	September	-3	**8**	0	0	0
Chief Joseph	October	0	0	0	0	0

Table 6-3. Difference in Number of Days the TDG Criteria is Exceeded at the Tailwater Sites of Grand Coulee and Chief Joseph for the Multiple Objective 3 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Grand Coulee	April	0	-5	0	0	0
Grand Coulee	May	0	-4	0	-8	0
Grand Coulee	June	0	0	0	0	0
Grand Coulee	July	0	0	0	0	-1
Grand Coulee	August	0	0	0	-1	0
Grand Coulee	September	-2	0	0	0	0
Grand Coulee	October	**3**	0	0	0	0
Chief Joseph	January	**1**	0	-1	0	0
Chief Joseph	February	0	0	0	0	**2**
Chief Joseph	March	0	0	0	**1**	**3**
Chief Joseph	April	-3	-18	0	-11	0
Chief Joseph	May	-1	-1	-2	-6	**1**
Chief Joseph	June	0	0	0	0	-5
Chief Joseph	July	0	0	0	0	-1

6.1.3 Other Physical, Chemical, and Biological Processes

6.1.3.1 Libby and Hungry Horse Dams and Reservoirs

MO3 modifies operations at Libby Dam resulting in changes in reservoir drawdown rates and water elevations of Lake Koocanusa that may impact physical, chemical, and biological water quality parameters when compared to existing conditions and the No Action Alternative. In general, the MO3 reservoir drawdowns would result in lower water elevations in Lake Koocanusa from November through April, with substantially lower end-of-April water elevations (11 to 19 feet) in the driest 40 percent of years. Reservoir refill and summer pool elevations are improved over the No Action Alternative with the reservoir reaching full pool by the end of July, and maintaining August and September reservoir elevations at about 1 to 4 feet greater than under the No Action Alternative. For water quality concerns, of particular interest are the 11- to 19-foot lower end-of-April water elevations because they equate to less volume of water in Lake Koocanusa during the spring runoff and a shorter water retention time.

Retention time, which is the inverse of the flushing rate, refers to the length of time water remains in a waterbody. Water quality chemical and biological parameters of concern in Lake Koocanusa that may be impacted by changes in the reservoir elevation and retention times, under MO3, include suspended sediments, nutrients such as phosphorus and nitrogen, trace metals such as selenium, and phytoplankton such as cyanobacteria and diatoms. For a long, narrow, deep waterbody like Lake Koocanusa, shorter retention times may allow certain chemical constituents in inflowing waters to move farther down-reservoir toward the forebay and outflow before settling out or transforming.

It is likely that the end-of-April drawdown elevation and the corresponding reservoir volume, as well as spring runoff volume and the corresponding phosphorus and sediment concentrations, are all factors in determining how far down-reservoir total phosphorus and suspended sediments reach. Historical data show that Lake Koocanusa is a sink for phosphorus and sediments, with little inflow concentrations moving down-reservoir past Libby Dam. A recent study by Yassien and Ward (2018) concluded that from 2014 through 2017, the total phosphorus retention in the reservoir ranged from 80 to 93 percent. Under MO3, the lower reservoir elevations for the driest 40 percent of years would likely allow sediments and total phosphorus from the inflow to move farther down-reservoir before settling out.

Lake Koocanusa does not appear to be a sink for nitrogen, and most of the inflowing nitrate passes down-reservoir to the forebay and Kootenai River regardless of reservoir elevations and retention times. Increased nitrate loadings to Lake Koocanusa, largely due to coal mining operations in British Columbia and low phosphorus concentrations, have created a large imbalance in the nitrogen-to-phosphorus ratio, with the ratio often exceeding 100:1 at the forebay, resulting in strong phosphorus limitation. Despite rising nitrate concentrations in Lake Koocanusa, algal blooms appear to have been kept in check by the strong phosphorus limitation under existing conditions and the No Action Alternative. However, it is possible that the operational changes proposed for MO3 may increase total phosphorus concentrations in Lake Koocanusa, which could result in changes in phytoplankton densities and functional types.

Increasing selenium concentrations in Lake Koocanusa from coal mining operations in British Columbia are a concern, and have been thoroughly discussed for the No Action Alternative and MO1. Over the next 25 years, it is expected that coal production in the Kootenai River watershed will continue. Although there does not yet appear to be an increasing trend in water column selenium concentrations in the reservoir, there is concern that without water quality treatment, the continued selenium loadings to Lake Koocanusa may lead to additional selenium contamination. It is possible that the lower end-of-April reservoir elevations for the driest 40 percent of years under MO3 may alter the movement, cycling and transformation of selenium in the reservoir and downstream in the Kootenai River, possibly resulting in water and sediment quality impacts.

Median reservoir elevations under MO3 would be lower during the spring, potentially flushing some early food sources from Libby Reservoir; however, during the growing season, mid-June through September, reservoir elevations would be 1 to 4 feet higher as compared to the No Action Alternative. As such, Lake Koocanusa should not experience major changes to the physical, chemical, or biological processes compared to the No Action Alternative. Additionally, changes in the median average monthly outflows from Libby Dam during the mid-June through September time frame are relatively minor (reduction of 5 to 9 percent when compared to the No Action Alternative), which result in only a 0.3-foot decrease in median monthly elevation in the Kootenai River downstream of Libby Dam, and should not greatly impact the variability of (periodically wetted) zone productivity.

Hungry Horse median reservoir elevations are expected to be lower under MO3 as compared to the No Action Alternative, particularly in early spring and summer (Figure 6-3). These elevations combined with higher outflows in late spring/early summer could reduce in-lake productivity and food availability for resident fish species (ISAB 1997, Fraley et. al 1989).

Water level fluctuations in reservoirs may increase methyl-mercury concentrations in the waterbody as seasonally inundated areas of a reservoir have higher rates of methylation activity when compared to permanently inundated areas of a reservoir (Willacker et al. 2016). Studies suggest that methyl-mercury has a greater probability of entering the food web during the spring and summer growing seasons (January to July) (Willacker et al. 2016). This may lead to increased fish consumption advisories for Lake Roosevelt, which would adversely affect tribes. Under MO3, the measures don’t change the cyclic occurrence of inundation and exposure but do result in earlier and longer exposure of sediments that may have some impact on mercury methylation in Hungry Horse Reservoir. However, unlike other downstream locations such as Lake Roosevelt, mercury has not been recorded as a concern at Hungry Horse Reservoir as the only likely mercury input at this location is through airborne pollution deposition.

6.1.3.2 Albeni Falls Dam and Reservoir

Under MO3, there are little to no changes to operations at Albeni Falls Dam. The physical, chemical, and biological water quality of Lake Pend Oreille and the Pend Oreille River described under the No Action Alternative are expected to remain unchanged.

6.1.3.3 Grand Coulee and Chief Joseph Dams and Reservoirs

Under MO3, retention time of water through the reservoir could increase during the growing season as compared to the No Action Alternative (Figure 6-19). Lake Roosevelt tends to display relatively low primary productivity throughout the year. However, with slightly longer water retention times, some locations of the reservoir may experience phytoplankton blooms. These blooms have the potential to increase pH and decrease dissolved oxygen during die-off

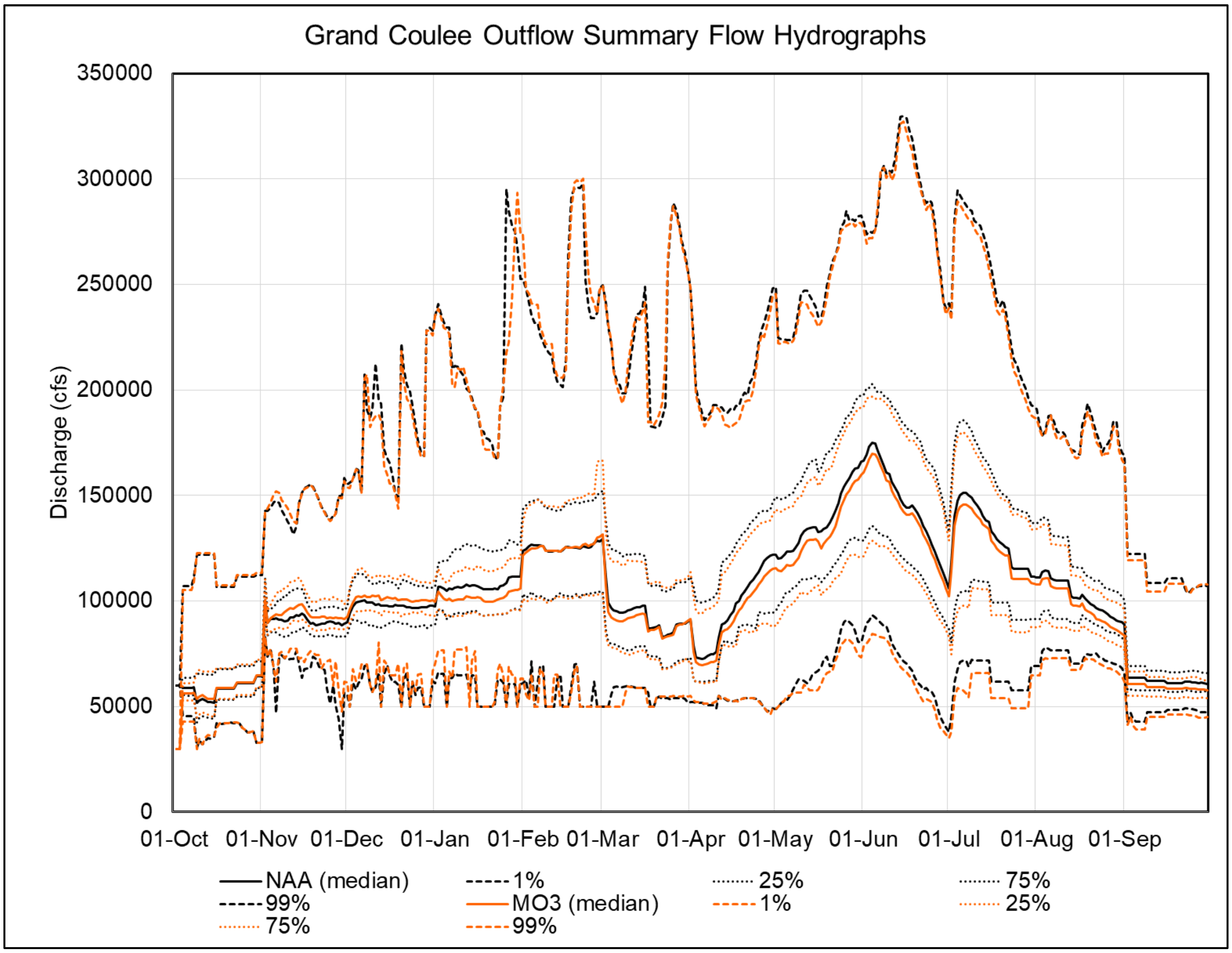


Figure 6-19. Summary Discharge Hydrograph, Grand Coulee Dam, for Multiple Objective Alternative 3 Versus No Action Alternative

The operational measure, *Decrease to Grand Coulee Draft Rate*, changes the target maximum drawdown from 1.0 foot per day to a target of 0.8 foot per day. Mass wasting, such as small local landslides and bank erosion within Lake Roosevelt, has been related to the rate of drawdown and refill at Grand Coulee Dam. Decreases in these mass wasting events should result in decreases in turbidity.

Water level fluctuations in reservoirs have been attributed to increased methyl-mercury in the waterbody because seasonally inundated areas of a reservoir can have higher rates of methylation activity when compared to permanently inundated areas of a reservoir (Willacker et al. 2016). Studies suggest that methyl-mercury has a greater probability of entering the food web during the spring and summer growing seasons (January to July) (Willacker et al. 2016). Under MO3, the measures would not change the cyclic occurrence of inundation and exposure, but may result in earlier and longer exposure of sediments that may have some impact on mercury methylation in Lake Roosevelt. The lower panel of Figure 6-20 shows the difference in Lake Roosevelt water elevation throughout the year between MO3 and the No Action Alternative. Modeling indicates that the average reservoir elevation is expected to remain about 7 feet lower under this alternative as compared to No Action Alternative. Overall, MO3 may slightly increase the rate of mercury cycling within Lake Roosevelt.

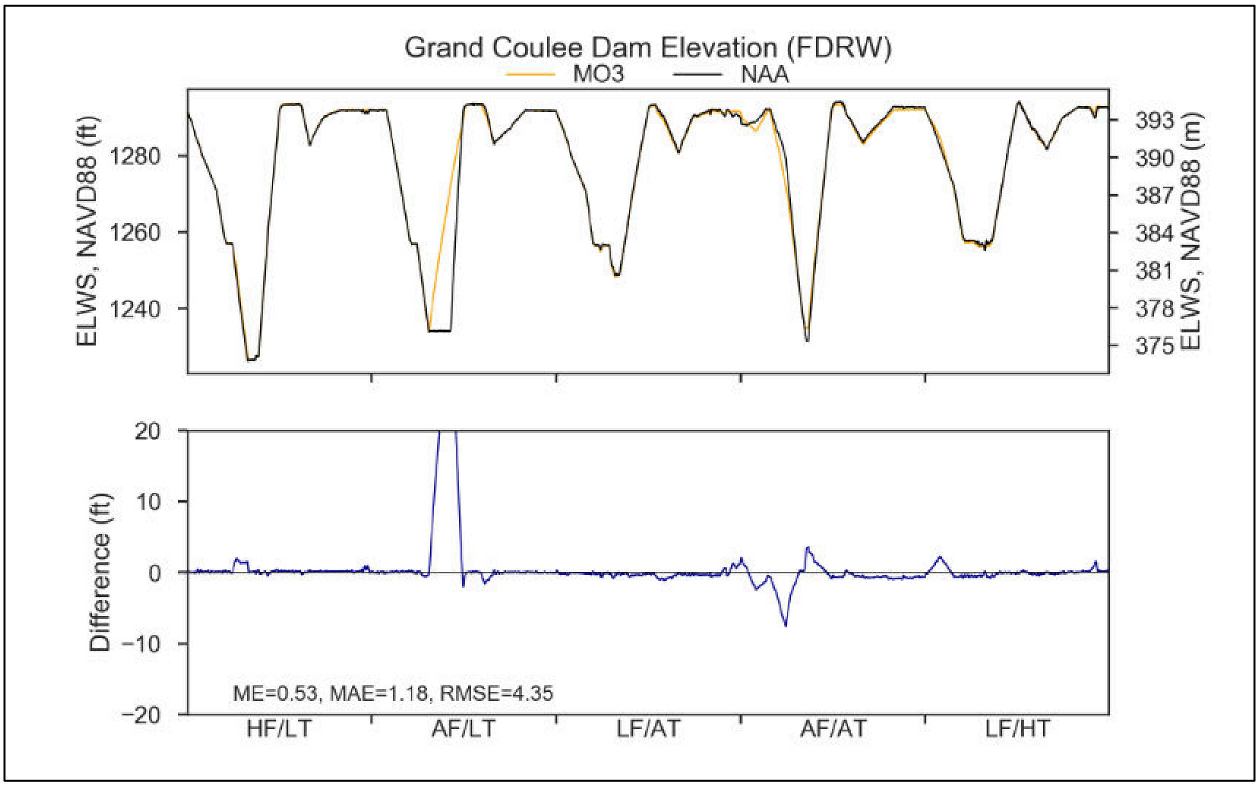


Figure 6-20. Modeled Forebay Elevations for the No Action Alternative and Multiple Objective Alternative 3 at Grand Coulee Dam Under a 5-Year Range of River and Meteorological Conditions

MO3 includes modified operations at Grand Coulee Dam that would result in some changes in monthly outflows to Rufus Woods Lake and Chief Joseph Dam. However, only minor changes to operational conditions at Chief Joseph Dam are expected. As such, the physical, chemical, and biological water quality of Rufus Woods Lake and the Columbia River downstream of Chief Joseph Dam under MO3 are expected to remain relatively unchanged from the No Action Alternative.

6.2 LOWER SNAKE RIVER BASIN

There would not be any operational or structural changes at Dworshak Dam that would directly impact reservoir elevations or outflow.

The primary structural change associated with MO3 that would affect water quality in the lower Snake River is breaching the earthen embankments and adjacent structures, as required, at each of the four dams to facilitate reservoir drawdown and dam breaching. Breaching the dams would result in dramatic changes in water levels throughout the reach. The four current impoundments would be replaced with a free-flowing river, forming a relatively consistent hydraulic gradient paralleling the grade of the canyon itself.

6.2.1 Water Temperature

Two models were used to predict MO3 water temperatures. The 2D W2 model was applied to Dworshak Dam releases as it has been for the other alternatives. The one-dimensional HEC-RAS model was used for the lower Snake River MO3 evaluation because that model is better suited for mixed river conditions that would occur if the dams were breached (Section 2.2.2).

6.2.1.1 Dworshak Dam and Reservoir

Since project operations at Dworshak Dam would not change in MO3, the outflow temperatures modeled for MO3 would be very similar to the modeled results for the No Action Alternative, with temperatures remaining less than 52°F throughout the year (Figure 6-21). Thermal stratification in the reservoir would also not change.

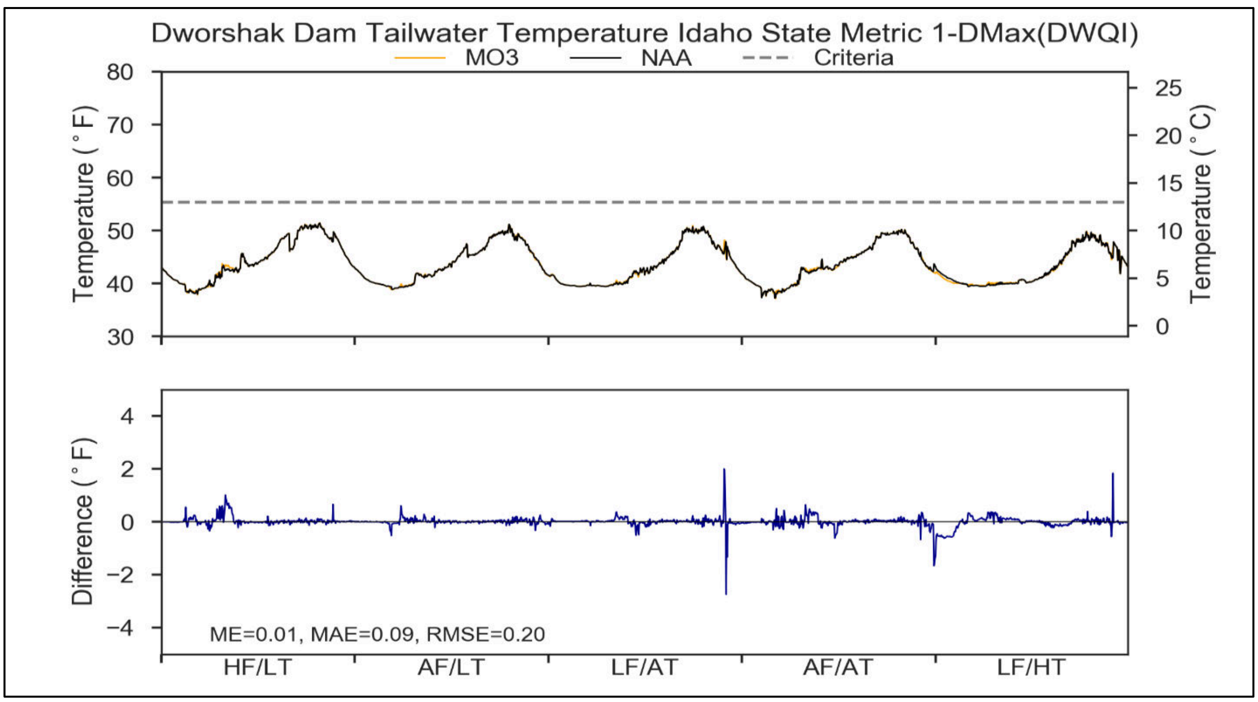


Figure 6-21. Modeled Tailwater Temperature for the No Action Alternative and Multiple Objective Alternative 3 at Dworshak Dam Under a 5-Year Range of River and Meteorological Conditions

6.2.1.2 Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams and Reservoirs

Water temperatures in the lower Snake River would change from the No Action Alternative if MO3 was implemented (Figure 6-22 through Figure 6-25). One difference would be the rate of warming and cooling that would occur in the Snake River. Water temperatures would warm sooner in the spring and cool more quickly in the fall under MO3 due to the elimination of the reservoirs, which are known to cause water temperature lags in the Snake River under No Action conditions. Figure 6-26 also shows that the differences between MO3 and the No Action Alternative increase as the water flows toward the Columbia River. What this suggests is that water temperature conditions at Lower Granite will continue to be dominated by Dworshak operations. The effect of the Dworshak operations, however, will diminish as water travels the ~140 river miles down to the Ice Harbor Dam location.

In general, Snake River water temperatures would be warmer in the spring under MO3, with the exception of May. During this month, total river flows are highest due to snowmelt (i.e. spring freshet), resulting in overall cooler water temperatures throughout the lower Snake River as compared to the No Action Alternative. Summer water temperatures would be both warmer and cooler than the No Action Alternative, depending on meteorological conditions. During summer heat waves, water temperatures would warmer than the No Action Alternative, but would respond much more quickly to cooling events that follow. The lower Snake River would begin to cool August and throughout the remainder of the year, with larger differences between MO3 and No Action Alternative occurring as the water progresses from upstream to downstream. August temperatures at Lower Granite Dam would only be expected to cool 0.2 degree Fahrenheit on average under MO3, as compared to No Action, while water temperatures at Ice Harbor would cool by upwards of 1.8 degrees Fahrenheit. Temperature differences between MO3 and No Action Alternative would be largest during November, ranging from an average of 3.6 degrees Fahrenheit at Lower Granite to 8.4 degrees Fahrenheit at Ice Harbor Dam.

Maximum daily temperatures that would be expected under MO3 are shown in Figure 6-27. Maximum temperatures generally increase downstream and the warmest daily temperatures would occur during June or July when LF/HT and LF/AT conditions were present. Maximum temperatures at that time would range from approximately 72°F at Lower Granite Dam to 76°F at Ice Harbor Dam. Maximum temperatures would also be greater than 68°F during August at all locations under all flow/air temperatures, as well as during September when HF/LT, LF/AT, and AF/AT conditions occur.

Diel temperature fluctuations would also increase if MO3 was implemented. Average diel temperature differences seldom exceed 1 degree Fahrenheit under the No Action Alternative, and are typically between 0.5 and 1.0 degrees Fahrenheit from April through August. Average differences would range from 2.5 to 3.5 degrees Fahrenheit for the same time period if MO3 was implemented (Figure 6-28). Daily temperature differences during the winter would typically be less than 1 degree Fahrenheit near Lower Granite Dam and range from 1 to 1.5 degrees Fahrenheit at the three remaining river locations that were modeled.

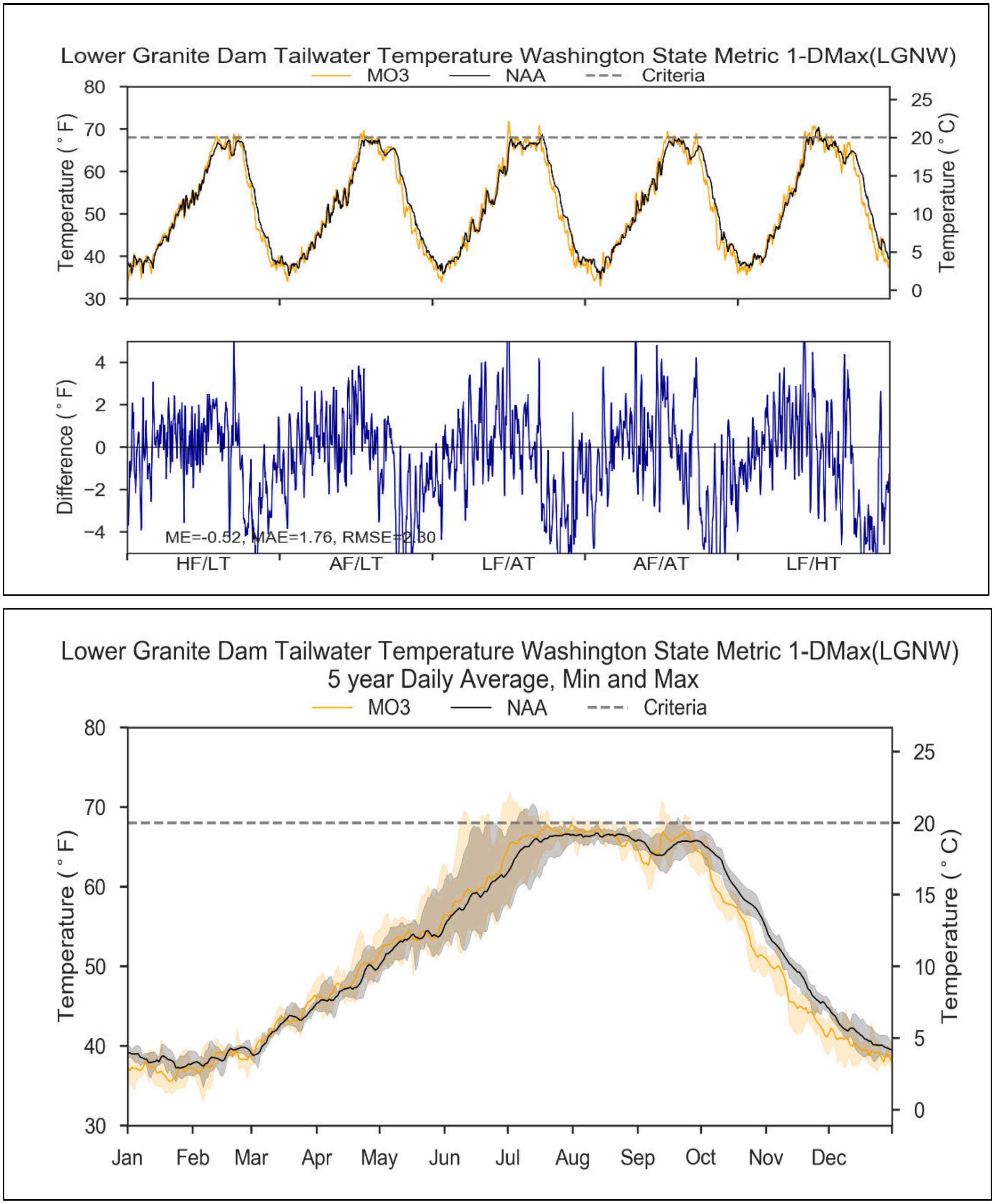
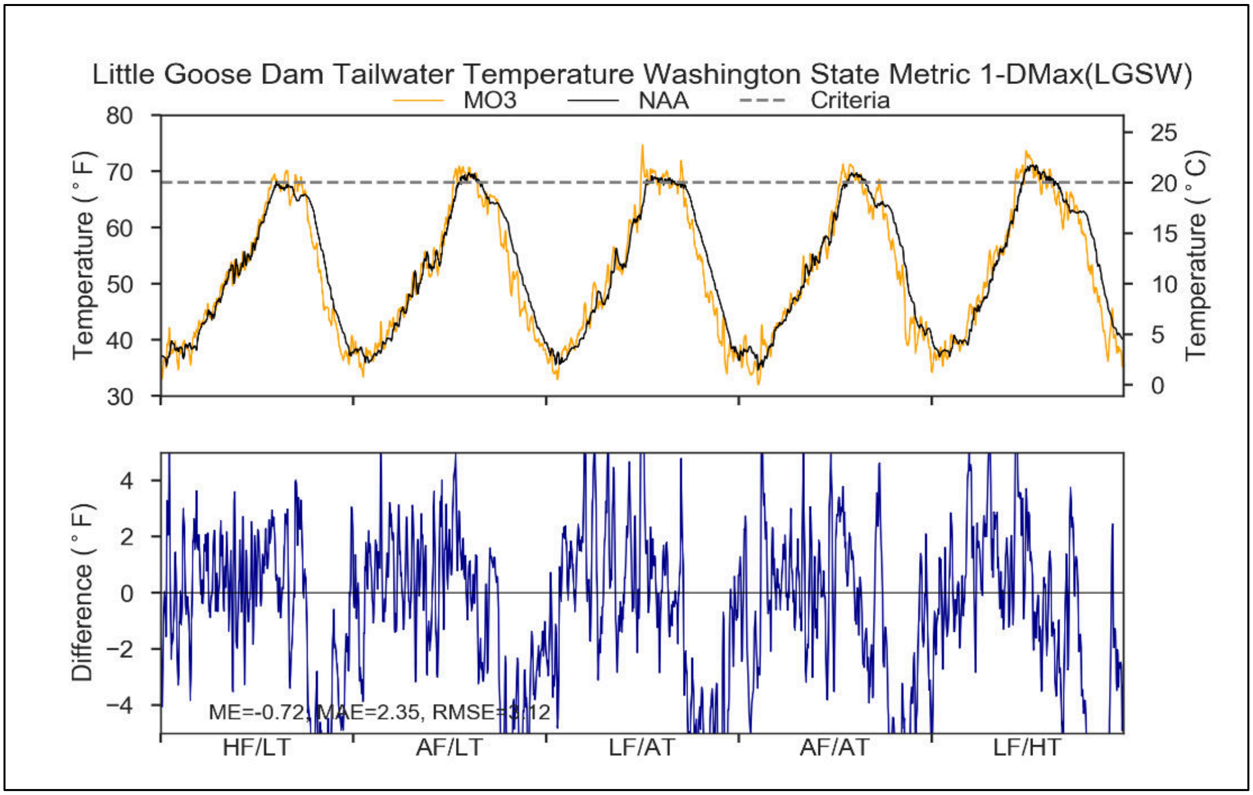


Figure 6-22. Modeled Tailwater Temperatures for the No Action Alternative and Multiple Objective Alternative 3 at Lower Granite Dam for Individual Flow and Meteorological Conditions and Averaged 5-Year Conditions



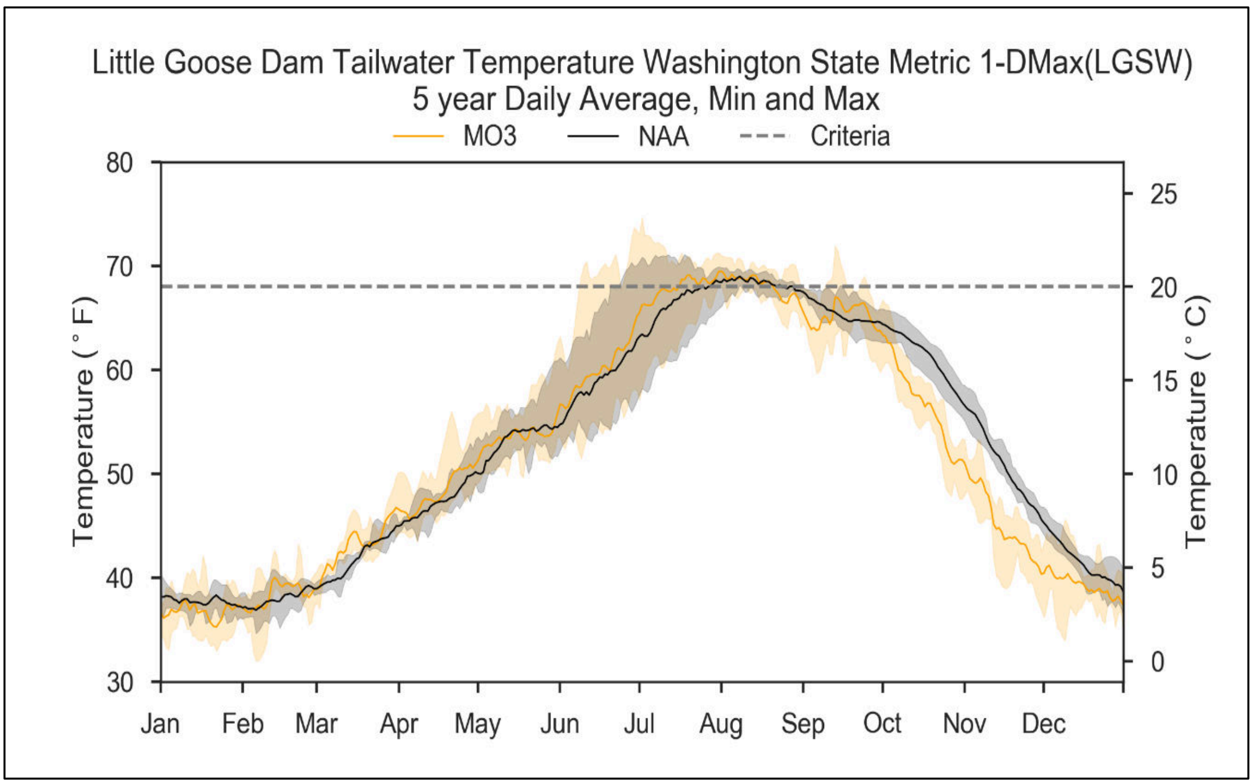


Figure 6-23. Modeled Tailwater Temperatures for the No Action Alternative and Multiple Objective Alternative 3 at Little Goose Dam for Individual Flow and Meteorological Conditions and Averaged 5-Year Conditions

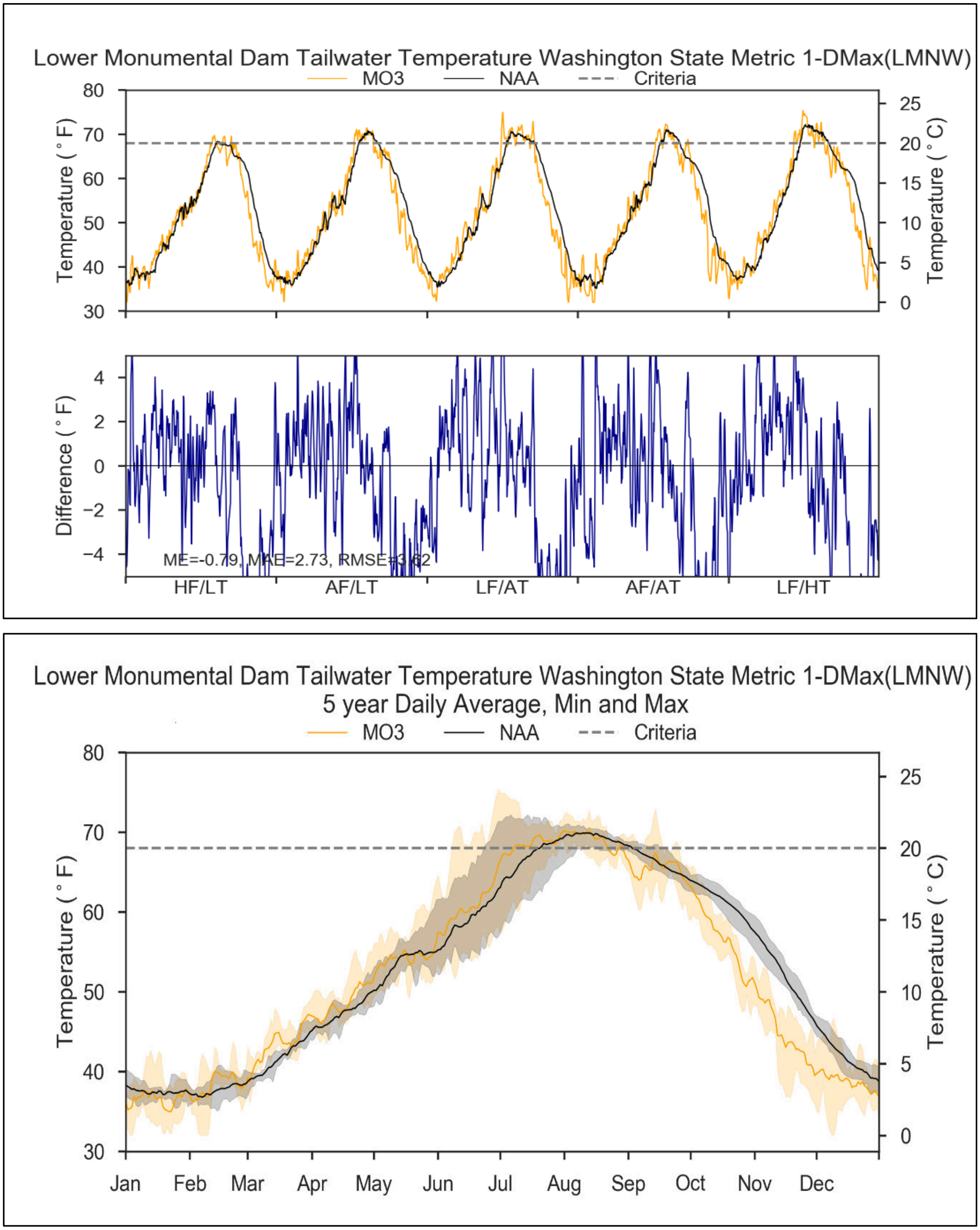
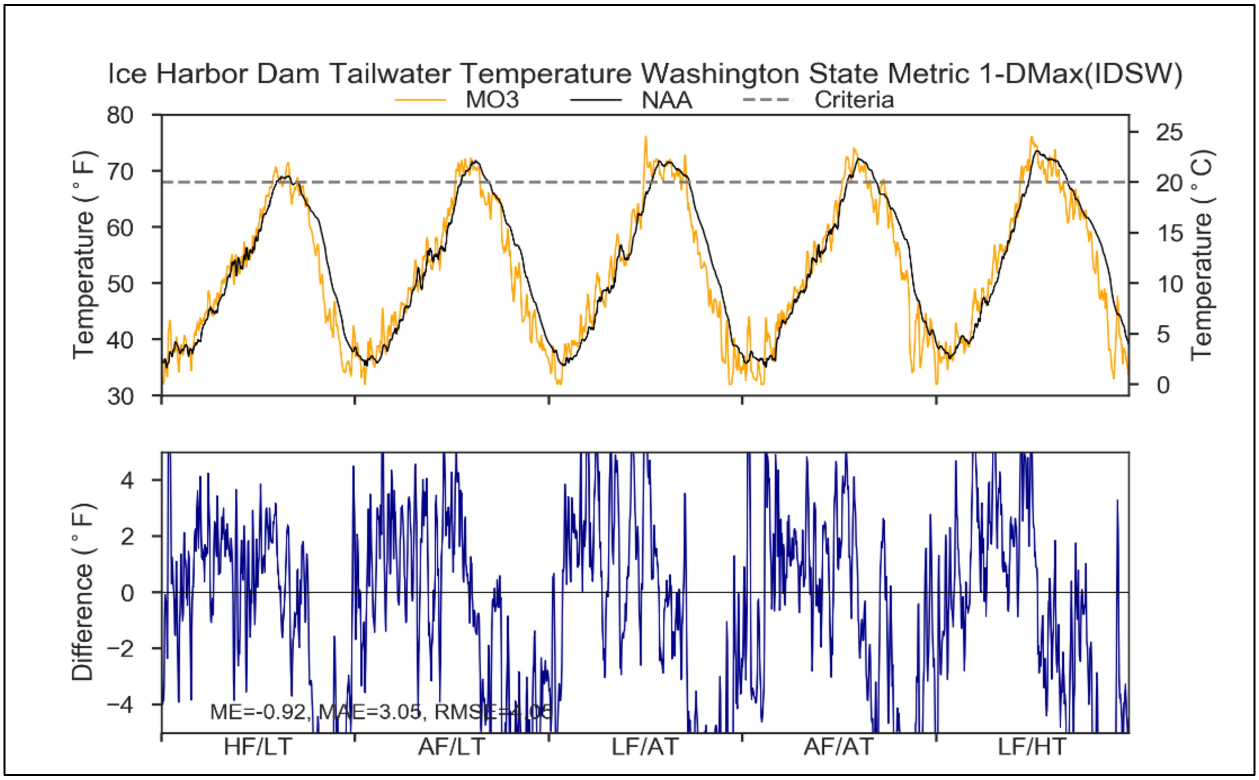


Figure 6-24. Modeled Tailwater Temperatures for the No Action Alternative and Multiple Objective Alternative 3 at Lower Monumental Dam for Individual Flow and Meteorological Conditions and Averaged 5-Year Conditions



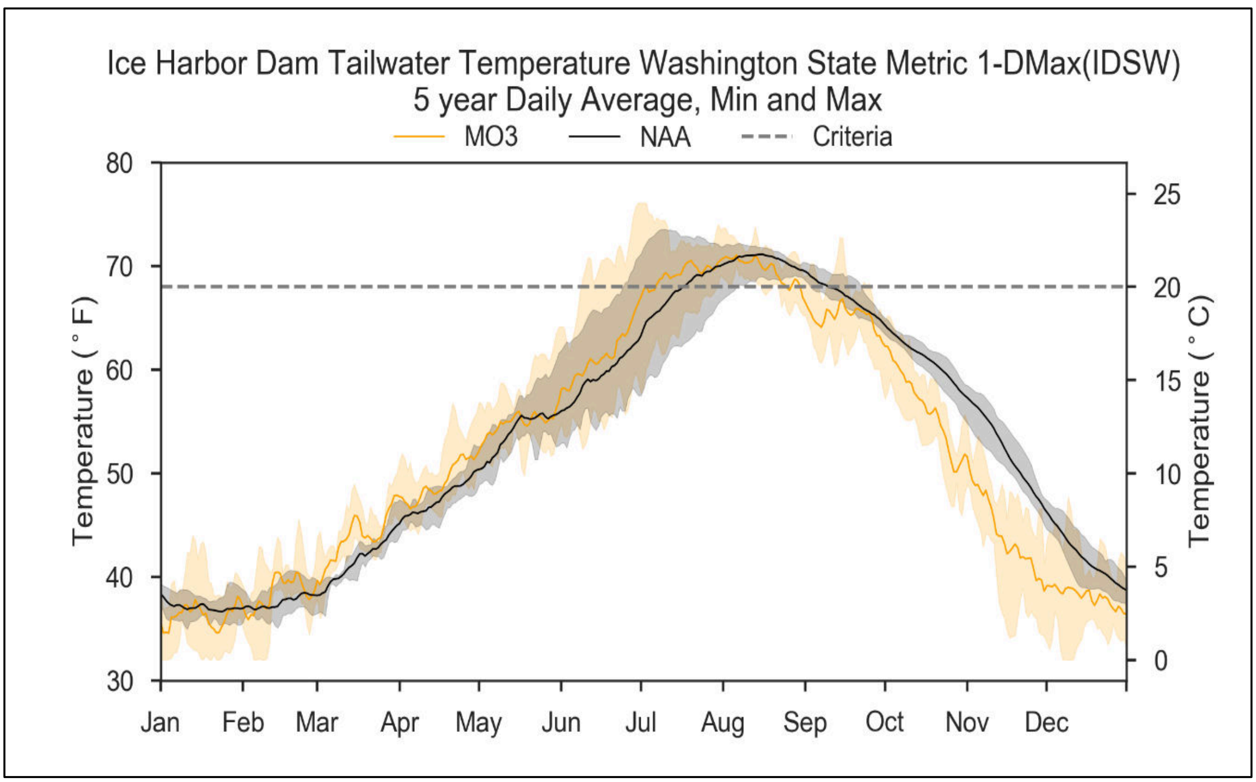


Figure 6-25. Modeled Tailwater Temperatures for the No Action Alternative and Multiple Objective Alternative 3 at Ice Harbor Dam for Individual Flow and Meteorological Conditions and Averaged 5-Year Conditions

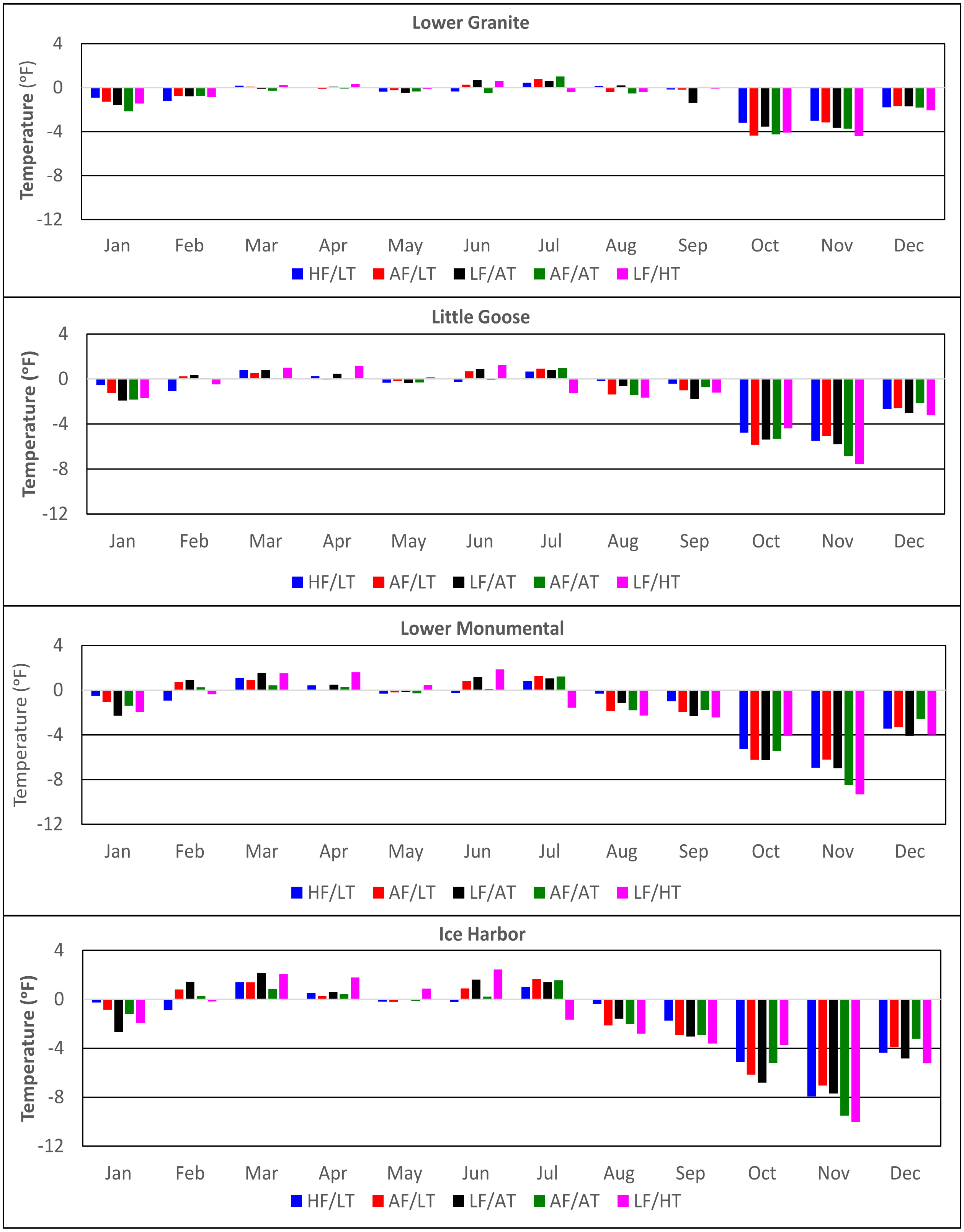


Figure 6-26. Average Temperature Differences Between Multiple Objective Alternative 3 and No Action Alternative for each Month at the Four Lower Snake River Dam Locations

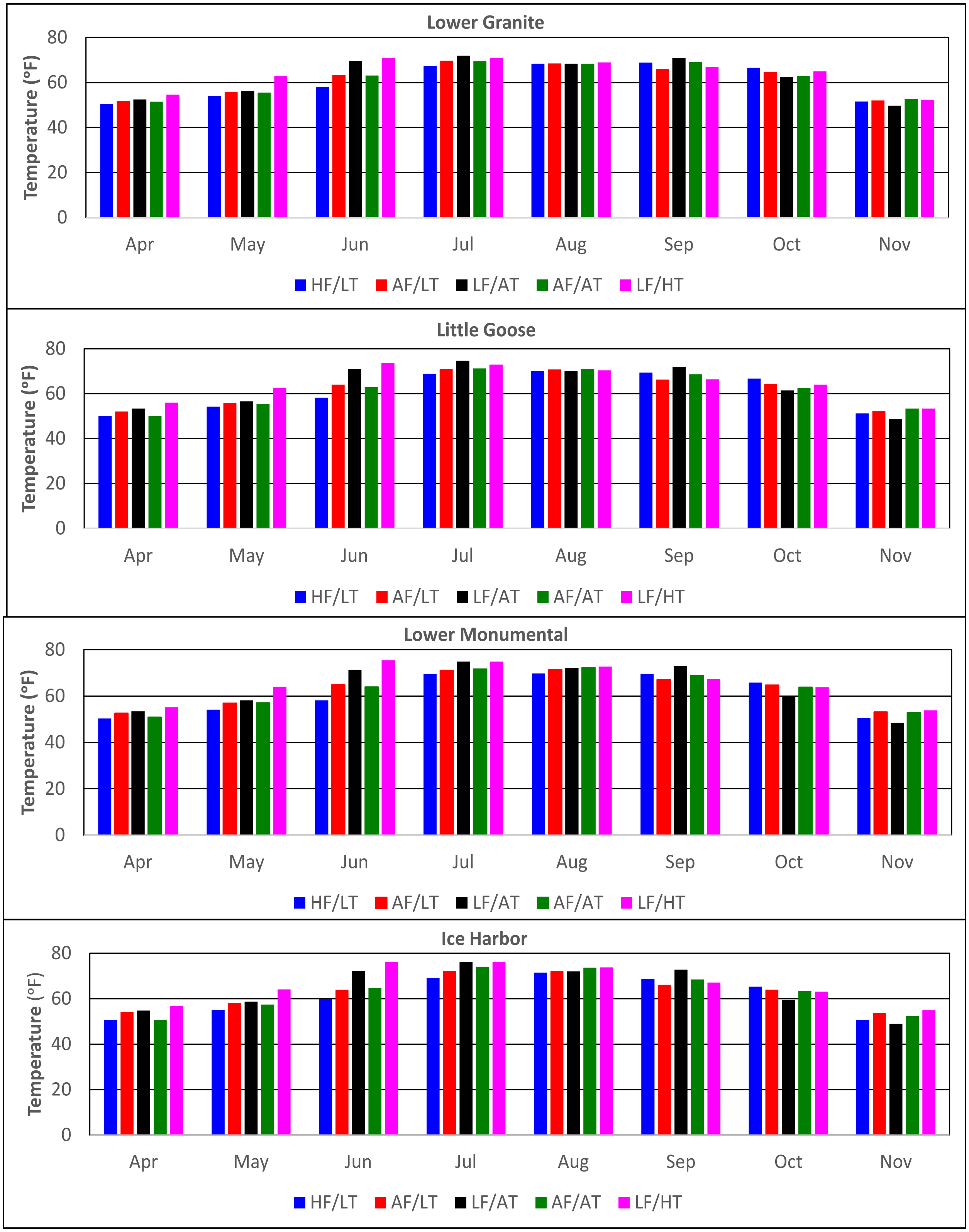


Figure 6-27. Model Results for the Maximum Daily Temperatures that Would be Anticipated at the Four Lower Snake River Dam Locations if Multiple Objective Alternative 3 is Implemented

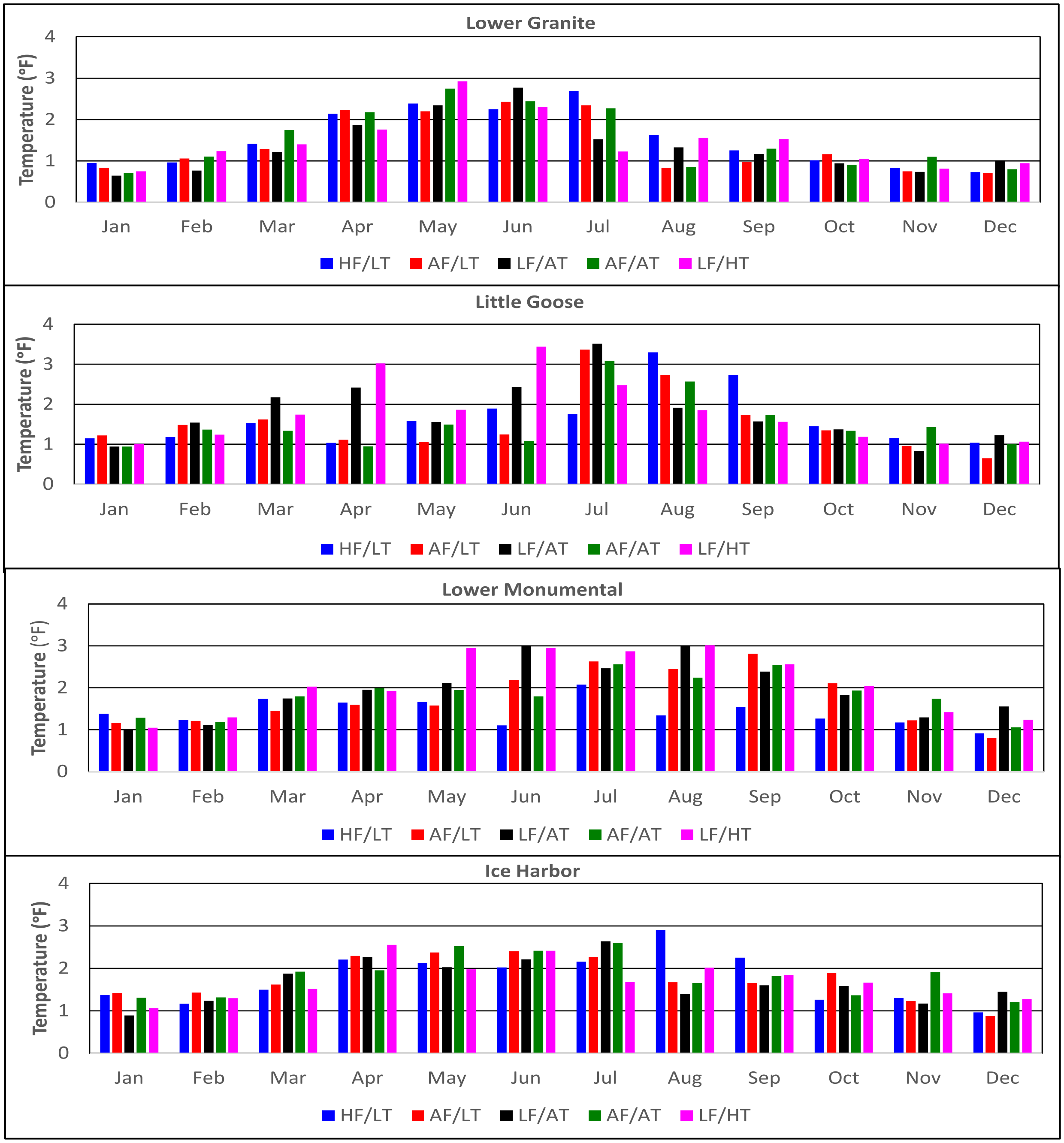


Figure 6-28. Average Diel Temperature Differences by Month that Would Occur at the Four Current Lower Snake River Station Locations if Multiple Objective Alternative 3 is Implemented

The water temperatures modeled for MO3 are also compared to available lower Snake River pre-dam field measurements. During 1956, 1957, and 1958, the USGS measured river temperatures near Central Ferry, Washington, at the bridge on U.S. Highway 295, or approximately 24 miles downstream from the current location of Lower Granite Dam (USGS 1960, 1961, 1964). The measurements were recorded once per day at 4 p.m. Water temperatures were also recorded in 1958 approximately 0.25 mile upstream from Clarkston, Washington, at the Yacht Club by an operator identified as BCF (Corps 2002a). The historical May through October data, along with daily average water temperatures for MO3 and the No Action Alternative at the Lower Granite tailwater location are shown in Figure 6-29. During July and August, the 1950s water temperatures averaged 7 to 8 degrees Fahrenheit higher than the average MO3 model results. Maximum daily differences were 10 to 12 degrees Fahrenheit higher in the 1950s. The data also shows that the river warmed-up sooner during June prior to construction of the four lower Snake River projects. Average June temperatures ranged from 1.6 degrees Fahrenheit higher in 1956 to 5.4 degrees Fahrenheit higher in 1958. The delayed heating predicted for MO3 may be a consequence of slower heating due to the middle and upper Snake River reservoirs combined with the influence that Dworshak Dam operations have on the lower Snake River.

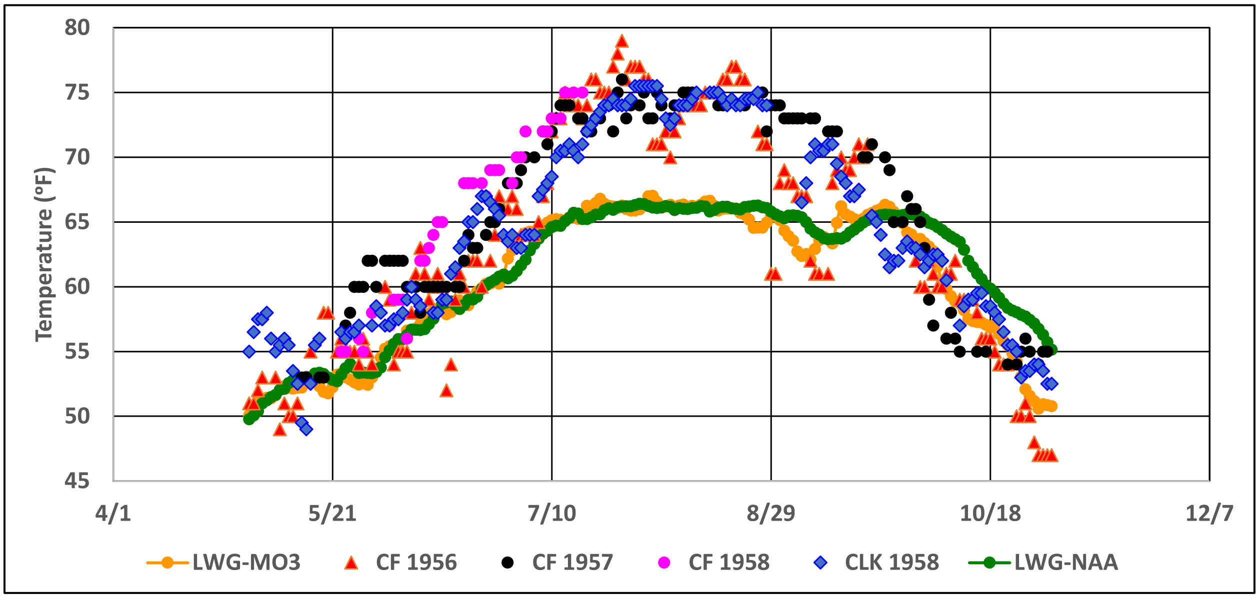


Figure 6-29. Comparison of Average Multiple Objective Alternative 3 and No Action Alternative Model Results for the Current Lower Granite Tailwater Location to Historical Snake River Water Temperatures Recorded near Central Ferry and Clarkston, Washington

Note: CF = Central Ferry; CLK = Clarkston.

Air temperature comparisons between the late 1950s and more recent intervals were also made using data from the National Weather Service station at the Nez Perce County Airport in Lewiston, Idaho. The average May through October air temperatures from that location all show an increasing trend from 1948 when the period of record starts through 2018. The monthly averages for 1956, 1957, 1958, and 2011 to 2015 mean are shown in Table 6-4. The comparison shows that the mean 2011 to 2015 air temperatures were slightly cooler during May than they were from 1956 through 1958, the same in June, and warmer during July through October.

A comparison of Snake River flows in the late 1950s and the 2011 to 2015 interval were also made. The 1956 to 1958 flow data was obtained from the discontinued USGS gaging station (number 13343500) that was located downstream from Clarkston, Washington, where it operated between 1915 and 1972. The 2011 to 2015 flow data was obtained from the Lower Granite Dam project. The May and June 1956 to 1958 river flows were higher than the 1916 to 1972 average, and 1.4 to 1.8 times greater than the 2011 to 2015 mean (Table 6-4 through Table 6-6). In contrast, average 2011 to 2015 July through September flows were 1.1 to 1.4 times greater than the mean for the 1956 to 1958 flows, likely due in part to the summer Dworshak Dam releases. Average October flows were approximately 1.2 times higher in the late 1950s. The upstream Brownlee Dam was completed in 1958, but any effect of this project on the flows for this time period could not be separated from inter-annual variability.

Table 6-4. Average Monthly Air Temperatures (°F) at the Lewiston Nez Perce County Airport Weather Station in Lewiston, Idaho for 1956, 1957, 1958, and 2011 to 2015

Year	May	June	July	August	September	October
1956	60.1	62.7	74.0	69.9	62.8	49.6
1957	60.7	65.7	71.5	69.6	65.9	50.5
1958	64.6	68.6	75.5	76.3	62.4	53.1
2011–2015	59.8	67.5	77.2	76.6	67.5	54.5

Table 6-5. Average Monthly Snake River Flows (kcfs) at the Discontinued USGS Gaging Station (13343500) Downstream from Clarkston, Washington for 1956, 1957, and 1958

Year	May	June	July	August	September	October
1956	186.5	149.3	42.3	25.0	23.3	27.4
1957	199.4	127.5	35.9	21.9	22.1	25.6
1958	161.4	104.0	30.2	19.2	22.6	23.5

Table 6-6. Average Monthly Snake River Discharge (kcfs) at Lower Granite Dam for 2011 to 2015

Year	May	June	July	August	September	October
2011–2015	98.7	90.6	50.7	27.5	24.1	21.2

The operational changes for MO3 do cause a fairly significant temperature differences as can be seen in the figures above. In terms of the actual number of days of the criteria being exceeded, those changes can be seen in Table 6-7. The Snake River dams in July and August have a total of 130 more temperature violations in MO3 as compared to NAA; additionally, excluding Lower Granite, the dams actually meet the criteria 120 additional days in August and September. The blue highlighted cells show when an increased number of exceedances occurs as compared to NAA. Only the months where the criteria is exceeded is shown in the table. In general, the difference in the number of exceedances decreases as the water moves through the river.

Table 6-7. Difference in Number of Days the Temperature Criteria is Exceeded at the Tailwater Sites of Lower Granite, Little Goose, Lower Monumental, and Ice Harbor for the Multiple Objective 3 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Lower Granite	June	0	0	**1**	0	**10**
Lower Granite	July	0	**11**	**6**	**7**	0
Lower Granite	August	**7**	**2**	**2**	**4**	**5**
Lower Granite	September	**5**	0	0	**2**	0
Little Goose	June	0	0	**2**	0	**13**
Little Goose	July	**2**	**11**	**7**	**11**	-5
Little Goose	August	**16**	-5	-11	-9	-10
Little Goose	September	**7**	0	**7**	**2**	0
Lower Monumental	June	0	0	**2**	0	**15**
Lower Monumental	July	**3**	**11**	**8**	**10**	-2
Lower Monumental	August	**7**	-8	-3	-8	-9
Lower Monumental	September	**3**	-1	-4	0	-1
Ice Harbor	June	0	0	**2**	0	**16**
Ice Harbor	July	**2**	**11**	**12**	**9**	-1
Ice Harbor	August	**2**	-8	0	-6	-10
Ice Harbor	September	-1	-8	-8	-6	-5

6.2.2 Total Dissolved Gas

TDG saturation related to MO3 was modeled for Dworshak Dam tailwater but not for the lower Snake River dam forebay or tailwater locations. Predicting TDG in a free-flowing river would have been outside the model's calibration range, and the results would not be reliable. TDG during the breaching phase was estimated from data collected during the 1992 drawdown.

6.2.2.1 Dworshak Dam and Reservoir

Dworshak Dam tailwater TDG under MO3 would be very similar to the No Action Alternative (Figure 6-30 and Table 6-8), with a few exceptions. First, there would be 89 fewer hours during late May of an AF/LT year and 17 fewer hours during June of an AF/AT year when the TDG would exceed 110 percent. Second, there are two additional periods when the TDG is already less than 110 percent under No Action Alternative, but would be even lower under MO3 for an extended period of time. The one instance would occur during April of a HF/LT year when the TDG would be 4 to 6 percent less or approximately 300 hours. The second instance would occur during May and June of a LF/AT year when there would be approximately 600 hours when the average TDG would be 3.7 percent less during MO3, but the difference could be as high as 5 percent for several days. These differences are due to changes in total outflow and spill that would occur as a result of shifts in flow at the other Columbia River Basin projects and regional power demands.

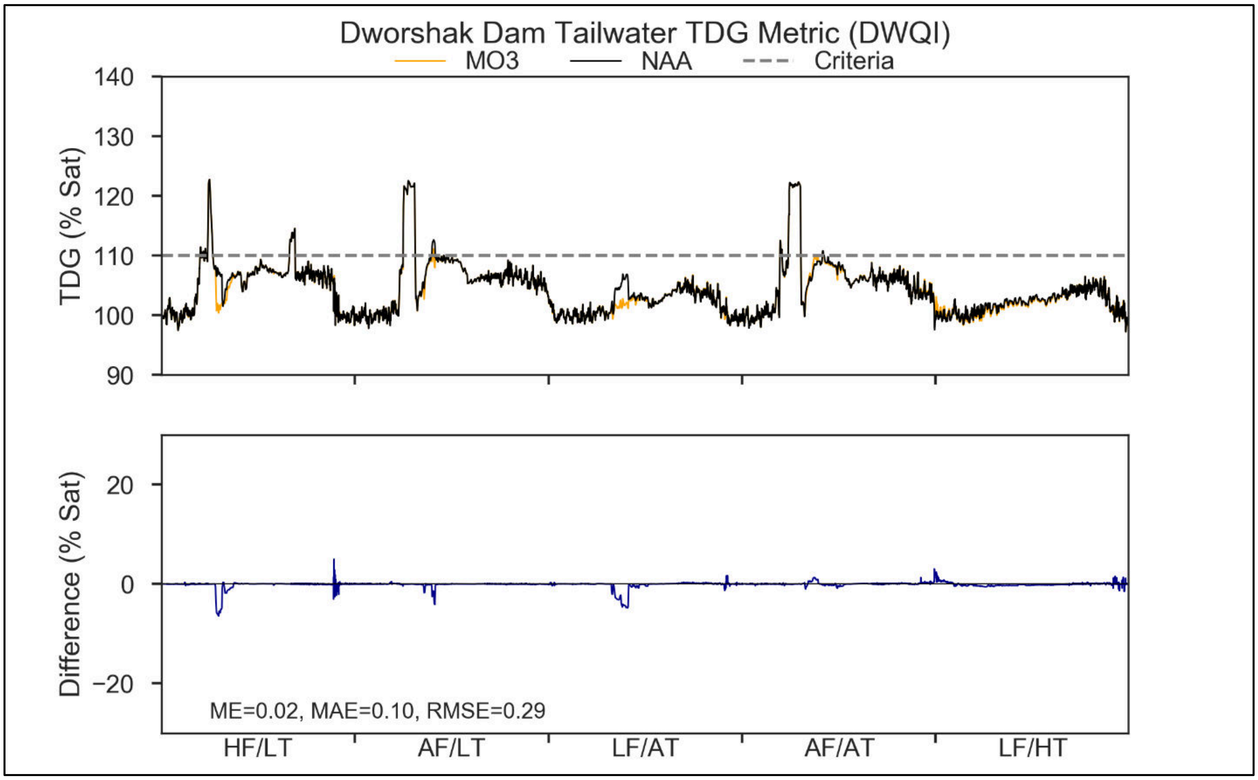


Figure 6-30. Modeled Tailwater Total Dissolved Gas for the No Action Alternative and Multiple Objective Alternative 3 at Dworshak Dam Under a 5-Year Range of River and Meteorological Conditions

Table 6-8. Difference in Number of Days the Total Dissolved Gas Criteria is Exceeded at the Tailwater Site of Dworshak for the Multiple Objective 3 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

Month	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
April	0	0	0	0	0
May	0	-4	0	0	0
June	0	0	0	-1	0
July	0	0	0	0	0
August	0	0	0	0	0

6.2.2.2 Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams and Reservoirs

TDG would increase during part of the year prior to breaching. This would occur because only three powerhouse units, which can pass a total of approximately 60 kcfs, would be available. Since average spring runoff flows can average 140 to 150 kcfs, and daily flows can exceed 200 kcfs, during a high-flow year additional water would have to be discharged over the spillways. The 1992 drawdown study at Lower Granite Dam identified the following spill/TDG relationships for 2- to 3-hour spill durations: approximately 30 kcfs resulted in TDG ranging from 113 to 119 percent; approximately 65 kcfs resulted in TDG ranging from 119 to 123 percent; and a spill of approximately 100 kcfs resulted in TDG ranging from 126 to 135 percent (Corps 1993). These relationships are very similar to the ones currently observed at the project. During implementation of the 1992 drawdown, the TDG saturation also exceeded the current 1-hour, 125 percent limit (applicable during the fish spill season) at Lower Granite Dam and reached 134.7 percent on one occasion (Corps 1993).

A few additional results from the 1992 drawdown study that are relevant to MO3 include:

- Lowering the forebay elevation did not reduce TDG.
- Lowering the tailwater elevation caused an increase in TDG at higher flow rates compared to what would occur at normal tailwater elevations under equal flow amounts.
- Discharges from a combination of powerhouse and spillway operations did not significantly mix within the first few miles of the dam.
- The TDG data obtained during the 1992 drawdown test did not reflect the cumulative increase in TDG that would occur if consecutive dams were spilling water. For a given spill quantity, an increase of an additional 80 percent of the increase observed at the previous dam would occur (Corps 1993). For example, if an increase in saturation of 20 percent was measured from the forebay to tailwater at Lower Granite Dam (100 percent in the forebay and 120 percent in the tailwater) for a given spill quantity, then the expected tailwater saturation levels below Little Goose Dam would be approximately 136 percent. This estimate would depend on factors such as powerhouse discharge, tailwater depth, dissipation rates, etc.

Lower Snake River TDG was not modeled for MO3 due to using HEC-RAS to model the reach. As described above, elevated TDG would occur during the breaching process. However, once the dams were breached, the hydraulic head currently present as a result of each dam would no longer occur and spill that entrains air would no longer occur. Under new river conditions, geographically localized TDG above 110 percent may periodically occur for short durations due to formation of plunge pools and turbulence during high-flow conditions.

6.2.3 Other Physical, Chemical, and Biological Processes

6.2.3.1 Dworshak Dam and Reservoir

The physicochemical and biological process in Dworshak Reservoir and downstream of the project would not differ from the No Action Alternative if MO3 is implemented.

6.2.3.2 Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams and Reservoirs

Elevated suspended solids concentrations that would occur during and for some time after breaching would affect water quality. Suspended solids concentration is expected to peak at more than 24,000 mg/L during the first breach and 16,000 mg/L during the second event (Appendix C, *River Mechanics*). Concentrations greater than 5,000 mg/L would last for 26 and 18 days during the first and second dam removal events, respectively.

Since the concentrations of nitrogen and phosphorus associated with the sediments and interstitial water are higher than in the overlying water, a net transfer of these nutrients to the river would occur. Ammonia concentrations are of particular interest since they can be toxic to aquatic life, and are dependent on seasonal pH and temperature conditions. The pH of the river during late summer and fall when breaching would occur, as well as during May and June when peak runoff occurs, typically ranges from 7.5 to 8.0 units, but can reach 8.5 units. Mid-October through December water temperatures range from 35.6°F (2°C) to 62.6°F (17°C), with an average of 46.4°F (8°C). May through June temperatures are warmer, ranging from 48.2°F (9°C) to 73.4°F (23°C), with an average of 57.2°F (14°C). The EPA (2013) provides a detailed discussion and tables regarding the dependence of acute and chronic ammonia toxicity on temperature and pH. At an average temperature of 57.2°F (14°C) the chronic criterion ranges from 1.1 mg/L to 2.1 mg/L of total ammonia between a pH range of 7.5 to 8.0 units. The chronic concentration ranges are higher at lower water temperatures and pH values. For example, at the same temperature but with a pH range of 6.5 to 7.0 units, the criteria ranges from 2.8 to 3.1 mg/L, and at a temperature of 46.4°F (8°C) and pH values again ranging from 7.5 to 8.0 units, the criteria ranges from 1.7 mg/L to 3.0 mg/L. Average ammonia elutriate concentrations that were determined for the four lower Snake River reservoirs in 1997 (USACE, 2002) range from 2.5 mg/L to 3.6 mg/L, with some individual values exceeding 12 mg/L. Actual water column concentrations would differ from elutriate concentrations, but these comparisons indicate that there is a potential for ammonia toxicity under MO3. A more concise estimate of the magnitude, duration, and frequency of possible in-water ammonia concentrations and resulting toxicity to fish would require additional sediment characterization coupled with fate/transport modeling.

The current concentrations of nitrogen and phosphorus in the lower Snake River are a blend of the higher concentrations originating from the middle Snake River and the very low concentrations in the Clearwater River. These inflow concentrations vary seasonally, and the resulting downstream concentrations are influenced by the percentage of flow originating from each source. Nutrient concentrations currently do not display statistically significant changes from RM 129 down to RM 2. With anticipated mean travel time reduced from 25 to 2 days under MO3, it is not expected that lower Snake River concentrations would differ from inflows as a result of free-flowing river conditions.

Dissolved oxygen concentrations in the river would be affected if MO3 is implemented. Very low, and even anoxic, conditions would occur during breaching and periodically afterward as sediments become re-suspended and create an oxygen demand. This would especially be anticipated under the first year of breaching when Lower Granite and Little Goose are deconstructed, sending high amounts of suspended sediments into Lower Monumental Reservoir where few tributaries exist to counteract the oxygen demand that would be created. To estimate the short-term effects of reservoir drawdown and breaching on dissolved oxygen concentrations, a simplistic modeling approach that focused on Lower Monumental Reservoir was pursued using two methods (Annex C). The first method was developed using correlations of measured data from Fall Creek Lake, Oregon (USGS Gage 14151000, Fall Creek Blw Winberry Creek, Near Fall Creek, OR). The second method was based on the mobilization of anoxic pore water and the biochemical oxidation of organic matter associated with deposited and re-mobilized/re-suspended sediments during reservoir drawdown and dam breach. This method assumed sediment oxygen demand (SOD) rates of 0.1, 0.5, 1.0, and 2.0 grams per square meter per day (g/m^2/day). The two highest rates are based on measurements obtained from several Snake River sediment cores that were collected in 1997 (Normandeau 1999) and ranged from 0.8 to 2.2 g/m^2/day (https://www.nwd.usace.army.mil/CRSO/Documents). The grain size and organic matter content of these samples correspond reasonably well with the sediment composition assumptions made by the H&H River Mechanics team—83 percent silt/clay and 5 percent organic matter (Appendix C, *River Mechanics)*.

A comparison of volume-weighted dissolved oxygen concentration results from both methods are summarized for two model segments/locations (at the head of Lower Monumental Reservoir and in the forebay) for each pulse of high total suspended solids following drawdown and breach (Table 6-9 through Table 6-11[5]). The estimated number of days when the oxygen concentrations would be less than 5 mg/L, 2.5 mg/L, and 0.5 mg/L (anoxia) under Method 1 (data correlation) and Method 2 (with an SOD of 0.5 g/m^2/d) in the headwater are similar and range from 21-23 days, 15-19 days, and 11-17 days, respectively. The estimated number of days when the oxygen concentrations would be less than 5 mg/L, 2.5 mg/L, and 0.5 mg/L (anoxia) under Method 1 (data correlation) and Method 2 (with an SOD of 0.5 g/m^2/d) in the forebay range from 17-20 days, 4-7 days, and 0 days, respectively. Method 2 with a SOD of 0.1 g/m^2/d results in nominal dissolved oxygen concentration effects with respect to the three dissolved oxygen criteria and locations selected, while estimated dissolved oxygen concentration effects with SOD rates of 1.0 and 2.0 g/m^2/d suggest the longest periods of low dissolved oxygen within the Lower Monumental pool.

Extended periods of anoxia would be greater in the headwater segment of the Lower Monumental pool as compared to the forebay, or area of reservoir just upstream of Lower Monumental Reservoir. In addition, the first peak of sediment (during reservoir drawdown) would likely create worse dissolved oxygen conditions as compared to the second peak (dam breach) based on estimated total suspended sediment concentrations predicted by the sediment transport model, HEC-RAS 5.0.7 (Appendix C, *River Mechanics*).

[5] Note that Tables 6-10 and 6-11 include the same information that can be found in Table 6-9, but are formatted differently for 508-compliance purposes.

Table 6-9. Number of Days when the Volume-Weighted Average Dissolved Oxygen Concentration in Lower Monumental Reservoir is Estimated to be Below Selected Criteria During the Two Peaks in Suspended Sediment Derived from a Hypothetical Dam Breach

TSS Pulses	DO Criteria (mg/L)	Headwater (Segment 2)					Forebay (Segment 28)				
		Method 1	Method 2				Method 1	Method 2			
		Data Correlation	SOD 0.1	SOD 0.5	SOD 1.0	SOD 2.0	Data Correlation	SOD 0.1	SOD 0.5	SOD 1.0	SOD 2.0
First Peak August–September)	< 5	21	5	23	32	37	17	1	20	27	29
	< 2.5	15	1	19	27	33	4	0	7	14	22
	< 0.5	11	0	17	23	32	0	0	0	0	0
Second Peak October–December)	< 5	10	2	14	19	22	14	1	18	26	28
	< 2.5	7	0	10	18	20	8	0	9	19	23
	< 0.5	6	0	7	15	19	0	0	0	0	0

Notes: DO = dissolved oxygen.

Table 6-10. Number of Days when the Volume-Weighted Average Dissolved Oxygen Concentration in Lower Monumental Reservoir is Estimated to be Below Selected Criteria During the Two Peaks in Suspended Sediment Derived from a Hypothetical Dam Breach Using Method 1 (Data Correlation)

TSS Pulses	DO Criteria (mg/L)	Location	Number of Days
First Peak	< 5	Segment 2	21
First Peak	< 5	Segment 28	17
First Peak	< 2.5	Segment 2	15
First Peak	< 2.5	Segment 28	4
First Peak	< 0.5	Segment 2	11
First Peak	< 0.5	Segment 28	0
Second Peak	< 5	Segment 2	10
Second Peak	< 5	Segment 28	14
Second Peak	< 2.5	Segment 2	7
Second Peak	< 2.5	Segment 28	8
Second Peak	< 0.5	Segment 2	6
Second Peak	< 0.5	Segment 28	0

Notes: DO = dissolved oxygen. First Peak occurs from August through September; and the Second Peak occurs in October through December.

Table 6-11. Number of Days when the Volume-Weighted Average Dissolved Oxygen Concentration in Lower Monumental Reservoir is Estimated to be Below Selected Criteria During the Two Peaks in Suspended Sediment Derived from a Hypothetical Dam Breach Using Method 2 (Varying SOD Rates in the Headwater)

-	-	-	SOD	SOD	SOD	SOD
TSS Pulses	DO Criteria (mg/L)	Location	0.1	0.5	1	2
First Peak	< 5	Segment 2	5	23	32	37
First Peak	< 5	Segment 28	1	20	27	29
First Peak	< 2.5	Segment 2	1	19	27	33
First Peak	< 2.5	Segment 28	0	7	14	22
First Peak	< 0.5	Segment 2	0	17	23	32
First Peak	< 0.5	Segment 28	0	0	0	0
Second Peak	< 5	Segment 2	2	14	19	22
Second Peak	< 5	Segment 28	1	18	26	28
Second Peak	< 2.5	Segment 2	0	10	18	20
Second Peak	< 2.5	Segment 28	0	9	19	23
Second Peak	< 0.5	Segment 2	0	7	15	19
Second Peak	< 0.5	Segment 28	0	0	0	0

Notes: DO = dissolved oxygen. First Peak occurs from August through September; and the Second Peak occurs in October through December.

Dissolved oxygen concentrations that would occur during subsequent spring freshet events were not modeled. However, concentrations are anticipated to be greater than the 8 mg/L Washington State criterion after the free-flowing river state becomes established.

Primary production in the lower Snake River reservoirs is currently based mainly on pelagic (open water) phytoplankton and would undergo changes during and after the 2-year dam breaching period. The overall contribution of phytoplankton to system productivity would be reduced due to the increased suspended solids concentrations, surface scums that can occur as a result of the nutrients in the suspended solids, turbidity that would limit light transmission, and the reduction in river volume per unit length. Most of the attached benthic algae, as well as benthic macroinvertebrates that currently inhabit shoreline areas, would die from desiccation after the water level is reduced (Corps 1993). The accumulated fine material would be moved downstream over time. The Corps (2002b) estimated that it would take 5 to 10 years to erode embedded sediments and return the substrate to a combination of sand, cobble, and bedrock, depending on river location, annual runoff, and precipitation. The recent river mechanics study prepared for this EIS estimated that it would take from 2 to 7 years following removal for the coarser sands and gravels stored in the reservoirs to scour down to pre-dam bed elevation throughout the reach and establish a new quasi-equilibrium condition.

A return to riverine conditions would allow the development of attached benthic algae that would replace pelagic phytoplankton as the dominant primary producers (Corps 2002a). Benthic colonization of new substrate could take several seasons to reach full productivity (Chapter 3.5, *Aquatic Habitat, Aquatic Invertebrates and Fish*). Therefore, there may be a period of reduced overall primary production as the contribution from phytoplankton diminishes but the attached benthic algae have not fully colonized new substrate. When the river reaches equilibrium, primary production would be expected to be higher per length of river than when it was impounded (Corps 2002a). The anticipated elevated benthic algal production is a function of more available substrate and shallower water depths that allow more sunlight to reach the river bottom.

Nuisance algal growth would also shift from pelagic, or open water, to epiphytic (growing on rocks) types. Blue-green algae blooms consisting of *Anabaena* sp., *Microcystis* sp, and *Aphanizomenon* sp. would not occur in the main river but could still appear in backwater areas. Attached filamentous algae such as *Didymosphenia* sp. (currently identified in the Clearwater River) along with *Cladophera* sp., *Melosira* sp., *Cymbella* sp., *Oscillatoria* sp., *Gomphomena* sp., and *Fragillaria* sp. that were identified during the 1997 attached benthic algae survey (Normandeau 1999) would drift downstream. Excessive growth would most likely occur downstream from wastewater treatment plant outfalls.

Secondary production would also change if MO3 is implemented (Corps 2002). Zooplankton would become minor components of the food web and aquatic insect larvae would become the main secondary producers (details regarding the expected changes to the benthic macroinvertebrate community are provided in Chapter 3.5, *Aquatic Habitat, Aquatic Invertebrates and Fish*.

The dam breaching under MO3 would transition the four lower Snake River reservoirs to a riverine environment. Water quality-based effluent limits identified in National Pollutant Discharge Elimination System (NPDES) permits would be affected for facilities that discharge to reservoirs as the assimilative capacity of the receiving water would decrease under MO3. This may result in the need for NPDES permit modifications, a change in treatment processes to meet more stringent effluent limits, and/or the need to extend outfall infrastructure to a deeper part of the river. Facilities with technology-based effluent limits may not be affected by the ability to discharge effluent, although it is likely that NPDES permits would need to be updated. In addition, facilities may need to adjust or modify outfalls given the new alignment of the river corridor. Additional studies related to water quality impacts, the ability to discharge wastewater, and facility modifications would need to be completed if MO3 were selected for implementation.

6.3 LOWER COLUMBIA RIVER

6.3.1 Water Temperature

The *Breach Snake Embankments* measure calls for the breaching of the lower four Snake River dams (Lower Granite, Little Goose, Lower Monumental, and Ice Harbor) and a return to a more river-like system for ESA-listed species. Due to the less surface area and shorter travel times resulting from removal of the lower Snake River dams, MO3 model results for the lower Snake River show, as compared to the No Action Alternative, faster heating and cooling in the spring and fall, respectively, and more diel and day-to-day variability. These impacts to water temperature are substantially diminished downstream of McNary Dam. Details are described below.

6.3.1.1 McNary, John Day, The Dalles, and Bonneville Dams and Reservoirs

The tailwater temperatures for MO3 at McNary, John Day, The Dalles, and Bonneville Dams were modeled under a 5-year range of river and meteorological conditions, and compared to the modeled results for the No Action Alternative (Figure 6-31 through Figure 6-34). Just as with the No Action Alternative model results, MO3 model results show that tailwater temperatures can exceed 68°F at all four dams during any of the years and conditions presented. Maximum water temperatures and the frequency of water temperature violations of state water quality criteria would be higher during a year when river flows were lower than normal and summer ambient air temperatures were higher (as in LF/HT). Under MO3, greater diel and day-to-day variability would be apparent in the lower Columbia River, but it would be far less pronounced than the lower Snake River, and the magnitude of variability would diminish from McNary to Bonneville. The average frequency of water temperature violations of the State water quality criteria would be nearly identical for the No Action Alternative and MO3 for all four Lower Columbia River dams, though there are some minor differences depending on the dam and the river and meteorological conditions (Figure 6-35). Generally, the difference in tailwater temperatures under the No Action Alternative and MO3 would be minor (Table 6-12), with differences up to 2 degrees Fahrenheit occurring occasionally.

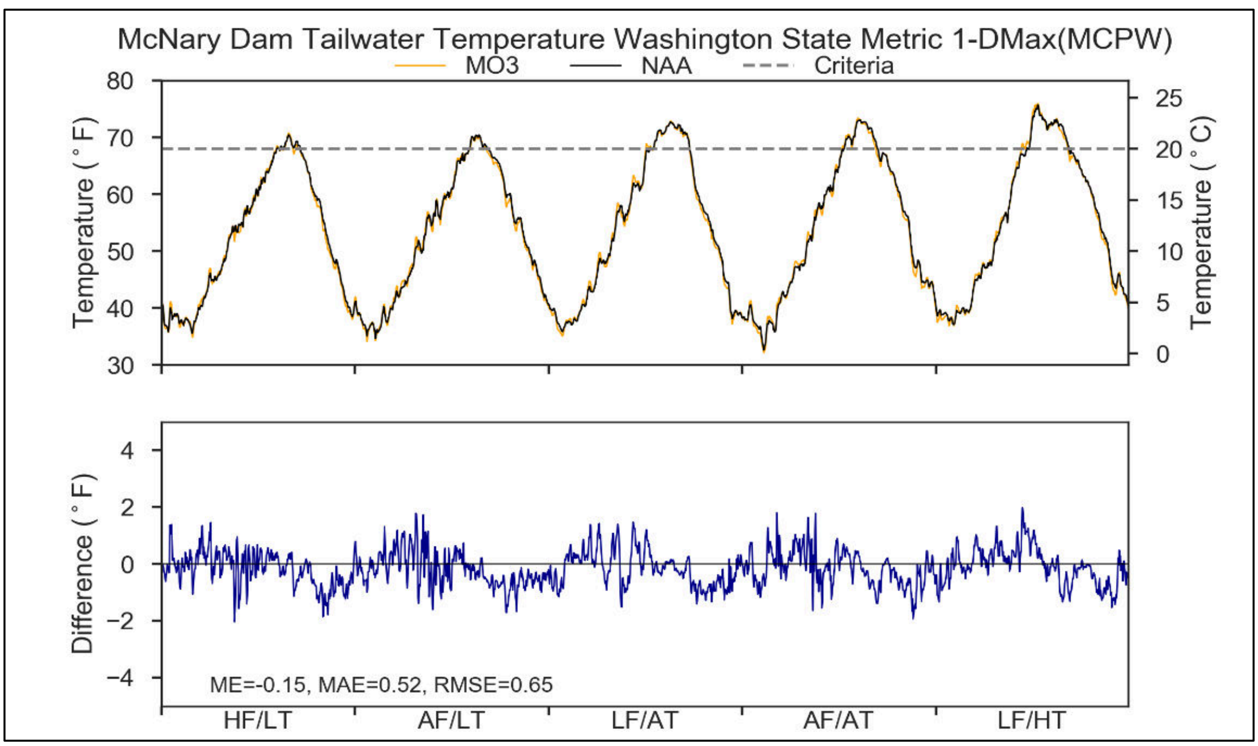


Figure 6-31. Modeled Tailwater Temperature for Multiple Objective Alternative 3 at McNary Dam Under a 5-Year Range of River and Meteorological Conditions

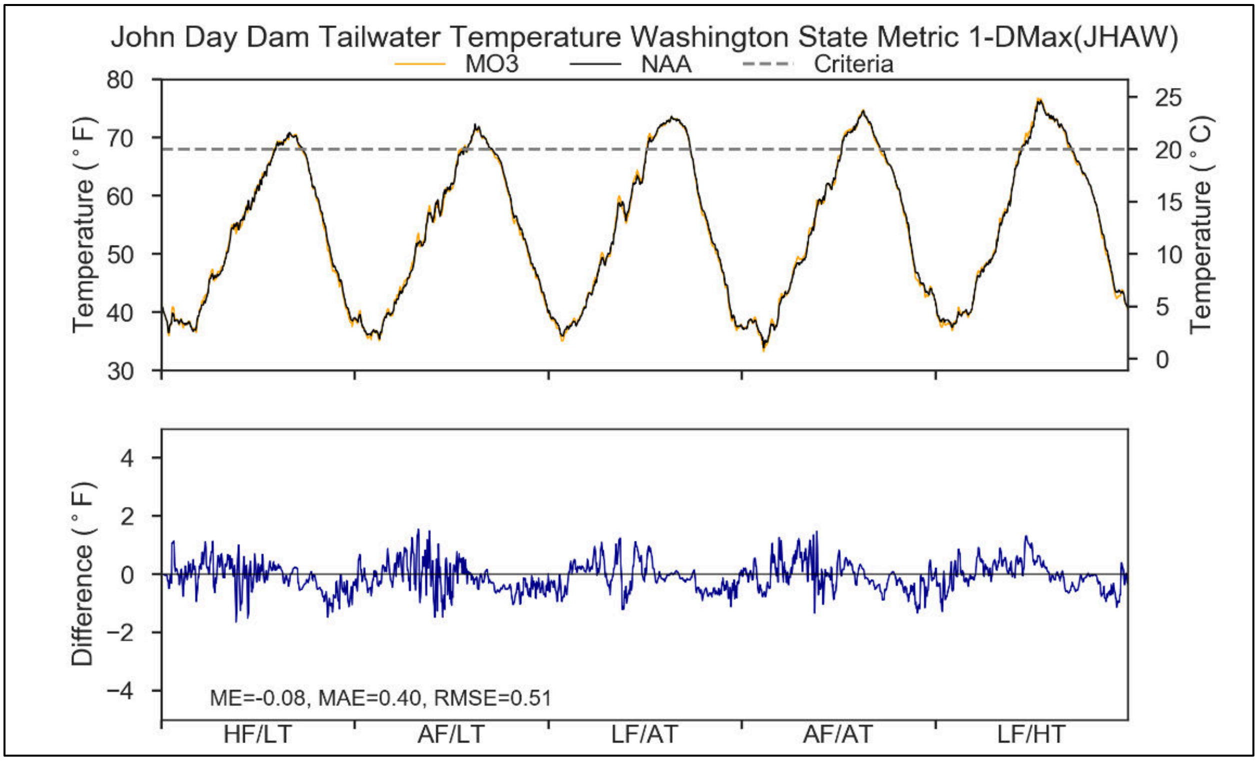


Figure 6-32. Modeled Tailwater Temperature for Multiple Objective Alternative 3 at John Day Dam Under a 5-Year Range of River and Meteorological Conditions

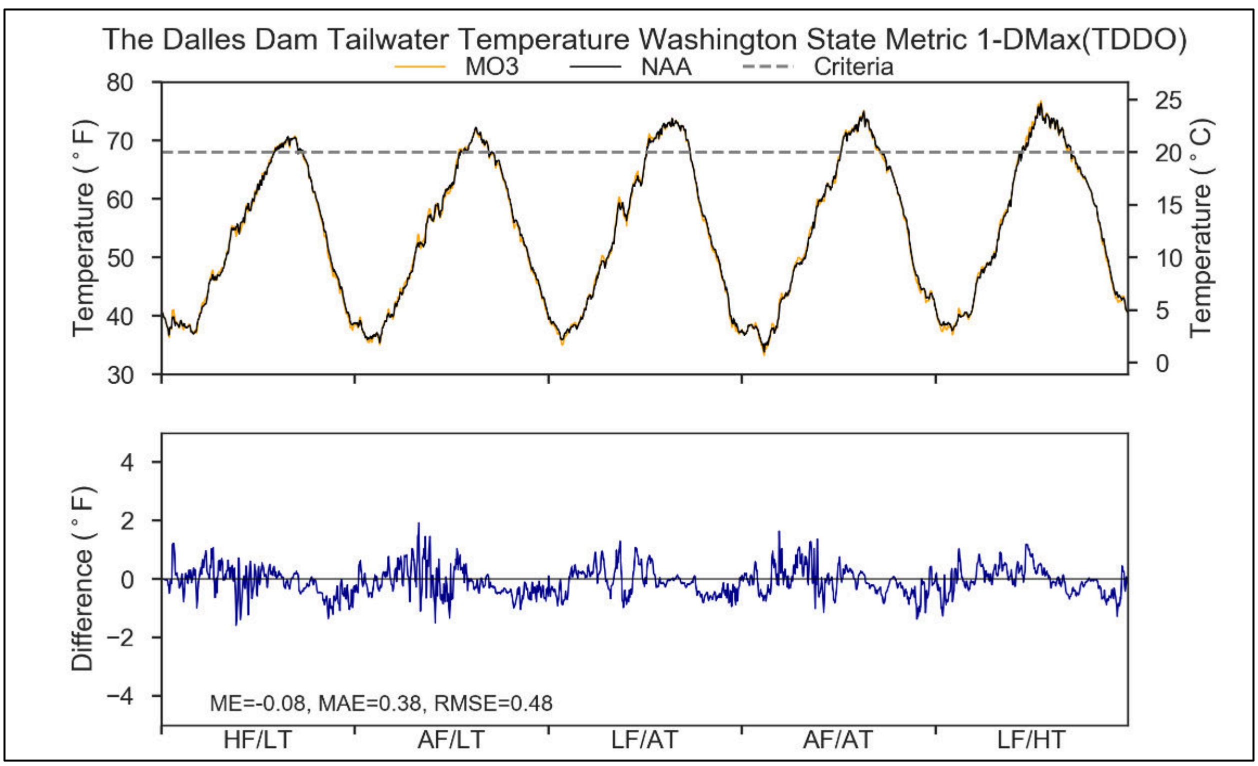


Figure 6-33. Modeled Tailwater Temperature for Multiple Objective Alternative 3 at The Dalles Dam Under a 5-Year Range of River and Meteorological Conditions

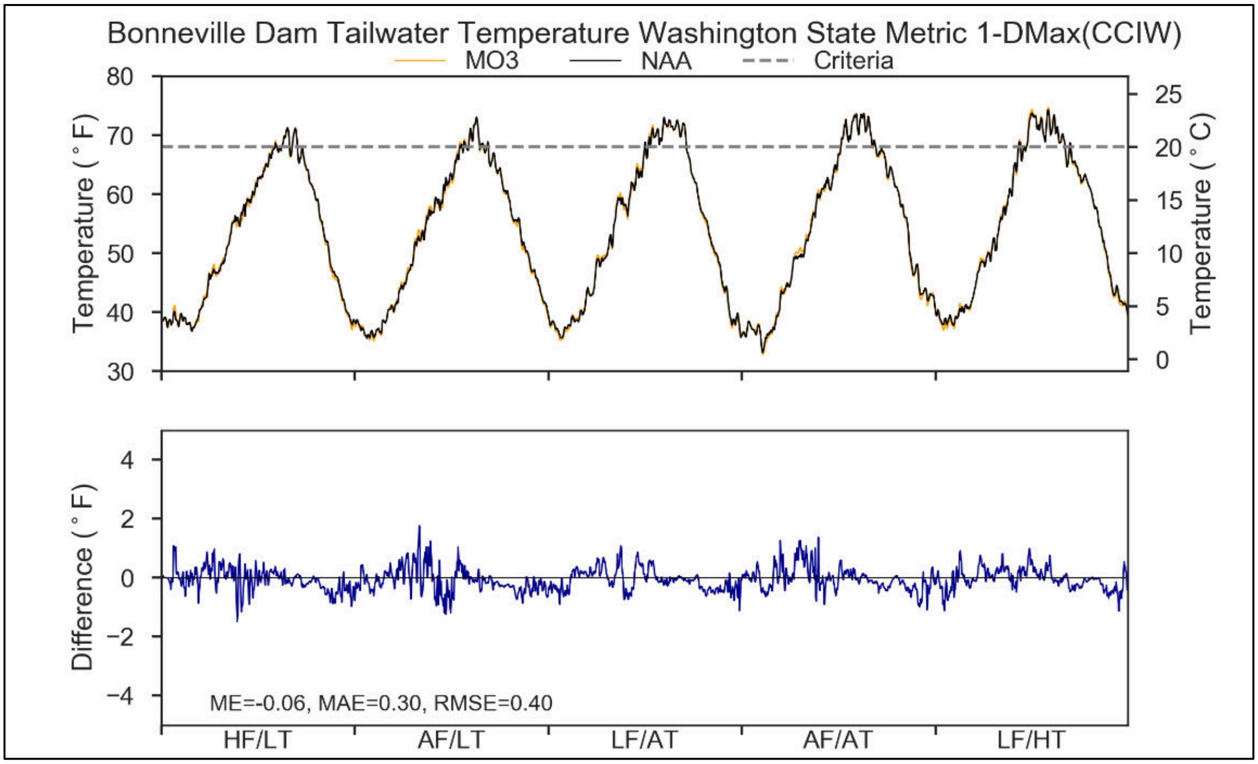


Figure 6-34. Modeled Tailwater Temperature for Multiple Objective Alternative 3 at Bonneville Dam Under a 5-Year Range of River and Meteorological Conditions

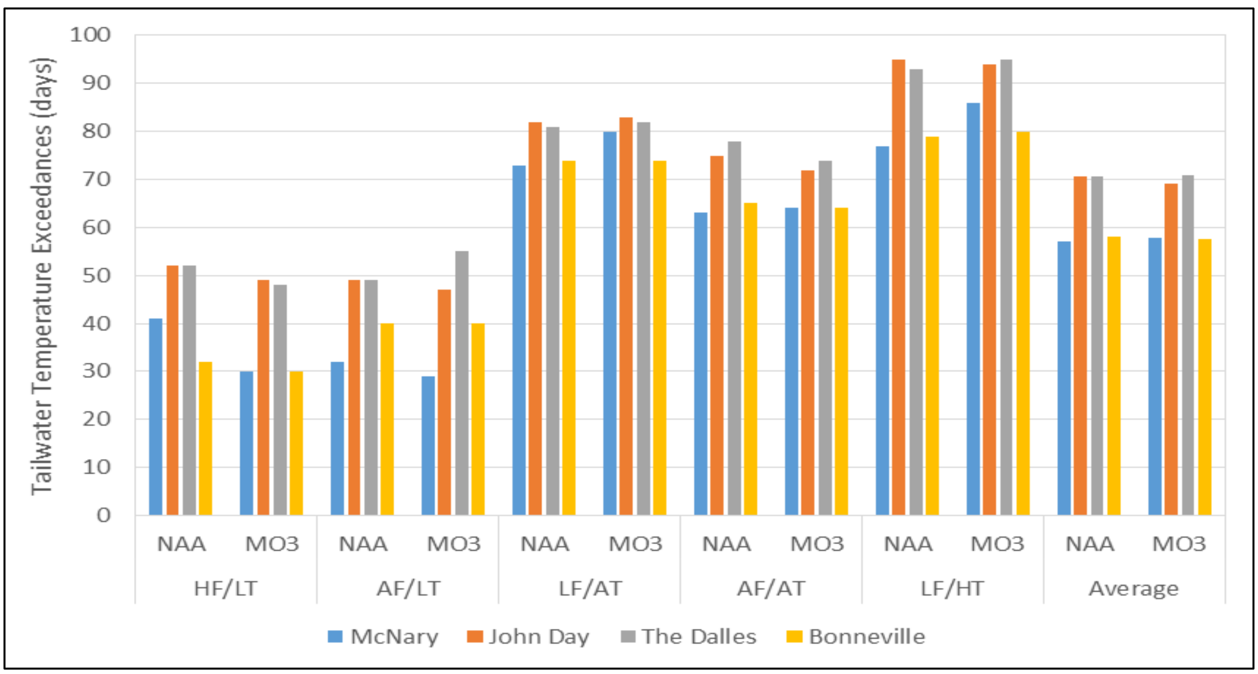


Figure 6-35. Frequency of Modeled Tailwater Temperature Violations to State Water Quality Criteria for the No Action Alternative and Multiple Objective Alternative 3 at McNary, John Day, The Dalles, and Bonneville Dams Under a 5-Year Range of River and Meteorological Conditions

Table 6-12. Difference in Number of Days the Temperature Criteria is Exceeded at the Tailwater Sites of McNary, John Day, The Dalles, and Bonneville for the Multiple Objective 3 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary	June	0	0	0	0	**12**
McNary	July	0	0	**7**	**4**	0
McNary	August	-4	-1	0	0	0
McNary	September	-7	-2	0	-3	-3
John Day	June	0	0	0	0	**2**
John Day	July	0	**2**	**1**	0	0
John Day	August	**2**	0	0	0	0
John Day	September	-5	-4	0	-3	-3
The Dalles	June	0	0	0	0	**3**
The Dalles	July	0	**8**	**1**	0	0
The Dalles	August	**2**	0	0	0	0
The Dalles	September	-6	-2	0	-4	-1
Bonneville	June	0	0	0	0	**2**
Bonneville	July	0	**3**	0	**1**	0
Bonneville	August	0	-2	0	0	0
Bonneville	September	-2	-1	0	-2	-1

6.3.2 Total Dissolved Gas

The *Breach Snake Embankments* measure calls for the breaching of the lower Snake River Dams. Without these dams in place, it is expected that forebay TDG, upstream of McNary Dam in particular, would be less than the No Action Alternative because sustained, elevated TDG is not expected to be produced in the lower Snake River without the dams.

The Spring Spill to 120% TDG limits juvenile fish passage spill to not exceed a 120 percent TDG in the tailrace of all four lower Columbia River dams from April 10 to June 15; there is no forebay TDG limit under MO3. Additionally, the *Reduced Summer Spill* measure aims to reduce the duration of summer juvenile fish passage spill at the lower Columbia River dams, ending summer spill on July 31. MO3 model results show, as compared to the No Action Alternative, similar or higher tailwater TDG saturations in April through June and lower tailwater TDG saturations in August. Details are described below.

6.3.2.1 McNary, John Day, The Dalles, and Bonneville Dams and Reservoirs

Forebay TDG saturations for MO3 at McNary, John Day, The Dalles, and Bonneville Dams were modeled under a 5-year range of river and meteorological conditions and compared to the modeled results for the No Action Alternative (Figure 6-36 to Figure 6-39). Although MO3 does not include a measure limiting forebay TDG, model results are compared to the current 115 percent TDG criterion for direct comparison to the No Action Alternative. Results show that forebay TDG saturations can exceed the current 115 percent forebay TDG criterion during the spill season at all four dams during most years and conditions presented; however, TDG levels are lower in McNary forebay under MO3 versus the No Action Alternative due to the elimination of TDG generation in the lower Snake River reach. Maximum forebay TDG saturation would be higher during a year when river flows were higher than normal (HF/LT). Maximum forebay TDG saturations in MO3, as compared to the No Action Alternative, would be higher at The Dalles and Bonneville Dams under low-flow and high air temperature conditions (LF/HT); under all other conditions, maximum forebay TDG saturations would be similar or lower under MO3 as compared to the No Action Alternative. This is due to the *Spring Spill to 120% TDG* measure, which calls for higher tailwater TDG, which would increase forebay TDG (as compared to the No Action Alternative), as well.

Under MO3, the average frequency of 110% TDG outside of the juvenile fish spill season would be similar to or slightly less under MO3 as compared to the No Action Alternative for all modeled river and meteorological conditions (Table 6-13). This is partially due to a reduction in the lack of market spill estimated for the No Action Alternative as compared to MO3. At John Day, The Dalles, and Bonneville, the frequency of 115% TDG exceedances during the juvenile fish spill season would be greater under MO3 than the No Action Alternative under all modeled river and meteorological conditions except average flow/low temperature (AF/LT), during which the frequency of 115% TDG exceedances would be about the same (Table 6-14). At McNary, the frequency of 115% TDG exceedances during the juvenile fish spill season would be lower under MO3 than the No Action Alternative (Table 6-14). Table 6-15 shows the difference in the number of violations under MO3 as compared to the NAA.

The MO3 model results show that tailwater TDG saturations can exceed the current 120 percent spill season TDG criterion at all four dams during most of the years and conditions presented (the only exceptions being at McNary and John Day under LF/HT conditions) (Figure 6-40 through Figure 6-43). Maximum tailwater TDG saturation would be higher during a year when river flows were higher than normal and summer ambient air temperatures were lower (as in the HF/LT year). Tailwater TDG saturations would be similar or higher in MO3 as compared to the No Action Alternative for all four dams from April 10 to June 15, but lower at all four dams in August. Under MO3, the frequency of 110% TDG exceedances outside the spill season would be similar to or slightly less than under the No Action Alternative for all modeled river and meteorological conditions (Table 6-16). This is partially due to a reduction in the lack of market spill estimated for the No Action Alternative as compared to MO3. Generally, the frequency of 120% TDG exceedances during the juvenile fish spill season would be greater under MO3 than the No Action Alternative under all modeled river and meteorological conditions, though there is some variation depending on the particular dam and condition (e.g., McNary and John Day under the LF/HT condition when no 120% exceedances are expected; Table 6-17). Table 6-18 shows the difference in the number of violations under MO3 as compared to the NAA.

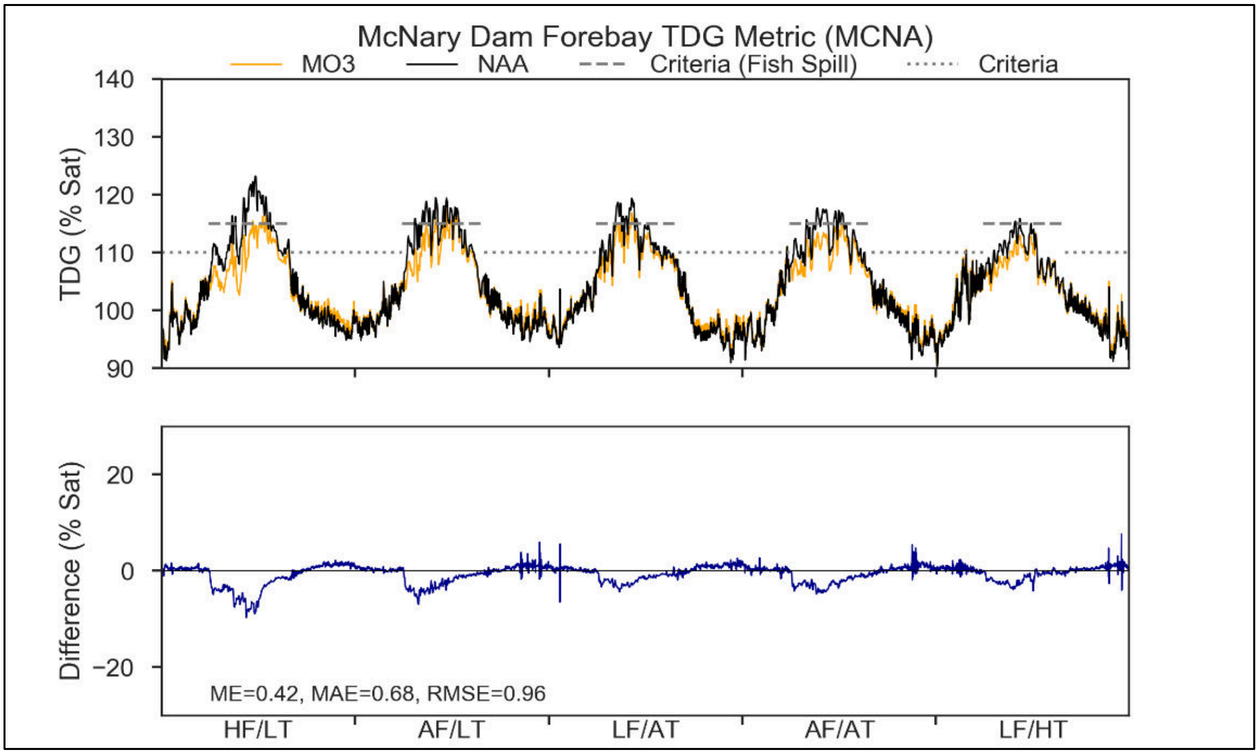


Figure 6-36. Modeled Forebay Total Dissolved Gas for Multiple Objective Alternative 3 at McNary Dam Under a 5-Year Range of River and Meteorological Conditions

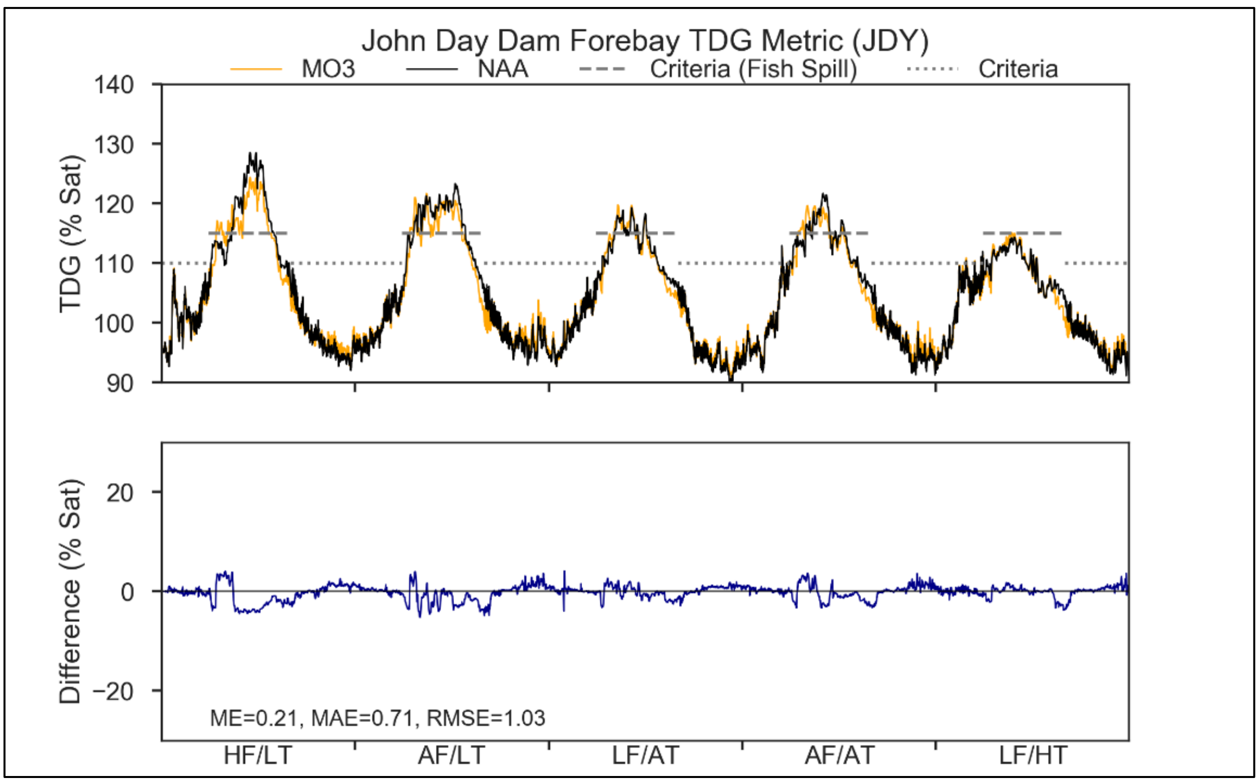


Figure 6-37. Modeled Forebay Total Dissolved Gas for Multiple Objective Alternative 3 at John Day Dam Under a 5-Year Range of River and Meteorological Conditions

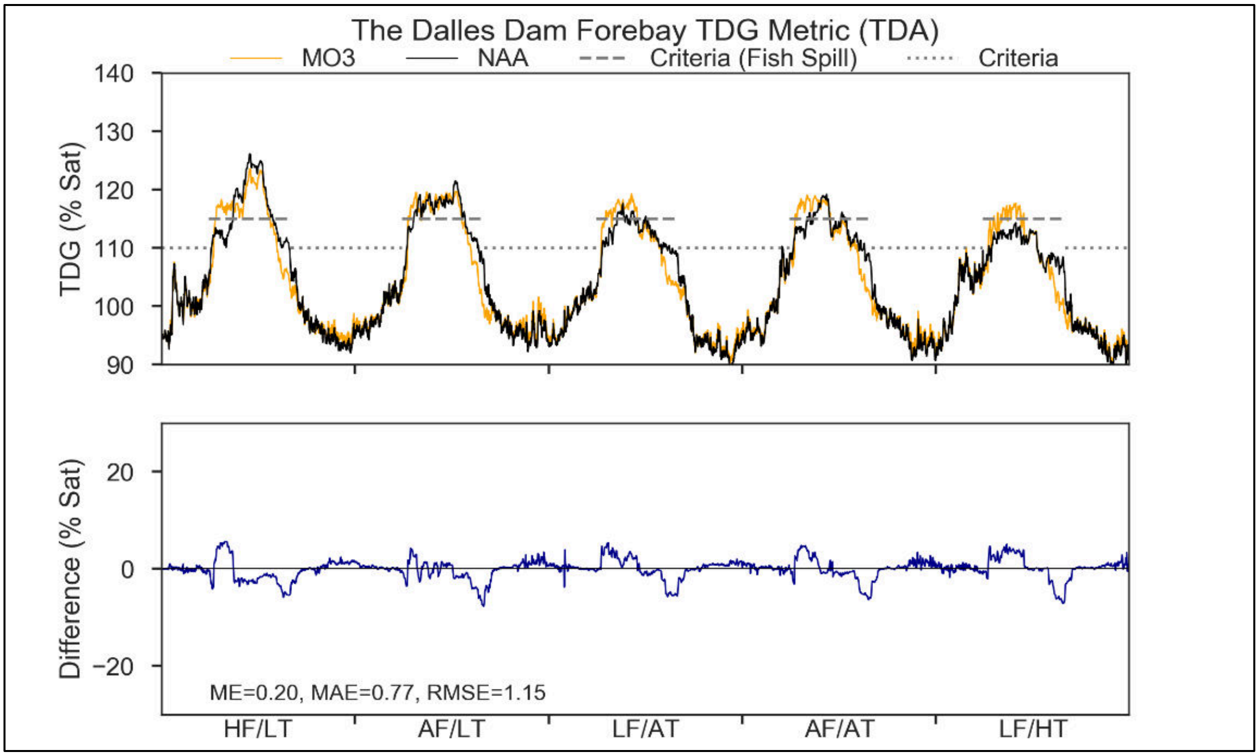


Figure 6-38. Modeled Forebay Total Dissolved Gas for Multiple Objective Alternative 3 at The Dalles Dam Under a 5-Year Range of River and Meteorological Conditions

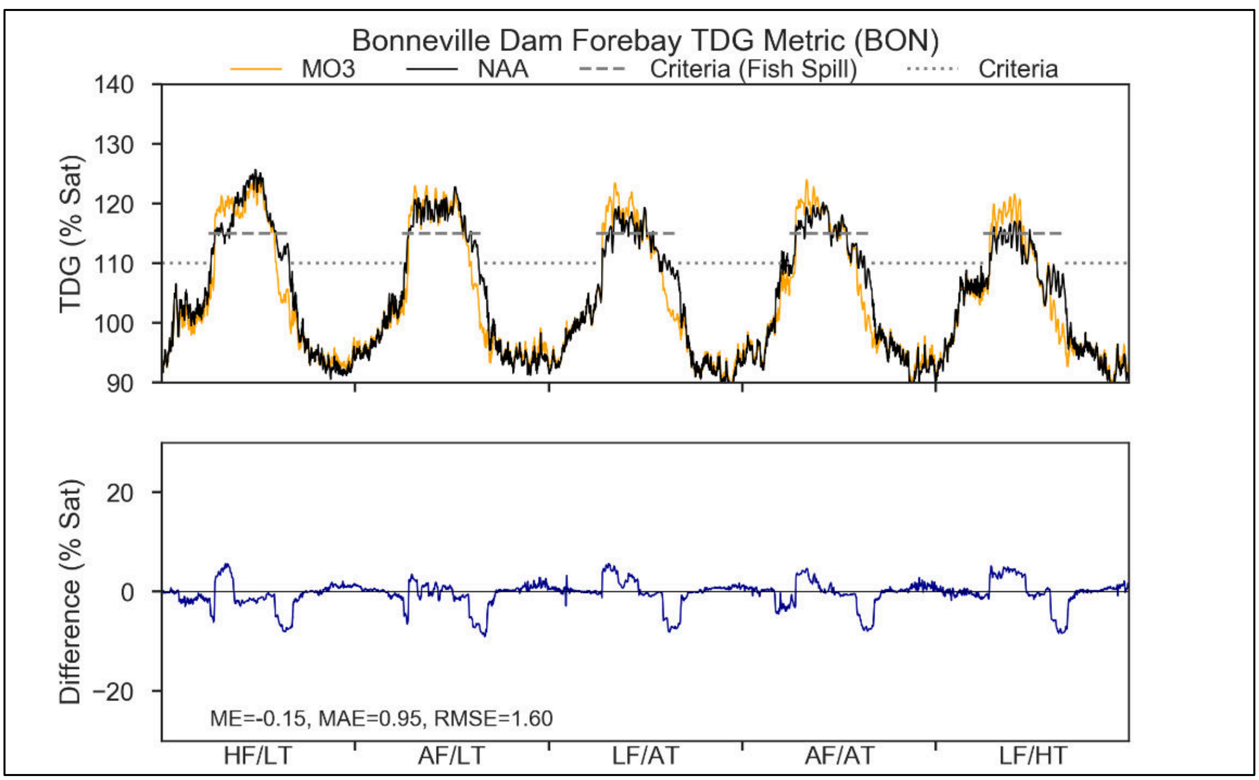


Figure 6-39. Modeled Forebay Total Dissolved Gas for Multiple Objective Alternative 3 at Bonneville Dam Under a 5-Year Range of River and Meteorological Conditions

Table 6-13. Difference in the Frequency of Modeled Forebay Total Dissolved Range Outside of Spill Season for the Multiple Objective Alternative 3 relative to the No Action Alternative at McNary, John Day, The Dalles, and Bonneville Dams Under a 5-Year Range of River and Meteorological Conditions

SITE	TDG Range (% Sat)	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary	<=110	0.00%	0.00%	0.00%	-0.12%	-0.04%
McNary	>110,<=115	0.00%	0.00%	0.00%	0.12%	0.04%
McNary	>115,<=120	0.00%	0.00%	0.00%	0.00%	0.00%
McNary	>120,<=125	0.00%	0.00%	0.00%	0.00%	0.00%
McNary	>125	0.00%	0.00%	0.00%	0.00%	0.00%
John Day	<=110	0.00%	0.00%	0.00%	0.20%	-0.45%
John Day	>110,<=115	0.00%	0.00%	0.00%	-0.20%	0.45%
John Day	>115,<=120	0.00%	0.00%	0.00%	0.00%	0.00%
John Day	>120,<=125	0.00%	0.00%	0.00%	0.00%	0.00%
John Day	>125	0.00%	0.00%	0.00%	0.00%	0.00%
The Dalles	<=110	0.00%	0.00%	0.00%	0.06%	0.00%
The Dalles	>110,<=115	0.00%	0.00%	0.00%	-0.06%	0.00%
The Dalles	>115,<=120	0.00%	0.00%	0.00%	0.00%	0.00%
The Dalles	>120,<=125	0.00%	0.00%	0.00%	0.00%	0.00%
The Dalles	>125	0.00%	0.00%	0.00%	0.00%	0.00%
Bonneville	<=110	0.00%	0.00%	0.00%	3.77%	0.00%
Bonneville	>110,<=115	0.00%	0.00%	0.00%	-3.77%	0.00%
Bonneville	>115,<=120	0.00%	0.00%	0.00%	0.00%	0.00%
Bonneville	>120,<=125	0.00%	0.00%	0.00%	0.00%	0.00%
Bonneville	>125	0.00%	0.00%	0.00%	0.00%	0.00%

Table 6-14. Difference in the Frequency of Modeled Forebay Total Dissolved Range During Spill Season for the Multiple Objective Alternative 3 relative to the No Action Alternative at McNary, John Day, The Dalles, and Bonneville Dams Under a 5-Year Range of River and Meteorological Conditions

SITE	TDG Range (% Sat)	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary	<=110	33.99%	24.18%	17.65%	20.92%	23.53%
McNary	>110,<=115	-5.23%	1.31%	-1.96%	3.92%	-19.61%
McNary	>115,<=120	-16.99%	-25.49%	-15.69%	-24.84%	-3.92%
McNary	>120,<=125	-11.76%	0.00%	0.00%	0.00%	0.00%
McNary	>125	0.00%	0.00%	0.00%	0.00%	0.00%
John Day	<=110	9.80%	6.54%	0.65%	3.92%	1.31%
John Day	>110,<=115	-16.34%	-0.65%	-1.96%	-9.15%	-2.61%
John Day	>115,<=120	20.26%	3.27%	1.31%	12.42%	1.31%
John Day	>120,<=125	5.23%	-9.15%	0.00%	-7.19%	0.00%
John Day	>125	-18.95%	0.00%	0.00%	0.00%	0.00%
The Dalles	<=110	18.95%	10.46%	6.54%	7.84%	-2.61%
The Dalles	>110,<=115	-36.60%	-12.42%	-27.45%	-21.57%	-24.84%
The Dalles	>115,<=120	26.14%	7.84%	20.92%	13.73%	27.45%
The Dalles	>120,<=125	-6.54%	-5.88%	0.00%	0.00%	0.00%
The Dalles	>125	-1.96%	0.00%	0.00%	0.00%	0.00%
Bonneville	<=110	19.61%	13.73%	5.88%	10.46%	-1.31%
Bonneville	>110,<=115	-25.49%	-11.11%	-15.69%	-11.76%	-21.57%
Bonneville	>115,<=120	10.46%	-3.27%	-5.88%	-15.69%	13.73%
Bonneville	>120,<=125	-1.96%	0.65%	15.69%	16.99%	9.15%
Bonneville	>125	-2.61%	0.00%	0.00%	0.00%	0.00%

Table 6-15. Difference in Number of Days the Total Dissolved Gas Criteria is Exceeded at the Forebay Sites of McNary, John Day, the Dalles, and Bonneville for the Multiple Objective 3 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary	April	0	-2	0	0	0
McNary	May	-4	-21	-17	-11	-2
McNary	June	-23	-11	-7	-17	-4
McNary	July	-17	-5	0	-10	0
John Day	February	0	0	0	0	**1**
John Day	March	0	0	0	0	0
John Day	April	**13**	**4**	0	**11**	0
John Day	May	**7**	-6	**3**	**2**	**2**
John Day	June	-2	0	-1	-3	0
John Day	July	-7	-7	0	-2	0
John Day	August	-1	0	0	0	0
The Dalles	April	**17**	**9**	**12**	**18**	**4**
The Dalles	May	**15**	0	**13**	**9**	**26**
The Dalles	June	0	0	**9**	**2**	**12**
The Dalles	July	-5	-6	-2	-8	0
Bonneville	March	0	0	0	-8	0
Bonneville	April	**7**	0	**14**	**2**	**12**
Bonneville	May	**6**	0	**3**	0	**16**
Bonneville	June	0	0	**1**	**2**	**7**
Bonneville	July	0	-1	-3	-2	0
Bonneville	August	-4	-3	0	0	0
Bonneville	September	0	0	0	0	0

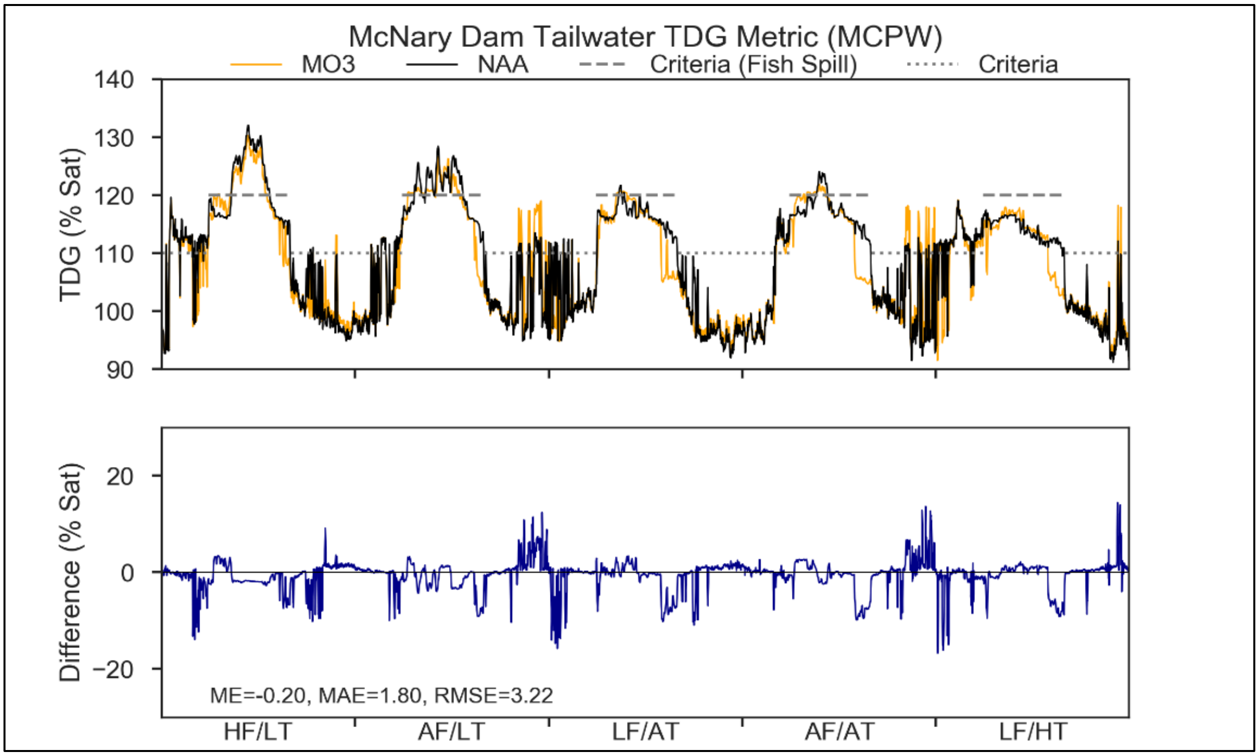


Figure 6-40. Modeled Tailwater Total Dissolved Gas for Multiple Objective Alternative 3 at McNary Dam Under a 5-Year Range of River and Meteorological Conditions

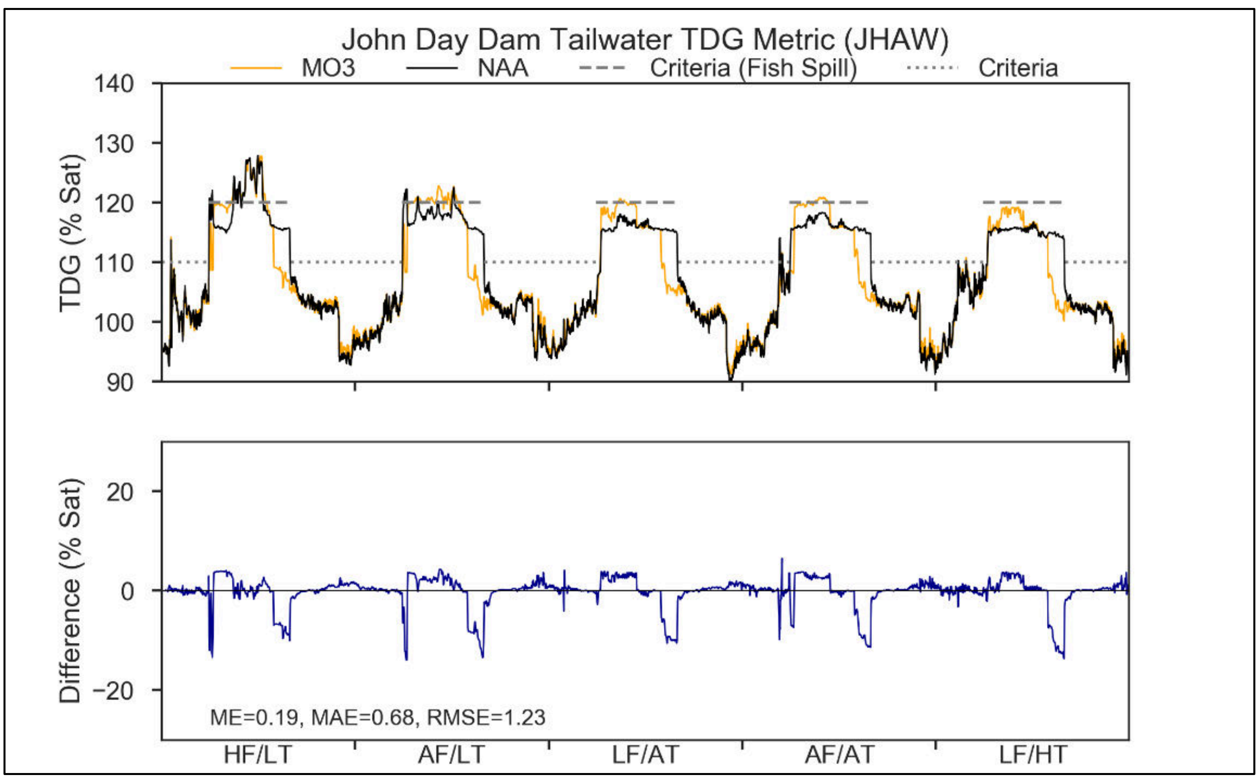


Figure 6-41. Modeled Tailwater Total Dissolved Gas for Multiple Objective Alternative 3 at John Day Dam Under a 5-Year Range of River and meteorological Conditions

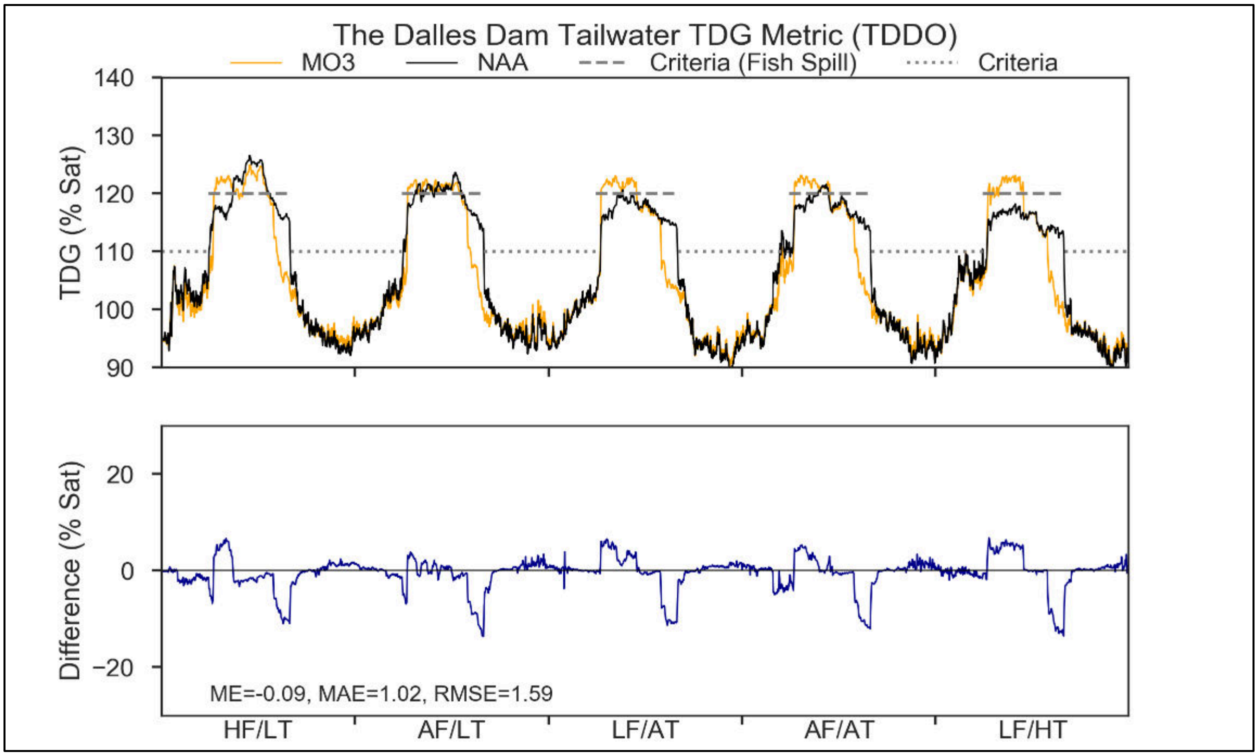


Figure 6-42. Modeled Tailwater Total Dissolved Gas for Multiple Objective Alternative 3 at The Dalles Dam Under a 5-Year Range of River and Meteorological Conditions

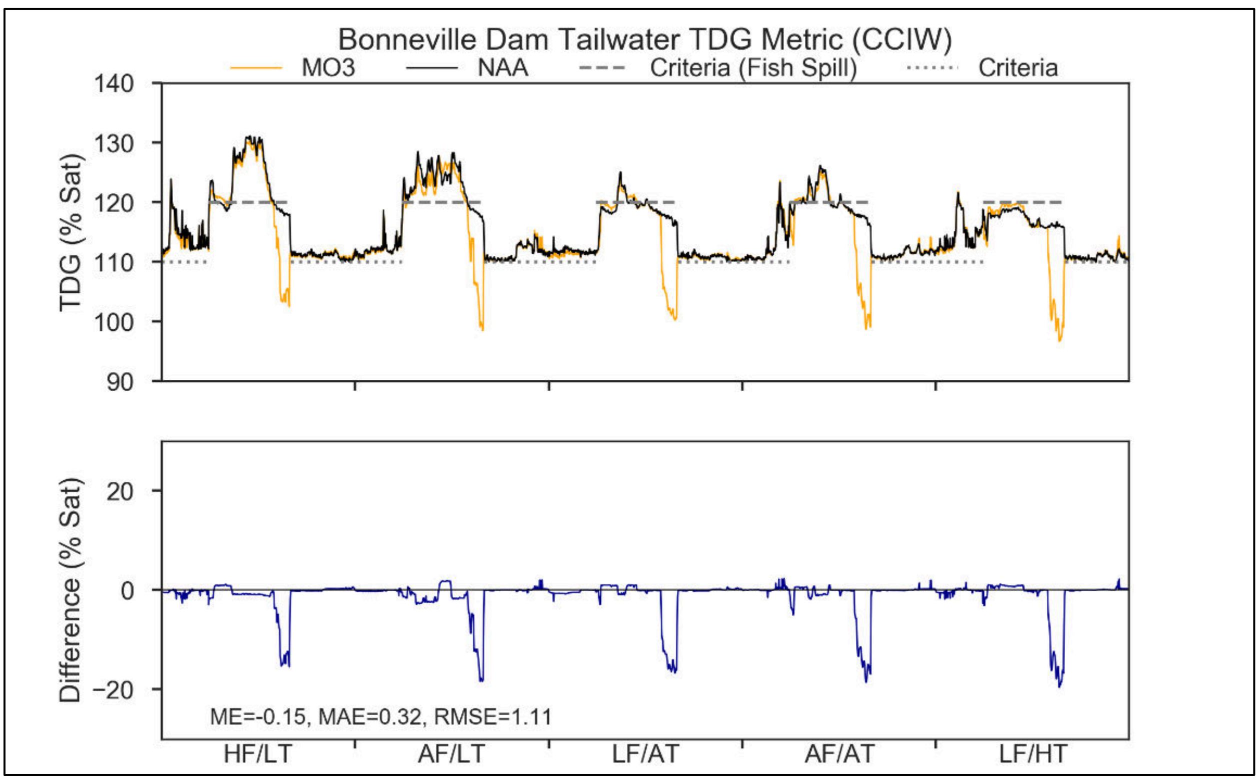


Figure 6-43. Modeled Tailwater Total Dissolved Gas for Multiple Objective Alternative 3 at Bonneville Dam Under a 5-Year Range of River and Meteorological Conditions

Table 6-16. Difference in the Frequency of Modeled Tailwater Total Dissolved Range Outside of Spill Season for the Multiple Objective Alternative 3 relative to the No Action Alternative at McNary, John Day, The Dalles, and Bonneville Dams Under a 5-Year Range of River and Meteorological Conditions

SITE	TDG Range (% Sat)	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary	<=110	5.30%	-0.71%	2.00%	-4.07%	3.25%
McNary	>110,<=115	-4.60%	-7.15%	-2.00%	-0.18%	-3.97%
McNary	>115,<=120	-0.69%	7.86%	0.00%	4.25%	0.72%
McNary	>120,<=125	0.00%	0.00%	0.00%	0.00%	0.00%
McNary	>125	0.00%	0.00%	0.00%	0.00%	0.00%
John Day	<=110	-0.04%	0.00%	0.00%	0.83%	-0.20%
John Day	>110,<=115	0.04%	0.00%	0.00%	-0.83%	0.20%
John Day	>115,<=120	0.00%	0.00%	0.00%	0.00%	0.00%
John Day	>120,<=125	0.00%	0.00%	0.00%	0.00%	0.00%
John Day	>125	0.00%	0.00%	0.00%	0.00%	0.00%
The Dalles	<=110	0.00%	0.00%	0.00%	7.24%	0.08%
The Dalles	>110,<=115	0.00%	0.00%	0.00%	-7.24%	-0.08%
The Dalles	>115,<=120	0.00%	0.00%	0.00%	0.00%	0.00%
The Dalles	>120,<=125	0.00%	0.00%	0.00%	0.00%	0.00%
The Dalles	>125	0.00%	0.00%	0.00%	0.00%	0.00%
Bonneville	<=110	-0.10%	0.04%	0.00%	0.00%	-0.40%
Bonneville	>110,<=115	3.00%	-0.06%	0.00%	-1.25%	0.86%
Bonneville	>115,<=120	-2.88%	0.02%	0.00%	1.01%	-0.92%
Bonneville	>120,<=125	-0.02%	0.00%	0.00%	0.24%	0.46%
Bonneville	>125	0.00%	0.00%	0.00%	0.00%	0.00%

Table 6-17. Difference in the Frequency of Modeled Tailwater Total Dissolved Range During Spill Season for the Multiple Objective Alternative 3 relative to the No Action Alternative at McNary, John Day, The Dalles, and Bonneville Dams Under a 5-Year Range of River and Meteorological Conditions

SITE	TDG Range (% Sat)	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary	<=110	8.39%	9.68%	20.00%	20.00%	20.65%
McNary	>110,<=115	0.00%	-3.87%	-12.90%	-14.84%	-10.32%
McNary	>115,<=120	-8.39%	-14.84%	-14.19%	-16.13%	-10.32%
McNary	>120,<=125	13.55%	16.13%	7.10%	10.97%	0.00%
McNary	>125	-13.55%	-7.10%	0.00%	0.00%	0.00%
John Day	<=110	23.23%	23.87%	18.71%	20.00%	20.00%
John Day	>110,<=115	0.00%	-2.58%	-0.65%	-2.58%	-23.87%
John Day	>115,<=120	-29.68%	-57.42%	-28.39%	-36.77%	3.87%
John Day	>120,<=125	7.10%	36.13%	10.32%	19.35%	0.00%
John Day	>125	-0.65%	0.00%	0.00%	0.00%	0.00%
The Dalles	<=110	21.29%	20.00%	20.00%	21.29%	20.65%
The Dalles	>110,<=115	0.00%	-5.81%	-10.32%	-11.61%	-22.58%
The Dalles	>115,<=120	-36.13%	-27.74%	-52.26%	-40.00%	-34.19%
The Dalles	>120,<=125	33.55%	13.55%	42.58%	30.32%	36.13%
The Dalles	>125	-18.71%	0.00%	0.00%	0.00%	0.00%
Bonneville	<=110	11.61%	11.61%	19.35%	17.42%	18.71%
Bonneville	>110,<=115	5.16%	7.10%	1.29%	5.16%	3.87%
Bonneville	>115,<=120	-24.52%	-15.48%	-27.74%	-32.90%	-23.23%
Bonneville	>120,<=125	9.03%	7.10%	7.74%	16.77%	0.65%
Bonneville	>125	-1.29%	-10.32%	-0.65%	-6.45%	0.00%

Table 6-18. Difference in Number of Days the Total Dissolved Gas Criteria is Exceeded at the Tailwater Sites of McNary, John Day, the Dalles, and Bonneville for the Multiple Objective 3 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary	January	0	0	-4	0	-7
McNary	February	0	0	0	0	0
McNary	March	-11	-7	0	-1	-2
McNary	April	**4**	**12**	0	**3**	0
McNary	May	**2**	**8**	**12**	**18**	0
McNary	June	0	-1	-1	-4	0
McNary	July	-6	-5	0	0	0
McNary	October	**6**	**1**	0	0	0
McNary	November	0	**2**	0	**1**	0
McNary	December	0	**6**	0	**7**	**1**
John Day	March	0	-1	0	-2	0
John Day	April	-3	**1**	0	0	0
John Day	May	**6**	**21**	**16**	**19**	0
John Day	June	**2**	**23**	0	**11**	0
John Day	July	**5**	**11**	0	0	0
The Dalles	March	0	0	0	-16	0
The Dalles	April	**20**	**15**	**21**	**21**	**10**
The Dalles	May	**10**	**9**	**29**	**24**	**31**
The Dalles	June	-3	-1	**16**	**2**	**15**
The Dalles	July	-4	-2	0	0	0
Bonneville	April	**8**	-4	**3**	**12**	0
Bonneville	May	**6**	0	**4**	**4**	0
Bonneville	June	0	0	**10**	**1**	**1**
Bonneville	July	-2	-1	-6	-1	0
Bonneville	December	0	0	0	0	**2**

6.3.3 Other Physical, Chemical, and Biological Processes

6.3.3.1 McNary, John Day, The Dalles, and Bonneville Dams and Reservoirs

The lower Columbia River contains a variety of human-sourced compounds, including metals and organic compounds. The introduction of pollutants and excess nutrients from farming and industrial activities, as well as urban runoff, is expected to continue under MO3. As with the No Action Alternative, emerging contaminants such as pharmaceuticals and new pesticides will also likely become more prevalent. This condition is expected to remain.

Breaching of the dams under MO3 would result in an estimated average annual sediment volume of 12.6 million cubic yards (Mcy) being transported downstream to the McNary forebay in the years immediately following breaching (near-term). As comparison, an annual average of 0.8 Mcy would be expected under the No Action Alternative (Appendix C, *River Mechanics*). Eventually, the Snake River will reach a new quasi-equilibrium condition and largely pass incoming sediment load; an annual average of 3.6 Mcy would be expected to enter the McNary Reservoir in the long term.

Approximately 30 to 35 percent of the total sediment entering the McNary Reservoir would be expected to pass McNary Dam under MO3, both in the near and long term. The sediment not trapped by McNary would be composed almost entirely of clay and silt and are expected to remain in suspension and travel to the estuary. Little material is expected to settle in the reservoirs downstream of McNary Reservoir.

Some negative impacts associated with the sediment transport would be expected in the McNary Reservoir. Dissolved oxygen, light attenuation, phytoplankton, zooplankton, and productivity would likely be depressed, while TSS, turbidity, nutrients, organics, and metals would likely increase. Near-term transport of silt- and clay-sized particles downstream of McNary Dam would not likely cause significant impacts to the downstream reservoirs, since the majority of sediment would be trapped by McNary Dam. The near-term increases in suspended sediment and turbidity (and associated impacts) would eventually level off, and more typical seasonal fluctuations would occur in the long term in the McNary forebay and downstream.

Additionally, under the *John Day Full Pool* measure, flow and pool elevation restrictions are partially lifted to increase hydropower generation and hydropower flexibility to integrate renewable resources. Safety-related restrictions would continue, including meeting FRM elevations and flows, maintaining ramp rates for minimizing dam erosion, and maintaining grid reliability. Specifically, the *Ramping Rates for Safety* measure calls for ramping rate limitations at all dams to be defined only for the purposes of safety and engineering; the *John Day Full Pool* measure reduces the restrictions on seasonal pool elevations at John Day, except as needed for FRM. Modeling results suggest there would be minor pool elevation differences between MO3 and the No Action Alternative (Figure 6-44 through Figure 6-47). Manipulating the water level could have minor, short-term TSS and associated impacts (turbidity, light attenuation, and/or chemicals that may be associated with TSS, such as nutrients, metals, and organics). However, the impact is expected to be negligible in the lower Columbia River reservoirs.

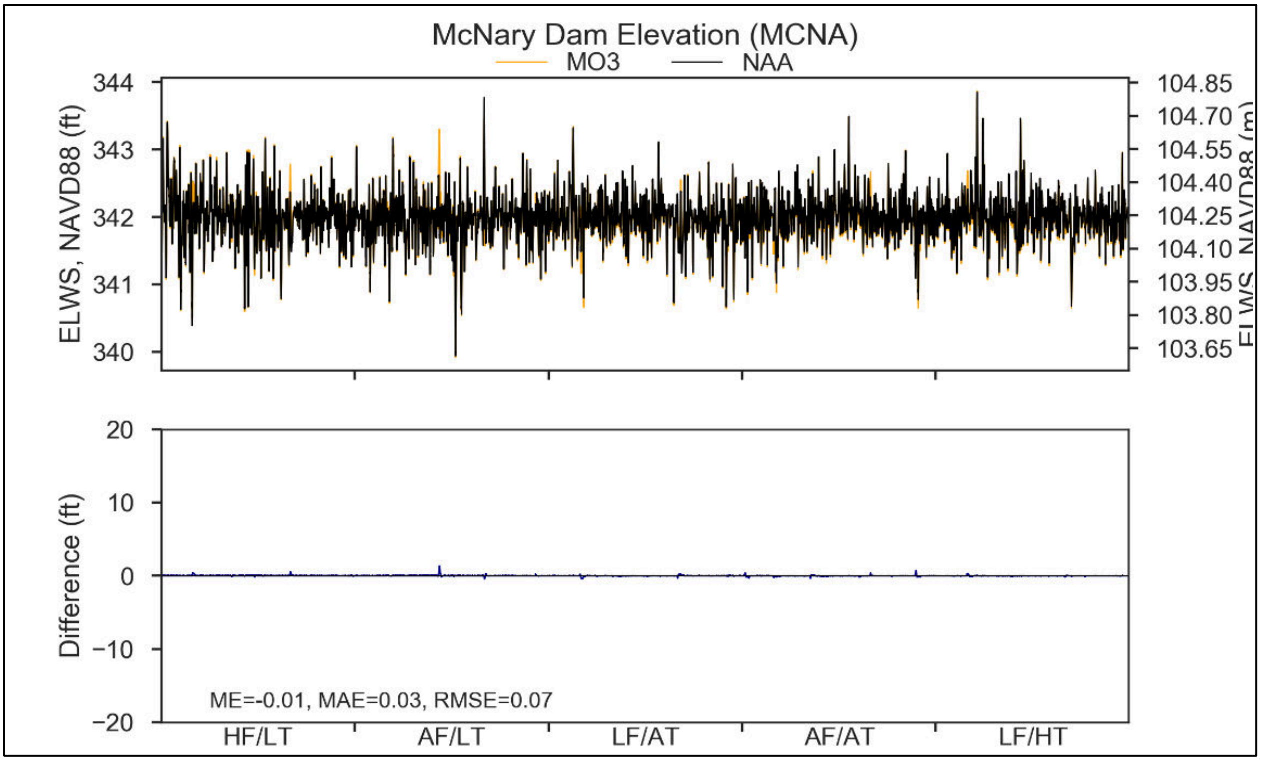


Figure 6-44. Modeled Forebay Elevation for Multiple Objective Alternative 3 at McNary Dam Under a 5-Year Range of River and Meteorological Conditions

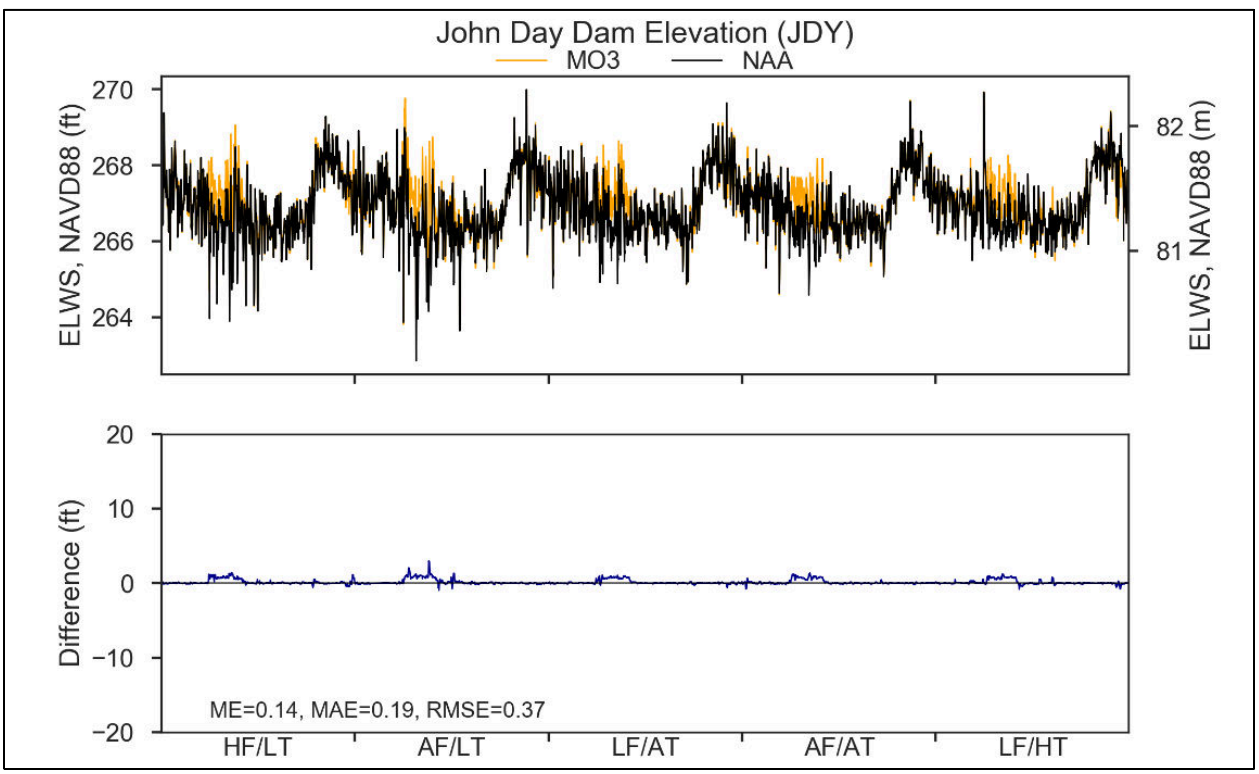


Figure 6-45. Modeled Forebay Elevation for Multiple Objective Alternative 3 at John Day Dam Under a 5-Year Range of River and Meteorological Conditions

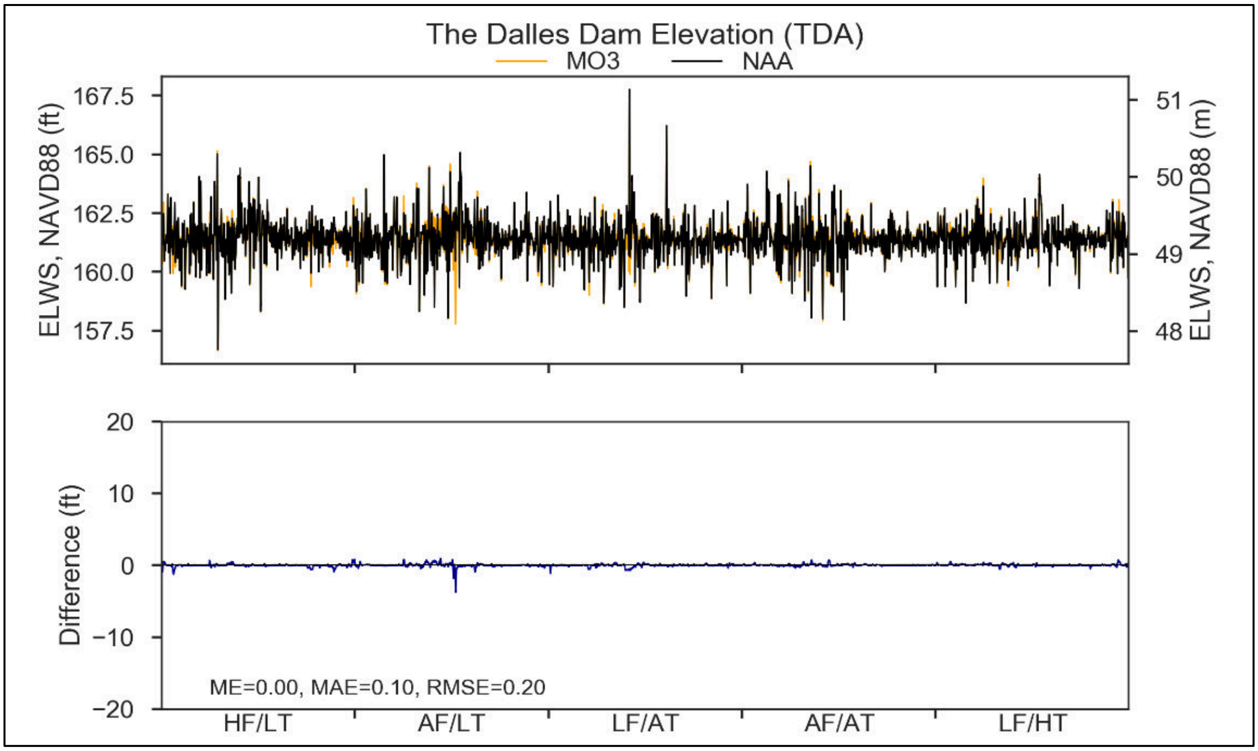


Figure 6-46. Modeled Forebay Elevation for Multiple Objective Alternative 3 at The Dalles Dam Under a 5-Year Range of River and Meteorological Conditions

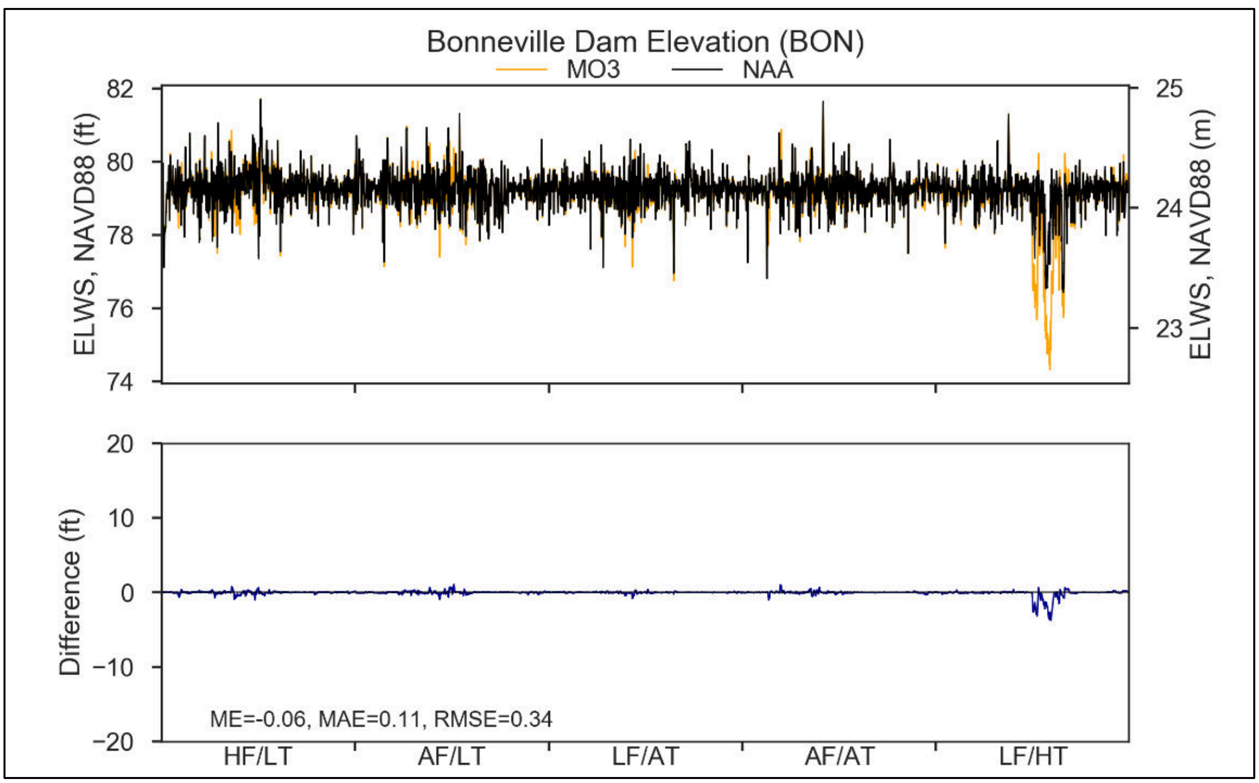


Figure 6-47. Modeled Forebay Elevation for Multiple Objective Alternative 3 at Bonneville Dam Under a 5-Year Range of River and Meteorological Conditions

6.4 SEDIMENT PROCESSES

6.4.1 Columbia River Sediment

MO3 includes various operational changes for the Columbia River dams. These changes would have little impact on sediment sources, movement, or contamination within the Columbia River sediment. Sediment shoaled behind the dams would remain at depth, undisturbed by water level fluctuations, the timing of water releases, hydropower generation or lack thereof, and fish passage activities. Historically sourced pollutants would remain in the shoaled sediment, with organic compounds slowly degrading over time and metals remaining in the sediment matrix. It is anticipated that sediment conditions within the Columbia River System, with the exception of McNary Reservoir, would remain similar to the No Action Alternative. Changes to McNary Reservoir sediment are discussed below, in conjunction with the lower Snake River sediment.

6.4.2 Lower Snake River Sediment

MO3 includes breaching the four lower Snake River dams, which would have a great impact on sediment shoaling, movement, and the distribution of pollutants associated with the sediment. The following discussion is based on the movement of sediment modeled by the River Mechanics group (Appendix C, *River Mechanics).* The reader is referred to that information on the details of sediment migration associated with the dam breach. The discussion in this section focuses on the pollutants associated with the sediment, the water quality impacts associated with the sediment movement, and changes to shoaling patterns.

Sediment began shoaling behind the lower Snake River dams as they were constructed. Since the dams were constructed in order from Ice Harbor to Lower Monumental, Little Goose, and then Lower Granite, sediment moving down the Snake River shoaled mainly behind the dam furthest upriver. Each of the dams has at least some amount of shoaled sediment. The quality of this material is not well documented for some areas within the lower Snake River; however, the sediment quality is assumed to be impacted by human-sourced chemicals. This is based on the age of the shoaled sediment; the prevalence of fish tissue impairments, which indicate that the sediment could be a reservoir for bio-accumulative compounds; and the sediment data available for some areas. Measurable concentrations of dioxins, glyphosate and its degradation byproduct aminomethylphosphonic acid, DDT and the degradation byproducts DDE and DDD, aldrin, PCBs, dibenzofuran, and hexachlorobenzene have been found in various sediment samples (https://www.nwd.usace.army.mil/CRSO/Documents/). In general, sandy sediment has accumulated above Silcott Island (in Lower Granite Reservoir), and material downstream from this, including below Lower Granite Dam and behind the other lower Snake River dams, is mostly silt and clay. The sediment shoaled behind the lower Snake River and McNary dams has not been sampled in over 20 years and there is uncertainty in the chemical characteristics of the sediment.

Sediment behind the dams is shoaled throughout the reservoirs, in the channel, and on what was originally the banks of the Snake River. The depth and distribution is variable, but the total volume estimated to be shoaled within the lower Snake River is approximately 178 Mcy

(Appendix C, *River Mechanics*). Based on the modeling conducted by the River Mechanics group, it is anticipated that most of this sediment would be released after the lower Snake River dams are breached. A conceptual model is used as the basis to discuss the conditions that would be experienced at different times during the dam breach process and afterward.

6.4.2.1 Conceptual Site Model

Based on the River Mechanics Team's work, it is possible to summarize the sediment release scenario by time period and to identify the sediment related water quality and other impacts for those times (Table 6-19). Figure 6-48 shows an example of the conceptual model for the system post-breach.

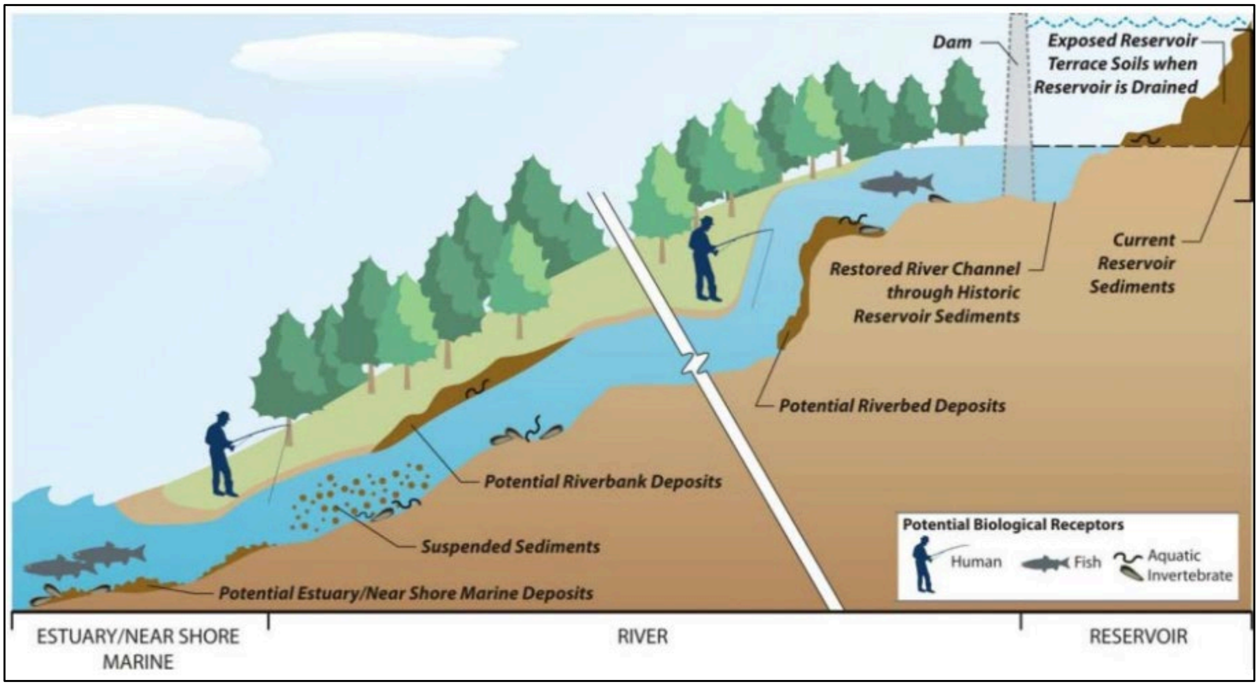


Figure 6-48. Conceptual Model of Sediment Within River System After Dam Breach
Source: Randle & Bountry 2017)

Table 6-19. Summary of Conceptual Model for Dam Breach-Related Sediment Releases Over Time

Year/Time Frame	Sediment Behavior	Sediment-Related Impacts
Year 1 (August–October)	Sediment within the channel behind Lower Granite and Little Goose Dams would be released during the dam breach process. Very high concentrations of suspended sediment would be liberated for several months. A large quantity of sediment would move. A majority of the sediment would temporarily accumulate above Lower Monumental Dam.	• Very high suspended solids result in loss of clarity in water, loss of sunlight penetration. • Very high suspended solids result in near zero dissolved oxygen because anaerobic sediments and associated organic material deplete oxygen in water. • Disturbance of sediment releases potentially high concentrations of nutrients, some metals, and other soluble pollutants into the water moving downstream. • Suspended solids move downstream and deposit in new locations, smothering benthic and aquatic biota (plants and animals). • Very high suspended solids interferes with water intakes/potable water uses. • Movement of bio-accumulative compounds with fine-grained sediment movement; pollutants deposit into new areas where aquatic organisms can be exposed.
Spring of Year 1 (spring immediately following the first two dam reaches)	Precipitation would wash shoaled bank material to the channel. Additional sediment within the channel, plus the bank material that erodes into the channel, would move downstream. The amount of sediment that moves would depend on spring high water conditions; higher flows would result in more sediment movement.	• Seasonally high suspended solids, but not as high as during dam breach. • Erosion of banks where sediment had previously shoaled. • Higher suspended sediment is associated with lower dissolved oxygen; however, the seasonally high flows and comparatively lower suspended solids concentrations would cause fewer oxygen impairment issues. Similarly, other water quality issues (high nutrient concentrations, for example) would be experienced but not as severely as during the dam breach process.
Year 2 (August – October)	Sediment within the channel behind Lower Monumental and Ice Harbor Dams would be released during the dam breach process, including material that had previously moved downstream from Little Goose and Lower Granite Dams. Very high concentrations of suspended sediment would be liberated during the breach. Again, a large quantity of sediment would move (12.6 Mcy). This sediment would deposit near the confluence of the Snake and Columbia Rivers and within McNary Reservoir.	• Very high suspended solids result in loss of clarity in water, loss of sunlight penetration. • Very high suspended solids result in near zero dissolved oxygen because anaerobic sediments and associated organic material deplete oxygen in water. • Disturbance of sediment releases potentially high concentrations of nutrients, some metals, and other soluble pollutants into the water moving downstream. • Suspended solids move downstream and deposit in new locations, smothering benthic and aquatic biota (plants and animals). • Very high suspended solids interferes with water intakes/potable water uses. • Movement of bio-accumulative compounds with fine-grained sediment movement; pollutants deposit into new areas where aquatic organisms can be exposed.

Year/Time Frame	Sediment Behavior	Sediment-Related Impacts
Spring of Year 2	Additional sediment within the channel plus some shoaled bank material would move. The amount would depend on spring high water conditions; higher flows would result in more sediment movement.	• Seasonally high suspended solids, but not as high as during dam breach. • Erosion of banks where sediment had previously shoaled. • Higher suspended sediment is associated with lower dissolved oxygen; however the seasonally high flows and comparatively lower suspended solids concentrations would cause fewer oxygen impairment issues. Similarly, other water quality issues (high nutrient concentrations, for example) would be experienced but not as severely as during the dam breach process.
Years 2–7 (depending on weather and river flow conditions)	Coarser-grained materials and bank materials would continue to erode during high flow conditions such as during spring run-off or large storm events. These materials would move downstream toward McNary Reservoir; the transport would continue until the sediment reaches a stable shoaled configuration.	• Newly shoaled material would be a potential source of pollution exposure for both aquatic and terrestrial species for several years until the system reaches a new normal. Fish tissue concentrations of pollutants are likely to be higher than pre-breach. (National Research Council, 2007, 2001) • Groundwater discharges and bank seepage along the new banks of the lower Snake River would continue to cause erosion as the system adjusts to the new river level. Contaminated groundwater at some locations may add pollution to the river. • Point dischargers may need to adjust their treatment and discharges in response to changes to the receiving waters, which will be a river and not a large lake. Some discharge points may need relocation. Some discharges could require changes to the treatment processes. • Continued erosion of banks where sediment had previously shoaled with dams. • Seasonally high suspended solids, but not as high as during dam breach process and with correspondingly fewer water quality impacts. • Sediment reaches more stable shoal configurations and released sediment becomes buried by new material (reducing pollutant exposure).

Year/Time Frame	Sediment Behavior	Sediment-Related Impacts
Longer Term (more than 5–10 years)	Sediment entering the lower Snake River would move downstream over time. Over the long term, very little material would shoal in the lower Snake River, with the exception of new backwater areas created by the dams after breach, and along historical backwater areas such as near islands within the channel. The bulk of the sediment entering the lower Snake River (estimated to total 3.6 Mcy per year) would move into McNary Reservoir, with approximately 2.4 Mcy shoaling in the reservoir, and the rest of the fine-grained materials passing downstream and ultimately to the estuary (Appendix C, *River Mechanics*).	• Lower Snake River experiences much less shoaling, with shoaling limited to backwater areas as seen historically. • Suspended solids are higher than pre-breach, but not "high" compared to other rivers. Suspended solids concentrations are anticipated to be in the range of 30 mg/L (Appendix C, *River Mechanics*). • River water quality experiences much more natural riverine conditions, including seasonal and daily fluctuations in temperature, dissolved oxygen, suspended solids, and other water quality parameters. • Fish tissue concentrations adjust to new conditions in the river (anticipated lower than pre-breach in Snake River, but possibly still elevated in McNary Reservoir due to existing pollution load in the sediment). • Some former shoaled material would be left on the banks of the river and would remain as "land" instead of eroding. Banks reach a more stable condition. Upland areas are vegetated or have erosion control installed as needed for localized conditions.

Note: By the end of the first 2 years of dam breach, a very large fraction of the fine-grained sediment would have moved into the end of the Snake River (near the confluence with the Columbia River) and into the McNary Reservoir within the Columbia River. This material would likely continue to redistribute within the river system and McNary Reservoir for several years until it eventually reaches a stable shoal configuration. However, it should be noted that the sediment study for MO3 did not include existing bridges and therefore does not consider bridge-related scour and deposition potential.

6.4.3 McNary Reservoir

Sediment released from the lower Snake River dams will move downstream and is anticipated to be mostly trapped within McNary Reservoir. Initially, released sediment will move downstream but may form temporary shoals along the end of the Snake River and into the Columbia River, including near the confluence. The sediment will continue to move for a number of years in response to seasonal high flows until the sediment reaches a more stable configuration.

The sediment released to McNary Reservoir will carry any sorbed pollutants along with it. This material will at least temporarily cover downstream areas, including habitat areas, with the result that initially McNary Reservoir will likely experience higher surficial pollutant concentrations. Over time, the released sediment will be covered with newer material that enters the system and covers the older material.

In the longer term, sediment from the Clearwater and Snake Rivers will no longer be detained behind dams on the lower Snake River, so that sediment will travel into McNary Reservoir. Estimates are that approximately two-thirds of the sediment entering the McNary Reservoir will settle within the reservoir. The remaining sediment will consist of fine-grained clays and silts that are suspended in the water and are expected to travel to the estuary. Little material is expected to settle past McNary Reservoir (Appendix C, *River Mechanics*).

6.4.4 Water Quality Issues

The release of a large volume of sediment in a short time would cause extreme short-term water quality changes in the lower Snake River (Table 6-20 suspended solids (fine sediment that mixes into the water column and is carried along with the water) would be extremely high during the breaching process and immediately afterward. Elevated concentrations of suspended solids would also be experienced during high flow (storm flow, spring freshet, snowmelts) conditions for the first few years after breaching, as material in the channel redistributes and material left on bank areas erodes into a more stable configuration. The elevated suspended solids concentrations could block light and could physically smother aquatic organisms, especially plants and benthic organisms.

Table 6-20. Estimated Suspended Solids Concentrations During Dam Breaching Process

	First Dam Removal	Second Dam Removal
Peak concentration	24,300 mg/L	16,100 mg/L
Location of peak concentration	RM 69.6	RM 7.59
Duration > 5,000 mg/L	26 days	17.75 days
Duration > 10,000 mg/L	76 days	48.75 days
Average concentration before dam removal	1.9 mg/L	2.3 mg/L
Average concentration after dam removal	30.4 mg/L	32.3 mg/L

1/ Average concentrations for years October 2024 to October 2041.

The fine-grained sediment released into the water column would also cause chemical changes to the water. The buried sediment is anoxic and contains organic compounds that exert biochemical oxygen demand (organic compounds react with oxygen or are consumed by microorganisms that use oxygen). When very large amounts of anoxic sediment are mixed with the water column, the dissolved oxygen would be used up. Oxygen would re-enter the water, but through the surface of the water column; the surface area would limit the reaeration of the river. The condition during breaching is expected to be a large plume of muddy water that contains little to no dissolved oxygen.

The impact of the suspended sediment on dissolved oxygen was estimated two different ways based on available information. First, suspended sediment data from the River Mechanics Team modeling was correlated to turbidity and dissolved oxygen concentrations following the relationships published by Schenk and Bragg (2014). These relationships were developed for Falls Creek Lake, Oregon; it is expected that the sediment in the lower Snake River is similar in grain size but perhaps different in chemical composition than the Falls Creek Lake material. Second, calculations were made based on assumed average characteristics of the lower Snake River sediment. Values chosen for calculations include an assumed sediment oxygen demand of 0.5 g/m2/day based on literature values, an assumed wet bulk density for the sediment of 1.5 g/cm3 to represent average conditions, and an assumption that 83 percent of the suspended solids were silt/clay and 5 percent of that material is volatile solids based on the information provided by River Mechanics. Both approaches yielded similar dissolved oxygen estimated conditions (Table 6-21.).

Table 6-21. Number of Days Below Dissolved Oxygen Thresholds in Lower Monumental Reservoir

Peak	DO Threshold	Forebay (Lower Monumental Reservoir)	Head of Lower Monumental Reservoir
First Peak	5 mg/L	18–21 days	24–28 days
First Peak	2.5 mg/L	9–11 days	16–20 days
Second Peak	5 mg/L	14–17 days	7–11 days
Second Peak	2.5 mg/L	5–7 days	6–8 days

It is noted that Lower Monumental Reservoir should experience more dissolved oxygen impacts than Ice Harbor or McNary Reservoirs. The Ice Harbor reservoir is expected to receive less sediment during the breach of Lower Granite and Little Goose dams than Lower Monumental, since a larger fraction of sediment will settle temporarily in Lower Monumental reservoir. After the second set of dam breaches, sediment will move into McNary Reservoir; however, that reservoir also receives high flows from the Columbia River, which are expected to provide an input of high dissolved oxygen content water that will help lessen the impacts of the sediment oxygen demand.

The fine-grained sediment also holds nutrients such as nitrogen (ammonia) and phosphorus compounds; these compounds tend to be very soluble and would be expected to be released when the shoaled sediment is disturbed as part of the dam breaching process. Nutrients can interfere with the ecological system balance and cause unbalanced growth of algae. Uncontrolled growth of algae in turn causes large dissolved oxygen swings (diurnal pattern with very high concentrations during the day and very low concentrations at night), pH changes, and loss of clarity. The release of nutrients from the sediment during dam breach would be a transient issue, however, because the large initial load of dissolved nutrients released during the breach would wash downstream with the water flow. It should be noted that the resulting river conditions would be quite different than the current reservoir conditions, with respect to algae and algal blooms. It is likely that cyanobacteria blooms would be eliminated from the lower Snake River. However, as long as nutrients are introduced to the river, either as point or non-point sources, the river conditions would show some water quality impacts related to the ensuing biological activity. Those long-term impacts are unrelated to the sediment condition.

Metals entrained in the sediment matrix may be released, depending on the chemical state and whether they are bound in undissolved minerals. Metals are naturally occurring; however, metals can also be human-sourced pollutants. Sediment data available for the Lower Granite Reservoir indicate that metals concentrations are generally low (https://www.nwd.usace.army.mil/CRSO/Documents/). Changes to dissolved oxygen concentration (redox state of the water) could affect metal solubility, although this would be expected to be a short-term issue for most metals. Mercury could be an exception to this conclusion, however, because the redox state could cause mercury cycling.

Independent of the water quality, the riverine physical conditions would be very different than the current reservoir configurations, which could impact point (National Pollutant Discharge Elimination System) dischargers to the river. There are at least 15 point dischargers along the lower Snake River, mostly located near the Lewiston and Clarkston areas. These include industrial and public treatment facilities. Point dischargers may need to adjust their treatment and discharges in response to changes to the receiving waters, which will be a river and not a large lake. Some discharge points may need relocation. Some discharges could require changes to the treatment processes.

The persistent, bio-accumulative compounds such as pesticides and other large organic compounds are not likely to be a short-term issue for water quality, since these compounds have very low solubility. These compounds would tend to stay with the sediment particles and would be redeposited in new shoals that form after the breach. These newly shoaled areas would represent fresh exposure opportunities for aquatic organisms, particularly benthic organisms that colonize the new shoals. Fish that consume the benthic organisms exposed to the pollutants would themselves potentially be exposed, leading to bioaccumulation throughout the food web (National Research Council 2007, 2001; Meier et al. 2015). This condition would likely persist for a number of years, until the sediment released during the dam breach process reaches a stable configuration and subsequent sediment deposits (presumably with lower pollution levels) cover the material. See the Future Research discussion below for additional thoughts on this topic.

Groundwater is naturally connected to rivers and lakes. Breaching the lower Snake River dams would lower the water level in the river. This would in turn impact the groundwater table of the land adjacent to the river. Some areas may discharge to the river at high rates as bank seeps, especially in the short term as the conditions around the river adjust to the new water level and flow patterns. There are a number of identified sites along the river where groundwater contamination exists (https://www.nwd.usace.army.mil/CRSO/Documents/). Some of these areas have the potential to discharge pollutants to the river. Soluble pollutants would move downstream with the water and would be very dilute. Less soluble compounds, including those that tend to bioaccumulate, would likely become sorbed to sediment particles and would remain in suspension or be deposited depending on shoaling conditions. Since very little sediment would be expected to shoal in the lower Snake River after dam breach (Appendix C, *River Mechanics*), much of this pollution would likely accumulate in McNary Reservoir.

6.4.5 Future Research

Additional sediment characterization is needed prior to the breach of dams along the lower Snake River. Specifically, the concentrations of bio-accumulative compounds and other pollutants needs to be better defined to determine whether mitigation is needed or is possible for sediment related impacts to water quality. Key goals of this investigation would include:

- The sediment shoaled behind the dams has not been sampled in over 20 years and there is considerable uncertainty in the chemical characteristics of the sediment. A general goal is to comprehensively characterizing the sediment following the SEF (RSET 2018). This includes the material shoaled in all four lower Snake River reservoirs.
- More specifically, it should be determined whether there are pockets of sediment that have high concentrations of pollutants such that the sediment does not meet in water placement criteria such as those laid out in the SEF (RSET 2018). The goal would be to determine if there are pockets of sediment that should be removed and disposed of in a confined location prior to dam breach activities. Contaminants of concern for this include bioaccumulative compounds and mercury.
- The potential for bio-accumulation of persistent compounds in fish during and immediately after the dam breach needs to be determined. Specific features of this investigation should include:
    - After additional sediment quality data are collected, a contaminant transport model (such as the Long-Term Fate model, LTFATE) should be used to investigate the fate of the contaminants associated with the sediment. Particular aspects of concern include the impact of sediment contaminant impacts on downstream drinking and irrigation water intakes.
    - Modeling the food web (bioaccumulation/biomagnifcation) using a model such as AQUATOX to help inform fish monitoring activities and predict impacts on subsistence fishing communities. Modeling metals using a biotic ligand model could help define transient or longer term impacts of the chemical changes to the water column that could be triggered by the dam breach. There are multiple models that could be used to

study various aspects of the potential water quality changes that accompany the release of the sediment.

- Fish tissue sampling and monitoring, commencing before the dam breach process and continuing for a number of years afterwards would confirm the modeling efforts. Fish monitoring would need additional coordination with State and Tribal officials, to ensure that efforts are coordinated and subsistence fisher populations are included in the analysis.

- Sediment oxygen demand and elutriate nutrient concentrations should be measured, and modeling and laboratory scale testing should be conducted to better estimate the impact of the dam breach on water quality during the high solids release events. Specific issues to investigate include the degree and extent of oxygen depletion, the concentration of nutrients released, the potential for ammonia toxicity, and the fate and transport of the soluble nutrients downstream including the impacts to downstream reservoirs.

These lines of investigation would help define the sediment-related impacts to the environment from the dam breach. Other water quality related impacts from the sediment release, such as the low dissolved oxygen concentrations during the high suspended solids events and the release of nutrients to the water column, are not easily controlled. Low dissolved oxygen concentrations could theoretically be off-set by adding temporary aeration systems, however given the magnitude of the flows in the lower Snake River, it is not known if this is possible in any meaningful sense. Additional investigation during design phase could be done to determine if aeration would be possible and beneficial. The timing and stages of the drawdown process could be further modeled and coupled with water quality modeling to determine whether it is possible to decrease the potential water quality impacts.

6.5 WATER AND SEDIMENT QUALITY CONCLUSIONS

The most notable MO3 measures that affect water quality include:

- *Breach Snake Embankments*: Remove earthen embankments as required at each lower Snake River dam. This will allow sediment shoaled behind the dams to transport downstream, including any sediment-bound contaminants.
- *Spring Spill to 120% TDG*: Modify spring juvenile fish passage spill to 120 percent tailwater TDG plus no forebay TDG spill cap in the lower Columbia River.
- *Reduce Summer Spill*: End summer juvenile fish passage spill in the lower Columbia River by July 31.
- *Above 1% Turbine Operations*: Operate turbines within and above 1 percent peak efficiency only at lower Columbia River dams.
- *Sliding Scale at Libby and Hungry Horse, Modified Draft at Libby, December Libby Target Elevation, Update System FRM Calculation, and Planned Draft Rate at Grand Coulee:* These measures maximize operating flexibility and improve overall systems operations, including winter FRM at Libby and Grand Coulee.

- *Grand Coulee Major Maintenance Operations*: Planned major maintenance at Grand Coulee.
- *Lake Roosevelt Additional Water Supply, Hungry Horse Additional Water Supply, and Chief Joseph Dam Project Additional Water Supply*: These measures modify operations to meet existing contractual water supply obligations at Grand Coulee, Hungry Horse, and Libby Dams.

6.5.1 Multiple Objective Alternative 3 Results – Water Temperature

In general, MO3 would result in little to no change in water temperature conditions at Libby, Hungry Horse, Albeni Falls, Dworshak, Grand Coulee, Chief Joseph and the lower Columbia River dams and reservoirs, as compared to the No Action Alternative (Figure 6-49 and Figure 6-50). Downstream of Libby Dam, higher November and December outflows, to meet the end-of-December draft, may delay the natural cooling of the Kootenai River downstream of the dam. The additional draft of 20 feet in Lake Koocanusa, however, may allow the reservoir to warm earlier in the spring and summer, providing earlier warming to water temperatures downstream of the dam. This could benefit downstream resident fish species. In general, water temperature effects downstream of Libby are negligible.

Considerable changes to water temperatures in the lower Snake River would be anticipated under MO3 due to the dam breach measures (Figure 6-51). Water temperatures would respond accordingly and shift from a lentic to lotic system, with more rapid warming in the spring and cooling in the fall as compared to the No Action Alternative condition. Water temperatures would respond to diel fluctuations in air temperatures and passing storm events. Warmer summer water temperatures could be expected at times, as compared to the No Action Alternative, with exceedances to the 68°F target in the Lower Granite tailrace during hot weather events. Little to no change in water temperatures would be expected in the lower Columbia River.

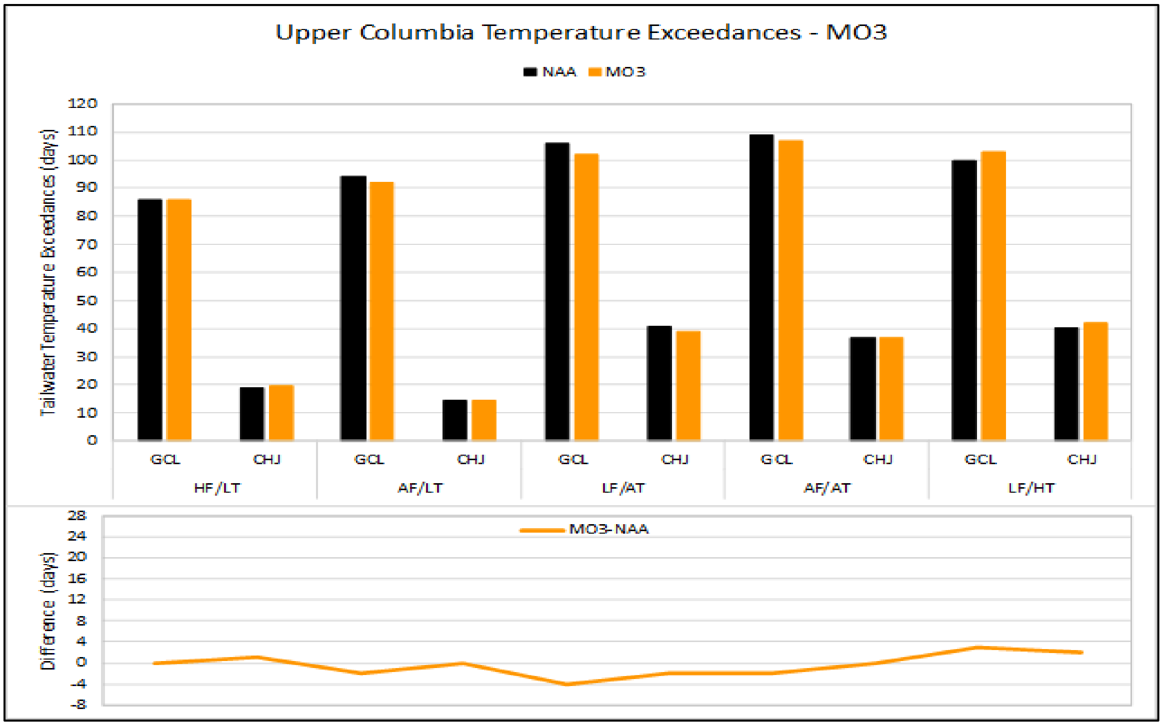


Figure 6-49. Modeled Tailwater Temperature Exceedances for the No Action Alternative and Multiple Objective Alternative 3 at Grand Coulee and Chief Joseph Dams Under a 5-Year Range of River and Meteorological Conditions

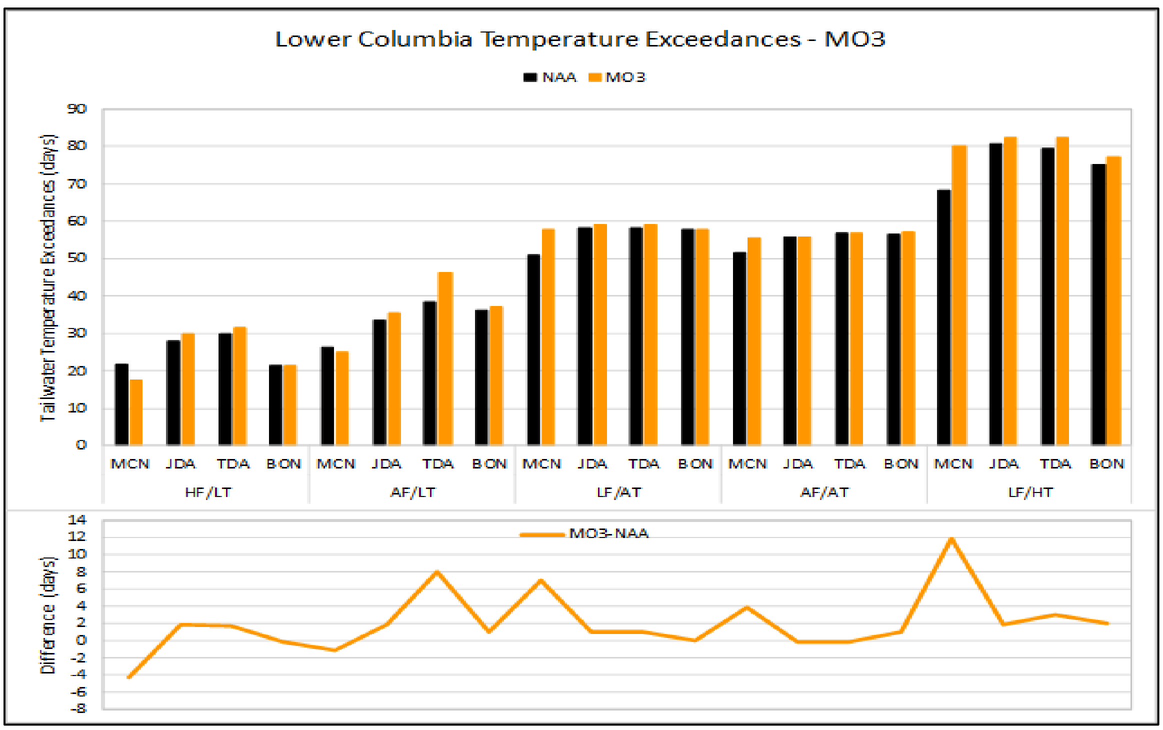


Figure 6-50. Modeled Tailwater Temperature Exceedances for the No Action Alternative and Multiple Objective Alternative 3 at McNary, John Day, The Dalles, and Bonneville Dams Under a 5-Year Range of River and Meteorological Conditions

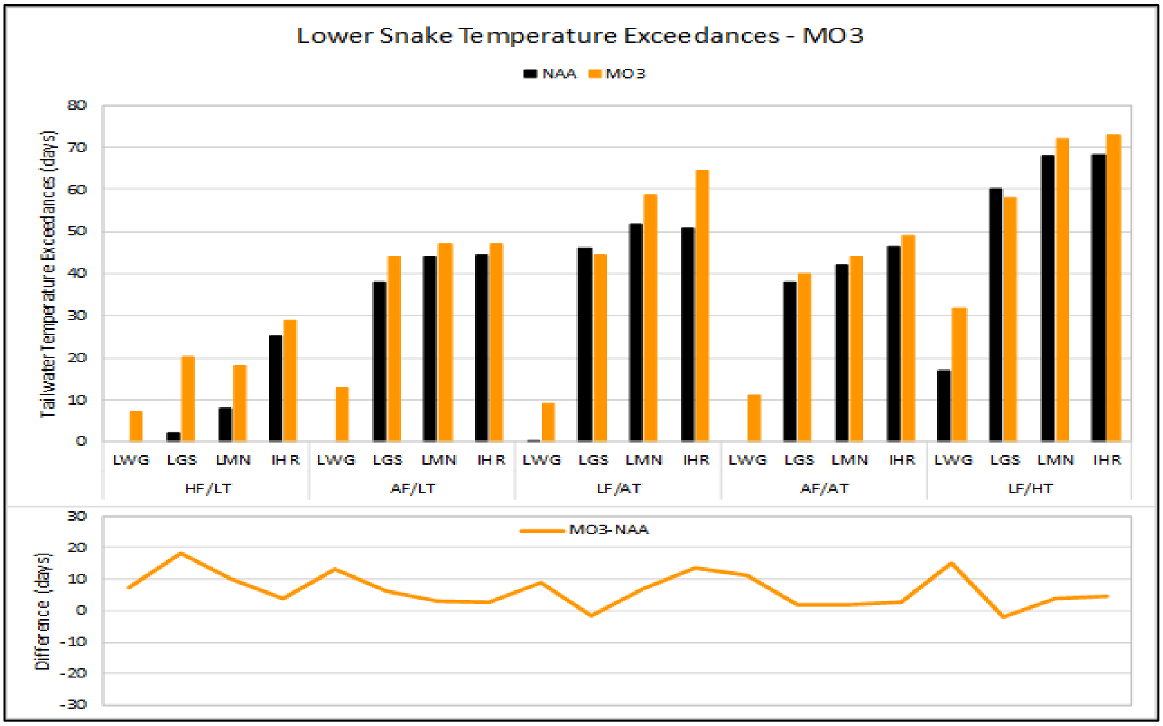


Figure 6-51. Modeled Tailwater Temperature Exceedances for the No Action Alternative and Multiple Objective Alternative 3 at Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams Under a 5-Year Range of River and Meteorological Conditions

6.5.2 Multiple Objective Alternative 3 Results – Total Dissolved Gas

In general, MO3 would have little to no impact on TDG conditions below Libby, Hungry Horse, Albeni Falls, Grand Coulee, Chief Joseph and Dworshak as compared to the No Action Alternative (Figure 6-52 and Figure 6-53). During high-flow years, the spillway deflectors at Chief Joseph Dam would provide some degassing of elevated TDG generated from upstream Canadian dam and Grand Coulee Dam operations.

TDG would be greatly reduced in the lower Snake River without the four lower Snake River dams in place. The hydraulic head currently present (under the No Action Alternative) would no longer exist and spill that entrains air would no longer occur. Under new river conditions, geographically localized TDG above 110 percent may periodically occur for short durations due to formation of plunge pools and turbulence during high-flow conditions; however, this is not expected to create persistent TDG like that observed under the No Action Alternative.

Minor reductions in TDG in the forebay and tailwater of McNary Dam would be expected under MO3. This is due to the lack of TDG received from upstream sources (dams in the lower Snake River) as is the case in the No Action Alternative. Under MO3, the *Spring Spill to 120 percent TDG*, measure calls for tailwater TDG limits to be set to 120 percent without a forebay TDG limit. As comparison, current TDG limits under the No Action Alternative are set to 120 percent in the tailwater and 115 percent in the forebay. In August, downstream juvenile fish passage spill would be curtailed *(Reduced Summer Spill* measure), and overall TDG in the lower Columbia River would be reduced as compared to the No Action Alternative, which calls for fish spill through the end of August. This would result in TDG effects at John Day, The Dalles and Bonneville dams to be minor to negligible, as compared to the No Action Alternative (Figure 6-54).

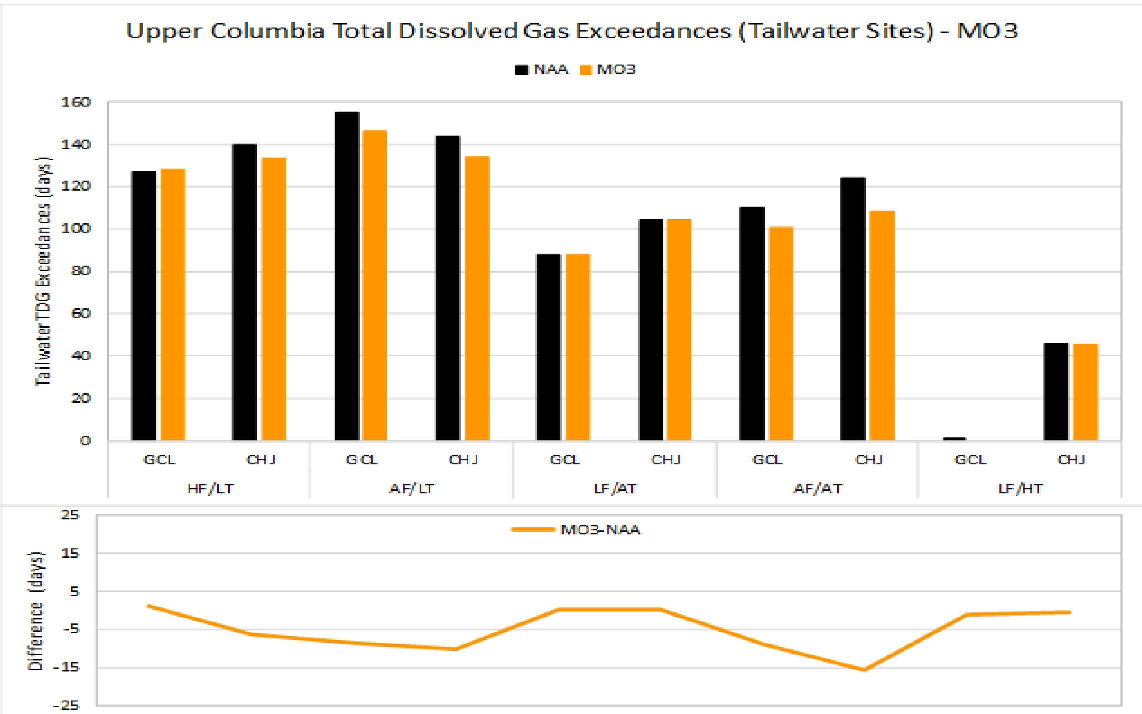


Figure 6-52. Modeled Tailwater Total Dissolved Gas Exceedances for the No Action Alternative and Multiple Objective Alternative 3 at Grand Coulee and Chief Joseph Under a 5-Year Range of River and Meteorological Conditions

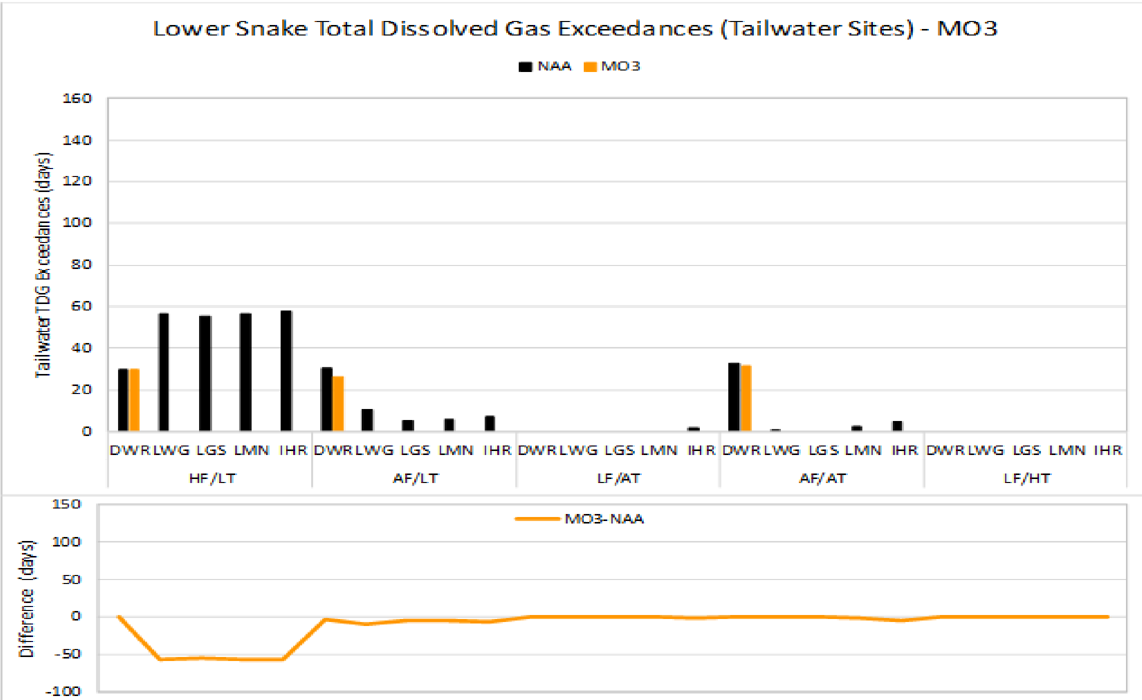


Figure 6-53. Modeled Tailwater Total Dissolved Gas Exceedances for the No Action Alternative and Multiple Objective Alternative 3 at Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams Under a 5-Year Range of River and Meteorological Conditions

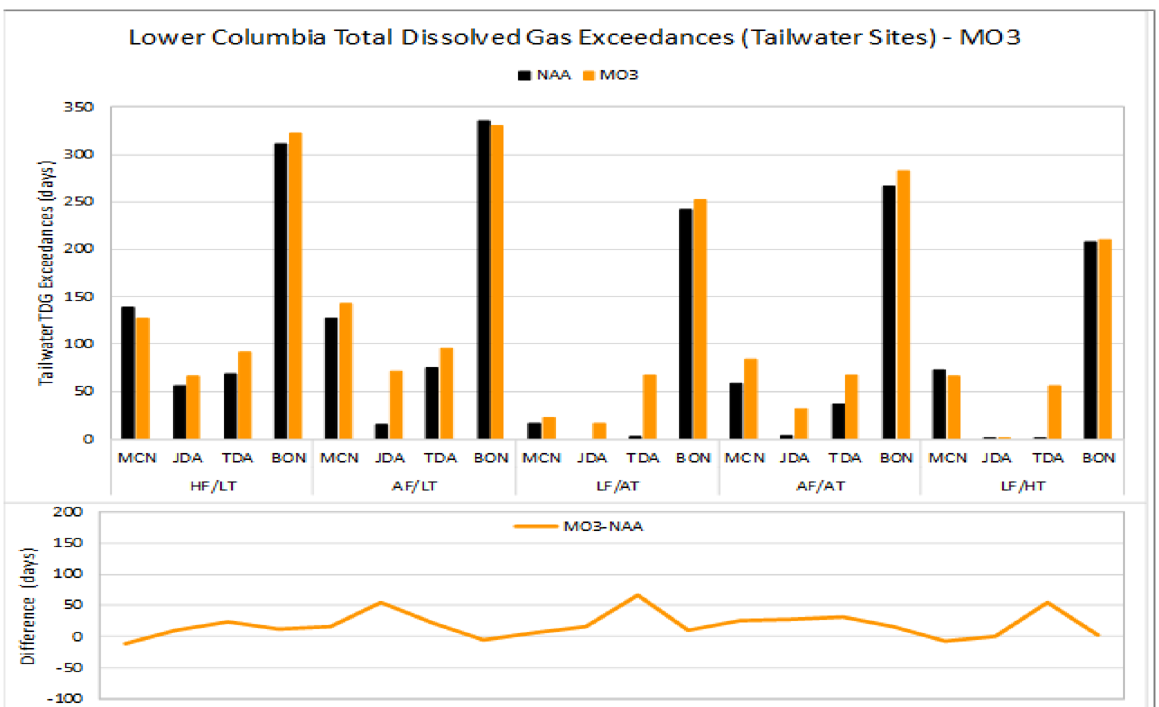


Figure 6-54. Modeled Tailwater Total Dissolved Gas Exceedances for the No Action Alternative and Multiple Objective Alternative 3 at McNary, John Day, The Dalles, and Bonneville Dams Under a 5-Year Range of River and Meteorological Conditions

6.5.3 Multiple Objective Alternative 3 Results – Other Water Quality Impacts

In general, MO3 would result in little to no change on other water quality parameters at Hungry Horse, Albeni Falls, and Chief Joseph dams and reservoirs, as compared to the No Action Alternative. Due to lower winter reservoir elevations at Libby, resulting from the *Modified Draft at Libby* measure combined with the change in the *December Libby Target Elevation* measure, which allows for an additional draft of 20 feet (a bit different from the end-of-December draft target described in MO1), reductions in lake productivity may occur. This could result in reduced growth rate of fish in the reservoir and downstream of Libby Dam. Changes to Grand Coulee water levels include higher elevations in January in below-average years, lower elevations in spring during wet years, and similar elevations the rest of the year. Most of the changes in Lake Roosevelt elevation are due to the drawdown draft rate that is built into the SRD shape (*Planned Draft Rate at Grand Coulee* measure) from January to April. The Update *System FRM Calculations* measure may also impact elevation by changing the end of April and/or May FRM requirement. The hydraulic capacity reduction for maintenance (*Grand Coulee Maintenance Operations* measure), and *Lake Roosevelt Additional Water Supply* measure do not have an effect on elevation, but do affect outflow and spill. The earlier and longer drawdown of the reservoir could lead to increased mercury methylation, while the *Planned Draft Rate at Grand Coulee* measure, which slows the reservoir draft rate to 0.8 feet per day, could result in a decrease in bank erosion, sloughing, and overall turbidity in the reservoir.

The MO3 lower Snake River dam breach measure would have considerable impacts on water quality in the lower Snake River in the near term; these impacts would be largest during reservoir drawdown and immediately following breaching. Based on sediment transport modeling conducted by the River Mechanics Team, reservoir drawdown and dam breaching will result in large amounts of suspended sediment moving downstream under both years of breach (Lower Granite and Little Goose in the first year of breaching, followed by Lower Monumental and Ice Harbor in the second year of breaching). This suspended sediment would result in high turbidity and low to anoxic dissolved oxygen conditions. This is of particular concern under the first year of breaching as there are few tributaries to dilute and re-oxygenate the river as it moves into Lower Monumental Reservoir. Analysis suggests that the upstream end of the Lower Monumental Reservoir could experience reduced dissolved oxygen (DO <2.5 mg/L) for 15 to 29 days, while the downstream end of the reservoir (near the dam) could see DO < 2.5 mg/L for 4 to 17 days, creating expansive dissolved oxygen problems for aquatic organisms. It is anticipated that during year two of breaching, dissolved oxygen conditions in McNary Reservoir would remain more oxygenated due to the influence of the Columbia River, which converges with the lower Snake River upstream of McNary Reservoir. Additional near-term impacts to dam breaching include the release of nutrients, metals, dioxins, PCBs, and pesticides, which may bioaccumulate. Smothering of benthics, amocetes, and plants could also occur. In the long-term, these impacts would lessen over time, and fish tissue concentrations of pollutants would be reduced over the long term to lower than No Action Alternative levels because contaminated sediments would no longer be present in the lower Snake River (contaminants would move downstream). The lower Snake River would revert back to a riverine system with water quality processes and species transitioning to more riverine in nature, as well. Longer-term impacts associated with the return to a riverine system may include impacts to groundwater discharges and impacts to point (National Pollutant Discharge Elimination System) dischargers along the river.

The lower Columbia River, particularly above McNary Reservoir, will experience some impacts from the lower Snake River dam breach. Dissolved oxygen, light attenuation, phytoplankton, zooplankton, and productivity would likely be depressed, while suspended sediments, nutrients, organics, and metals would likely increase in the near term. These effects would diminish considerably moving downstream toward Bonneville Dam.

6.5.4 Multiple Objective Alternative 3 Results – Sediment Quality

MO3 is not expected to affect land use along the Columbia River, including upland recreation, flood management, agricultural, timber, or mining activities, and it is not expected to change population growth patterns in the area of any of the Columbia River reservoirs. Land use and industries along the lower Snake River would potentially be impacted by the removal of the dams, particularly in industries that rely on navigation through the impounded river system.

Sediment released from the lower Snake River dams will move downstream and is anticipated to be mostly trapped within McNary Reservoir. Initially, released sediment will move downstream but may form temporary shoals along the end of the Snake River and into the Columbia River, including near the confluence. The sediment will continue to move for a number of years in response to seasonal high flows until the sediment reaches a more stable configuration.

The sediment released to McNary Reservoir will carry any sorbed pollutants along with it. This material will at least temporarily cover downstream areas, including habitat areas, with the result that initially McNary Reservoir will likely experience higher surficial pollutant concentrations. Over time, the released sediment will be covered with newer material that enters the system and covers the older material. The surficial pollutant concentrations may be reflected in aquatic organism tissue concentrations, for at least a period of several years.

CHAPTER 7 - MULTIPLE OBJECTIVE ALTERNATIVE 4

Multiple Objective Alternative 4 (MO4) was developed with the goal to examine an additional combination of measures to benefit ESA-listed fish species that were integrated with measures for water management flexibility for flood risk management and to adapt to changing environmental conditions, hydropower generation, and additional water supply. The alternative includes structural measures as well as operational measures (Chapter 2). The structural measures are related to powerhouse, turbine, spillway, and fish passage features, and do not include the removal of any dams or major structures. The operational measures include a long list of changes to current flow and power operations, including increasing the irrigation to authorized amounts.

7.1 UPPER COLUMBIA RIVER BASIN

7.1.1 Water Temperature

There are a few measures within MO4 that are expected to modify reservoir storage and outflow rates at some of the upper Columbia River Basin projects. Although these measures would not greatly impact downstream water temperature, some change is expected as compared to the No Action Alternative. These effects are described below.

7.1.1.1 Libby and Hungry Horse Dams and Reservoirs

MO4 would modify Libby Dam's draft and refill operations. The end of December sliding scale variable draft would be eliminated and replaced with a single draft target of 2,420 feet NGVD29, about 9 feet higher than with no action. The driest 25 percent of years would have about a 5-foot-deeper draft, and for most years, the reservoir would be lower from mid-July through the end of September due to the *McNary Dam Flow Target* measure. In general, MO4 would result in lower water elevations in Lake Koocanusa for most of the year, but the elevations would be higher for those years with a high water forecast in April. It should be noted that these changes do vary by water year, water forecast, and time of year. A summary hydrograph for Lake Koocanusa, representing the probability of the reservoir elevation on any given day under MO4 and the No Action Alternative is shown in Figure 7-1. Under MO4, median elevations in Lake Koocanusa are similar to No Action Alternative elevations from October through the end of November, held higher in December, and drafted down more aggressively through the end of March. In general, elevations are drafted slightly deeper in the spring, from March through mid-April, and increased in May and June. Full pool elevation is not held as high or for as long under MO4 as compared to the No Action Alternative due to increasing outflows in late June and July for McNary flow augmentation. Given this, by the end of September, the median MO4 elevation is about 9 feet lower than under the No Action Alternative.

In general, MO4 largely impacts Libby Dam outflows and Kootenai River flows from about November through April and again in late June and July (Figure 7-2). When compared to the No Action Alternative, median MO4 outflows are about 20 to 26 percent less in November and December, respectively; 18, 52, and 29 percent greater in January, February, and March, respectively; about 21 percent less in April; and about 25 percent greater in July. Modeled outflows presented in Figure 7-2 show that the greatest difference between MO4 and No Action Alternative flows occur from December through May. Typically, MO4 and No Action Alternative outflows follow a similar patter, albeit with much different flows, except for June and July when the McNary Dam flow augmentation measure under MO4 results in a substantial flow pattern change and increase in outflows.

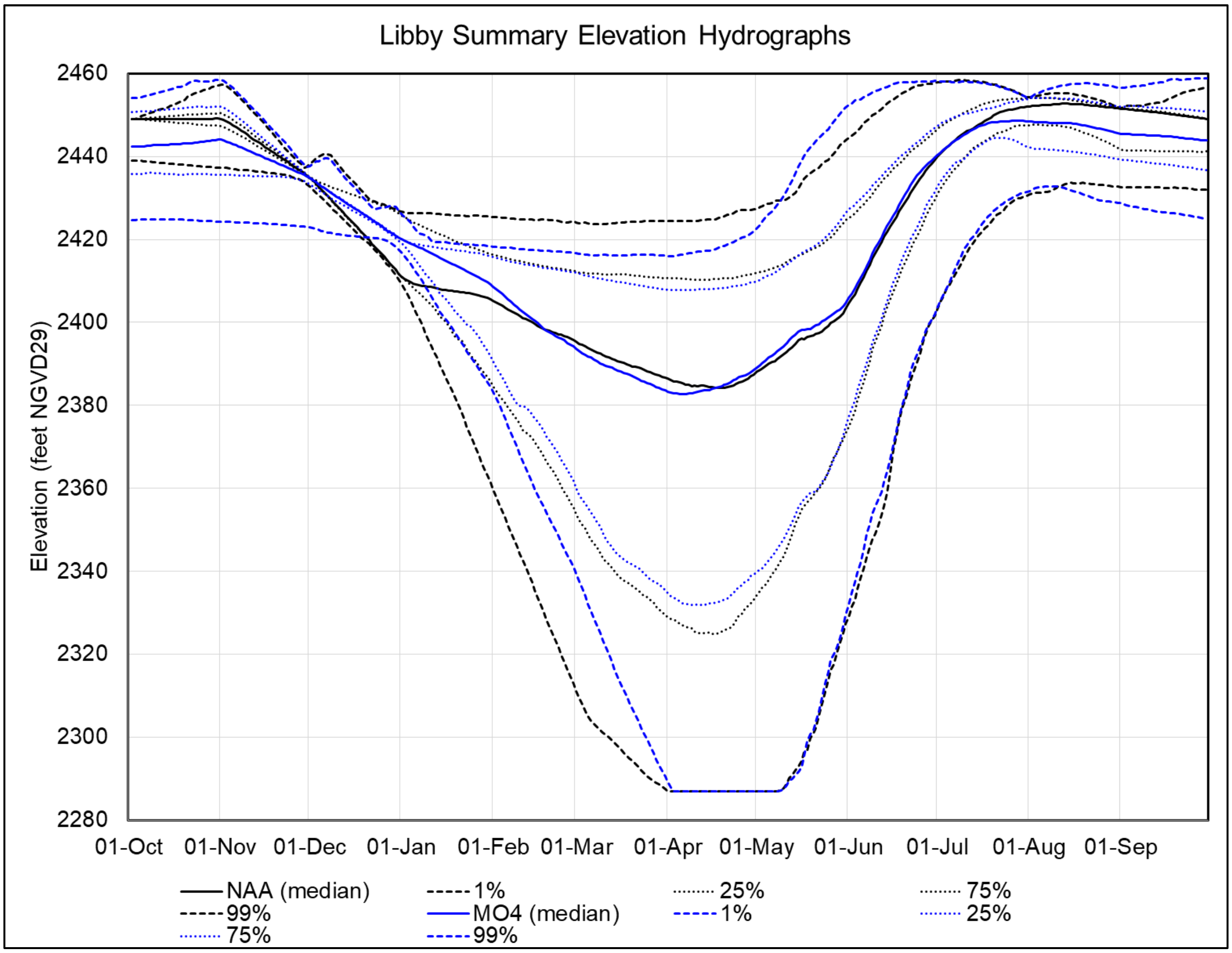


Figure 7-1. Libby Dam–Lake Koocanusa Summary Forebay Elevations for Multiple Objective Alternative 4 Versus No Action Alternative.

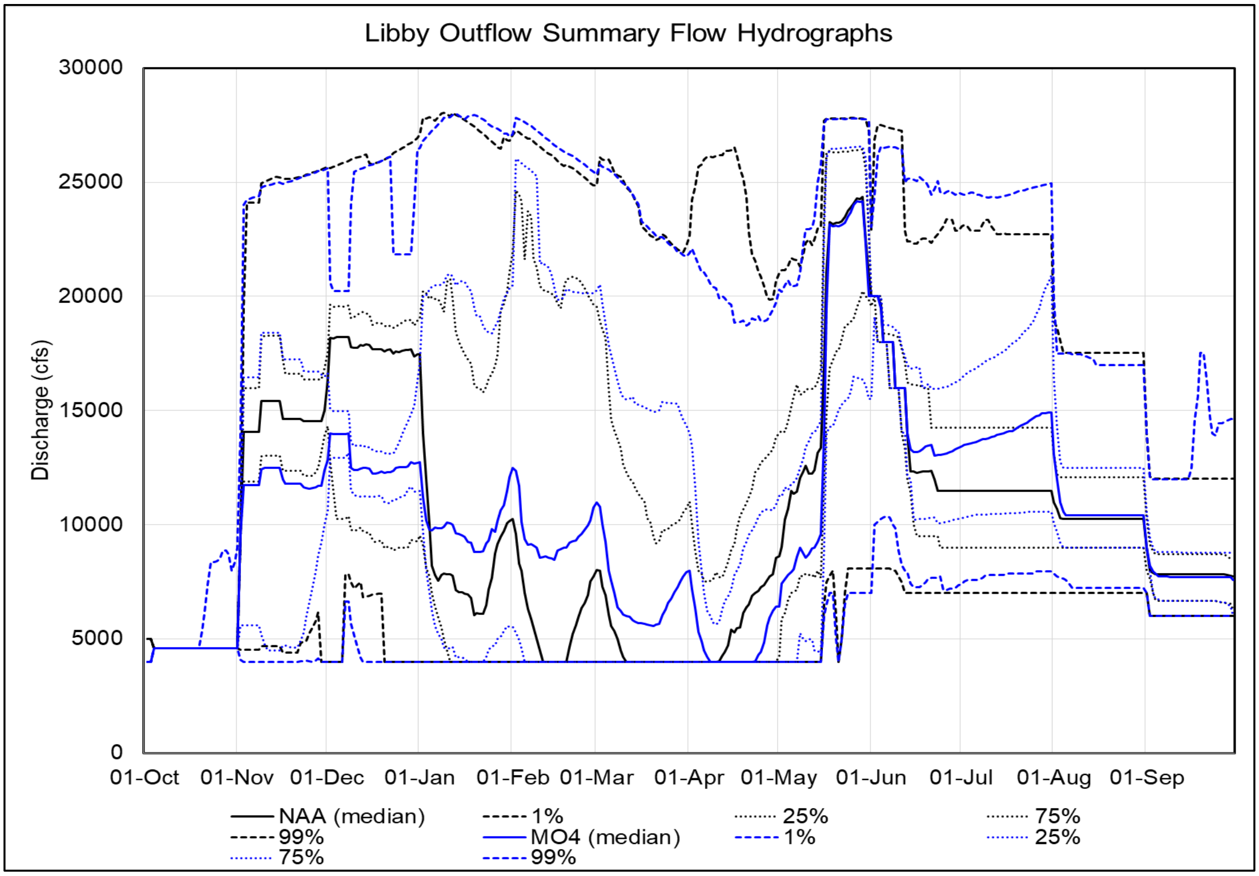


Figure 7-2. Libby Dam–Lake Koocanusa Summary Outflows for Multiple Objective Alternative 4 Versus No Action Alternative.

Similar to the No Action Alternative, Libby Dam's SWS provides some ability to adjust where in the water column water is drawn from. The range of the SWS bulkheads are from elevation 2,409 to 2,200 feet, NGVD29. Because SWS protocol maintains at least 30 feet of submergence over the top row of the bulkheads for hydraulic stability, the SWS has the ability to perform under the full range of possible MO4 drawdown operations with a similar efficiency as under the No Action Alternative. Modeled forebay elevations under MO4 are predicted to be well within the operating range of the SWS and similar to the ranges observed in the historical years described in Section 3.1.1.1 .

Changes in downstream temperatures from Libby Dam to Bonners Ferry may result from MO4 increasing the median monthly flows in January through March to draft the pool at a more aggressive rate. During the cold winter months, Kootenai River water can cool by several degrees between Libby Dam and Bonners Ferry if flows are held low. By increasing the flows to draw the pool down aggressively in the winter, MO4 may prevent the natural cooling of the river as it moves downstream. These higher winter temperatures in the Kootenai River may be an issue for certain fish species, such as burbot.

Hungry Horse Reservoir thermally stratifies in the summer and can provide some downstream water temperature management through use of the SWS. The SWS at Hungry Horse Dam is operated from approximately from June to the end of September. The selective withdrawal structure can be made/modified to operate over a pool elevation range from full (3,560 feet, NGVD29) down 160 feet (3,400 feet< NGVD29); however, major modification to the structure(s) is required to enable function over the lower 60 feet of this range, including removal of the upper and intermediate stationary gates. Three MO4 operational measures that apply to Hungry Horse Dam and influence the pool elevation in the reservoir and outflows to the river below the dam include:

- Sliding Scale at Libby and Hungry Horse
- Hungry Horse Additional Water Supply
- McNary Flow Target

These changes are not anticipated to affect the ability to operate the SWS, so downstream water temperatures in the South Fork Flathead River below the dam are expected to be similar to under the No Action Alternative. This conclusion is based on a comparison of the range of water levels in MO4 (Figure 7-3) with the range that the SWS can operate under (3,560 to 3,400 feet, NGVD29).

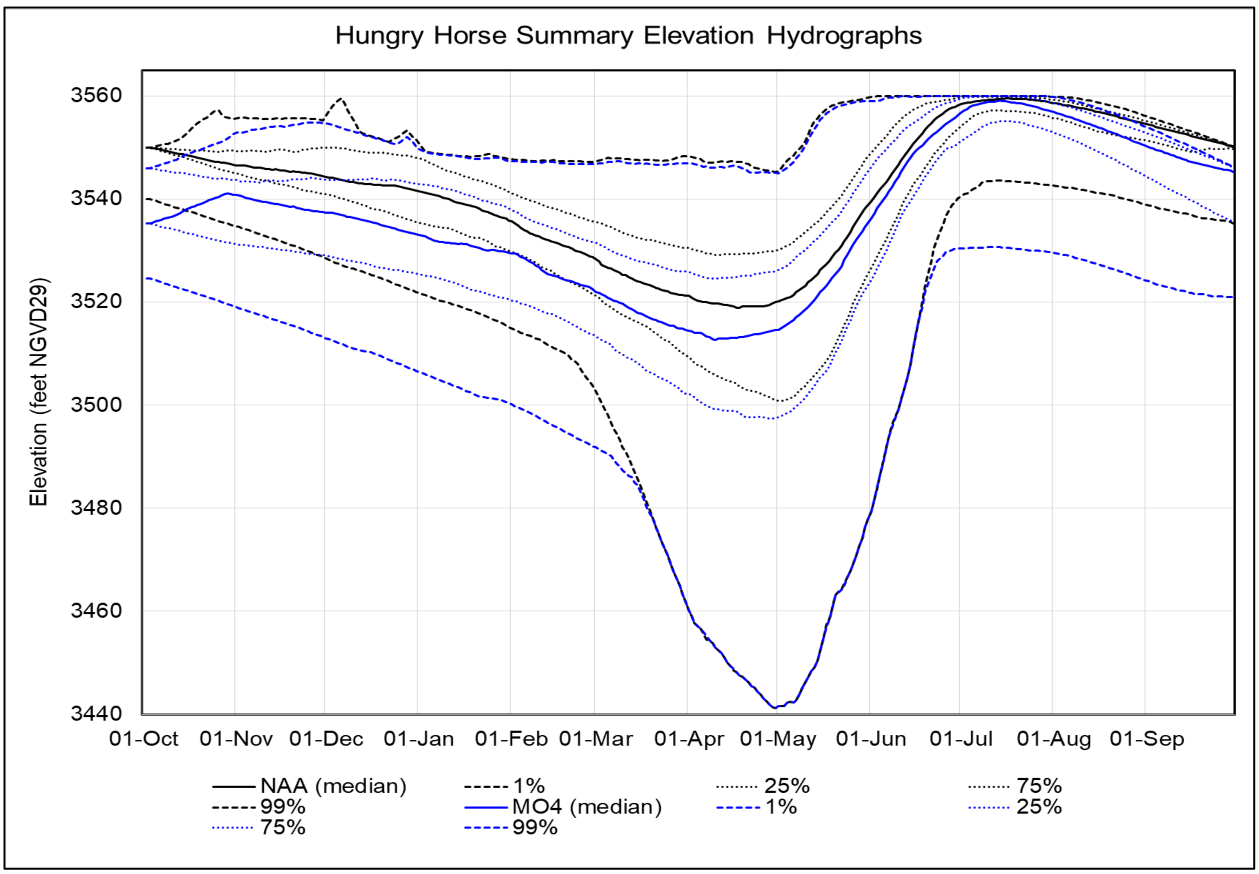


Figure 7-3. Hungry Horse Summary Forebay Elevations for Multiple Objective Alternative 4 Versus No Action Alternative

7.1.1.2 Albeni Falls Dam and Reservoir

Under MO4, Lake Pend Oreille and the Pend Oreille River will experience elevation changes during drier water years. For the median and wetter water years, elevations will remain similar to the No Action Alternative. However, for the drier 40 percent of water years, the elevation of Lake Pend Oreille will be up to 2.6 feet lower from about mid-June through the end of September (Figure 7-4 and Figure 7-5). This decrease is the result of increased outflows from Albeni Falls Dam to meet the McNary *Flow Target* measure.

Because of the size and depth of Lake Pend Oreille, and the depth of the Pend Oreille River upstream of Albeni Falls Dam, decreasing the lake elevation by up to 2.6 feet during the summer would not likely result in a large change in water temperature. However, increasing the flow through the Pend Oreille River during the summer might result in some cooling of the river during hot weather conditions but also some warming of the river during cool weather conditions. W2 model results indicate some of these changes in water temperatures below Albeni Falls Dam. The largest temperature differences between the MO4 and the No Action Alternative are about ± 0.9 to 1.8 degrees Fahrenheit (± 0.5 to 1.0 degrees Celsius) with increases and decreases evenly distributed (Figure 7-6 and Figure 7-6). Even with this potential cooling effect, water temperatures would continue to exceed the IDEQ Pend Oreille River temperature criteria (1-Day Maximum of 71.6°F and 1-Day Average of 66.2°F) during the summer.

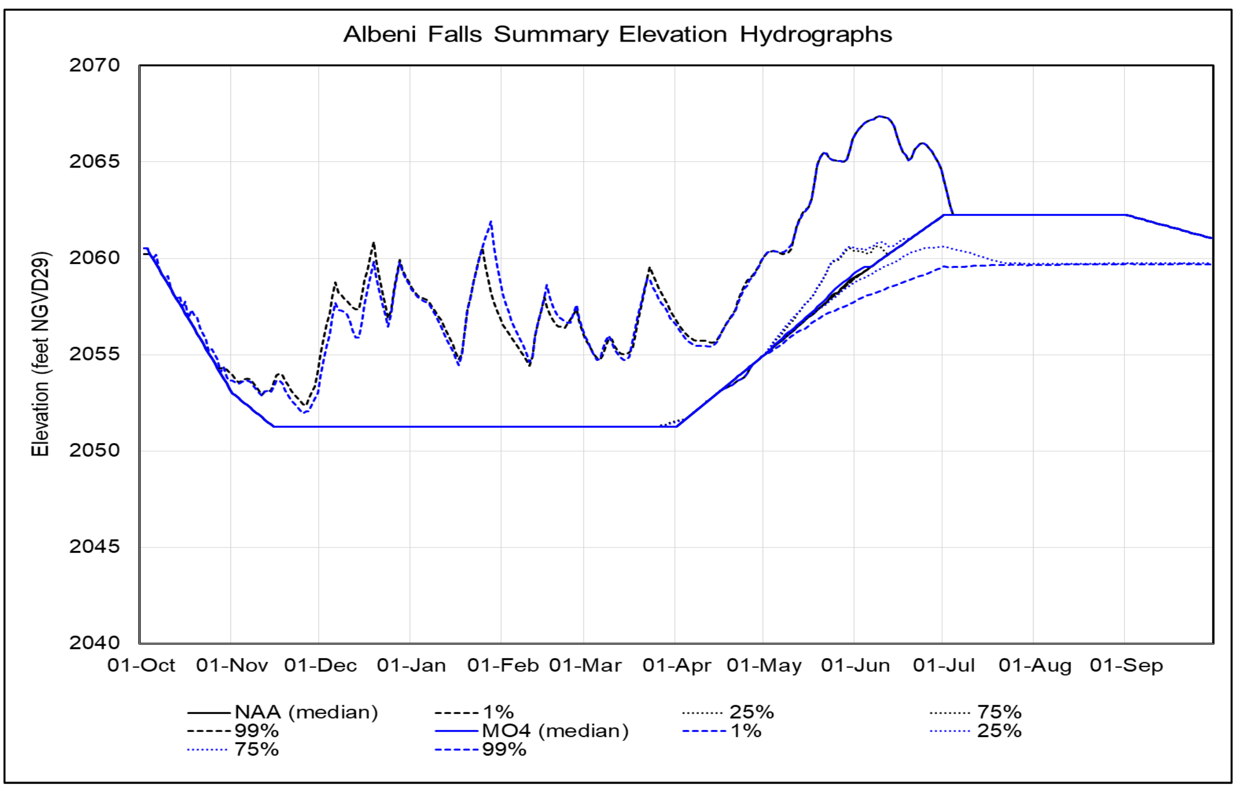


Figure 7-4. Albeni Falls Dam Summary Elevation Hydrographs for Multiple Objective Alternative 4 Versus the No Action Alternative

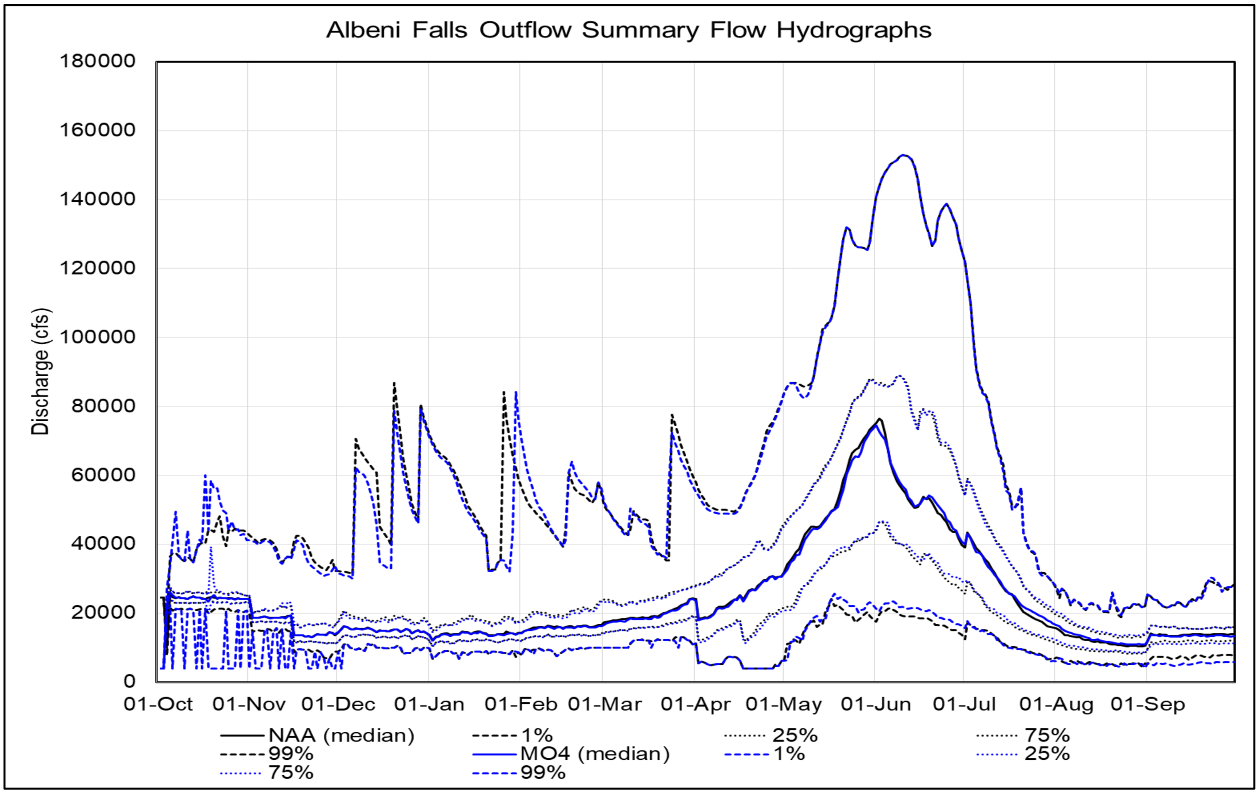


Figure 7-5. Albeni Falls Dam Summary Outflows for Multiple Objective Alternative 4 Versus the No Action Alternative

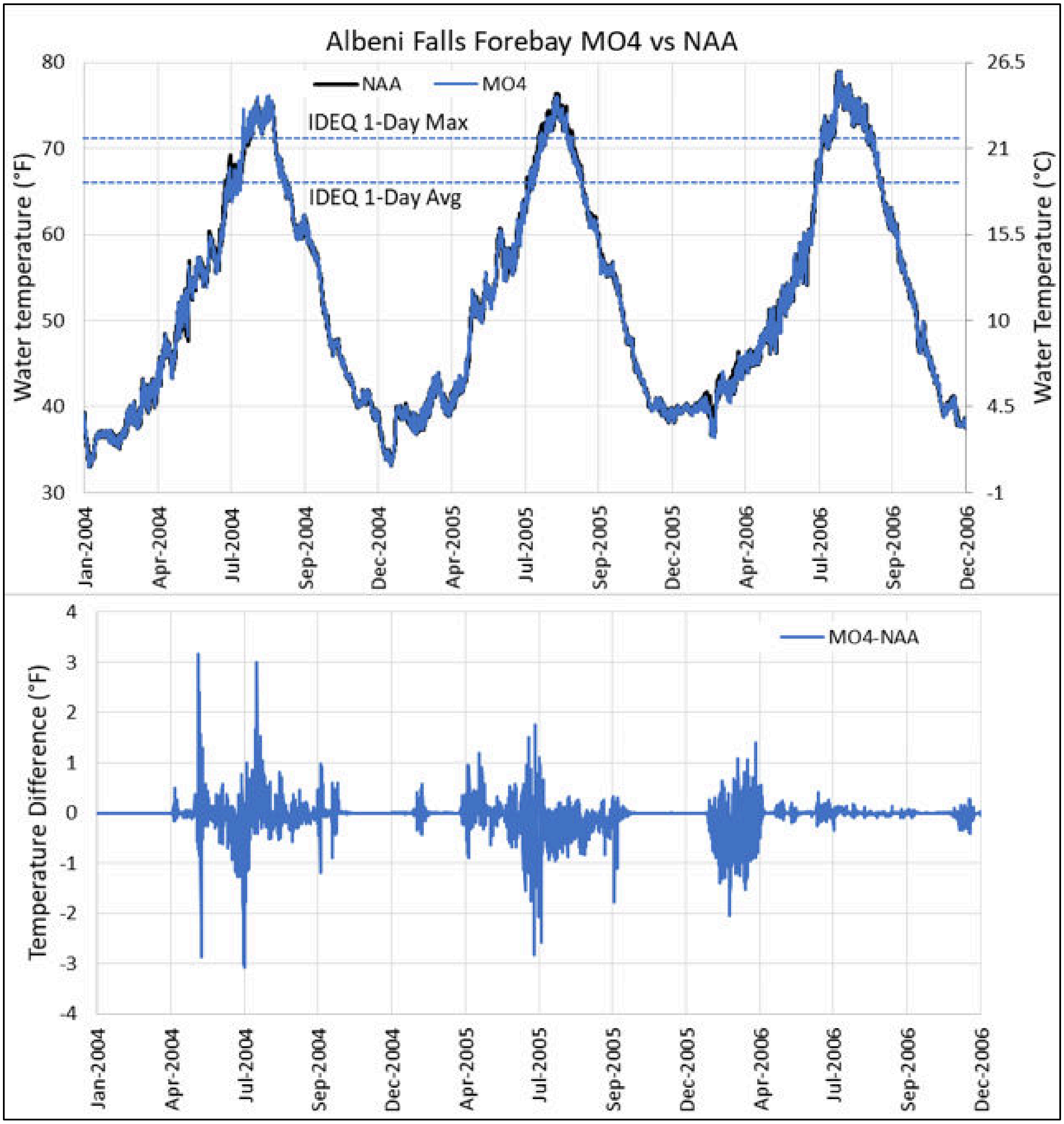


Figure 7-6. Modeled Forebay Temperatures for Multiple Objective Alternative 4 and No Action Alternative at Albeni Falls for 2004 to 2006

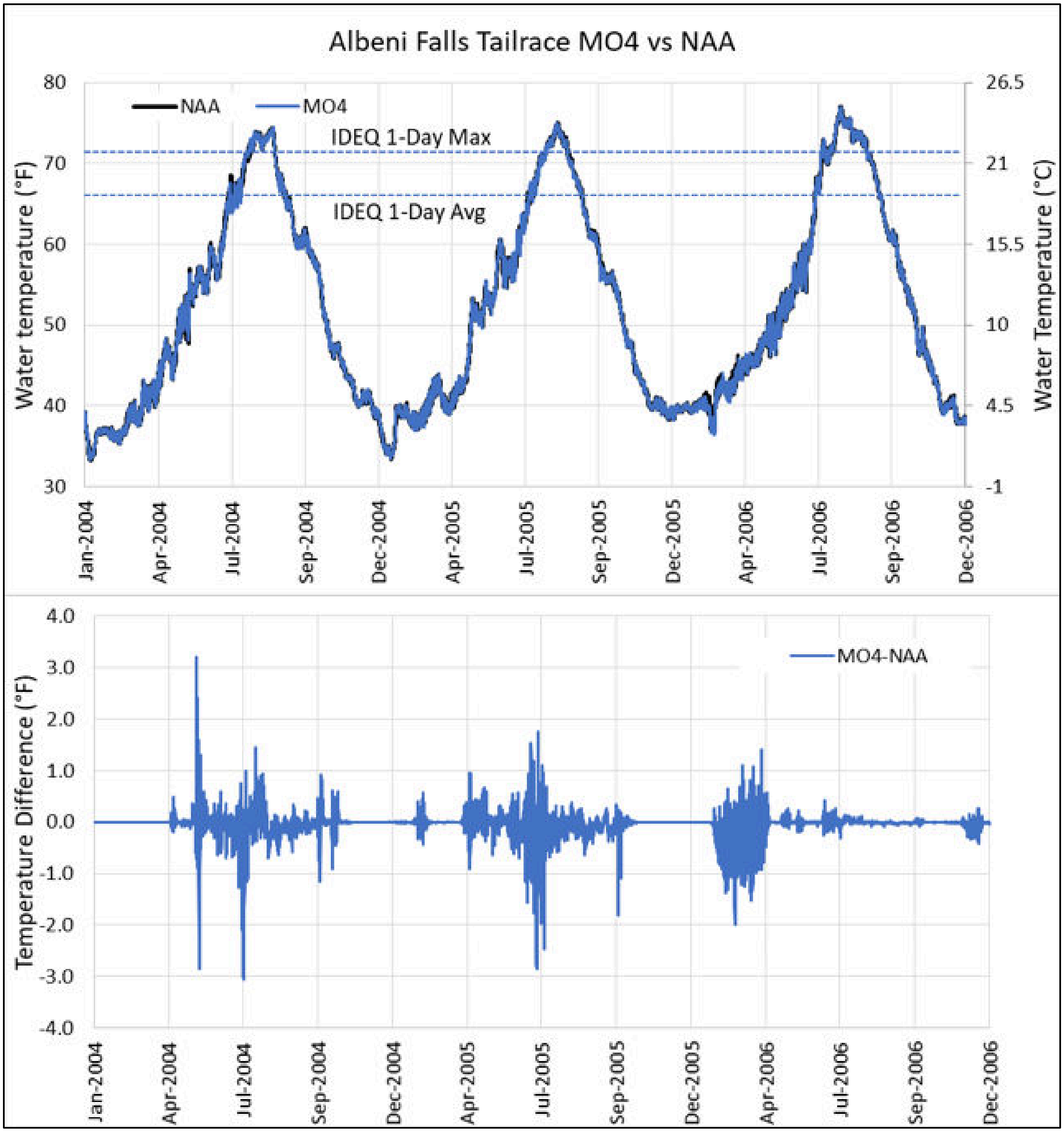


Figure 7-7. Modeled Tailwater Temperatures for Multiple Objective Alternative 4 and No Action Alternative at Albeni Falls for 2004–2006

7.1.1.3 Grand Coulee and Chief Joseph Dams and Reservoirs

Water temperature below Grand Coulee Dam has the potential to be affected by six operational measures:

- Update System FRM Calculation
- Grand Coulee Maintenance Operations
- Planned Draft Rate *a*t Grand Coulee
- Winter System FRM Space
- Lake Roosevelt Additional Water Supply
- McNary Flow Target

Under MO4, Winter System FRM Space drafts Grand Coulee in December to provide dedicated 650 kaf of space (Figure 7-8), resulting in a larger outflow (Figure 7-9). From January through March, more FRM space would be reserved in Lake Roosevelt for *Winter System FRM Space, Update System FRM Space,* and *Planned Draft Rate at Grand Coulee*. Similar to under the No Action Alternative, Lake Roosevelt would refill in July in average to wet years; however, in drier years, when Grand Coulee is managed to support operational measure *McNary Flow Target*, refill may be delayed or not occur (Figure 7-8). In these below-average years the outflows are larger than under the No Action Alternative for the *McNary Flow Target*.

Overall, temperatures in the reservoir are predicted to remain largely the same as under the No Action Alternative. The changes that do occur are short in duration or low in magnitude. In general, impacts are greatest at Grand Coulee Dam and are reduced towards the U.S.-Canada border, where the impacts are almost unnoticeable at Hall Creek. Overall, an increase of temperature at depth in the late summer/fall of all years is the most pronounced difference from the No Action Alternative near the dam; this is likely due to operational changes and potentially due to some modeling assumptions that warrants further investigation. Figure 7-10 shows predicted Grand Coulee tailwater temperatures under MO4. In wet years, there are almost no downstream temperature differences between MO4 and the No Action Alternative; however, during average or dry years, changes to downstream water temperature may occur. Temperature response under MO4 varies and appears to be dependent on a variety of factors such as reservoir elevation, total outflow, and powerhouse operations. Additional factors that impact the model results include the water year type (for example the LF/HT year may be more reactive to operational changes than a HF/LT year) and operational changes resulting in reduced outflows (FRM and Water Supply measures). An additional factor may be winter and spring operations that decrease storage during that period, which could potentially reduce the cold water mass that would dilute or cool the inflowing temperature signal from upstream through the spring and early summer months.

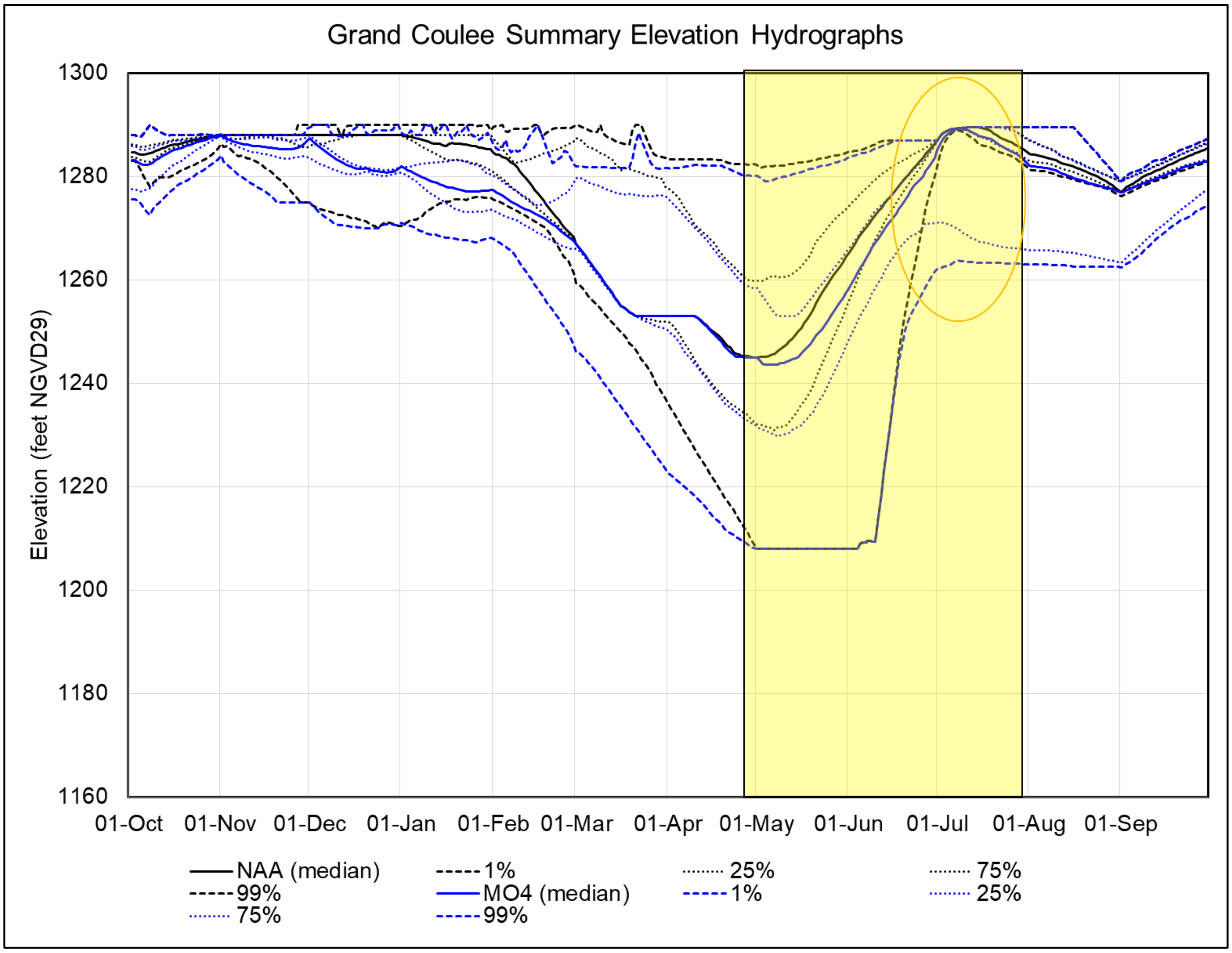


Figure 7-8. Grand Coulee Reservoir Summary Elevation Hydrograph for Multiple Objective Alternative 4 Versus No Action Alternative

In the dry years, the implementation of the *McNary Flow Target* measure prevents Grand Coulee Dam from refilling due to additional downstream flow requirements. Rather than being stored, warm water is passed through the reservoir in May and June, which can result in cooler summer water temperatures in some (LF/HT), but not all (LF/AT) cases. In most years, there tends to be a rise in water temperature in September under MO4, which coincides with a marked reduction in total project outflows that are lower under MO4 as compared to the No Action Alternative (Figure 7-9). Similar water temperatures can be seen downstream of Wells Dam (Figure 7-11), but the temperature signal, created by the operation of Grand Coulee Dam, is diluted by the time that water is discharged from Rocky Reach Dam, located approximately 115 miles downstream (Figure 7-12).

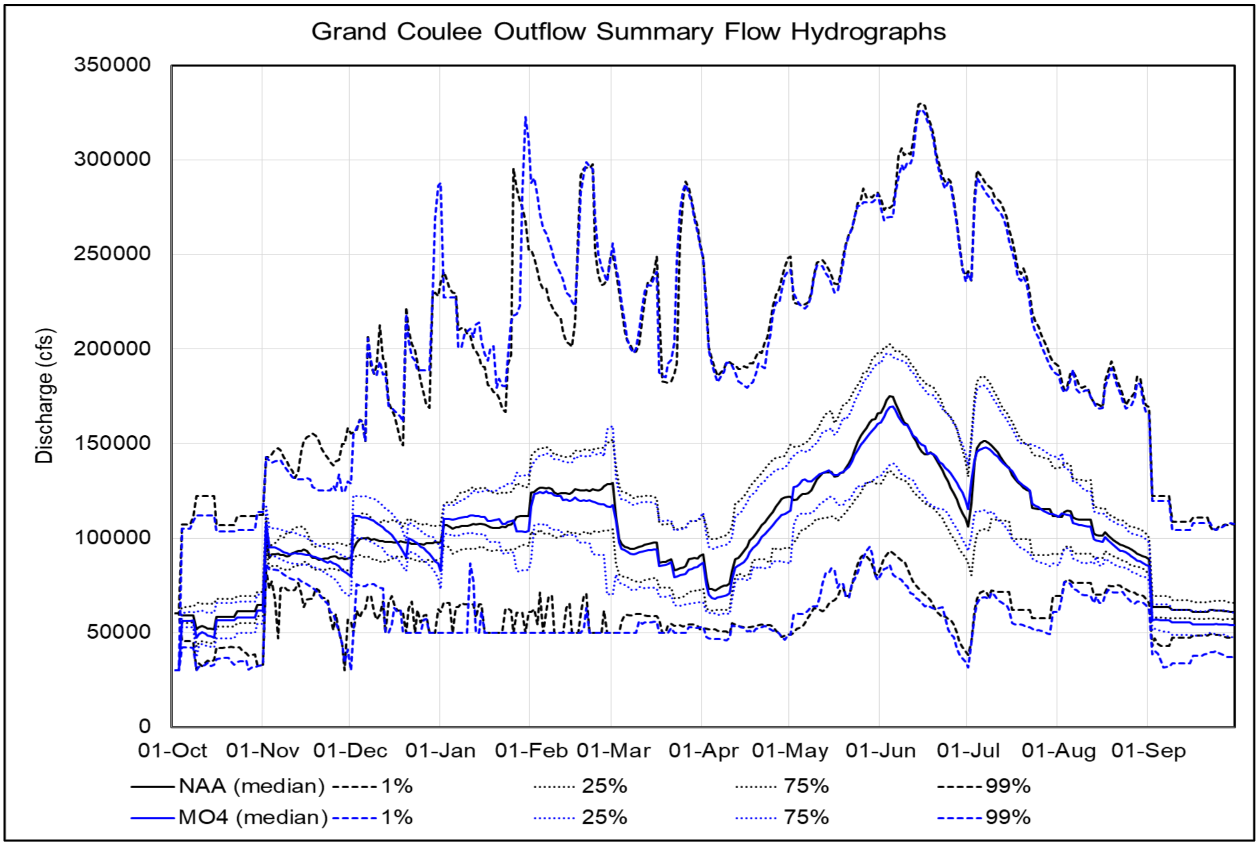


Figure 7-9. Grand Coulee Dam Summary Outflows for Multiple Objective Alternative 4 Versus No Action Alternative

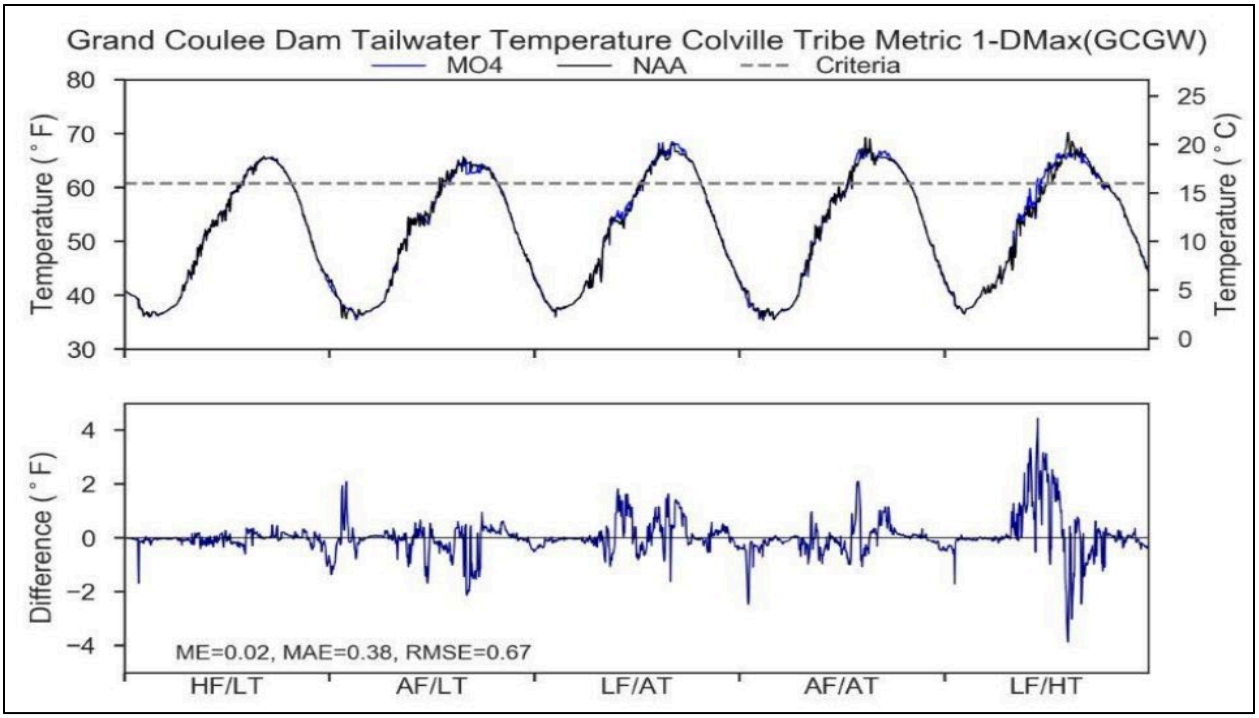


Figure 7-10. Modeled Tailwater Temperature for Multiple Objective Alternative 4 and No Action Alternative at Grand Coulee Dam Under a 5-year Range of River and Meteorological Conditions Compared to the Confederated Colville Tribe 1-D Maximum Water Quality Criterion

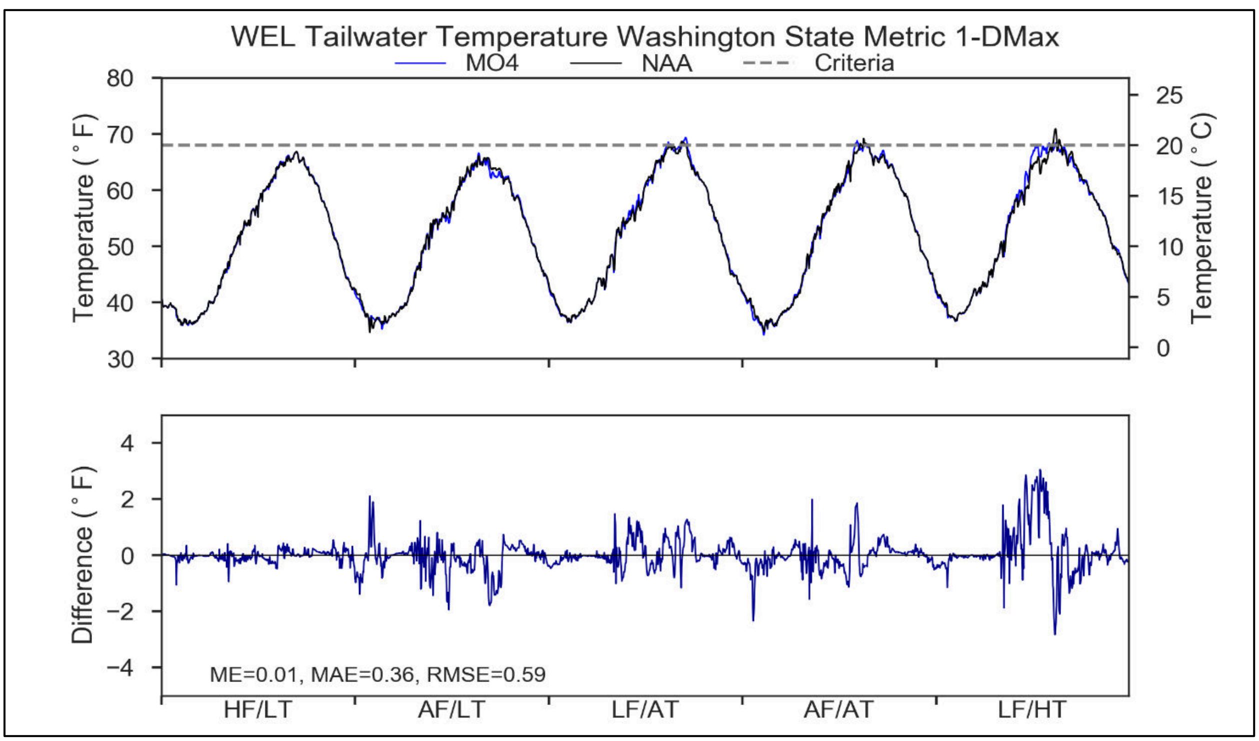


Figure 7-11. Modeled Tailwater Temperature for Multiple Objective Alternative 4 and No Action Alternative at Wells Dam Under a 5-year Range of River and Meteorological Conditions

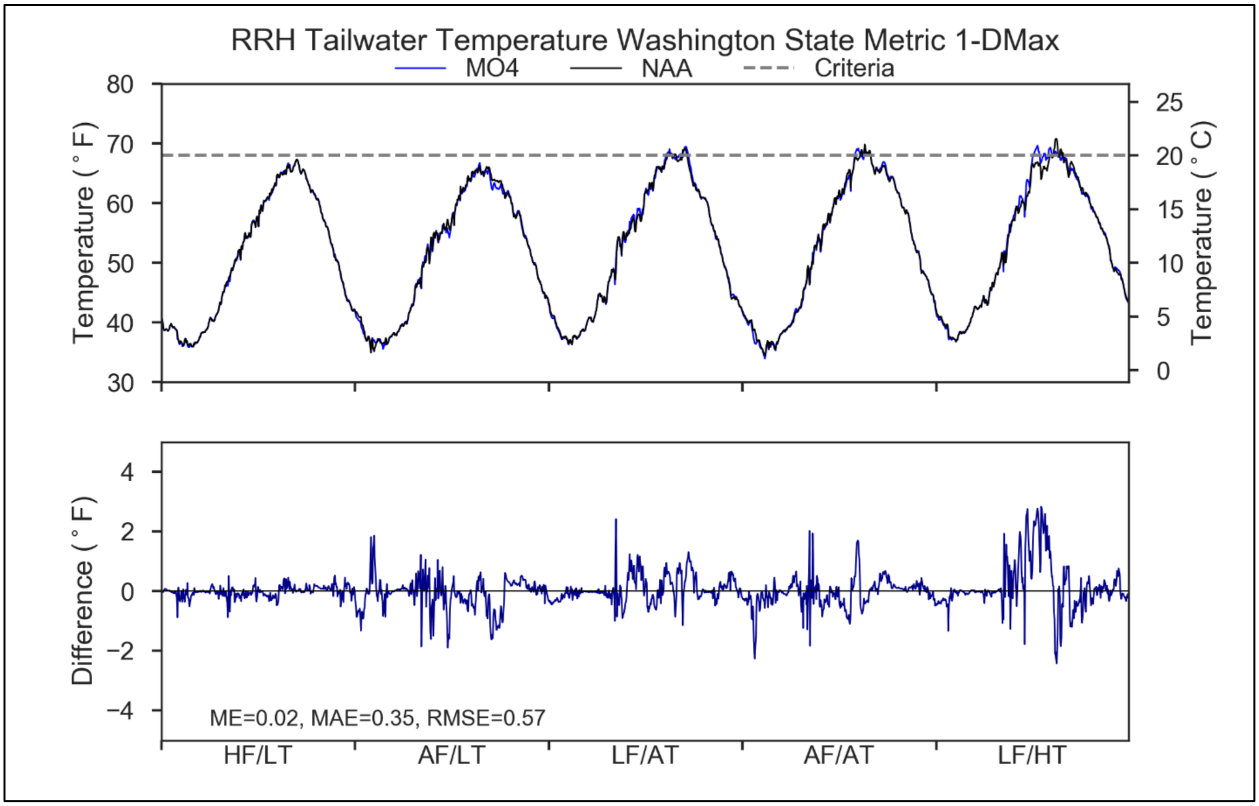


Figure 7-12. Modeled Tailwater Temperature for Multiple Objective Alternative 4 and No Action Alternative at Rocky Reach Dam Under a 5-year Range of River and Meteorological Conditions

Under MO4, reservoir elevation changes and corresponding project outflow changes predicted at Grand Coulee Dam would carry downstream through Rufus Woods Lake, Chief Joseph Dam, and downstream. In general, monthly outflows out of Chief Joseph Dam would be similar to the No Action Alternative except in September and October. Chief Joseph Dam outflows would be reduced in September and October by about 9 and 8 percent, respectively (Figure 7-13). Since Chief Joseph Dam is a run-of-river project, little change to forebay elevations would occur for MO4 when compared to the No Action Alternative (Figure 7-14). Tailwater temperatures under both MO4 and the No Action Alternative are predicted to exceed the Washington State and Tribal water quality criteria regardless of water year type or meteorological condition.

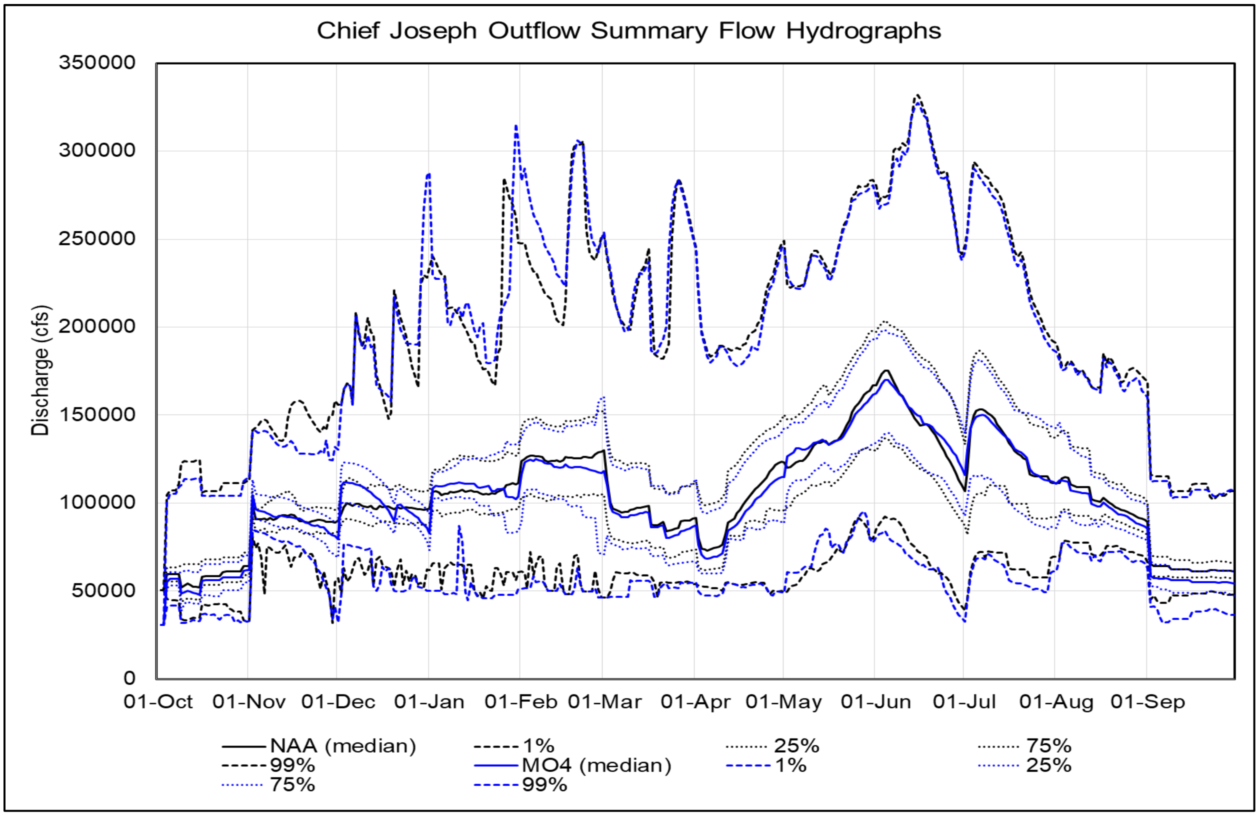


Figure 7-13. Chief Joseph Dam–Rufus Woods Lake Outflows for Multiple Objective Alternative 4 Versus No Action Alternative

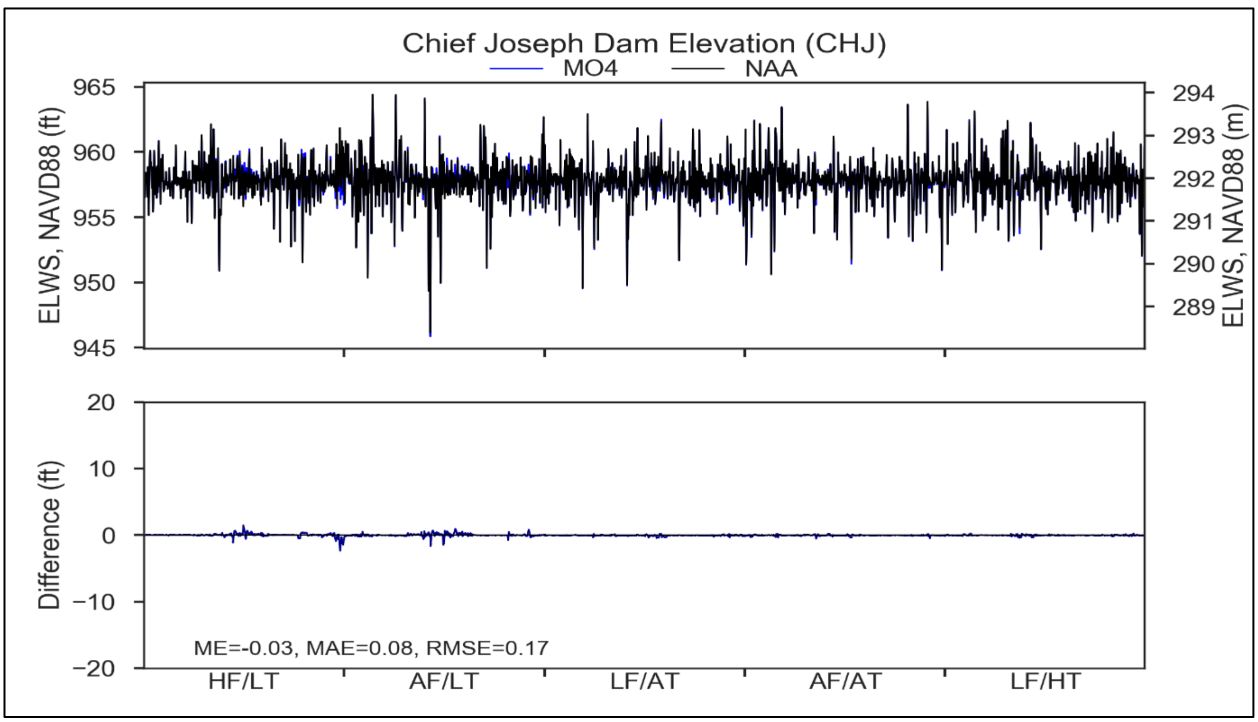


Figure 7-14. Chief Joseph Dam–Rufus Woods Lake Forebay Elevations for Multiple Objective Alternative 4 Versus No Action Alternative

Water temperatures under MO4 at Chief Joseph Dam tailwater are similar to or slightly warmer than under the No Action Alternative with the majority of temperature differences in the ±1 degree Fahrenheit range (Figure 7-15.). In general, temperatures modeled for MO4 are similar to the No Action Alternative for most river and meteorological conditions. An exception is for the low-flow scenarios (LF/AT and LF/HT) where river temperatures in the spring and summer are expected to be up to 1.5 degrees Fahrenheit (LF/AT) and 3 degrees Fahrenheit (LF/HT) greater under MO4. Tailwater temperatures under both the MO4 and No Action Alternative are predicted to exceed the Washington State criterion of 17.5°C (63.5°F) as measured by the 7-day average of the daily maximum temperature in August and September. Similar to the No Action Alternative, there is little difference in temperature between Grand Coulee Dam tailwater (Figure 7-10.) and Chief Joseph Dam tailwater (Figure 7-15.) under MO4, showing that water temperatures released from Lake Roosevelt are passed through Rufus Woods Lake unchanged.

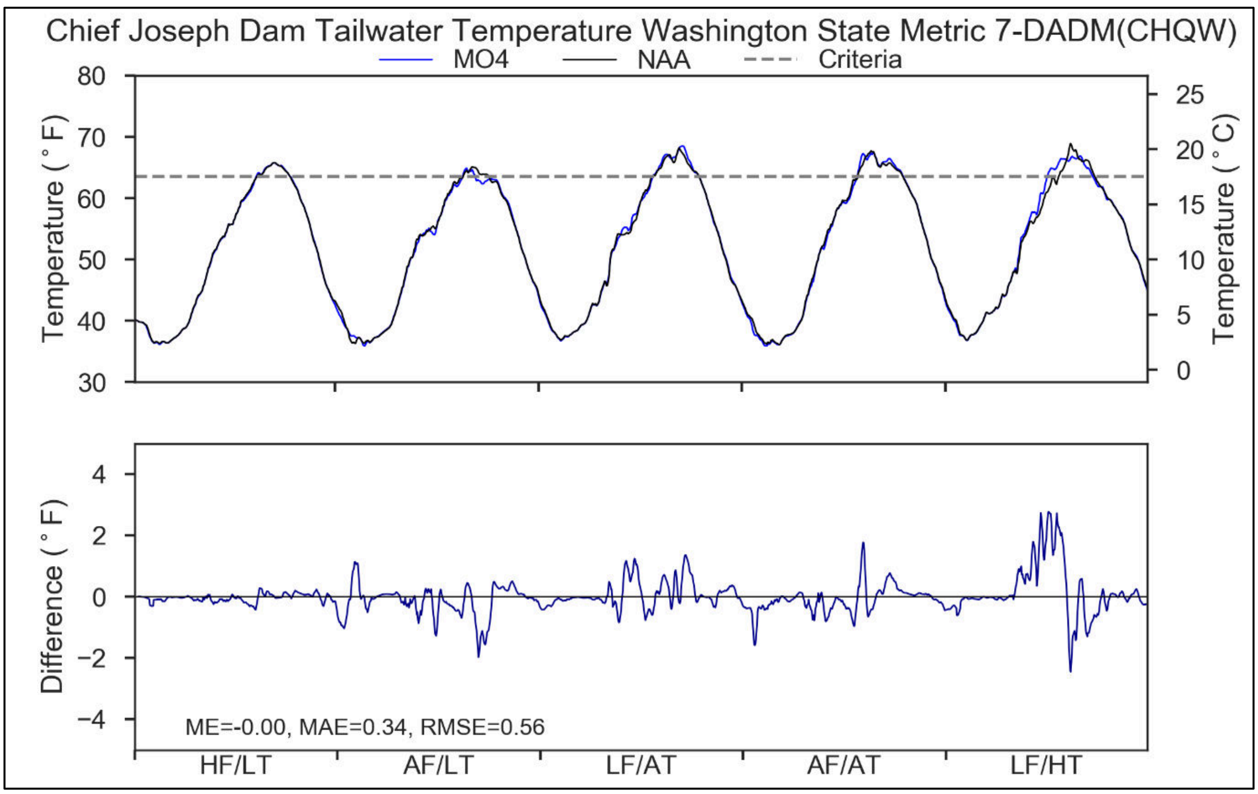


Figure 7-15. Modeled tailwater temperature for Multiple Objective Alternative 4 and No Action Alternative at Chief Joseph Dam Under a 5-year Range of River and Meteorological Conditions

The operational changes for MO4 do cause a few temperature differences as can be seen in the figures above. In terms of the actual number of days of the criteria being exceeded, those changes can be seen in Table 7-1. The blue highlighted cells show when an increased number of exceedances occurs as compared to NAA. Only the months where the criteria is exceeded is shown in the table. If a month has all zeroes shown, it is only because that month has exceeded criteria under a different alternative.

Table 7-1. Difference in Number of Days the Temperature Criteria is Exceeded at the Tailwater Sites of Grand Coulee and Chief Joseph for the Multiple Objective 4 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Grand Coulee	June	0	0	0	0	**12**
Grand Coulee	July	0	-2	-1	-2	**2**
Grand Coulee	August	0	0	0	0	0
Grand Coulee	September	0	0	0	0	0
Grand Coulee	October	0	**1**	0	0	-3
Chief Joseph	July	0	0	-2	0	**20**
Chief Joseph	August	**2**	**1**	0	0	0
Chief Joseph	September	0	-21	0	0	-4
Chief Joseph	October	**1**	-3	0	0	0

7.1.2 Total Dissolved Gas

There are a few measures within MO4 that are expected to modify reservoir storage and outflow rates at the upper Columbia River Basin projects. Although these measures would not greatly affect downstream TDG, some change is expected as compared to the No Action Alternative. These effects are described below.

7.1.2.1 Libby and Hungry Horse Dams and Reservoirs

Libby Dam is typically operated to minimize spill due to associated water quality concerns such as elevated TDG. Under MO4, Libby Dam's draft and refill operations will be modified, resulting in an increase in the highest releases from the dam. This operational change is predicted to increase the chance of spill at Libby Dam. The 80-year period of record flows (1928 to 2008) were used to predict TDG, as presented in Figure 7-16. This shows that under MO4, the number of years where spill could occur increases threefold, as compared to the No Action Alternative over the 80-year period. The number of days exceeding 110 percent would increase as well, from 8 days for the No Action Alternative to 43 days for MO4. Although spill from Libby Dam for the 80-year model period is predicted to increase under MO4, the frequency of spill is still very small.

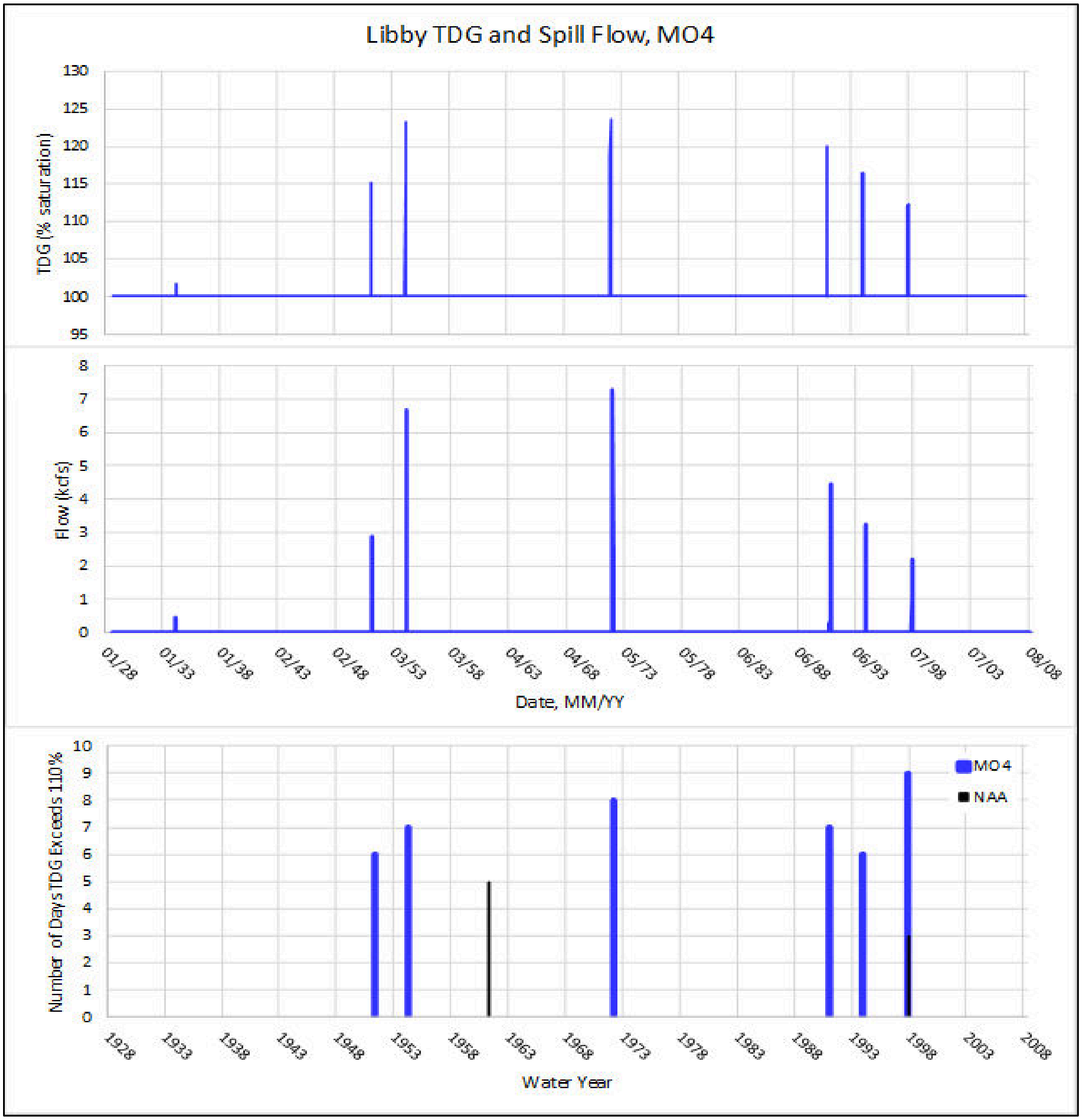


Figure 7-16. Modeled Tailwater Total Dissolved Gas and Spillway Flows for the Multiple Objective Alternative 4 and the Number of Exceedances for No Action Alternative and Multiple Objective Alternative 4 at Libby Dam over an 80Year Period.

In general, the number of days that TDG is anticipated to exceed 110 percent below Hungry Horse Dam under MO4 is similar to what is expected under No Action Alternative (Figure 7-17). That said, MO4 operations could lead to reductions in TDG in the winter and spring following a dry year due to changes in pool elevations at the end of September. The reduced elevation would provide additional storage to capture runoff, thereby resulting in less spill and associated TDG.

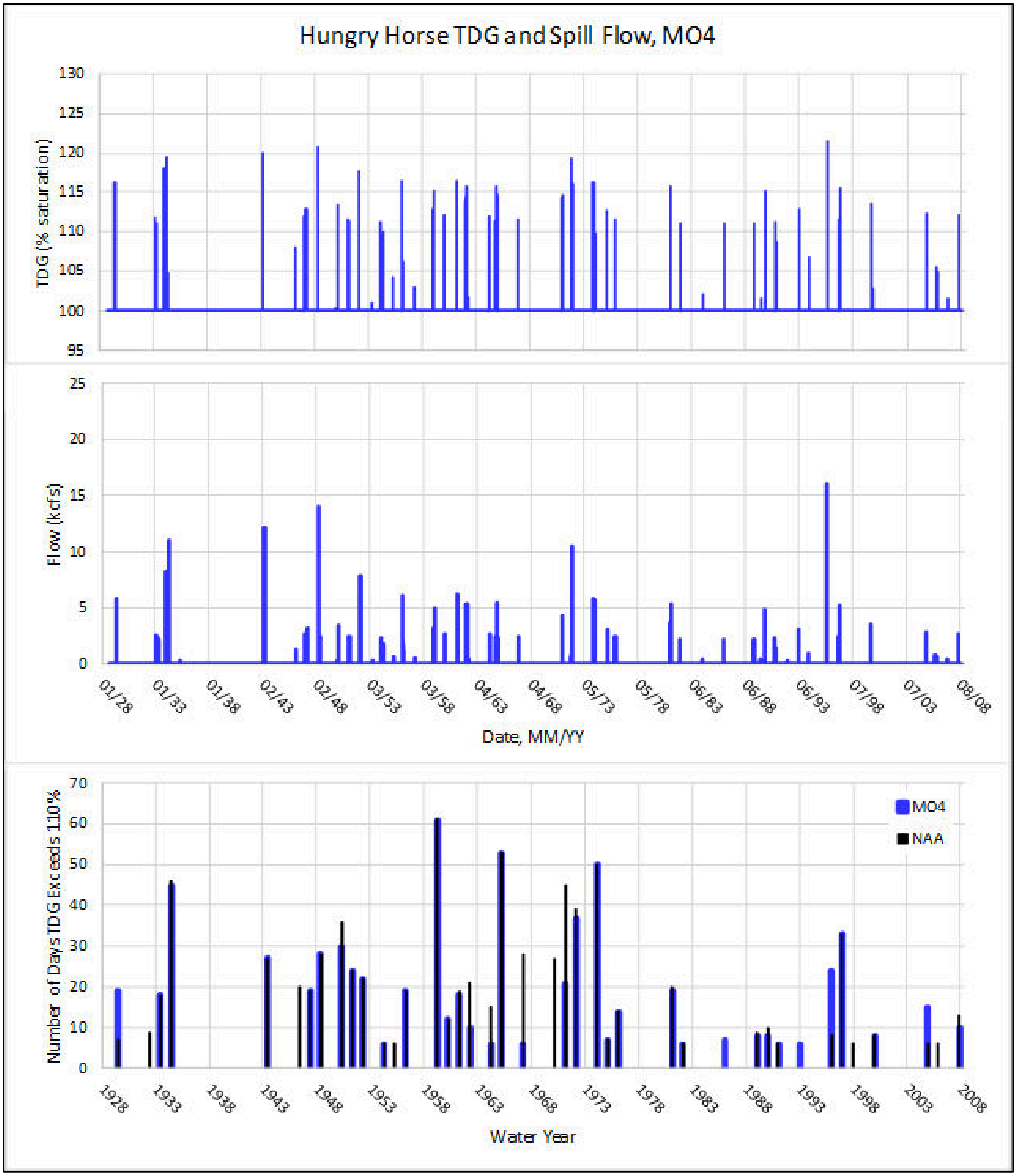


Figure 7-17. Modeled Tailwater Total Dissolved Gas and Spillway Flows for the Multiple Objective Alternative 4 and the Number of Exceedances for No Action Alternative and Multiple Objective Alternative 4 at Hungry Horse Dam over an 80Year Period

7.1.2.2 Albeni Falls Dam and Reservoir

TDG in the Pend Oreille River upstream of Albeni Falls Dam can be greater than 110 percent largely because of spillway releases from Cabinet Gorge Dam located on the Clark Fork River about 55 miles upstream of Albeni Falls Dam. During most years, Albeni Falls Dam spills during high-flow spring runoff. In general, spillway discharges up to about 10 kcfs can increase TDG saturations over forebay levels by about 1 to 2 percent, while spill between 10 to 50 kcfs can increase TDG saturations downstream of Albeni Falls by about 5 to 9 percent. When Pend Oreille River flows exceed about 50 to 60 kcfs, Albeni Falls Dam powerhouse operations are suspended and the spillway gates are raised, allowing the river to flow relatively un-impounded across the dam. Under these high-flow conditions Albeni Falls Dam produces no TDG as the river is essentially free flowing. Spillway flows at Albeni Falls Dam were modeled under MO4 and the No Action Alternative for the 80-year period from 1928 to 2008 using the ResSim model (Figure 7-18). There was little difference in spillway flows under MO4 and the No Action Alternative. For both alternatives, spillway flows were predicted to range between 1 and 50 kcfs in nearly every year at Albeni Falls Dam, with many years having spill exceed about 60 kcfs, resulting in free-flowing conditions. The similar spillway flows under MO4 and No Action Alternative are expected to result in no change in TDG saturations downstream of Albeni Falls Dam.

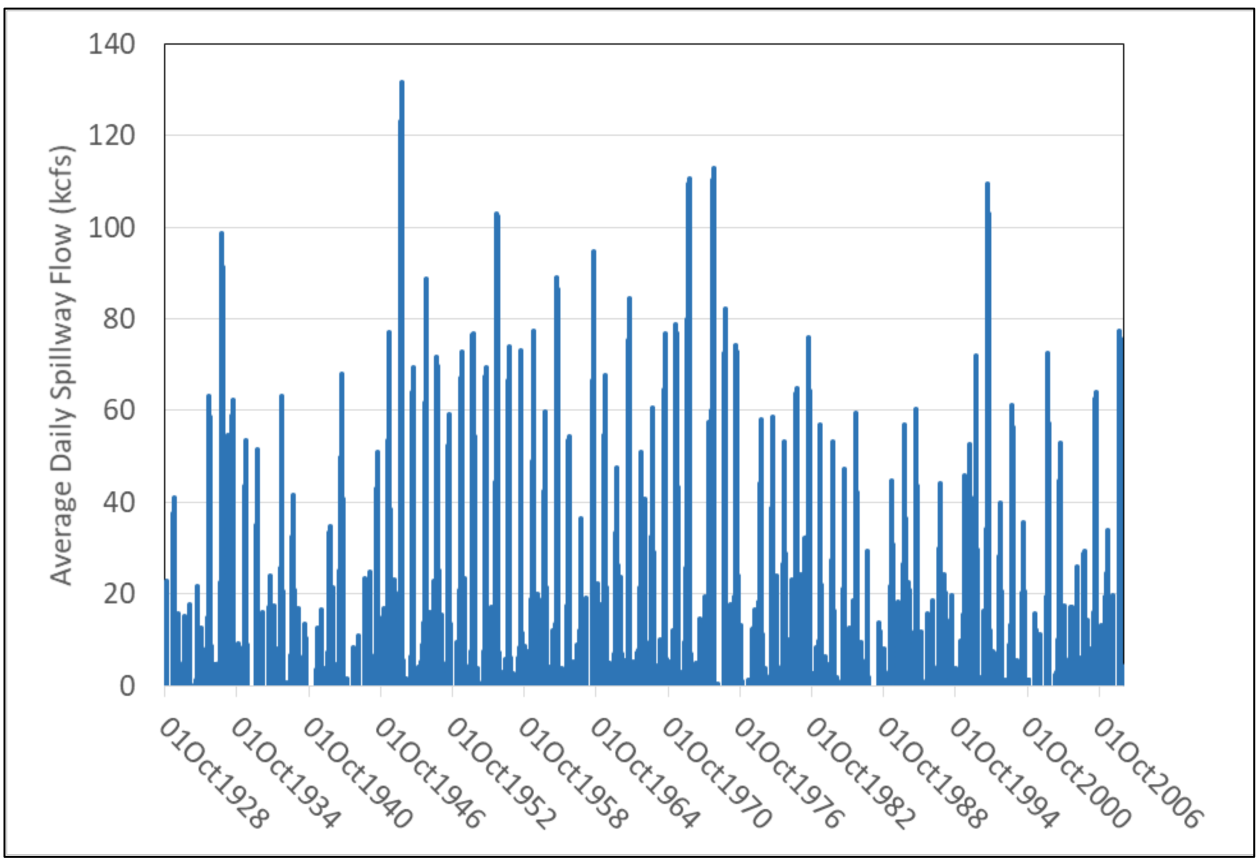


Figure 7-18. Modeled Tailwater Spillway Flows for Multiple Objective Alternative 4 and No Action Alternative at Albeni Falls Dam over an 80-year Period

7.1.2.3 Grand Coulee and Chief Joseph Dams and Reservoirs

There are multiple measures under MO4 that result in changed operations at Grand Coulee Dam: *Update System FRM Calculation, Planned Draft Rate at Grand Coulee, Grand Coulee Maintenance Operations, Winter System FRM Space, Lake Roosevelt Additional Water Supply,* and *McNary Flow Target*.

In addition to the measures listed above, changes in operations of upstream projects result in changes to inflows at Grand Coulee, which may have minor impacts on inflowing TDG but are not captured by the system modeling.

During drier years, operational measure *McNary Flow Target* may require the release of an additional 2 Maf (up to 1 Maf of water will be released from upstream projects to offset part of these releases) of water from Grand Coulee Dam to help maintain fish flow objectives in the lower river. *Winter System FRM Space* could result in a deeper draft and larger outflow in the month of December, however TDG responses under MO4 and the No Action Alternative are not all that different this time of year (Figure 7-19). From January through March, because the reservoir is lower for the FRM measures, including the *Winter System FRM* measure, there are typically lower outflows and in some situations less spill (and corresponding TDG) is predicted in those following few months (mid-April to mid-June). *Grand Coulee Maintenance Operations* measure has the potential to increase spill through the reduction in the hydraulic capacity of the powerhouse at Grand Coulee; however, the other actions tend to minimize effects and higher TDG associated with this measure is not reflected in modeled results (Figure 7-19 and Figure 7-20). The Grand Coulee Maintenance Operations in isolation could result in significant increases in spill and TDG, in some cases producing TDG in excess of 130 percent for a limited duration. An additional impact that is expected from Grand Coulee Maintenance Operations is the potential for slightly deeper spill over the drum gates (when the forebay elevation is greater than 1,267 feet, NGVD29). Information to assess the magnitude of water quality impacts is unavailable but would likely result in small increases in TDG. In wet conditions, potential maintenance activities could be delayed in advance of spill, to allow spill over more gates. Another factor not considered in the analysis is that as maintenance occurs there would be an increase in hydraulic capacity as more units become available. This would result in reduced spill and TDG in some cases; however, the other actions would have a larger impact on outflows and associated spill.

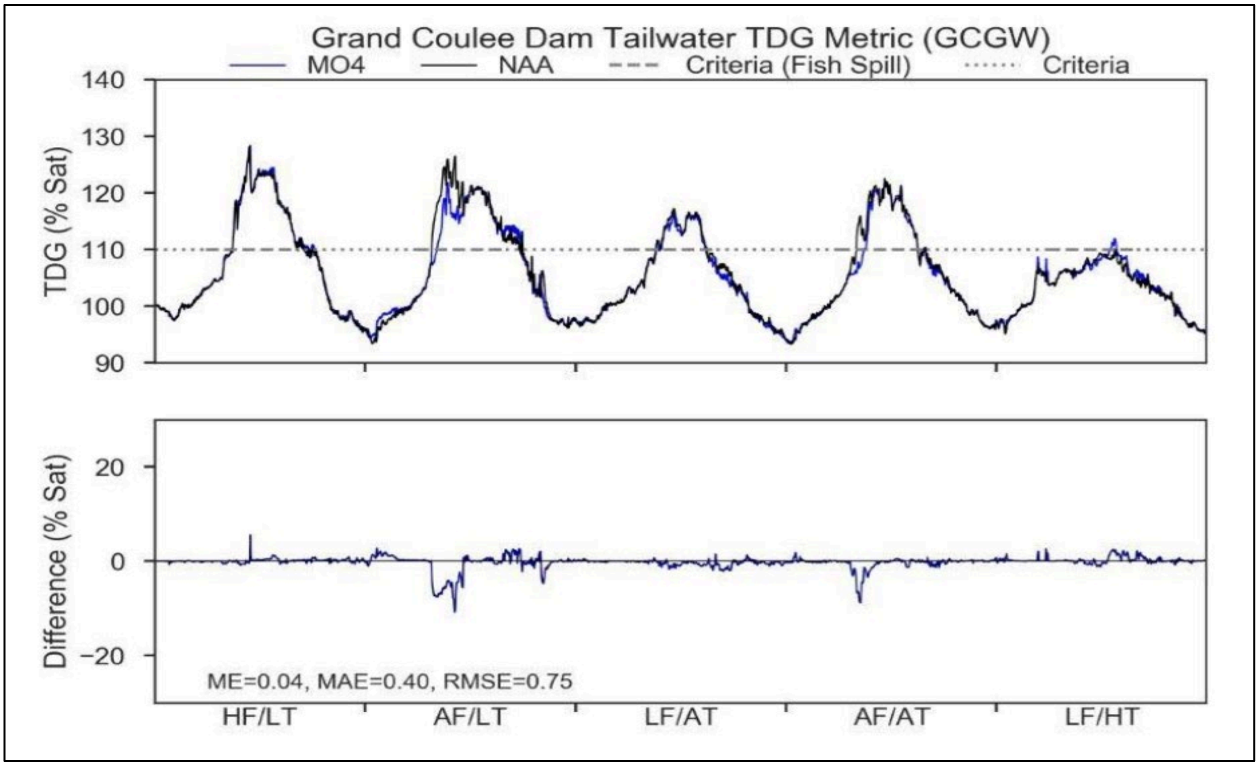


Figure 7-19. Modeled Tailwater Total Dissolved Gas for Multiple Objective Alternative 4 and No Action Alternative at Grand Coulee Dam Under a 5-year Range of River and Meteorological Conditions

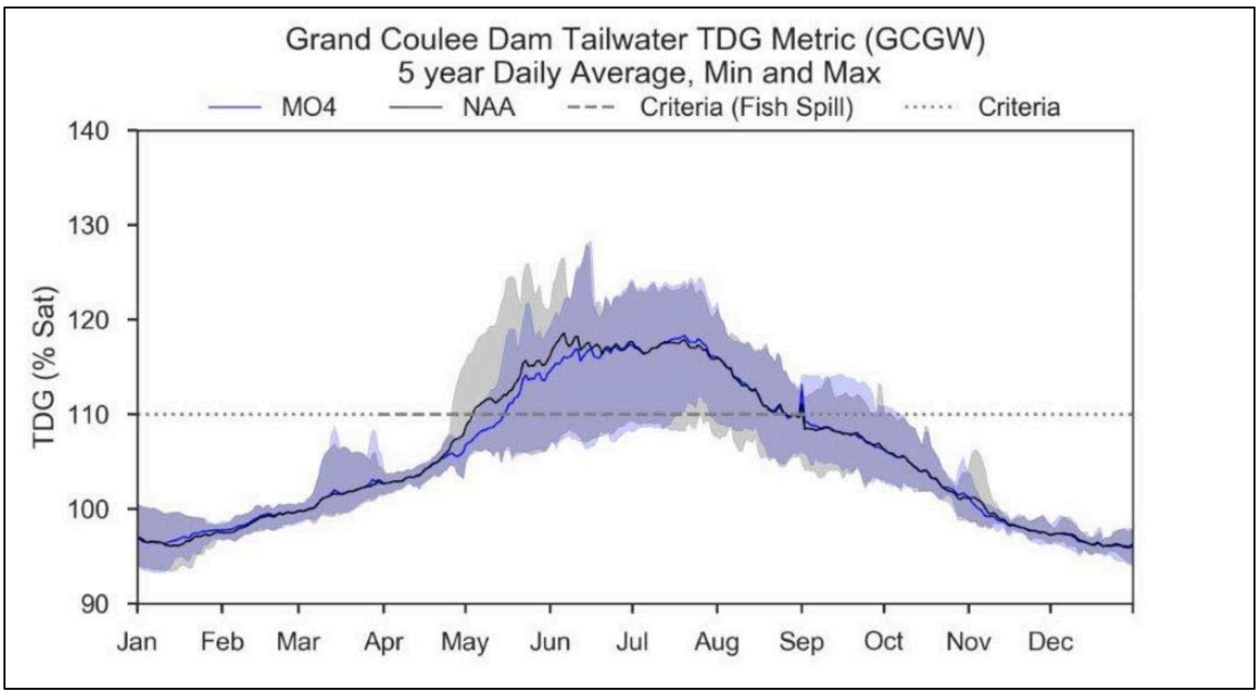


Figure 7-20. Modeled Tailwater Total Dissolved Gas 5-year Daily Average, Minimum, and Maximum for Multiple Objective Alternative 4 and No Action Alternative at Grand Coulee Dam

TDG at the forebay of Chief Joseph Dam is largely a function of the TDG released upstream from Lake Roosevelt and Grand Coulee Dam, because little degassing occurs in Rufus Woods Lake. High inflowing TDG to Lake Roosevelt from Canada as well as spill from Grand Coulee Dam via the outlet tubes can increase TDG saturations in Rufus Woods Lake at the Chief Joseph Dam forebay to over 130 percent for a limited time. During periods when incoming TDG levels are above approximately 120 percent, spilling at Chief Joseph Dam over the spillway deflectors can degas the water and reduce downstream system TDG loading. Therefore, Chief Joseph Dam is often used to help manage overall system TDG production in the mainstem Columbia River. In addition, to avoid spilling through the outlet tubes at Grand Coulee Dam, spill is often shifted from Grand Coulee to Chief Joseph Dam to take advantage of the lower TDG produced by spilling over the deflectors. These operational strategies are expected to continue under MO4.

Chief Joseph Dam TDG saturations at the forebay and tailwater modeled under MO4 were compared to the No Action Alternative (Figure 7-21). In general, MO4 forebay TDG saturations are predicted to be similar to the No Action Alternative under a wide range of flow and air temperature conditions. Tailwater TDG saturations under MO4 are predicted to be both lower and higher than the No Action Alternative depending on flow and meteorological conditions. The number of days the tailwater exceeds the 110 percent TDG criteria is predicted to be slightly lower under MO4 for all flow and meteorological conditions (Figure 7-22). Decreased TDG saturations between the forebay and tailwater during high-flow and high-spill years (HF/LT) modeled under the No Action Alternative would continue under MO4. It is expected that under MO4, Chief Joseph Dam would continue to decrease TDG during high-flow years when elevated TDG saturations occur in the forebay.

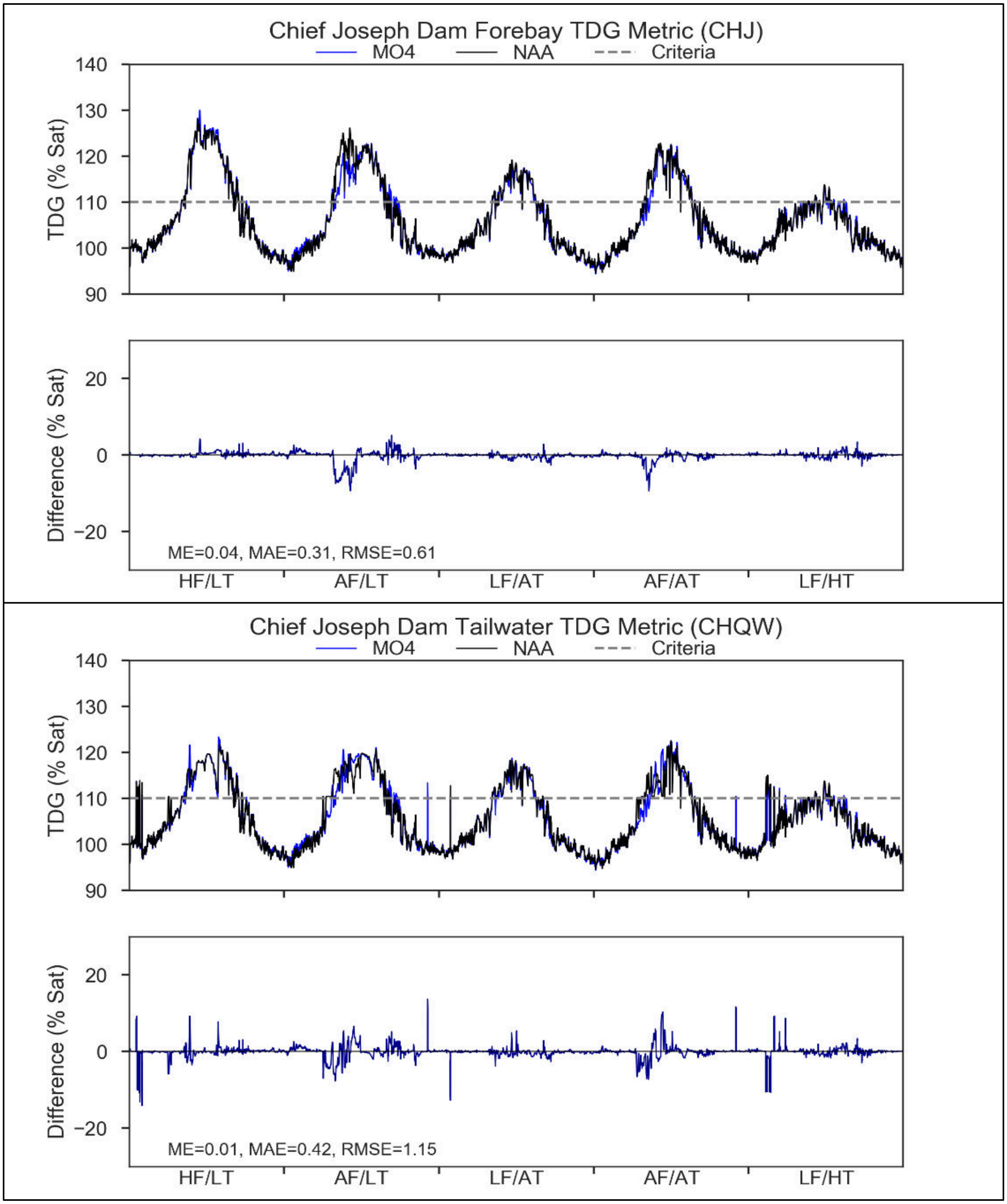


Figure 7-21. Modeled forebay and tailwater Total Dissolved Gas saturations for Multiple Objective Alternative 4 and No Action Alternative at Chief Joseph Dam Under a 5-year Range of River and Meteorological Conditions

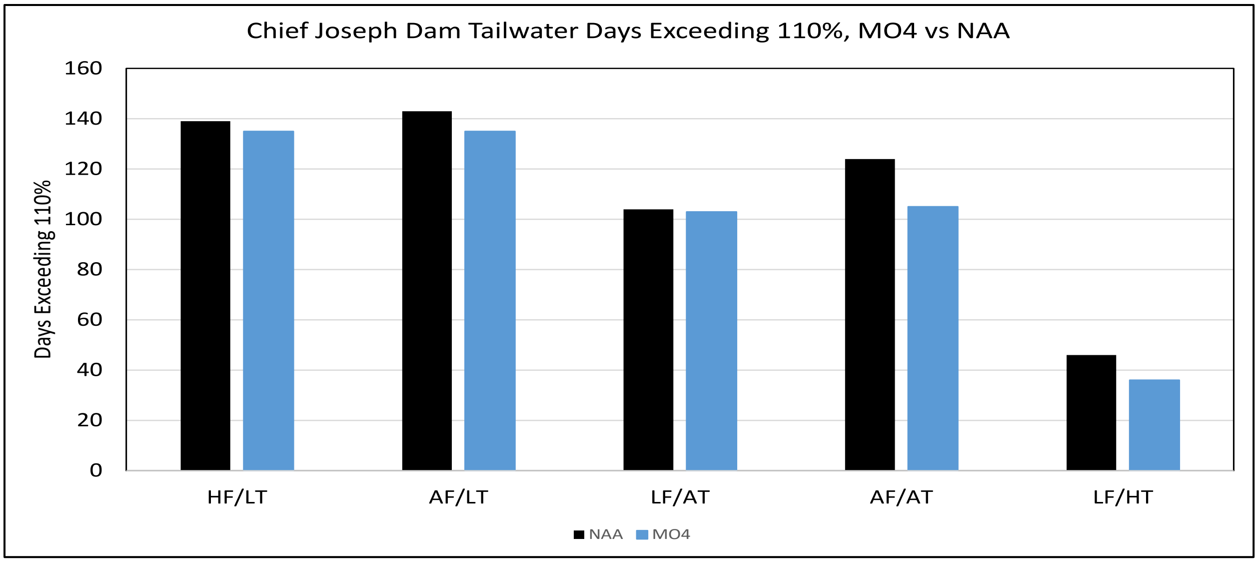


Figure 7-22. Days Exceeding the 110 percent Total Dissolved Gas Criteria for Multiple Objective Alternative 4 and No Action Alternative at Chief Joseph Dam Tailwater Under a 5-year Range of River and Meteorological Conditions

The operational changes for MO4 do cause a few TDG differences as can be seen in the figures above. In terms of the actual number of days of the criteria being exceeded, those changes can be seen in Table 7-2 and Table 7-3. Most differences seen at Grand Coulee do not propogate down to Chief Joseph. The blue highlighted cells show when an increased number of exceedances occurs as compared to NAA. Only the months where the criteria is exceeded is shown in the table. If a month has all zeroes shown, it is only because that month has exceeded the criteria under a different alternative.

Table 7-2. Difference in Number of Days the TDG Criteria is Exceeded at the Forebay Sites of Grand Coulee and Chief Joseph for the Multiple Objective 4 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Grand Coulee	April	0	**4**	0	0	0
Grand Coulee	May	**4**	**1**	0	-2	0
Grand Coulee	June	**1**	-1	**4**	-1	0
Grand Coulee	July	0	-1	**4**	**6**	0
Grand Coulee	August	**2**	**3**	0	0	0
Grand Coulee	September	0	0	0	0	0
Chief Joseph	April	0	-1	0	-1	0
Chief Joseph	May	0	-2	**4**	-8	-3
Chief Joseph	June	0	0	0	0	-4
Chief Joseph	July	0	0	0	0	-4
Chief Joseph	August	0	0	0	0	**4**
Chief Joseph	September	0	**9**	0	0	0
Chief Joseph	October	1	0	0	0	0

Table 7-3. Difference in Number of Days the TDG Criteria is Exceeded at the Tailwater Sites of Grand Coulee and Chief Joseph for the Multiple Objective 4 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Grand Coulee	April	0	-5	0	0	0
Grand Coulee	May	0	-4	-2	-14	0
Grand Coulee	June	0	0	0	0	0
Grand Coulee	July	0	0	0	0	**11**
Grand Coulee	August	0	0	-3	0	0
Grand Coulee	September	**2**	**1**	0	0	0
Grand Coulee	October	**4**	0	0	0	0
Chief Joseph	January	-2	0	-1	0	0
Chief Joseph	February	0	0	0	0	-5
Chief Joseph	March	0	0	0	0	**1**
Chief Joseph	April	-3	-17	0	-11	0
Chief Joseph	May	-1	-2	-1	-9	-3
Chief Joseph	June	0	0	0	0	-4
Chief Joseph	July	0	0	0	0	-4

7.1.3 Other Physical, Chemical, and Biological Processes

MO4 operations do have an impact on storage (reservoir elevation) and retention time (flow) in many of the upper basin CRSO projects. These changes may create shifts in nutrient dynamics and food availability for resident fish species. Details are discussed below.

7.1.3.1 Libby and Hungry Horse Dams and Reservoirs

Retention time, which is the inverse of the flushing rate, refers to the length of time water remains in a water-body. Water quality chemical and biological parameters of concern in Lake Koocanusa that may be impacted by changes in the reservoir elevation and retention times, under MO4, include nutrients such as phosphorus and nitrogen, trace metals such as selenium, and phytoplankton such as cyanobacteria and diatoms. Water quality concerns for MO4 would be similar to those discussed for MO1. The MO4 median water year retention time would likely be slightly less than under the No Action Alternative. For a long, narrow, deep water-body like Lake Koocanusa, a shorter retention time may allow certain chemical constituents in inflowing waters to move further down reservoir towards the forebay and outflow before settling out or transforming.

Median reservoir elevations under MO4 would be up to 9 feet lower from mid-June through the end of September when compared to the No Action Alternative. These lower MO4 summer pool elevations correspond to about a 4 percent decrease in the volume of the reservoir's photic/productive zone. In addition, the increased outflow under MO4 from Libby Dam would create a moving, increasing hydrograph, which may reduce variability of (periodically wetted) zone productivity by moving the photic zone with increasing flow. Because water quality parameters in Lake Koocanusa and the Kootenai River were not modeled, the potential decreases in productivity from a lower reservoir pool elevation and an increasing river hydrograph are a hypothesis and additional studies may be needed.

The MO4 operational measures *McNary Flow Target, Hungry Horse Additional Water Supply,* and *Sliding Scale at Libby and Hungry Horse* could result in deeper drafts and lower reservoir elevations, stratification and thermocline depths in the reservoir. These elevations combined with higher outflows in late spring/early summer could reduce in-lake productivity and food availability for resident fish species (ISAB 1997, Fraley et. al 1989).

Water level fluctuations in reservoirs may increase methyl-mercury concentrations in the waterbody as seasonally inundated areas of a reservoir have higher rates of methylation activity when compared to permanently inundated areas of a reservoir (Willacker 2016). Studies suggest that methyl-mercury has a greater probability of entering the food web during the spring and summer growing seasons (January to July) (Willacker 2016). Under MO4 the measures do not change the cyclic occurrence of inundation and exposure but do result in earlier and longer exposure of sediments that may have some impact on mercury methylation in Hungry Horse Reservoir. However, unlike other downstream locations such as Lake Roosevelt, mercury has not been recorded as a concern at Hungry Horse Reservoir as the only likely mercury input at this location is through airborne pollution deposition.

7.1.3.2 Albeni Falls Dam and Reservoir

Under MO4 there are only proposed changes to operations at Albeni Falls Dam for the drier 40 percent of years when the elevation of Lake Pend Oreille would be up to 2.6 feet lower in the summer. The change in summer elevation of Lake Pend Oreille during drier years would not likely impact the physical, chemical, or biological water quality in the open water areas of Lake Pend Oreille. However, shallow nearshore areas that currently have a nutrient TMDL in place would become substantially shallower, which might allow for more growth of periphyton and macrophytes in these bays. Such an increase in macrophytes and periphyton may impact nutrient cycling, dissolved oxygen concentrations, and pH levels in these shallow bays. Additionally, nearshore areas used for recreation may be more difficult to access due to the lower lake level, as well as due to greater macrophyte and periphyton growth.

7.1.3.3 Grand Coulee and Chief Joseph Dams and Reservoirs

Lake Roosevelt tends to display relatively low primary productivity throughout the year. However, with slightly longer water retention times in the spring due to greater volumes of water being stored for refill, some locations in the reservoir may experience algal blooms. These blooms have the potential to increase pH and decrease dissolved oxygen when they decay. Under MO4, retention time of water in through the reservoir could decrease slightly from March through May and in the fall of low-flow years, and sharply increase for a short period of time in late December and early January. In the section of reservoir where the Spokane River flows in, anoxic conditions may be greater under the LF/HT year for MO4 as compared to the No Action Alternative. This may be related to water retention time and temperature conditions in that year (Figure 7-23).

Turbidity generated from local landslides along Lake Roosevelt has been related to the rate of drawdown and refill at Grand Coulee Dam. Operational measure *Winter System FRM Space* changes the planning draft rate to a target of 0.8 feet per day. A slower drawdown rate may result in lower turbidity throughout the reservoir as a byproduct of a reduced likelihood of mass wasting events.

Water level fluctuations in Lake Roosevelt may have an impact on mercury cycling within the reservoir, especially when the lowest lake levels occur during peak fish growing season, which typically occurs from April through July (Figure 7-24). Studies suggest that methyl-mercury has a greater probability of entering the food web, especially fish, when growth is greatest. Effects such as this under some MO4 measures—particularly the release of an additional 2 Maf under the operational measure *McNary Flow Target*—could be expected since larger variations in water elevation are predicted. This variation may promote a higher rate of mercury cycling in Lake Roosevelt under MO4 than is seen in the No Action Alternative.

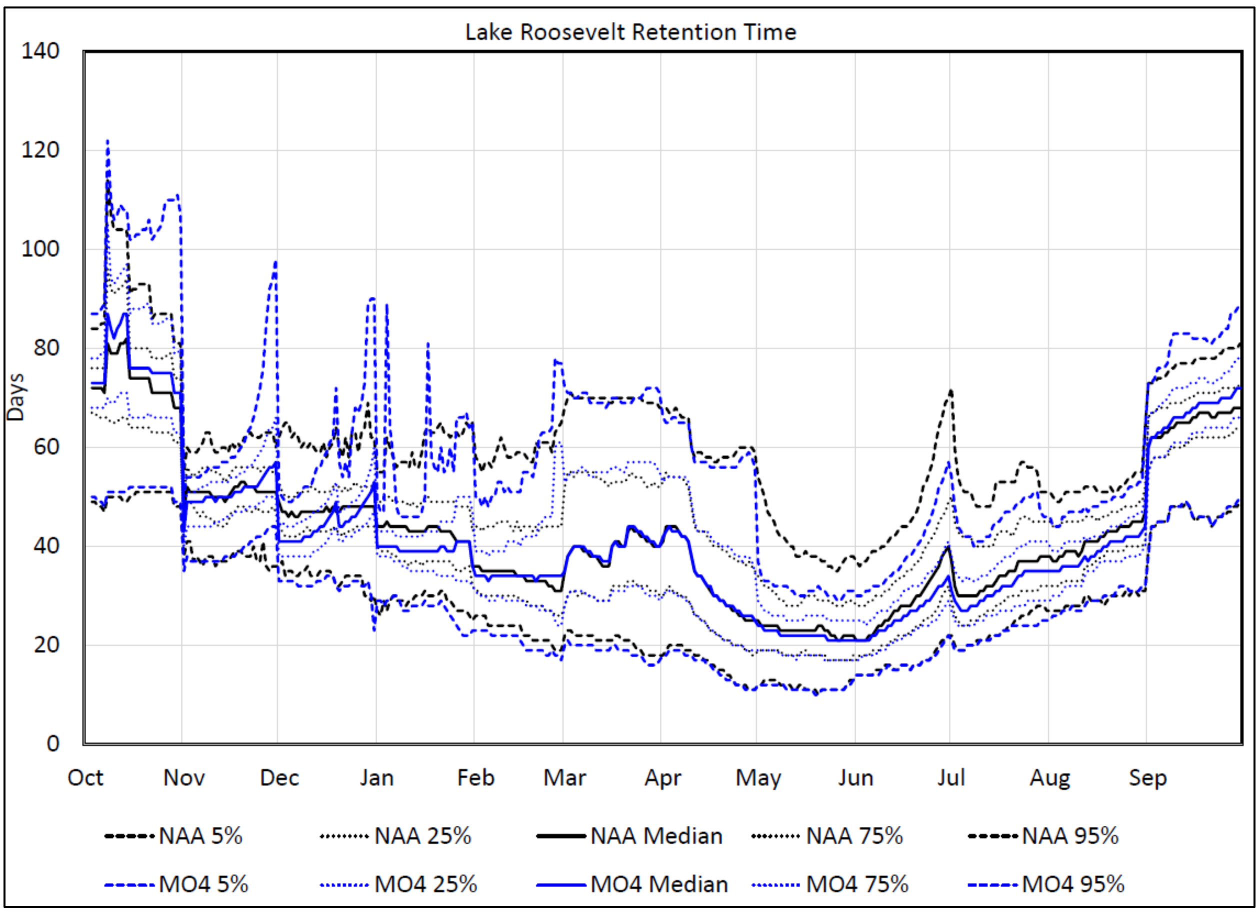


Figure 7-23. Modeled Retention Times at Lake Roosevelt for No Action Alternative and Multiple Objective Alternative 4

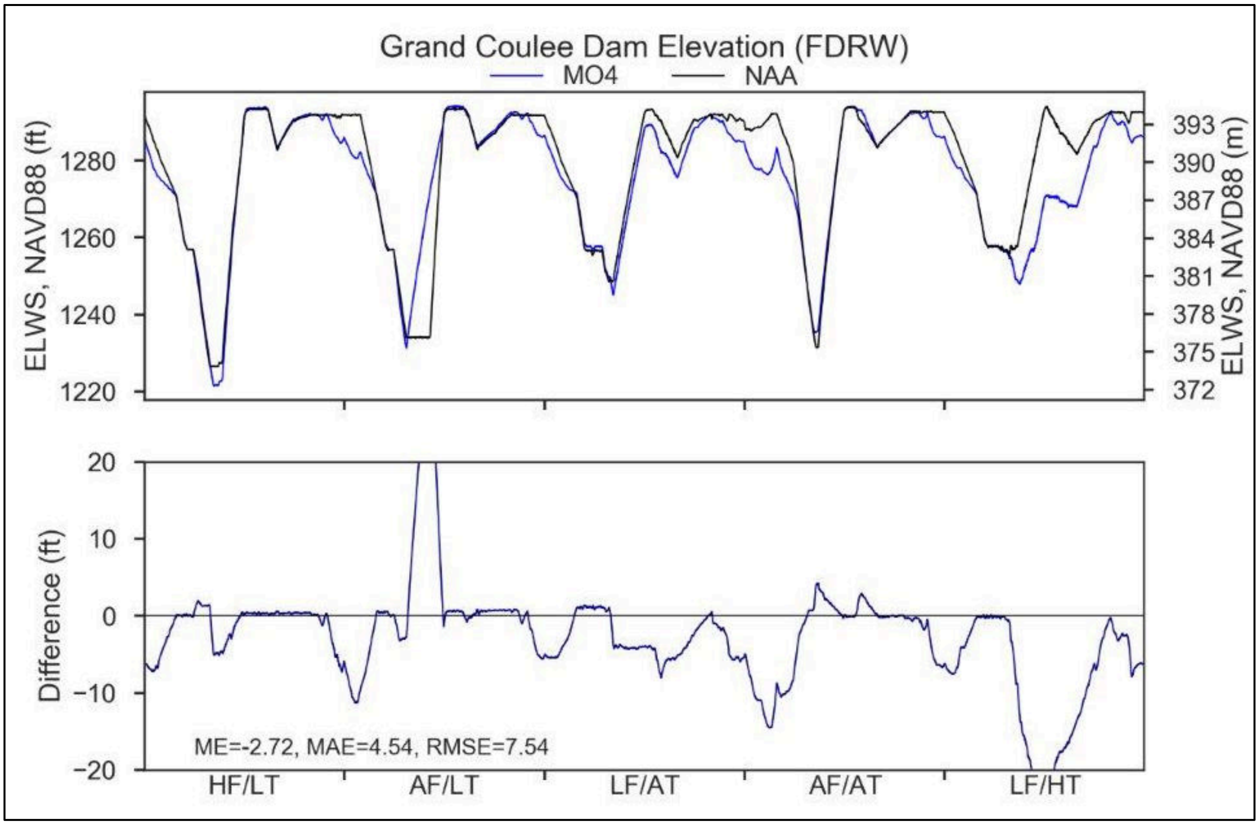


Figure 7-24. Modeled Forebay Elevations for Multiple Objective Alternative 4 and No Action Alternative Grand Coulee Dam Under a 5-year Range of River and Meteorological Conditions

MO4 includes modified operations at Grand Coulee Dam, which would result in some changes in monthly outflows to Rufus Woods Lake and Chief Joseph Dam. However, only minor changes to operational conditions at Chief Joseph Dam are expected. Given this, the physical, chemical, and biological water quality of Rufus Woods Lake and the Columbia River downstream of Chief Joseph Dam under MO4 are expected to remain relatively unchanged from under the No Action Alternative.

7.2 LOWER SNAKE RIVER BASIN

7.2.1 Water Temperature

There are no measures within MO4 directed at changing water temperature management in the lower Snake River. It is not anticipated that fish ladder water temperature improvements at Lower Monumental and Ice Harbor Dams (*Lower Snake Ladder Pumps* measure) would have any meaningful impact to downstream river water temperatures. These structural changes are anticipated to affect fish ladder conditions only.

7.2.1.1 Dworshak Dam and Reservoir

Outflow temperatures from Dworshak Dam, modeled for MO4, would be very similar to the modeled results for the No Action Alternative, with temperatures remaining less than 52°F throughout the year (Figure 7-25).

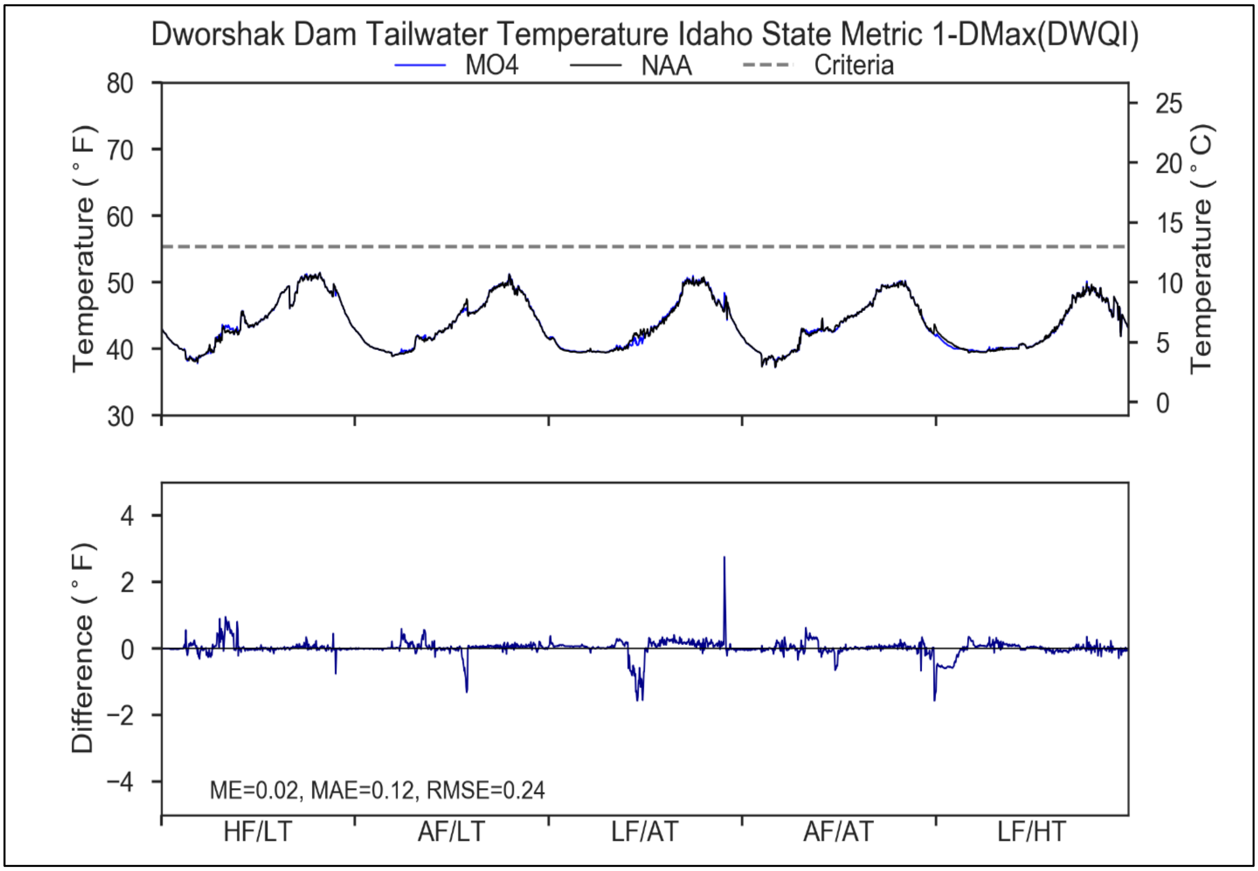


Figure 7-25. Modeled Tailwater Temperature for Multiple Objective Alternative 4 and No Action Alternative at Dworshak Dam Under a 5-year Range of River and Meteorological Conditions

7.2.1.2 Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams and Reservoirs

Modeled tailwater temperatures at the four lower Snake River dams would be very similar under MO4 and No Action Alternative (Figure 7-26 and Figure 7-29) as well. The differences that would occur are expected to be less than 0.5 degree Fahrenheit, which is within the margin of error for the model. This suggests that water temperatures are not sensitive to increased spill on the lower Snake River (Table 7-4), as called for in MO4.

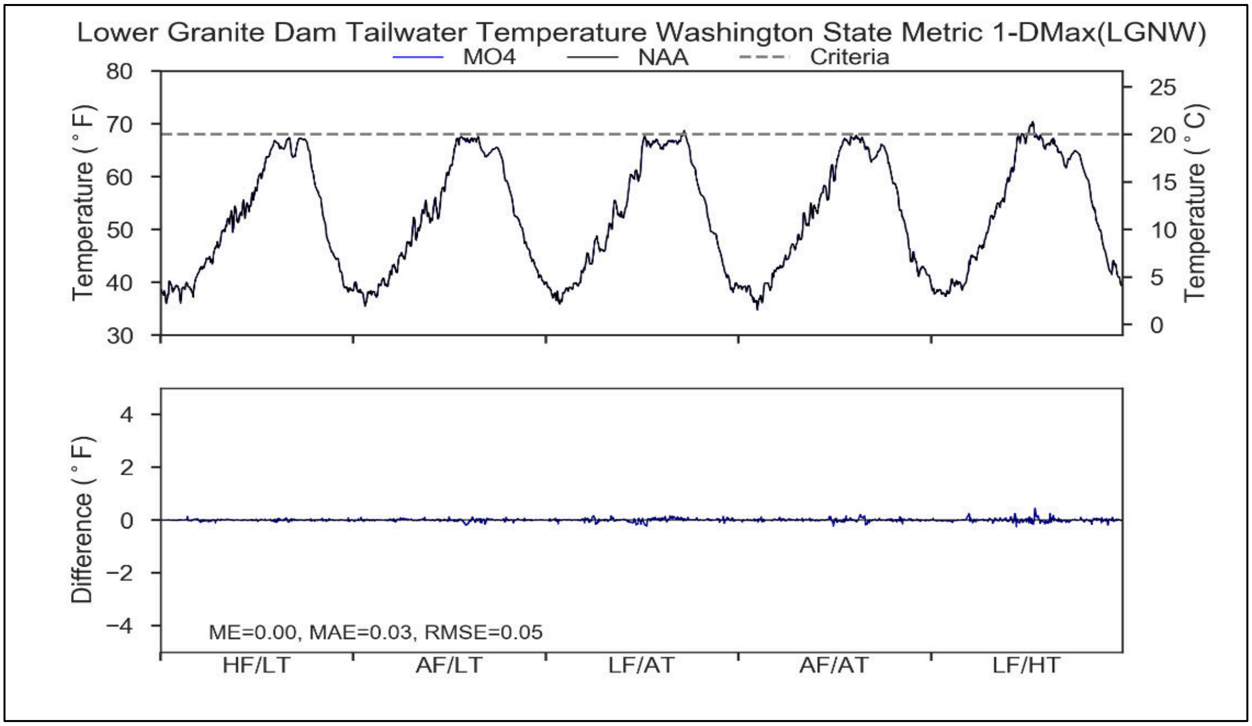


Figure 7-26. Modeled Tailwater Temperatures for Multiple Objective Alternative 4 and No Action Alternative at Lower Granite Dam Under a 5-year Range of River and Meteorological Conditions

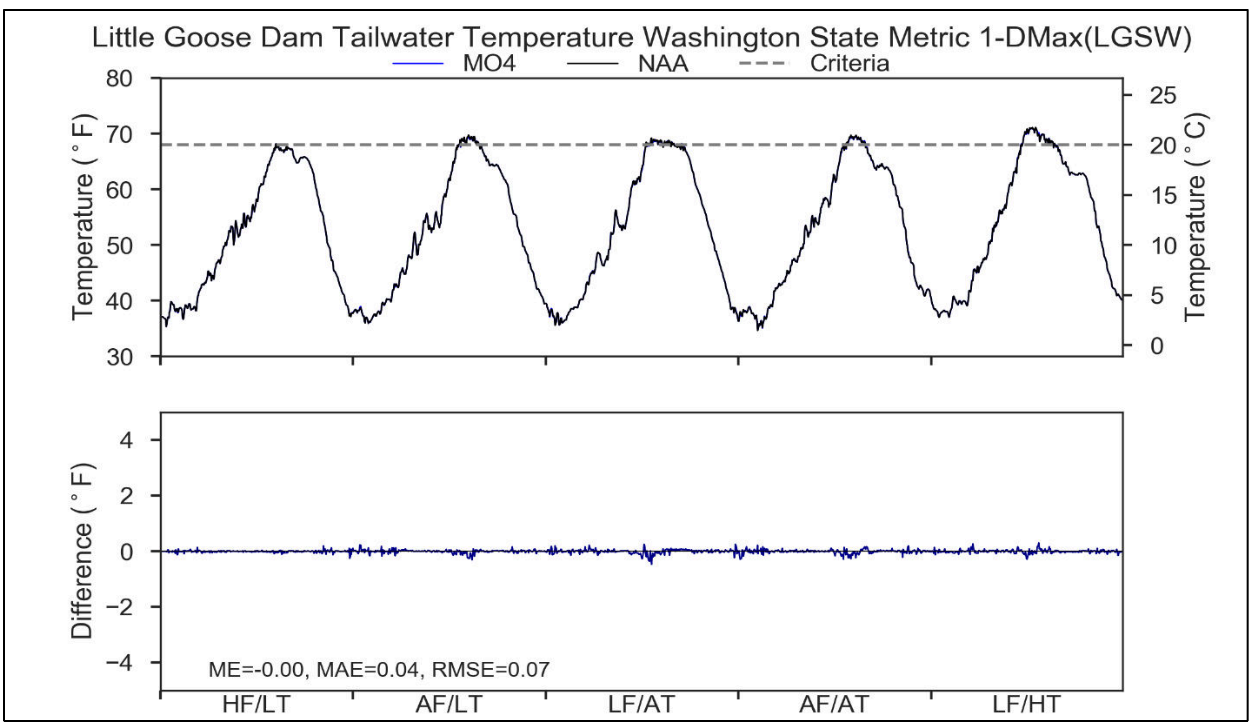


Figure 7-27. Modeled Tailwater Temperatures for Multiple Objective Alternative 4 and No Action Alternative at Little Goose Dam Under a 5-year Range of River and Meteorological Conditions

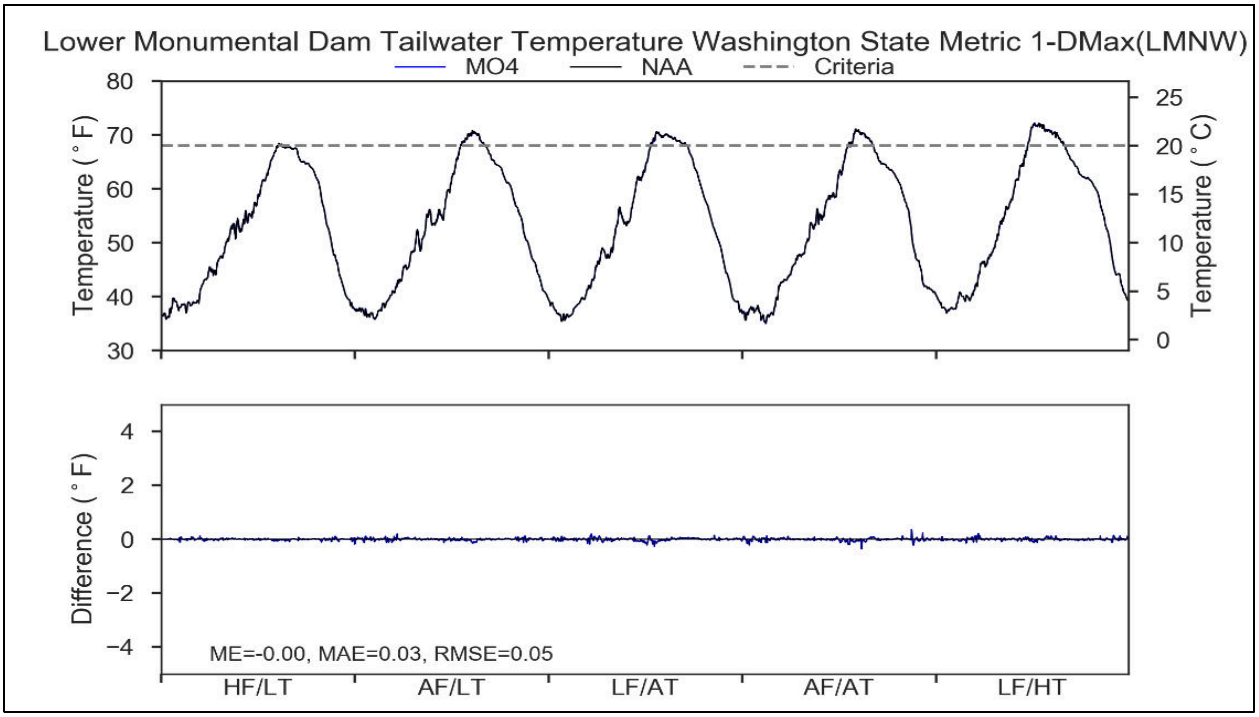


Figure 7-28. Modeled Tailwater Temperatures for Multiple Objective Alternative 4 and No Action Alternative at Lower Monumental and Ice Harbor Dams Under a 5-year Range of River and Meteorological Conditions

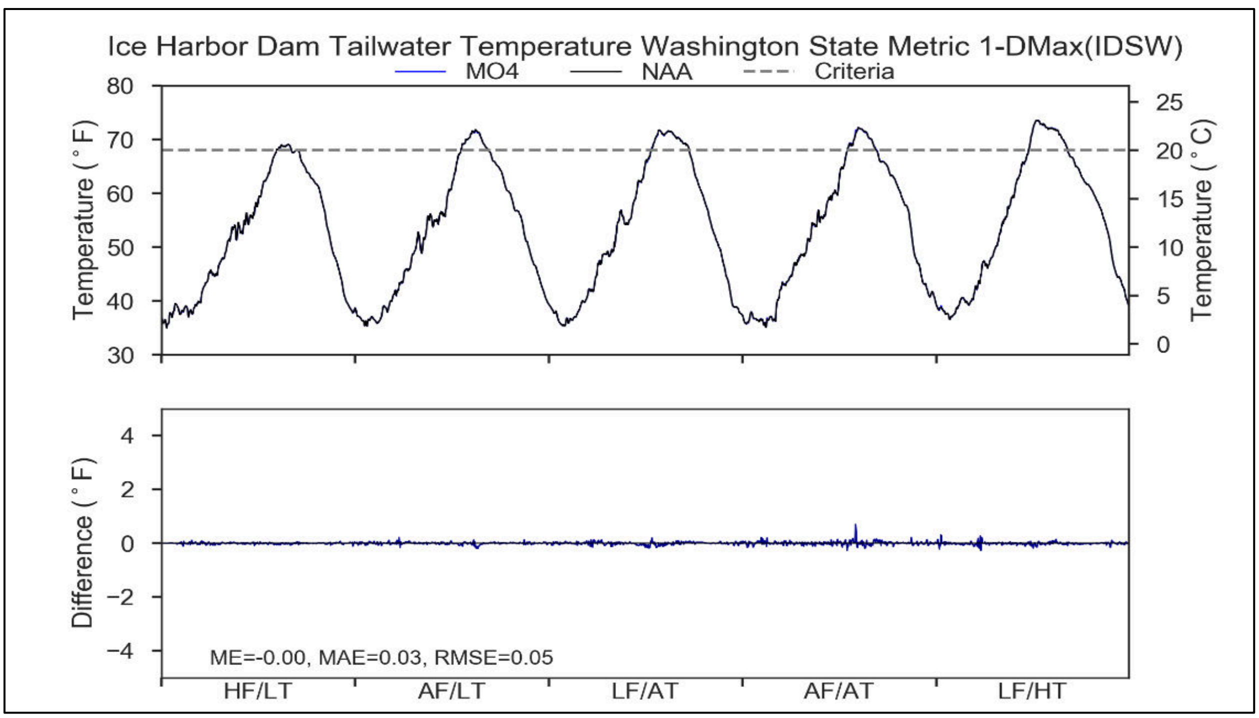


Figure 7-29. Modeled Tailwater Temperatures for Multiple Objective Alternative 4 and No Action Alternative at Lower Monumental and Ice Harbor Dams Under a 5-year Range of River and Meteorological Conditions

Table 7-4. Difference in Number of Days the Temperature Criteria is Exceeded at the Tailwater Sites of Lower Granite, Little Goose, Lower Monumental, and Ice Harbor for the Multiple Objective 4 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Lower Granite	June	0	0	0	0	-1
Lower Granite	July	0	0	0	0	**2**
Lower Granite	August	0	0	0	0	0
Lower Granite	September	0	0	**1**	0	0
Little Goose	June	0	0	0	0	0
Little Goose	July	0	0	-4	-1	0
Little Goose	August	-1	0	-1	0	0
Little Goose	September	0	0	**1**	0	0
Lower Monumental	June	0	0	0	0	0
Lower Monumental	July	0	0	0	-2	0
Lower Monumental	August	0	0	0	0	**1**
Lower Monumental	September	0	0	0	**2**	0
Ice Harbor	June	0	0	0	0	0
Ice Harbor	July	0	0	**1**	-1	0
Ice Harbor	August	0	0	0	0	0
Ice Harbor	September	**1**	0	0	**1**	0

7.2.2 Total Dissolved Gas

There are four measures in MO4 that would modify fish passage spill operations in the lower Snake River; no fish spill operations are included in MO4 for Dworshak Dam. The *Spill to 125% TDG* measure increases the tailwater gas cap at all four lower Snake River projects from 120 percent to 125 percent when sufficient flow is available. This operational measure does not call on additional upstream storage to meet the 125 percent TDG target when total river flows are low. To implement this measure, a change in the State water quality criterion from the baseline No Action Alternative would be required[6]. Results from this measure, as shown in the sections below, are compared to the 2016 water quality criteria and the No Action Alternative criterion to make comparisons among all MO measures easier. The *Spill to 125%* TDG measure extends the implementation of juvenile fish passage spill operations by 1 month as compared to the No Action Alternative, with fish spill under MO4 running from March through August. Structural measure *Spillway Weir Notch Inserts* calls for the modification of one existing spillway weir, with a notch gate, at each lower Snake River dam, while operational measure, *Spill for Adult Steelhead*, calls for around 2 kcfs of spill through these notch gates to increase adult steelhead survival from October 1 to November 31.

[6] Washington and Oregon are currently undergoing criterion revision to potentially revise the criteria for TDG in the four lower Snake and four lower Columbia River dams.

7.2.2.1 Dworshak Dam and Reservoir

TDG below Dworshak Dam under MO4 would be very similar to the No Action Alternative model results (Figure 7-30), with a few notable exceptions. First, there would be 135 fewer hours during late May and early June of an AF/LT year when the TDG would exceed 110 percent (Figure 7-31 and Table 7-5). Second, there are two additional periods when the TDG is already less than 110 percent under No Action Alternative, but would be even lower under MO4 for an extended period of time. The one instance would occur during April of a HF/LT year when the TDG would be approximately 6 percent less for about 300 hours during April. The second instance would occur during May and June of a LF/AT year when there would be over 1,300 hours when the average TDG would be 2.6 percent less during MO4, but the difference could be as high as 5 percent for several days (Figure 7-30).

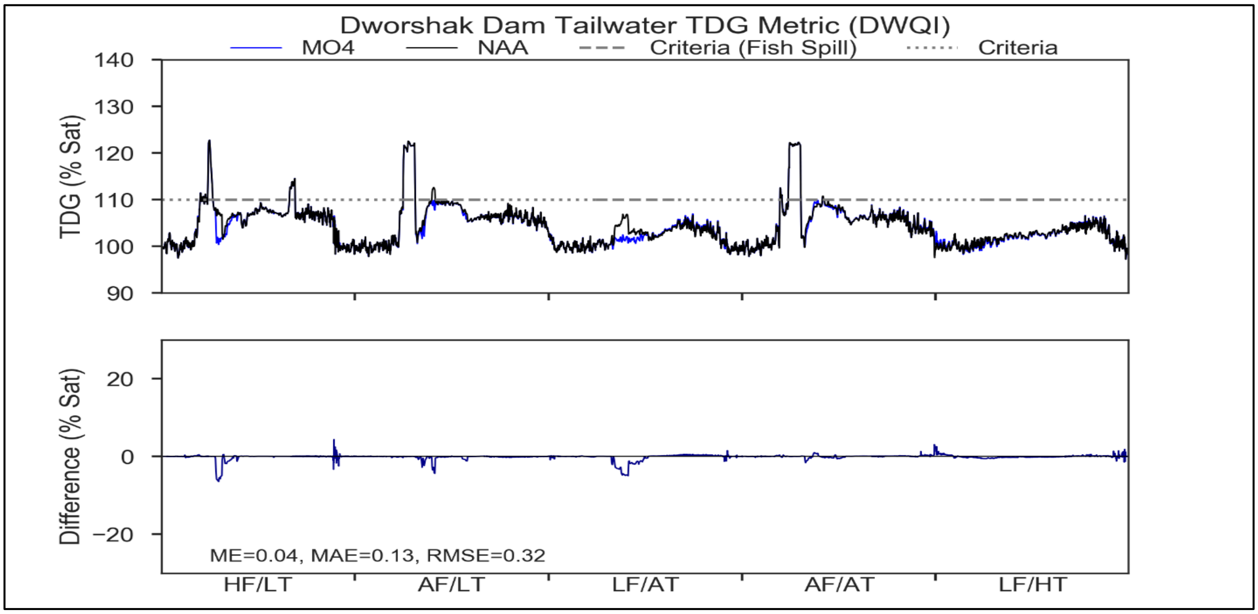


Figure 7-30. Modeled Tailwater Total Dissolved Gas for Multiple Objective Alternative 4 and No Action Alternative at Dworshak Dam Under a 5-year Range of River and Meteorological Conditions

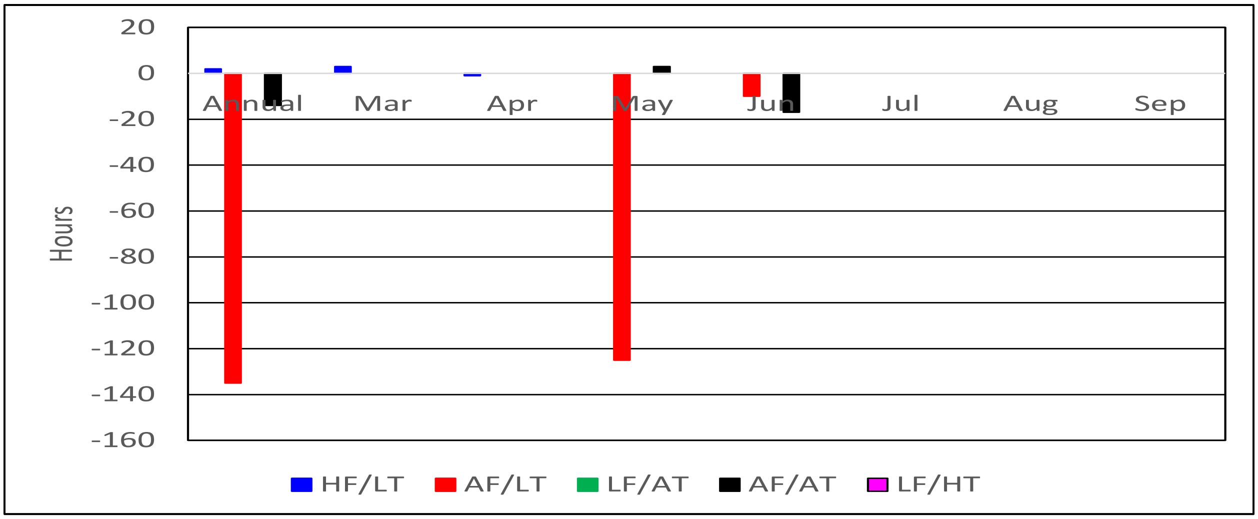


Figure 7-31. Difference in the Number of Hours each Year when Total Dissolved Gas Would Violate Idaho's 110 percent Water Quality Criterion at the Dworshak Dam Tailwater Fixed Monitoring Station, for Each Flow/Temperature Condition, Under Multiple Objective Alternative 4 and No Action Alternative

Table 7-5. Difference in Number of Days the Total Dissolved Gas Criteria is Exceeded at the Tailwater Site of Dworshak for the Multiple Objective 3 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
April	0	0	0	0	0
May	0	-6	0	0	0
June	0	-1	0	-1	0
July	0	0	0	0	0
August	0	0	0	0	0

7.2.2.2 Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams and Reservoirs

Tailwater TDG would increase at the four lower Snake River projects under MO4 because the gas cap would be 125 percent rather than the 120 percent considered for the No Action Alternative, and fish spill would begin March 1 instead of April 1 (Figure 7-32 to Figure 7-35). The 125 percent TDG target would be achievable in the high-flow and average-flow years, but less achievable in the low-flow years. This is because in the low-flow years there is not enough total river flow to meet both minimum hydropower generation and spill enough water to reach the 125 percent TDG target. A small increase in TDG would also be expected in the fall due to spill for adult steelhead migration. This increase would be minimal and well below state water quality criteria for TDG.

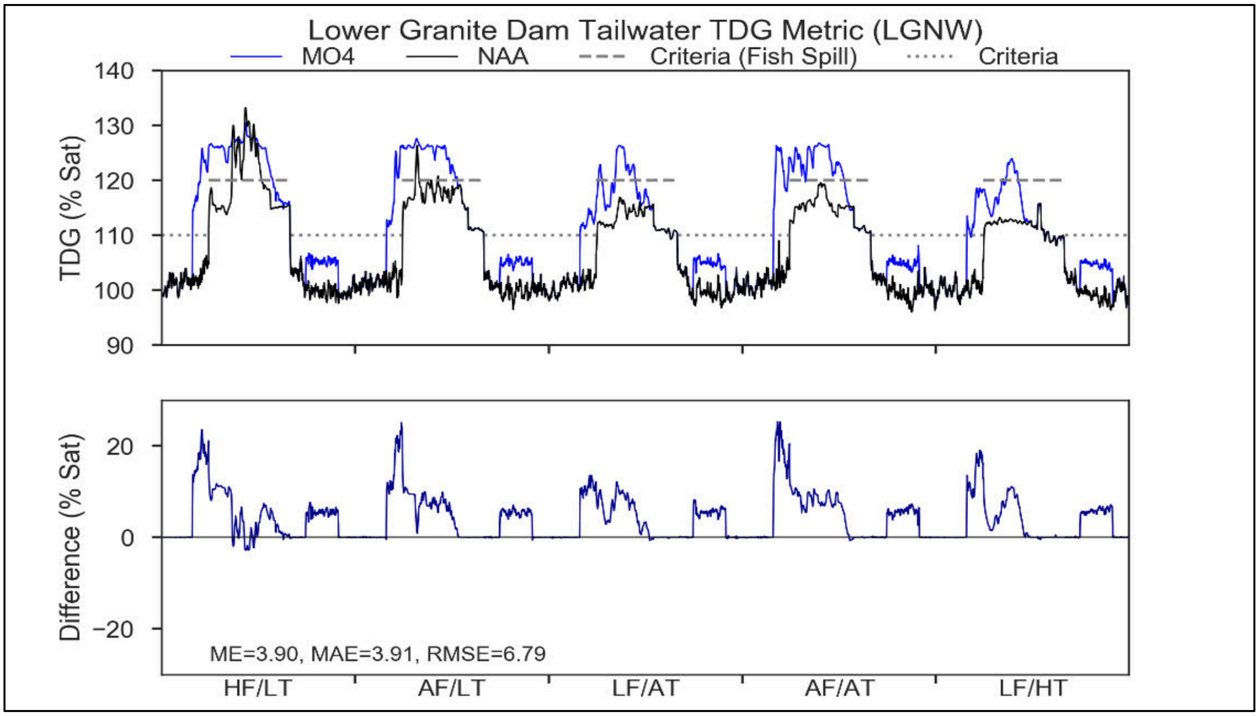


Figure 7-32. Modeled Tailwater Total Dissolved Gas for the Multiple Objective Alternative 4 and No Action Alternative at Lower Granite Dam Under a 5-year Range of River and Meteorological Conditions

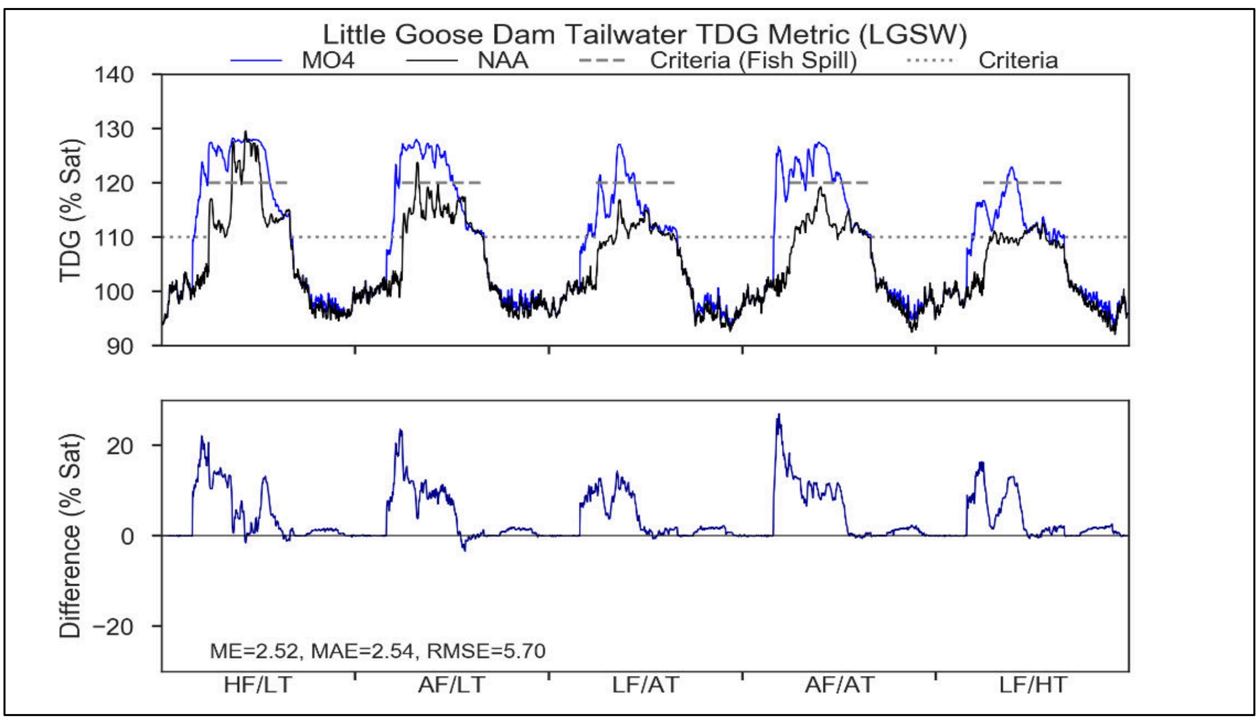


Figure 7-33. Modeled Tailwater Total Dissolved Gas for the Multiple Objective Alternative 4 and No Action Alternative at Little Goose Dam Under a 5-year Range of River and Meteorological Conditions

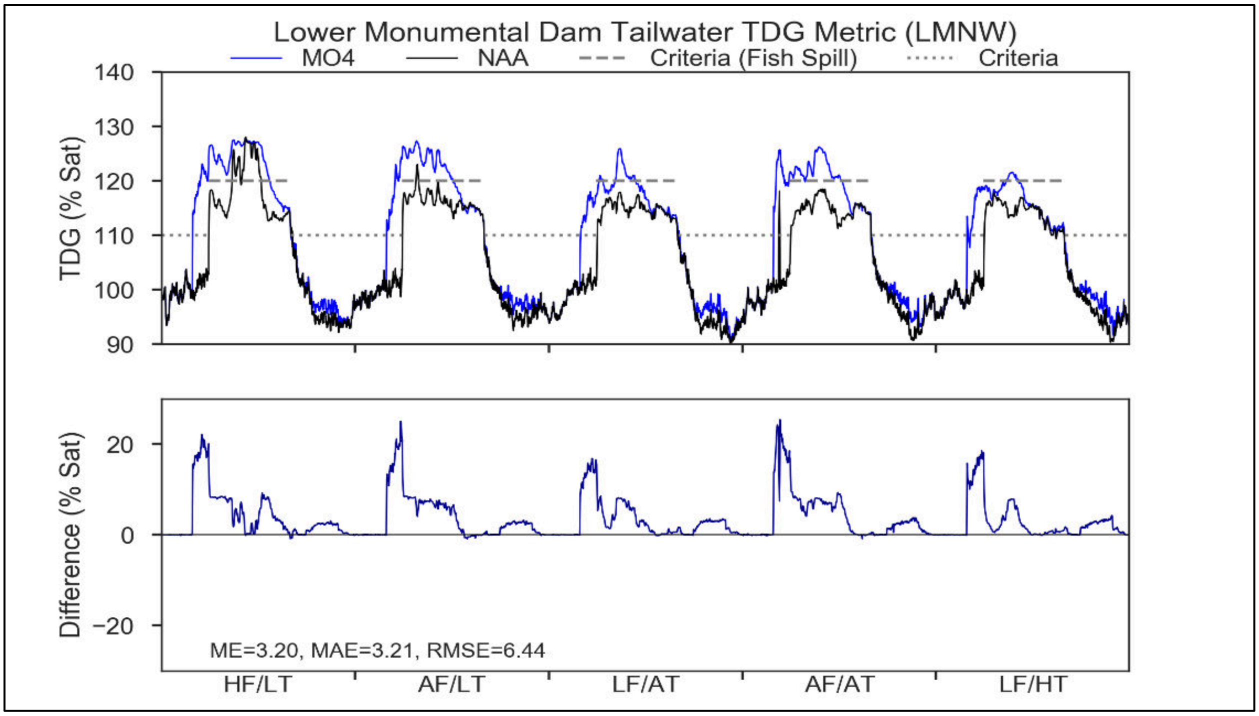


Figure 7-34. Modeled Tailwater Total Dissolved Gas for Multiple Objective Alternative 4 and No Action Alternative at Lower Monumental Dam Under a 5-year Range of River and Meteorological Conditions

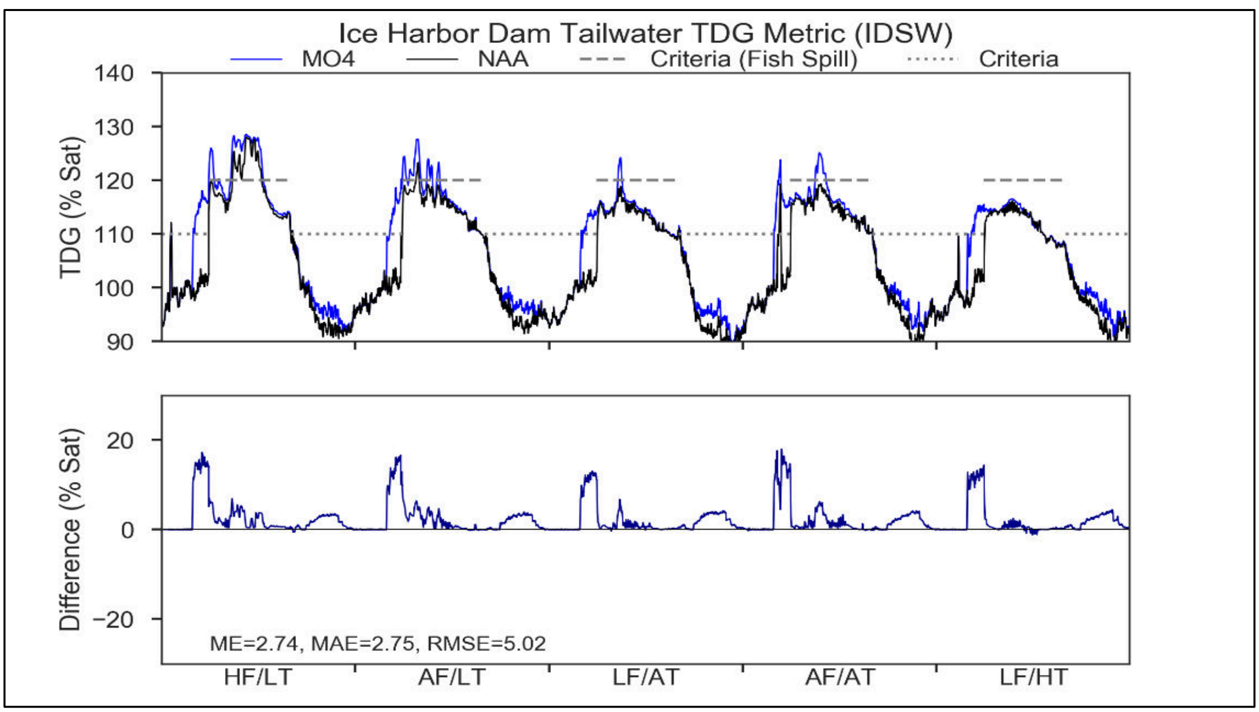


Figure 7-35. Modeled Tailwater Total Dissolved Gas for Multiple Objective Alternative 4 and No Action Alternative at Ice Harbor Dam Under a 5-year Range of River and Meteorological Conditions

Since the number of days when fish spill would occur increases from 153 to 184, and the gas cap increases from 120 to 125 percent under MO4, the comparison of tailwater TDG under MO4 relative to No Action Alternative is presented in two ways. First, the frequency distributions of March through August TDG for selected intervals for both alternatives is shown in Table 7-6. The general pattern is that the percentage of time when TDG would be less than 115 percent is higher under the No Action Alternative, and the percentage of time when it is greater than 120 percent is higher under MO4. For example, during HF/LT conditions at Lower Granite Dam, 38 percent of the data would be less than 115 percent TDG under the No Action Alternative, but only 3 percent would be less than this value under MO4. There would also typically be a higher percentage of values greater than 120 percent during high flows, followed by average flows, and then low flows under MO4.

Table 7-6. Differences of the Frequency of the Total Dissolved Gas that Would Occur Within Selected Ranges During Juvenile Spill Season (April-August) if Multiple Objective Alternative 4 is Implemented when Compared to the No Action Alternative at the Four Lower Snake River Dam Tailwater Locations Under a 5-Year Range of River and Meteorological Conditions

SITE	TDG Range (% Sat)	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Lower Granite	<=110	0.00%	-0.65%	-1.29%	0.00%	-1.29%
Lower Granite	>110,<=115	-20.00%	-0.65%	-40.65%	-19.35%	-40.00%
Lower Granite	>115,<=120	-21.94%	-60.00%	12.26%	-47.10%	23.87%
Lower Granite	>120,<=125	0.00%	12.26%	20.00%	40.00%	17.42%
Lower Granite	>125	41.94%	49.03%	9.68%	26.45%	0.00%
Little Goose	<=110	-1.94%	-2.58%	-27.10%	-10.32%	-54.84%
Little Goose	>110,<=115	-40.65%	-28.39%	-18.06%	-49.03%	21.94%
Little Goose	>115,<=120	3.23%	-28.39%	19.35%	-1.94%	20.00%
Little Goose	>120,<=125	-5.81%	14.84%	18.06%	40.65%	12.90%
Little Goose	>125	45.16%	44.52%	7.74%	20.65%	0.00%
Lower Monumental	<=110	-0.65%	-0.65%	-2.58%	-1.94%	-5.16%
Lower Monumental	>110,<=115	-36.77%	-3.87%	-25.81%	-39.35%	-16.13%
Lower Monumental	>115,<=120	-2.58%	-54.19%	-1.29%	-21.94%	6.45%
Lower Monumental	>120,<=125	9.68%	30.32%	25.16%	50.32%	14.84%
Lower Monumental	>125	30.32%	28.39%	4.52%	12.90%	0.00%
Ice Harbor	<=110	0.00%	-0.65%	-1.29%	-1.29%	-1.94%
Ice Harbor	>110,<=115	-5.81%	-5.16%	-12.90%	-14.19%	-14.19%
Ice Harbor	>115,<=120	-5.81%	-20.65%	9.03%	1.94%	16.13%
Ice Harbor	>120,<=125	-12.90%	21.94%	5.16%	12.26%	0.00%
Ice Harbor	>125	24.52%	4.52%	0.00%	1.29%	0.00%

A further evaluation of the differences between the No Action Alternative and MO4 was completed by comparing tailwater TDG to the current and proposed criteria on a monthly basis (Table 7-7). Changes in the number of days that TDG would be greater than the 110 percent March criterion and the 120 percent April through August waiver if MO4 is implemented are shown in the column identified as "Curr." The difference in the number of days that the proposed 125 percent criteria would be exceeded if MO4 is implemented compared to the No Action Alternative are shown in the column labeled "Prop." Several trends are apparent in the table. First, the number of days when the 110 percent criteria would be exceeded increases in most instances simply because the spill cap would be increased to 125 percent under MO4. Second, the largest changes occur in the March through May/June period at all of the projects and for most flow/temperature conditions. This is related to the higher river flow during those months since there are fewer changes, and in several cases, no change during July/August and low-flow conditions. Third, changes in the number of daily exceedances would be lower at Ice Harbor Dam than at the three upstream projects. The operational changes for MO4 do cause a more TDG exceedances at the lower Snake tailwater sites as shown in Table 7-8.

Table 7-7. Changes in the Number of Days Total Dissolved Gas Would be Greater or Less Than the 2016 Tailwater Criteria Under Multiple Objective Alternative 4 Relative to No Action Alternative

–	–	HF/LT		AF/LT		LF/AT		AF/AT		LF/HT	
SITE	**Month**	**Curr**	**Prop**	**Curr**	**Prop**	**Curr**	**Prop**	**Curr**	**Prop**	**Curr**	**Prop**
Lower Granite	March	30	4	30	7	31	0	30	11	30	0
Lower Granite	April	30	30	24	27	6	0	29	3	0	0
Lower Granite	May	13	14	30	27	26	15	31	23	22	0
Lower Granite	June	1	8	28	19	12	0	30	13	4	0
Lower Granite	July	21	15	11	0	0	0	11	0	0	0
Lower Granite	August	0	0	0	0	0	0	0	0	0	0
Little Goose	March	29	1	21	5	20	0	31	8	0	0
Little Goose	April	30	24	25	30	3	0	27	0	0	0
Little Goose	May	13	20	31	22	25	11	30	19	16	0
Little Goose	June	1	10	30	12	10	0	29	12	3	0
Little Goose	July	17	14	3	0	0	0	7	0	0	0
Little Goose	August	0	0	0	0	0	0	0	0	0	0
Lower Monumental	March	31	0	30	1	31	0	28	4	29	0
Lower Monumental	April	30	9	26	24	6	0	29	0	0	0
Lower Monumental	May	16	18	31	11	26	7	31	14	18	0
Lower Monumental	June	1	12	30	4	13	0	30	5	4	0
Lower Monumental	July	15	9	3	0	0	0	6	0	0	0
Lower Monumental	August	0	0	0	0	0	0	0	0	0	0

–	–	HF/LT		AF/LT		LF/AT		AF/AT		LF/HT	
SITE	**Month**	**Curr**	**Prop**	**Curr**	**Prop**	**Curr**	**Prop**	**Curr**	**Prop**	**Curr**	**Prop**
Ice Harbor	March	30	0	21	0	28	0	27	0	26	0
Ice Harbor	April	11	4	19	7	0	0	0	0	0	0
Ice Harbor	May	3	17	14	0	7	0	14	2	0	0
Ice Harbor	June	0	14	5	0	0	0	6	0	0	0
Ice Harbor	July	3	6	0	0	0	0	0	0	0	0
Ice Harbor	August	0	0	0	0	0	0	0	0	0	0

Note: Curr = Change in the number of days TDG would be greater than 110 percent during March and greater than 120 percent from April through August if MO4 was implemented when compared to No Action Alternative operations. Prop = Change in the number of days TDG would be greater than 125 percent between March through August if MO4 was implemented when compared to the No Action Alternative.

Table 7-8. Difference in Number of Days the TDG Criteria is Exceeded at the Tailwater Sites of Lower Granite, Little Goose, Lower Monumental, and Ice Harbor for the Multiple Objective 4 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Lower Granite	March	**31**	**31**	**31**	**31**	0
Lower Granite	April	**30**	**24**	**7**	**29**	0
Lower Granite	May	**13**	**29**	**26**	**31**	**22**
Lower Granite	June	0	**28**	**13**	**30**	**5**
Lower Granite	July	**21**	**12**	0	**12**	0
Little Goose	March	**29**	**21**	**19**	**30**	0
Little Goose	April	**30**	**25**	**4**	**27**	0
Little Goose	May	**13**	**31**	**25**	**30**	**15**
Little Goose	June	**1**	**30**	**11**	**30**	**4**
Little Goose	July	**16**	**4**	0	**7**	0
Little Goose	September	**1**	0	0	0	0
Lower Monumental	March	**31**	**30**	**30**	**29**	0
Lower Monumental	April	**30**	**25**	**7**	**29**	0
Lower Monumental	May	**15**	**31**	**26**	**31**	**18**
Lower Monumental	June	**1**	**30**	**13**	**30**	**3**
Lower Monumental	July	**15**	**3**	0	**7**	0
Lower Monumental	September	-1	0	**1**	0	0
Ice Harbor	March	**30**	**25**	**26**	**28**	0
Ice Harbor	April	**12**	**20**	0	0	0
Ice Harbor	May	**3**	**15**	**8**	**14**	0
Ice Harbor	June	0	**5**	0	**7**	0
Ice Harbor	July	**3**	0	0	0	0
Ice Harbor	September	-1	0	-2	-1	0

Since tailwater TDG would be increased to 125 percent under MO4, downstream forebay TDG would also increase at the three downstream lower Snake River projects when compared to the No Action Alternative (Figure 7-36 through Figure 7-39). Lower Granite Dam forebay TDG would remain less than 115 percent since there are no changes in upstream operations (Table 7-9). TDG at the three remaining forebay locations would reach maximum values ranging from 126 to 131 percent. The frequency of time when forebay TDG would be above 115 percent between March and August is very similar at Little Goose and Lower Monumental Dams. During LF/HT conditions this level of saturation would be surpassed about 26 percent of the time, increasing to almost 80 percent of the time during HF/LT conditions. During average flow conditions the 115 percent criteria would be surpassed 62 to 72 percent of the time. The frequency of TDG greater than 115 percent under MO4 would be greater at the Ice Harbor Dam forebay. During LF/HT and LF/AT conditions 60 and 64 percent of the measurements would be above 115 percent, respectively. During AF/AT and HF/LT conditions the frequencies would increase to 82 and 86 percent of the time, respectively.

A request to “eliminate forebay criteria” would be made under MO4. Given this, a comparison between MO4 and No Action Alternative forebay TDG exceedances similar to the one made for the tailwater cannot be completed. However, a comparison to the 12-hour average 115 percent criterion was made to show the changes in the number of days that criterion would be exceeded if MO4 was implemented (Table 7-10). As was the case for the tailwater stations, the largest changes occur between March and May and taper off through August regardless of the flow/temperature conditions. . The operational changes for MO4 do cause a more TDG exceedances at the lower Snake tailwater sites as shown in Table 7-11.

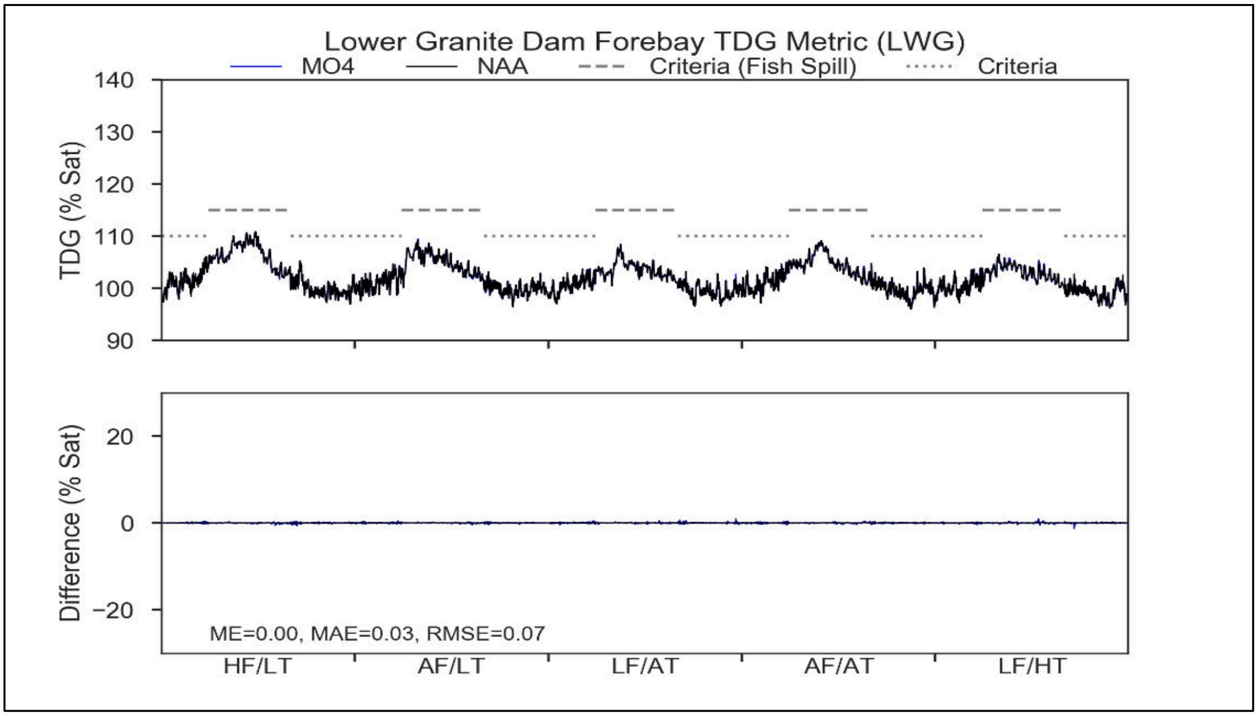


Figure 7-36. Modeled Forebay Total Dissolved Gas for Multiple Objective Alternative 4 and No Action Alternative at Lower Granite Dam Under a 5-year Range of River and Meteorological Conditions

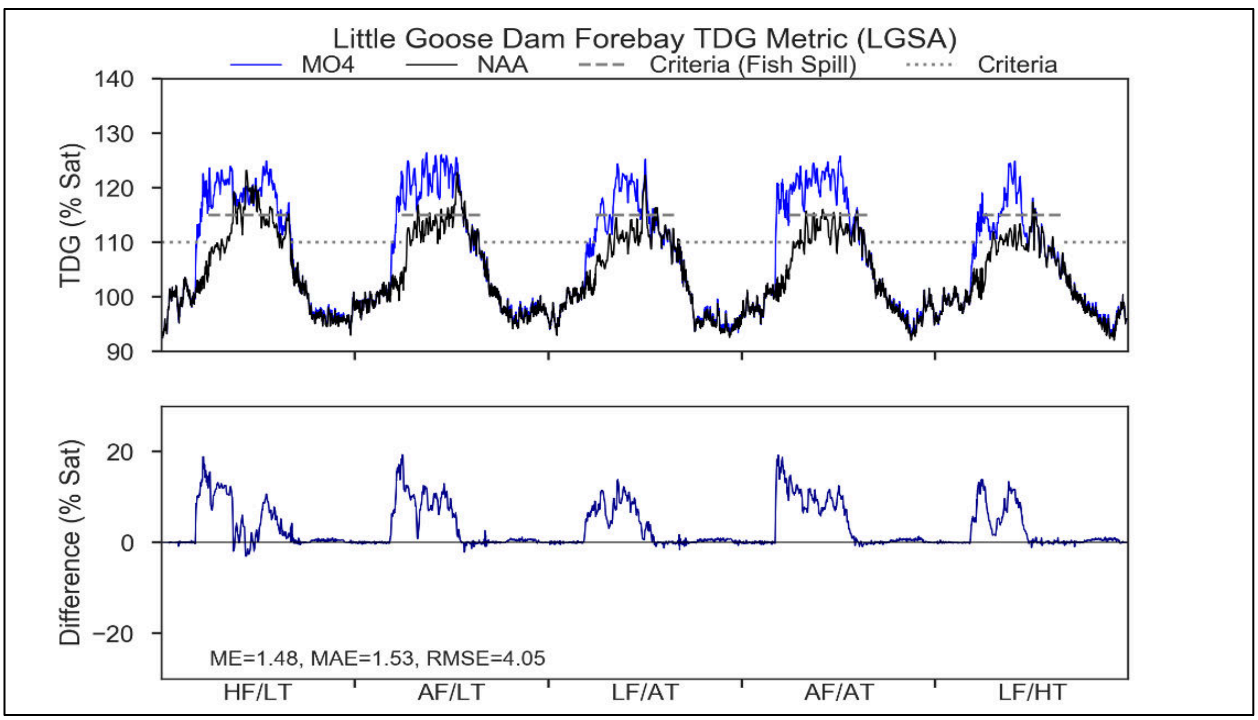


Figure 7-37. Modeled Forebay Total Dissolved Gas for Multiple Objective Alternative 4 and No Action Alternative at Little Goose Dam Under a 5-year Range of River and Meteorological Conditions

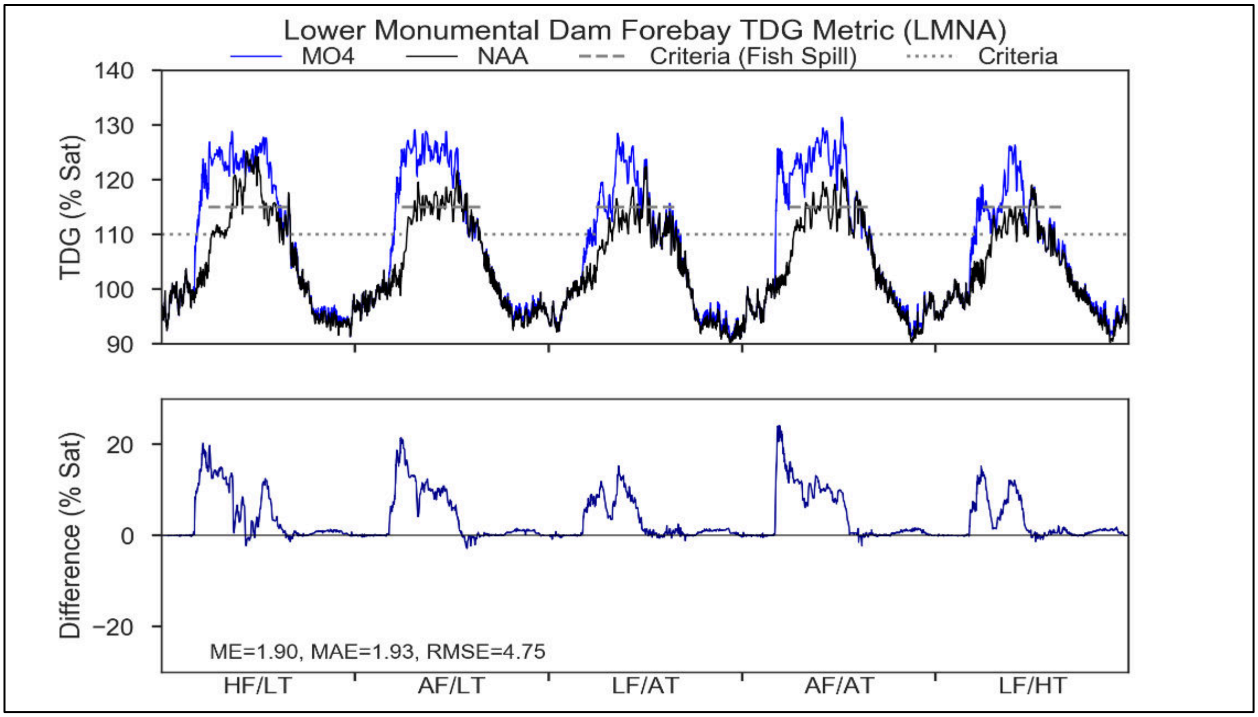


Figure 7-38. Modeled Forebay Total Dissolved Gas for Multiple Objective Alternative 4 and No Action Alternative at Lower Monumental and Ice Harbor Dams Under a 5-year Range of River and Meteorological Conditions

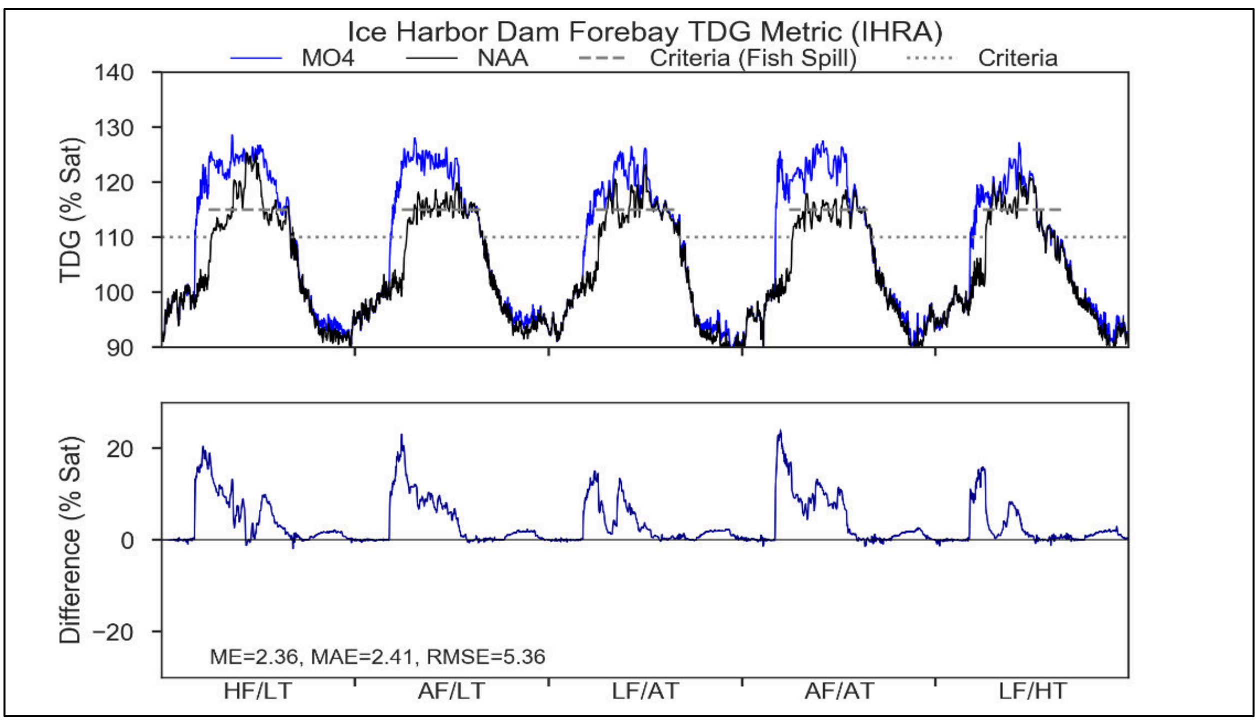


Figure 7-39. Modeled Forebay Total Dissolved Gas for Multiple Objective Alternative 4 and No Action Alternative at Lower Monumental and Ice Harbor Dams Under a 5-year Range of River and Meteorological Conditions

Table 7-9. Differences of the Frequency of the Total Dissolved Gas that Would Occur Within Selected Ranges During Juvenile Spill Season (April-August) if Multiple Objective Alternative 4 is Implemented when Compared to the No Action Alternative at the Four Lower Snake River Dam Forebay Locations Under a 5-Year Range of River and Meteorological Conditions

SITE	TDG Range (% Sat)	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Lower Granite	<=110	0.65%	0.00%	0.00%	0.00%	0.00%
Lower Granite	>110,<=115	-0.65%	0.00%	0.00%	0.00%	0.00%
Lower Granite	>115,<=120	0.00%	0.00%	0.00%	0.00%	0.00%
Lower Granite	>120,<=125	0.00%	0.00%	0.00%	0.00%	0.00%
Lower Granite	>125	0.00%	0.00%	0.00%	0.00%	0.00%
Little Goose	<=110	-22.88%	-7.84%	-25.49%	-20.92%	-29.41%
Little Goose	>110,<=115	-31.37%	-44.44%	-18.95%	-46.41%	-1.31%
Little Goose	>115,<=120	14.38%	4.58%	22.22%	15.69%	18.30%
Little Goose	>120,<=125	39.87%	39.22%	21.57%	50.33%	12.42%
Little Goose	>125	0.00%	8.50%	0.65%	1.31%	0.00%
Lower Monumental	<=110	-9.15%	-2.61%	-16.99%	-7.19%	-18.30%
Lower Monumental	>110,<=115	-32.68%	-25.49%	-20.92%	-36.60%	-13.07%
Lower Monumental	>115,<=120	-14.38%	-37.25%	11.76%	-18.95%	15.03%
Lower Monumental	>120,<=125	33.99%	28.10%	16.99%	34.64%	10.46%
Lower Monumental	>125	22.22%	37.25%	9.15%	28.10%	5.88%
Ice Harbor	<=110	-3.27%	-3.92%	-3.27%	-3.92%	-5.23%
Ice Harbor	>110,<=115	-46.41%	-26.80%	-28.76%	-43.79%	-11.76%
Ice Harbor	>115,<=120	-8.50%	-37.25%	-1.96%	-20.26%	-3.92%
Ice Harbor	>120,<=125	43.14%	52.29%	26.80%	48.37%	18.95%
Ice Harbor	>125	15.03%	15.69%	7.19%	19.61%	1.96%

Table 7-10. Change in the Number of days Total Dissolved Gas Would be Greater or Less Than the 2016 Forebay Criteria Under Multiple Objective Alternative 4 Relative to No Action Alternative

–	–	HF/LT		AF/LT		LF/AT		AF/AT		LF/HT	
SITE	**Month**	**Curr**	**Prop**	**Curr**	**Prop**	**Curr**	**Prop**	**Curr**	**Prop**	**Curr**	**Prop**
Lower Granite	March	0	0	0	0	0	0	0	0	0	0
Lower Granite	April	0	–	0	–	0	–	0	–	0	–
Lower Granite	May	0	–	0	–	0	–	0	–	0	–
Lower Granite	June	0	–	0	–	0	–	0	–	0	–
Lower Granite	July	0	–	0	–	0	–	0	–	0	–
Lower Granite	August	0	–	0	–	0	–	0	–	0	–
Little Goose	March	24	16	18	13	6	0	27	22	14	6
Little Goose	April	28	–	29	–	8	–	30	–	1	–
Little Goose	May	30	–	31	–	27	–	31	–	28	–
Little Goose	June	25	–	27	–	22	–	30	–	13	–
Little Goose	July	11	–	18	–	9	–	20	–	3	–
Little Goose	August	11	–	0	–	-1	–	2	–	0	–
Lower Monumental	March	24	18	18	14	12	0	27	26	17	10
Lower Monumental	April	30	–	25	–	14	–	30	–	3	–
Lower Monumental	May	16	–	13	–	27	–	20	–	25	–
Lower Monumental	June	2	–	11	–	14	–	12	–	14	–
Lower Monumental	July	15	–	4	–	1	–	5	–	-1	–
Lower Monumental	August	8	–	0	–	1	–	2	–	0	–
Ice Harbor	March	27	23	24	19	21	7	28	27	24	14
Ice Harbor	April	30	–	25	–	18	–	30	–	16	–
Ice Harbor	May	15	–	16	–	23	–	21	–	10	–
Ice Harbor	June	1	–	8	–	7	–	12	–	4	–
Ice Harbor	July	18	–	8	–	1	–	13	–	0	–
Ice Harbor	August	13	–	-1	–	1	–	1	–	0	–

Note: Curr = Change in the number of days TDG would be greater than 110 percent during March and greater than 115 percent from April through August if MO4 was implemented when compared to No Action Alternative operations Prop = Change in the number of days TDG would be greater than 115 percent during March if MO4 was implemented when compared to the No Action Alternative.

Table 7-11. Difference in Number of Days the TDG Criteria is Exceeded at the Forebay Sites of Little Goose, Lower Monumental, and Ice Harbor for the Multiple Objective 4 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Little Goose	March	**23**	**16**	**4**	**26**	0
Little Goose	April	**30**	**28**	**10**	**30**	**2**
Little Goose	May	**19**	**28**	**29**	**27**	**31**
Little Goose	June	**4**	**22**	**25**	**24**	**20**
Little Goose	July	**16**	**2**	**4**	**21**	**10**
Little Goose	August	**14**	0	0	**1**	0
Little Goose	September	**1**	0	0	0	0
Lower Monumental	March	**23**	**17**	**6**	**27**	0
Lower Monumental	April	**30**	**24**	**16**	**30**	**1**
Lower Monumental	May	**14**	**10**	**25**	**19**	**26**
Lower Monumental	June	**1**	**8**	**14**	**12**	**16**
Lower Monumental	July	**12**	**1**	**1**	**6**	**1**
Lower Monumental	August	**7**	0	**2**	0	0
Lower Monumental	September	0	0	0	0	0
Ice Harbor	March	**26**	**23**	**20**	**27**	0
Ice Harbor	April	**30**	**24**	**19**	**30**	**4**
Ice Harbor	May	**14**	**12**	**22**	**21**	**7**
Ice Harbor	June	0	**4**	**5**	**10**	**4**
Ice Harbor	July	**17**	**7**	**2**	**12**	**3**
Ice Harbor	August	**15**	0	**1**	0	0
Ice Harbor	September	0	0	0	0	0

7.2.3 Other Physical, Chemical, and Biological Processes

7.2.3.1 Dworshak Dam and Reservoir

The remaining water quality parameters considered for the No Action Alternative would not change if MO4 was implemented.

7.2.3.2 Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams and Reservoirs

The remaining water quality parameters considered for the No Action Alternative would not change if MO4 was implemented.

7.3 LOWER COLUMBIA RIVER

7.3.1 Water Temperature

There are no specific structural or operational measures in MO4 that are expected to influence water temperatures in the lower Columbia River. Details are provided below.

7.3.1.1 McNary, John Day, The Dalles, and Bonneville Dams and Reservoirs

The tailwater temperatures for MO4 at McNary, John Day, The Dalles, and Bonneville Dams were modeled under a 5-year range of river and meteorological conditions, and compared to the modeled results for the No Action Alternative (Figure 7-40 to Figure 7-43). Just as with the No Action Alternative model results, MO4 model results show that tailwater temperatures can exceed 68°F at all four dams during any of the years and conditions presented, and maximum water temperatures and the frequency of water temperature violations of state water quality criteria would be higher during a year when river flows are lower than normal and summer ambient air temperatures are higher (as in LF/HT). The average frequency of water temperature violations of the state water quality criteria would be nearly identical for the No Action Alternative and MO4 for all four lower Columbia River dams (Figure 7-44 and Table 7-12), even with the *McNary Flow Target* measure in place.

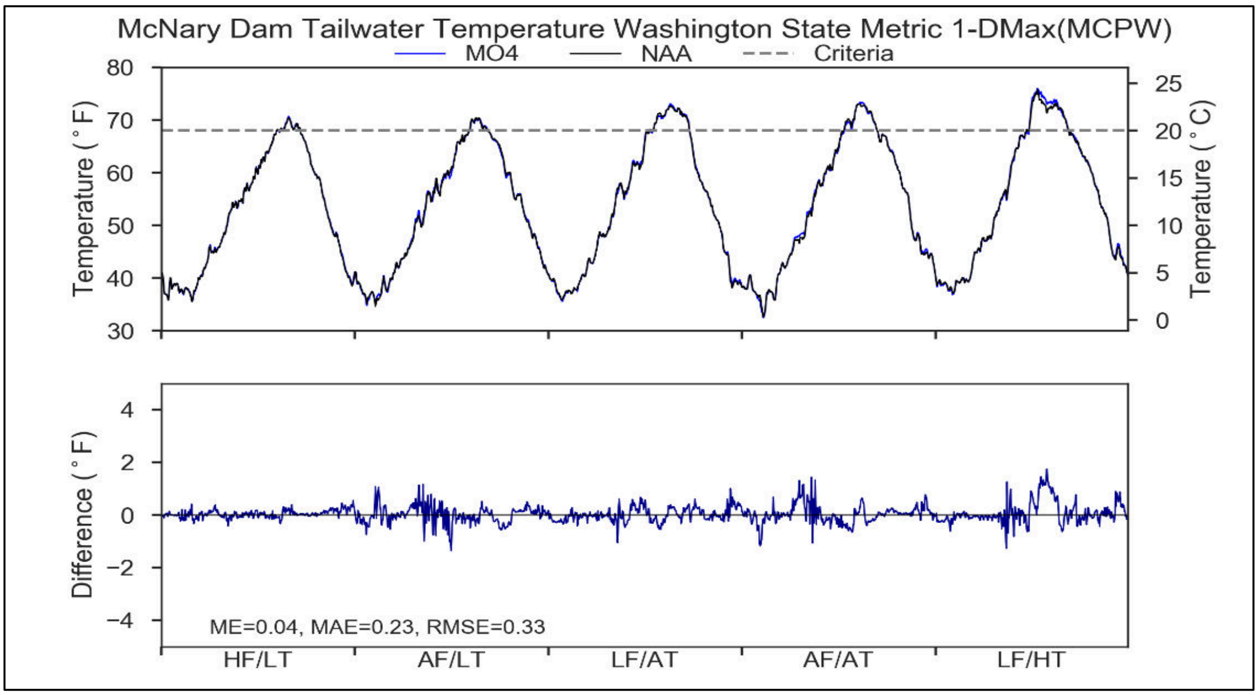


Figure 7-40. Modeled Tailwater Temperature for Multiple Objective Alternative 4 at McNary Dam Under a 5-year Range of River and Meteorological Conditions

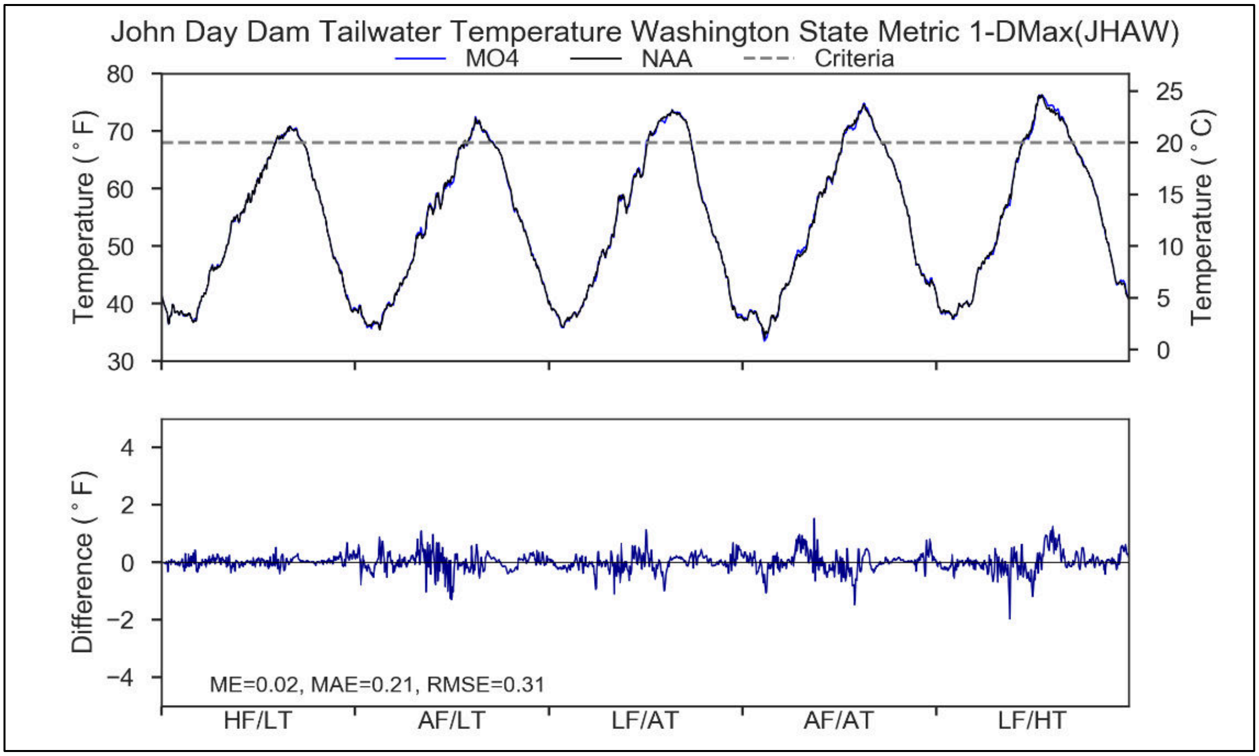


Figure 7-41. Modeled Tailwater Temperature for Multiple Objective Alternative 4 at John Day Dam Under a 5-year Range of River and Meteorological Conditions

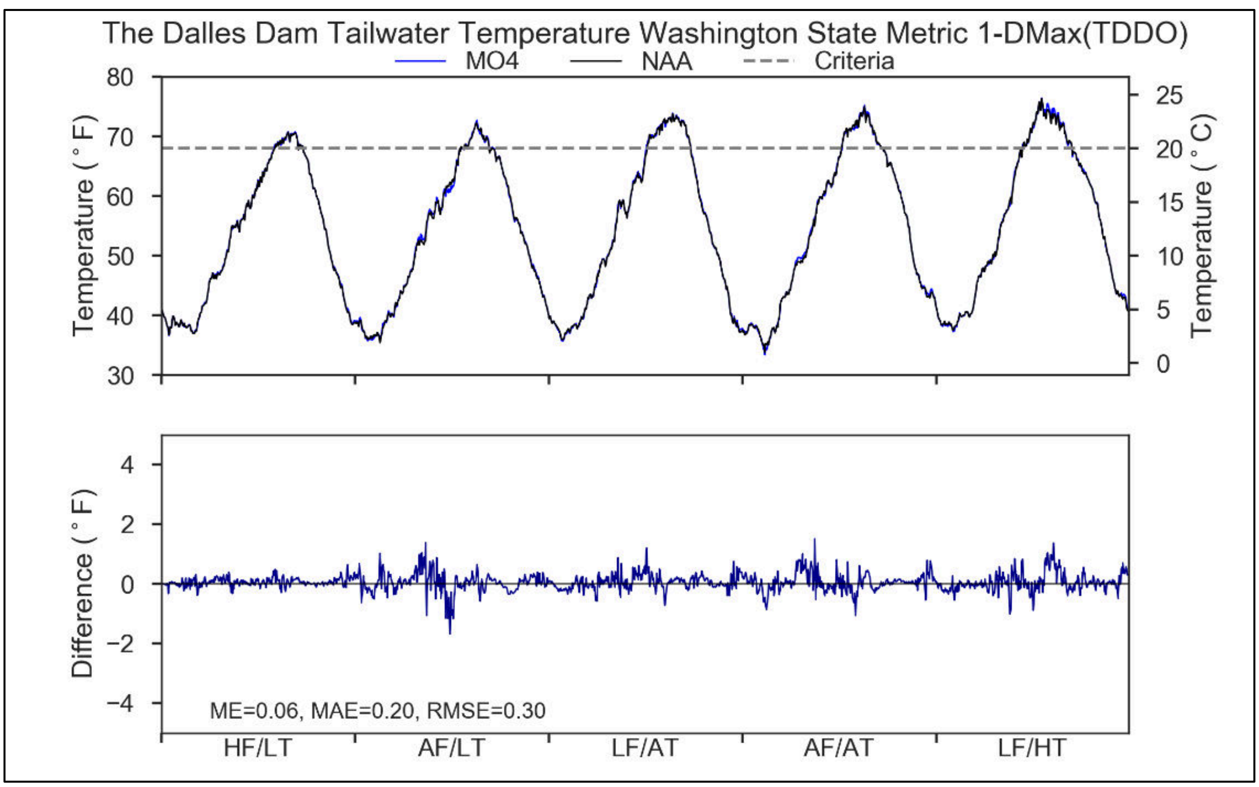


Figure 7-42. Modeled Tailwater Temperature for Multiple Objective Alternative 4 at The Dalles Dam Under a 5-year Range of River and Meteorological Conditions

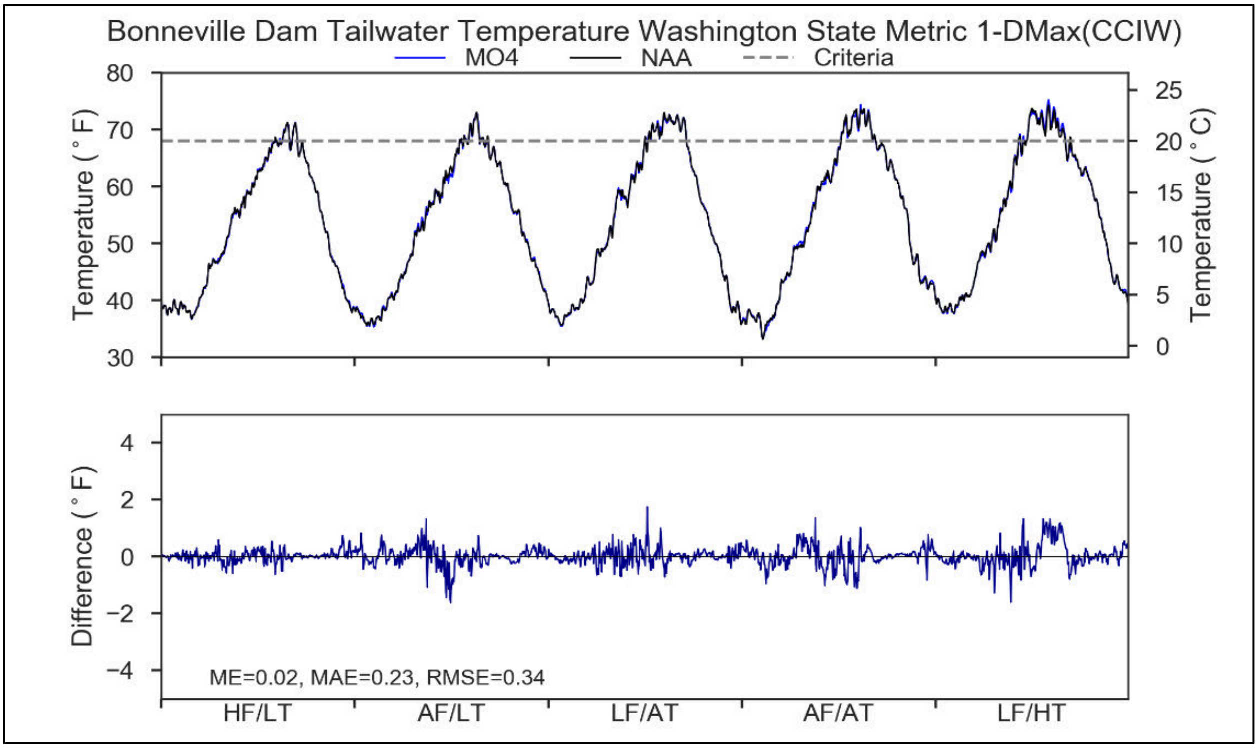


Figure 7-43. Modeled Tailwater Temperature for Multiple Objective Alternative 4 at Bonneville Dam Under a 5-year Range of River and Meteorological Conditions

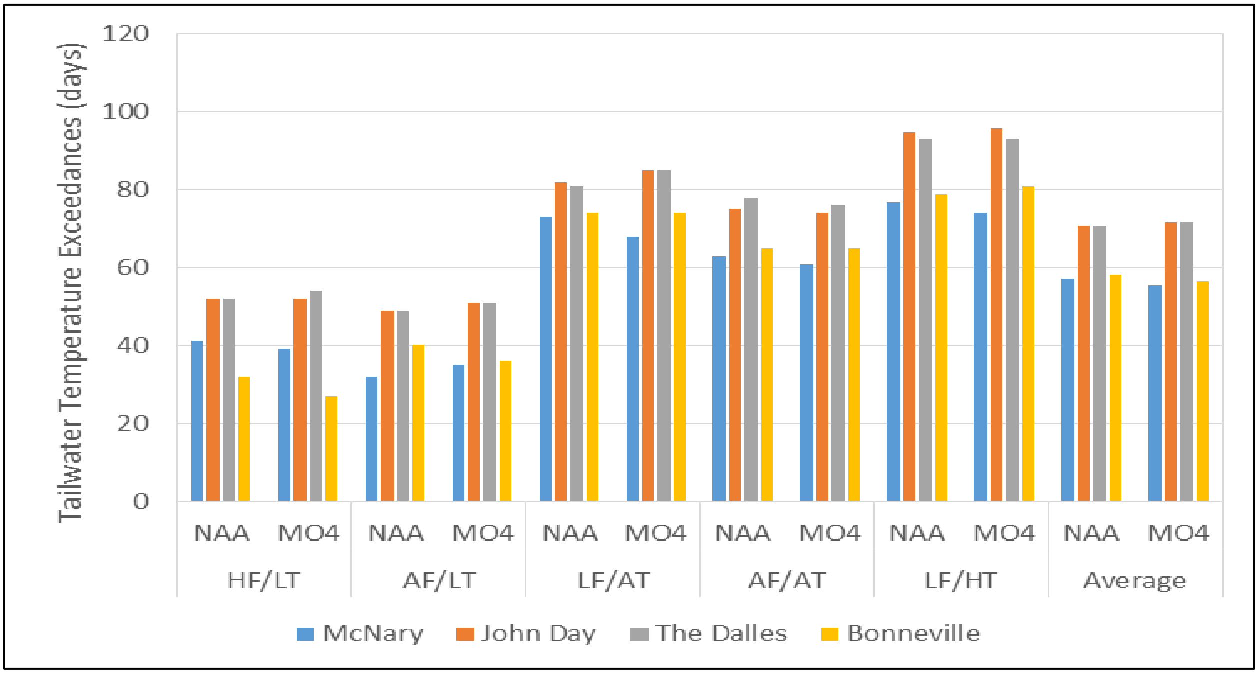


Figure 7-44. Frequency of Modeled Tailwater Temperature Violations of State Water Quality Criteria for Multiple Objective Alternative 4 and No Action Alternative at McNary, John Day, The Dalles, and Bonneville Dams Under a 5-year Range of River and Meteorological Conditions

Table 7-12. Difference in Number of Days the Temperature Criteria is Exceeded at the Tailwater Sites of McNary, John Day, The Dalles, and Bonneville for the Multiple Objective 2 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary	June	0	0	0	0	-2
McNary	July	0	0	-4	-1	0
McNary	August	-1	0	0	0	0
McNary	September	0	**3**	0	**1**	0
John Day	June	0	0	0	0	**2**
John Day	July	0	0	**2**	0	0
John Day	August	**1**	0	0	0	0
John Day	September	0	**1**	**1**	-1	0
The Dalles	June	0	0	0	0	**1**
The Dalles	July	0	**1**	**3**	-1	0
The Dalles	August	**2**	0	0	0	0
The Dalles	September	0	**3**	**1**	0	-1
Bonneville	June	0	0	0	0	**2**
Bonneville	July	0	**1**	**1**	**1**	0
Bonneville	August	-3	-3	0	0	0
Bonneville	September	-1	-1	0	-1	0

7.3.2 Total Dissolved Gas

The *Spill to 125%* TDG measure sets juvenile fish passage spill to not exceed 125 percent TDG saturation, as measured at the tailrace, at all lower Columbia River projects from March 1 to August 31. Due to the earlier start of fish passage spill and the higher tailwater TDG target, MO4 model results show notable increases in forebay and tailwater TDG saturations and the frequency of violations of 2016 state TDG criteria as compared to the No Action Alternative. Additionally, at McNary and John Day Dams, structural measure *Spillway Weir Notch Inserts* includes the addition of spillway weir notch gate inserts while the *Spill for Adult Steelhead* measure uses spill through existing surface passage structures from October 1 to November 30 to address adult steelhead passage. These measures would result in higher TDG in the McNary and John Day Dam tailwaters. Details are described below.

7.3.2.1 McNary, John Day, The Dalles, and Bonneville Dams and Reservoirs

Forebay TDG saturations for MO4 at McNary, John Day, The Dalles, and Bonneville Dams were modeled under a 5-year range of river and meteorological conditions, and compared to the modeled results for the No Action Alternative (Figure 7-45 to Figure 7-48). The MO4 model results show that forebay TDG saturations can exceed the 115 percent spill season TDG criterion at all four dams during all of the years and conditions presented. Maximum forebay TDG saturation would be higher during a year when river flows were higher than normal (as in

2011). Forebay TDG saturations would be higher in MO4 as compared to No Action Alternative for all four dams during spill season, and high TDG saturations would start earlier (beginning in March) due to the earlier fish spill start in MO4 as compared to the No Action Alternative. Generally, the frequency of 110% TDG exceedances outside of current fish passage spill seasons would be greater under MO4 than the No Action Alternative, though not at all or only slightly greater for a small number dam/condition combinations (e.g., McNary and John Day under LF/AT conditions; Table 7-13). At all four dam forebays, the frequency of 115% TDG exceedances during current fish passage spill season would be greater under MO4 than the No Action Alternative under all modeled river and meteorological conditions (Table 7-14). Overall, MO4 will significantly increase the exceedances as compared to the No Action Alternative (Table 7-15).

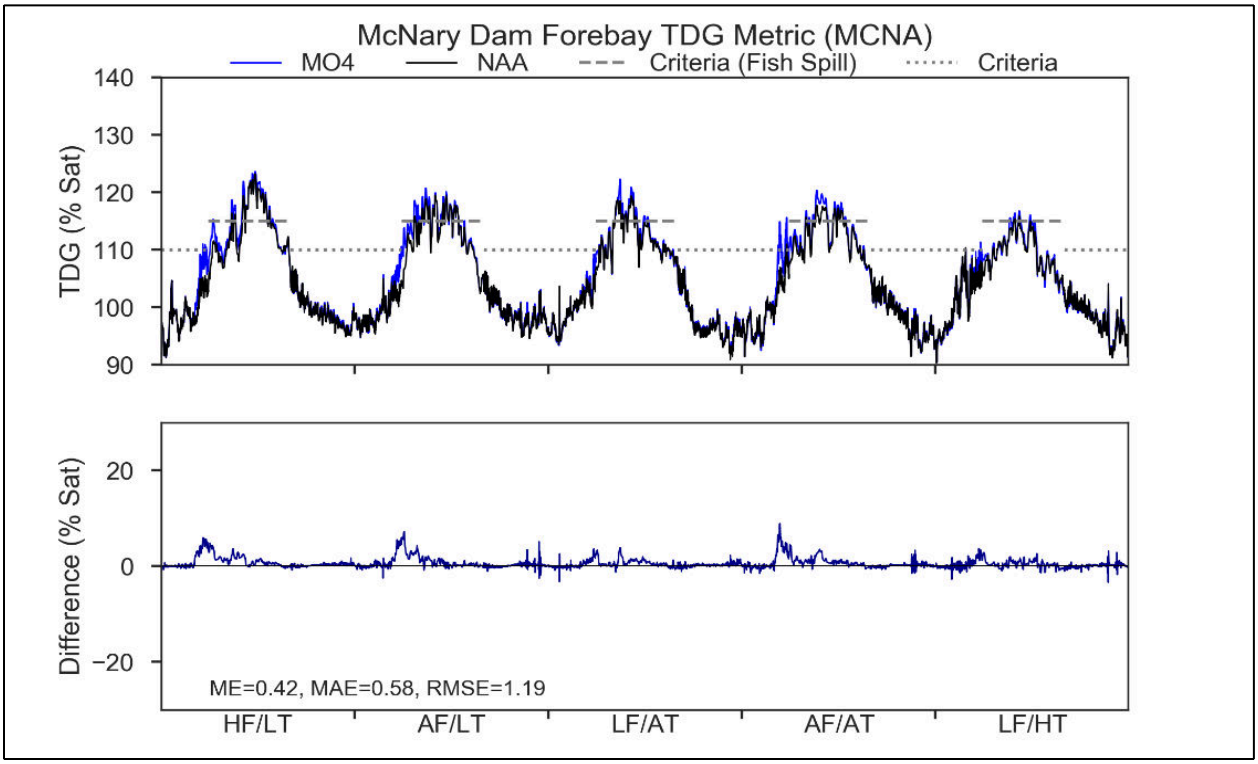


Figure 7-45. Modeled Forebay Total Dissolved Gas for the Multiple Objective Alternative 4 at McNary Dam Under a 5-year Range of River and Meteorological Conditions

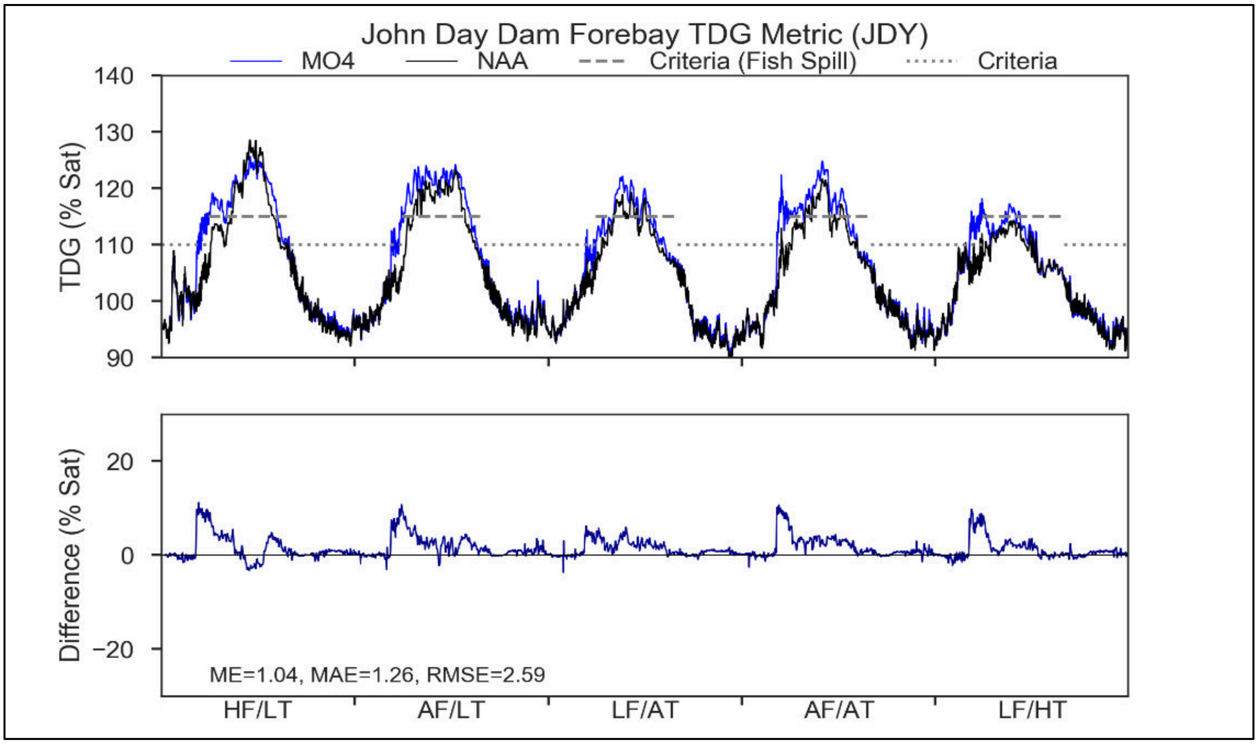


Figure 7-46. Modeled Forebay Total Dissolved Gas for Multiple Objective Alternative 4at John Day Dam Under a 5-year Range of River and Meteorological Conditions

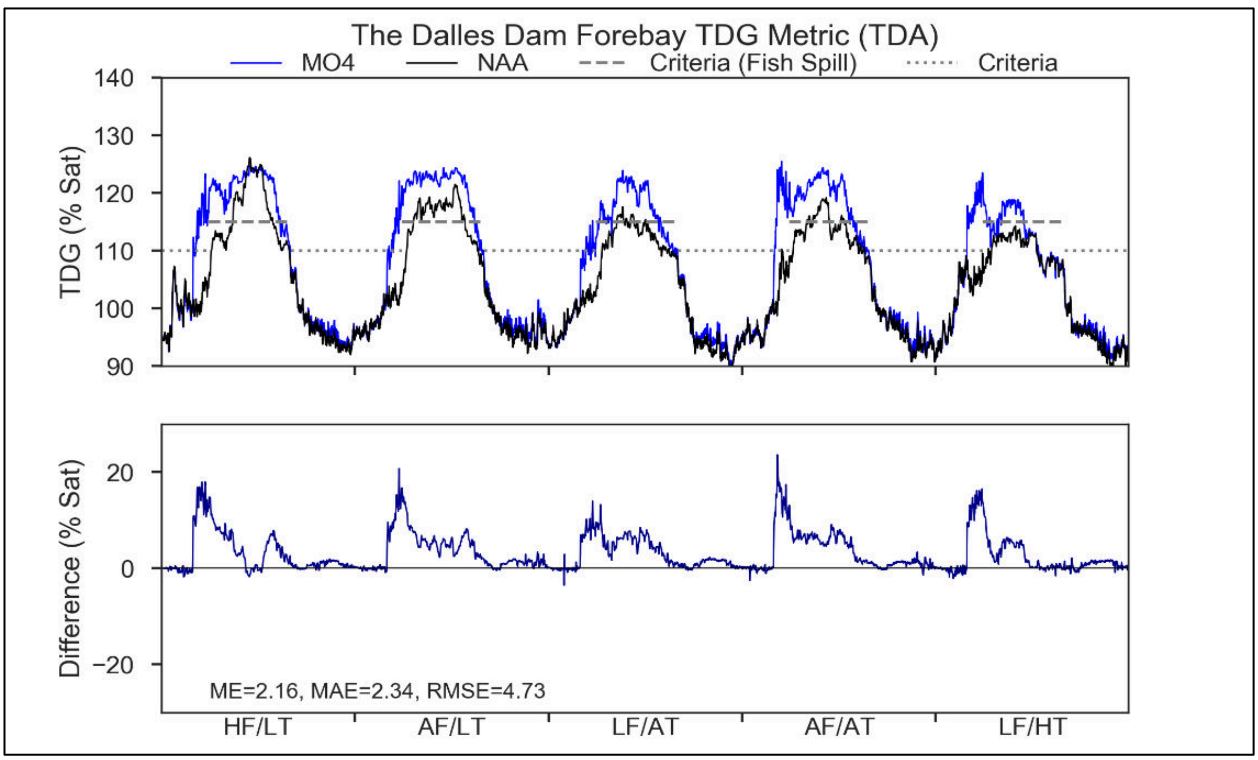


Figure 7-47. Modeled Forebay Total Dissolved Gas for Multiple Objective Alternative 4 at The Dalles Dam Under a 5-year Range of River and Meteorological Conditions

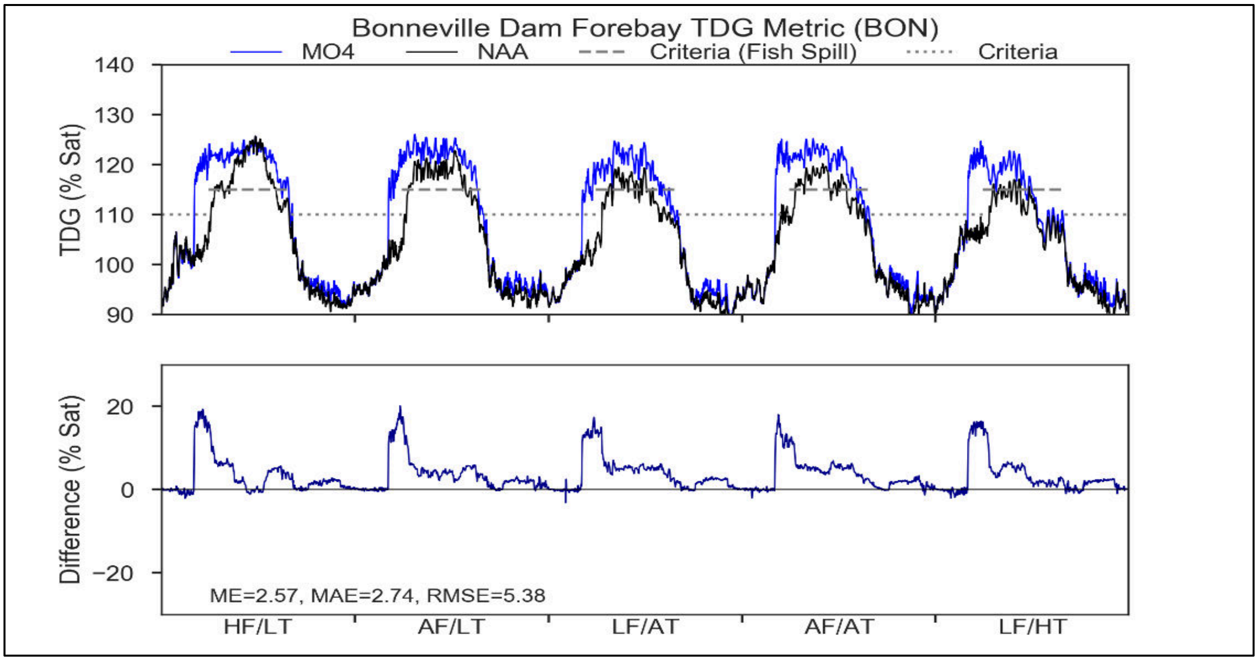


Figure 7-48. Modeled Forebay Total Dissolved Gas for Multiple Objective Alternative 4 at Bonneville Dam Under a 5-year Range of River and Meteorological Conditions

Table 7-13. Differences of the Frequency of the Total Dissolved Gas that Would Occur Within Selected Ranges Outside of Juvenile Spill Season if Multiple Objective Alternative 4 is Implemented when Compared to the No Action Alternative at the Four Lower Columbia River Dam Forebay Locations Under a 5-Year Range of River and Meteorological Conditions

SITE	TDG Range (% Sat)	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary	<=110	-0.22%	-0.10%	-0.02%	-4.09%	-0.14%
McNary	>110,<=115	0.22%	0.10%	0.02%	4.09%	0.14%
McNary	>115,<=120	0.00%	0.00%	0.00%	0.00%	0.00%
McNary	>120,<=125	0.00%	0.00%	0.00%	0.00%	0.00%
McNary	>125	0.00%	0.00%	0.00%	0.00%	0.00%
John Day	<=110	-9.83%	-9.72%	-4.66%	-10.04%	-11.63%
John Day	>110,<=115	9.48%	9.43%	4.66%	2.48%	9.38%
John Day	>115,<=120	0.35%	0.29%	0.00%	7.10%	2.25%
John Day	>120,<=125	0.00%	0.00%	0.00%	0.47%	0.00%
John Day	>125	0.00%	0.00%	0.00%	0.00%	0.00%
The Dalles	<=110	-13.35%	-11.60%	-10.67%	-13.42%	-14.45%
The Dalles	>110,<=115	5.58%	7.18%	10.50%	1.99%	2.45%
The Dalles	>115,<=120	7.19%	4.19%	0.18%	7.11%	10.66%
The Dalles	>120,<=125	0.57%	0.23%	0.00%	4.32%	1.34%
The Dalles	>125	0.00%	0.00%	0.00%	0.00%	0.00%
Bonneville	<=110	-13.86%	-12.91%	-13.13%	-9.26%	-13.75%
Bonneville	>110,<=115	0.92%	2.15%	5.72%	-3.52%	0.24%
Bonneville	>115,<=120	8.16%	8.04%	7.23%	3.36%	3.58%
Bonneville	>120,<=125	4.78%	2.72%	0.18%	9.41%	9.94%
Bonneville	>125	0.00%	0.00%	0.00%	0.00%	0.00%

Table 7-14. Differences of the Frequency of the Total Dissolved Gas that Would Occur Within Selected Ranges During Juvenile Spill Season (April-August) if Multiple Objective Alternative 4 is Implemented when Compared to the No Action Alternative at the Four Lower Columbia River Dam Forebay Locations Under a 5-Year Range of River and Meteorological Conditions

SITE	TDG Range (% Sat)	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary	<=110	-11.76%	-8.50%	-7.84%	-12.42%	-3.27%
McNary	>110,<=115	3.92%	0.65%	-2.61%	1.31%	-0.65%
McNary	>115,<=120	0.65%	5.88%	7.19%	9.80%	3.92%
McNary	>120,<=125	7.19%	1.96%	3.27%	1.31%	0.00%
McNary	>125	0.00%	0.00%	0.00%	0.00%	0.00%
John Day	<=110	-10.46%	-6.54%	-18.30%	-5.23%	-15.69%
John Day	>110,<=115	-20.92%	-13.07%	2.61%	-32.68%	-3.92%
John Day	>115,<=120	16.99%	-21.57%	-1.96%	20.92%	19.61%
John Day	>120,<=125	30.07%	41.18%	17.65%	15.69%	0.00%
John Day	>125	-15.69%	0.00%	0.00%	1.31%	0.00%
The Dalles	<=110	-3.27%	-11.76%	-19.61%	-13.73%	-22.88%
The Dalles	>110,<=115	-36.60%	-15.03%	-39.87%	-38.56%	-20.26%
The Dalles	>115,<=120	-4.58%	-47.71%	22.88%	-3.92%	43.14%
The Dalles	>120,<=125	41.83%	74.51%	36.60%	56.21%	0.00%
The Dalles	>125	2.61%	0.00%	0.00%	0.00%	0.00%
Bonneville	<=110	-3.92%	-9.15%	-20.92%	-11.11%	-18.95%
Bonneville	>110,<=115	-25.49%	-11.11%	-20.92%	-18.30%	-19.61%
Bonneville	>115,<=120	-15.03%	-35.95%	-9.15%	-35.29%	16.99%
Bonneville	>120,<=125	43.14%	46.41%	50.98%	62.75%	21.57%
Bonneville	>125	1.31%	9.80%	0.00%	1.96%	0.00%

Table 7-15. Difference in Number of Days the Total Dissolved Gas Criteria is Exceeded at the Forebay Sites of McNary, John Day, The Dalles and Bonneville Dams for the Multiple Objective 4 Alternative Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary	March	0	0	0	**9**	0
McNary	April	**3**	**5**	0	0	0
McNary	May	**4**	**2**	**5**	**11**	**3**
McNary	June	**2**	**3**	**5**	**2**	**3**
McNary	July	**3**	**2**	**6**	**4**	0
John Day	March	**21**	**21**	**10**	**21**	**25**
John Day	April	**28**	**17**	**4**	**28**	**6**
John Day	May	**12**	**1**	**3**	**4**	**16**
John Day	June	0	0	**8**	**13**	**8**
John Day	July	0	**4**	**9**	**13**	0
John Day	August	**8**	**8**	0	0	0
The Dalles	March	**28**	**25**	**22**	**28**	**31**
The Dalles	April	**30**	**20**	**25**	**30**	**17**
The Dalles	May	**15**	**1**	**14**	**9**	**31**
The Dalles	June	0	0	**23**	**16**	**18**
The Dalles	July	**1**	**5**	**28**	**22**	0
The Dalles	August	**15**	**15**	**1**	**3**	0
The Dalles	September	0	0	**1**	0	0
Bonneville	March	**28**	**28**	**27**	**20**	**29**
Bonneville	April	**18**	**11**	**25**	**13**	**25**
Bonneville	May	**6**	0	**3**	0	**16**
Bonneville	June	0	0	**7**	**9**	**17**
Bonneville	July	0	**4**	**22**	**15**	**1**
Bonneville	August	**21**	**16**	**7**	**8**	0
Bonneville	September	**1**	0	**1**	0	0

Tailwater TDG saturations for MO4 at McNary, John Day, The Dalles, and Bonneville Dams can be found in Figure 7-49 to Figure 7-52. The MO4 model results show that tailwater TDG saturations can exceed the 120 percent TDG criterion at all four dams during all of the years and conditions presented. Maximum tailwater TDG saturation would be higher during a year when river flows were higher than normal and summer ambient air temperatures were lower (as in 2011). Tailwater TDG saturations would be higher in MO4 as compared to No Action Alternative for all four dams during spill season, and high TDG saturations would start earlier (beginning of March) due to the earlier fish spill start in MO4 as compared to the No Action Alternative. Generally, the frequency of 110% TDG exceedances outside of current fish passage spill seasons would be greater under MO4 than the No Action Alternative, except at Bonneville, where TDG is expected to exceed 110% at nearly all times for both alternatives (Table 7-16). During the current fish passage spill season, the frequency of 120% TDG exceedances at all four dams would be substantially greater under MO4 than the No Action Alternative under all modeled river and meteorological conditions (Table 7-17). Additionally, at McNary and John Day, structural measure *Spillway Weir Notch Inserts* includes the addition of spillway weir notch gate inserts while the *Spill for Adult Steelhead* measure uses spill through existing surface passage structures from October 1 to November 30 to address adult steelhead passage. These measures would result in significantly higher October and November TDG in the McNary tailwater (Figure 7-49), though the effect in the John Day Dam tailwater would be far less pronounced (Figure 7-50). Overall, MO4 will significantly increase the exceedances as compared to the No Action Alternative (Table 7-18).

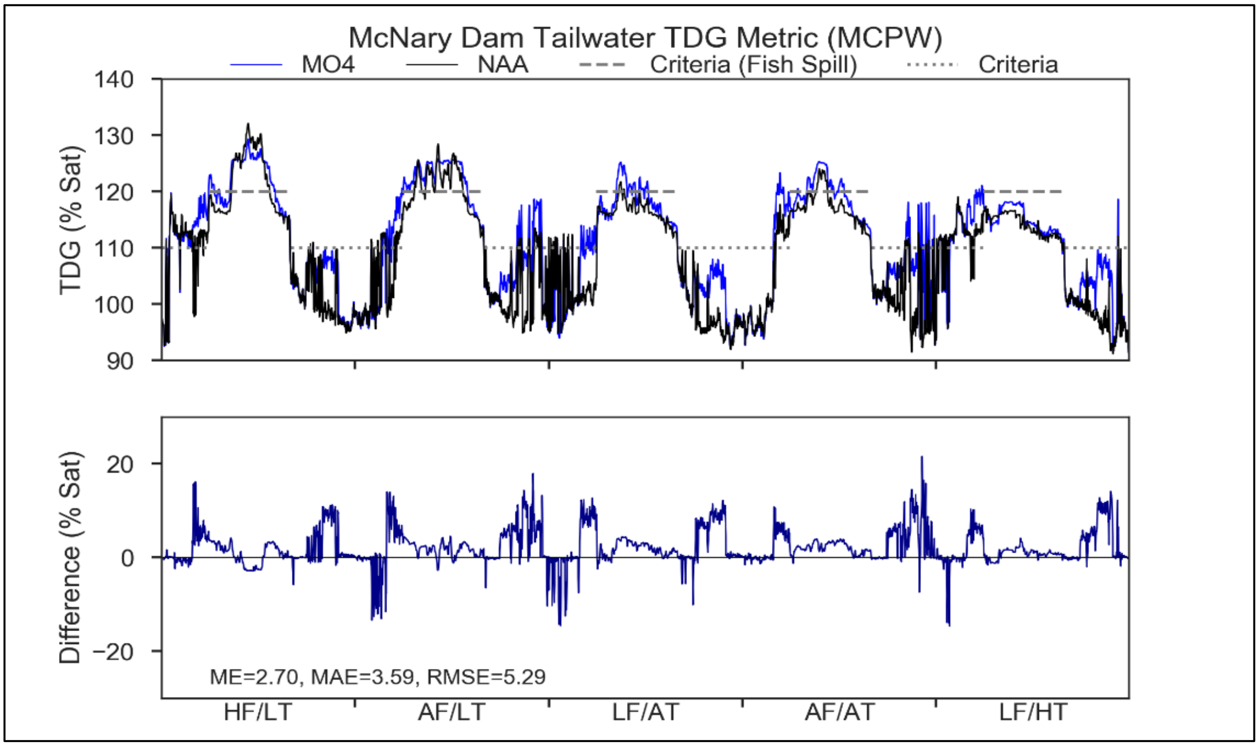


Figure 7-49. Modeled Tailwater Total Dissolved Gas for Multiple Objective Alternative 4 at McNary Dam Under a 5-year Range of River and Meteorological Conditions

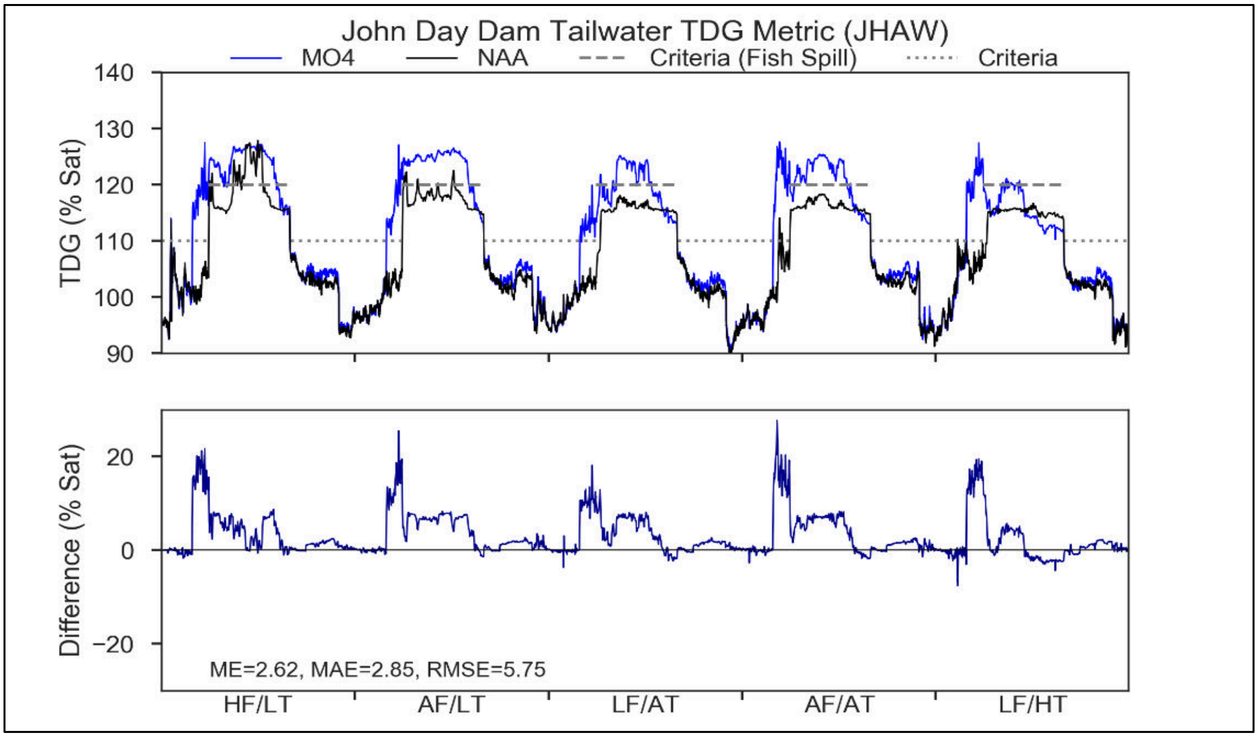


Figure 7-50. Modeled Tailwater Total Dissolved Gas for Multiple Objective Alternative 4 at John Day Dam Under a 5-year Range of River and Meteorological Conditions

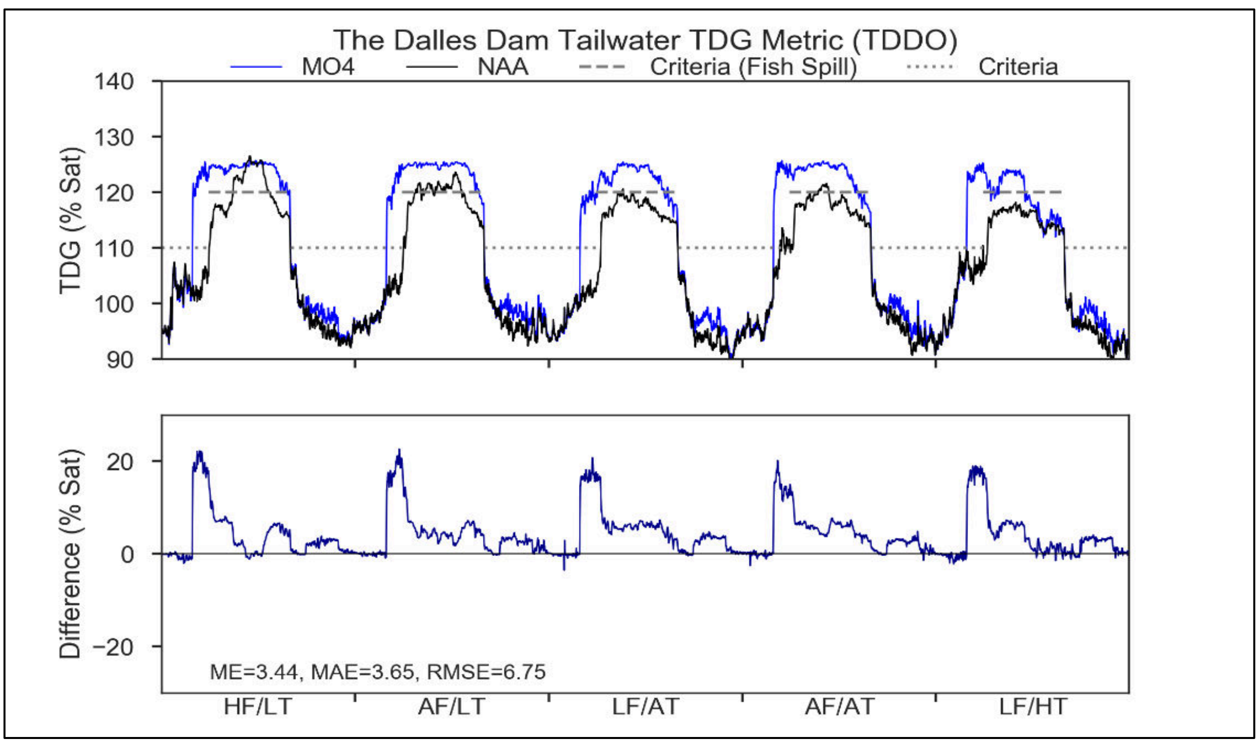


Figure 7-51. Modeled Tailwater Total Dissolved Gas for Multiple Objective Alternative 4 at The Dalles Dam Under a 5-year Range of River and Meteorological Conditions

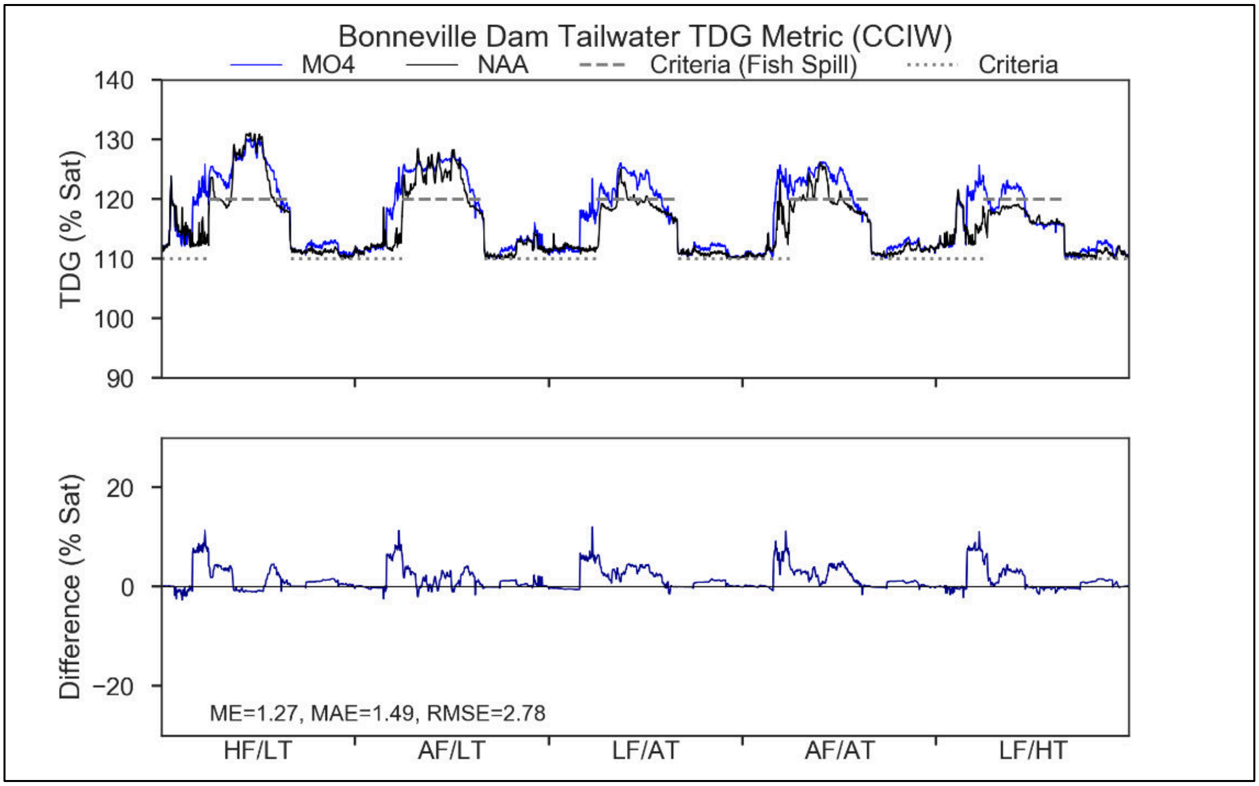


Figure 7-52. Modeled Tailwater Total Dissolved Gas for Multiple Objective Alternative 4 at Bonneville Dam Under a 5-year Range of River and Meteorological Conditions

Table 7-16. Differences of the Frequency of the Total Dissolved Gas that Would Occur Within Selected Ranges Outside of Juvenile Spill Season if Multiple Objective Alternative 4 is Implemented when Compared to the No Action Alternative at the Four Lower Columbia River Dam Forebay Locations Under a 5-Year Range of River and Meteorological Conditions

SITE	TDG Range (% Sat)	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary	<=110	-4.31%	-10.15%	-13.29%	-6.88%	-0.24%
McNary	>110,<=115	-8.43%	-6.06%	13.21%	-7.40%	-13.90%
McNary	>115,<=120	12.74%	16.09%	0.08%	10.32%	13.26%
McNary	>120,<=125	0.00%	0.12%	0.00%	3.97%	0.88%
McNary	>125	0.00%	0.00%	0.00%	0.00%	0.00%
John Day	<=110	-14.57%	-13.92%	-14.40%	-13.00%	-14.49%
John Day	>110,<=115	1.43%	5.37%	12.82%	-0.71%	0.00%
John Day	>115,<=120	11.01%	6.89%	1.59%	5.63%	7.10%
John Day	>120,<=125	2.10%	1.66%	0.00%	7.86%	7.40%
John Day	>125	0.02%	0.00%	0.00%	0.22%	0.00%
The Dalles	<=110	-14.49%	-13.94%	-14.37%	-7.02%	-14.65%
The Dalles	>110,<=115	0.12%	0.16%	0.36%	-7.30%	0.12%
The Dalles	>115,<=120	1.27%	4.82%	11.35%	0.71%	0.16%
The Dalles	>120,<=125	12.94%	8.97%	2.66%	13.27%	14.37%
The Dalles	>125	0.16%	0.00%	0.00%	0.34%	0.00%
Bonneville	<=110	-0.10%	0.32%	0.00%	0.00%	-1.06%
Bonneville	>110,<=115	-9.98%	-14.22%	-14.54%	-6.45%	-7.74%
Bonneville	>115,<=120	0.06%	7.76%	13.91%	-4.94%	-4.39%
Bonneville	>120,<=125	9.84%	6.06%	0.63%	10.38%	12.98%
Bonneville	>125	0.18%	0.08%	0.00%	1.01%	0.20%

Table 7-17. Differences of the Frequency of the Total Dissolved Gas that Would Occur Within Selected Ranges During Juvenile Spill Season (April-August) if Multiple Objective Alternative 4 is Implemented when Compared to the No Action Alternative at the Four Lower Columbia River Dam Forebay Locations Under a 5-Year Range of River and Meteorological Conditions

SITE	TDG Range (% Sat)	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary	<=110	0.00%	0.00%	-1.29%	0.00%	-0.65%
McNary	>110,<=115	-2.58%	-2.58%	-12.26%	-12.90%	-18.06%
McNary	>115,<=120	-15.48%	-21.29%	-14.19%	-18.71%	17.42%
McNary	>120,<=125	11.61%	-8.39%	23.23%	19.35%	1.29%
McNary	>125	6.45%	32.26%	4.52%	12.26%	0.00%
John Day	<=110	-0.65%	-0.65%	-5.81%	-1.29%	-5.81%
John Day	>110,<=115	-0.65%	0.65%	6.45%	0.65%	-1.29%
John Day	>115,<=120	-47.10%	-75.48%	-50.32%	-67.10%	-14.84%
John Day	>120,<=125	6.45%	15.48%	38.06%	46.45%	21.94%
John Day	>125	41.94%	60.00%	11.61%	21.29%	0.00%
The Dalles	<=110	-1.29%	-2.58%	-5.81%	-2.58%	-5.16%
The Dalles	>110,<=115	-3.87%	-10.32%	-10.97%	-13.55%	-25.16%
The Dalles	>115,<=120	-48.39%	-32.90%	-66.45%	-56.13%	-16.13%
The Dalles	>120,<=125	32.90%	-3.87%	69.03%	47.10%	46.45%
The Dalles	>125	20.65%	49.68%	14.19%	25.16%	0.00%
Bonneville	<=110	0.00%	0.00%	0.00%	0.00%	0.00%
Bonneville	>110,<=115	0.00%	0.00%	-4.52%	0.00%	-0.65%
Bonneville	>115,<=120	-24.52%	-10.32%	-48.39%	-41.94%	-36.13%
Bonneville	>120,<=125	14.19%	-19.35%	44.52%	29.68%	36.77%
Bonneville	>125	10.32%	29.68%	8.39%	12.26%	0.00%

Table 7-18. Difference in Number of Days the Total Dissolved Gas Criteria is Exceeded at the Tailwater Sites of McNary, John Day, The Dalles and Bonneville Dams for the Multiple Objective 4 Alternative Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary	January	0	0	-2	0	-6
McNary	February	0	-5	0	0	0
McNary	March	**9**	**16**	**31**	**3**	**5**
McNary	April	**15**	**20**	0	**3**	**1**
McNary	May	**2**	**8**	**14**	**18**	0
McNary	June	0	0	**21**	**16**	0
McNary	July	**7**	**8**	**8**	**12**	0
McNary	August	0	0	0	0	0
McNary	September	0	**1**	**1**	0	0
McNary	October	**6**	**1**	0	0	0
McNary	November	0	**2**	0	**1**	0
McNary	December	0	**6**	0	**7**	**1**
John Day	February	**1**	0	0	0	0
John Day	March	**31**	**30**	**31**	**28**	**31**
John Day	April	**27**	**22**	**7**	**22**	**1**
John Day	May	**18**	**31**	**26**	**31**	**22**
John Day	June	**2**	**28**	**30**	**30**	**10**
John Day	July	**20**	**26**	**14**	**21**	0
John Day	August	**7**	**8**	0	0	0
The Dalles	February	0	0	0	0	**1**
The Dalles	March	**31**	**31**	**31**	**14**	**31**
The Dalles	April	**30**	**25**	**29**	**30**	**21**
The Dalles	May	**15**	**11**	**29**	**24**	**31**
The Dalles	June	0	0	**30**	**17**	**19**
The Dalles	July	**8**	**11**	**31**	**31**	0
The Dalles	August	**29**	**22**	**9**	**9**	0
Bonneville	April	**11**	0	**19**	**21**	**8**
Bonneville	May	**12**	0	**12**	**4**	**31**
Bonneville	June	0	0	**25**	**15**	**17**
Bonneville	July	0	0	**25**	**24**	0
Bonneville	August	**14**	**14**	**1**	0	0
Bonneville	September	0	-1	0	0	0
Bonneville	October	0	0	0	0	**1**
Bonneville	November	0	0	0	0	0
Bonneville	December	0	0	0	0	**2**

7.3.3 Other Physical, Chemical, and Biological Processes

7.3.3.1 McNary, John Day, The Dalles, and Bonneville Dams and Reservoirs

Under the MO4 *Drawdown to MOP* measure, the McNary, John Day, The Dalles, and Bonneville Reservoir elevations would be drawn down to minimum operating pool from March 25 through August 15 to reduce travel times for anadromous fish outmigration (Figure 7-53 to Figure 7-56). Lowering the reservoir elevations could lead to minor total suspended solids (TSS) increases and associated impacts (turbidity, light attenuation, and/or chemicals that may be associated with TSS like nutrients, metals, and organics). However, the impacts are expected to be negligible in the large lower Columbia River reservoirs.

Otherwise, the introduction of pollutants and excess nutrients from farming and industrial activities as well as urban runoff is expected to continue under MO4. As with the No Action Alternative, emerging contaminants such as pharmaceuticals and new pesticides will also likely become more prevalent. The lower Columbia River contains a wide variety of human-sourced compounds, including trace metals and organic compounds. This condition is expected to remain generally unchanged, and it is expected that current water quality impairments would continue.

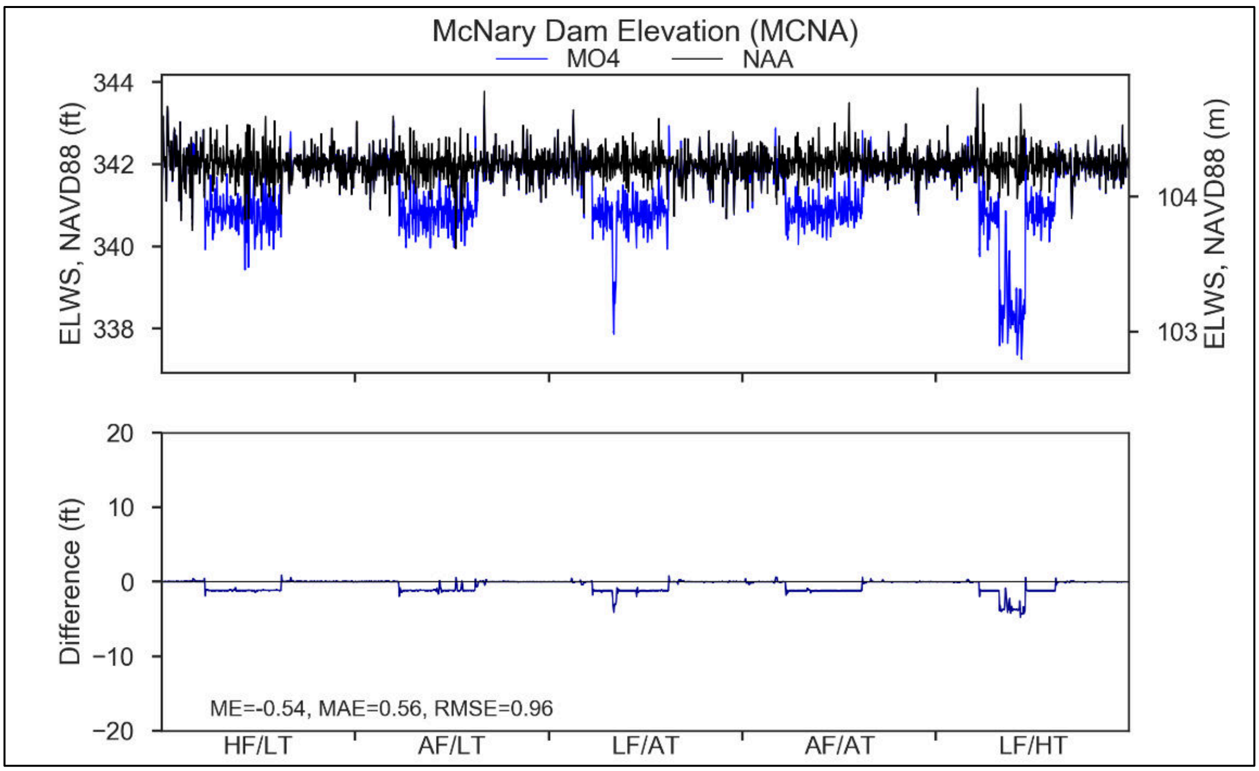


Figure 7-53. Modeled Forebay Elevation for Multiple Objective Alternative 4 at McNary Dam Under a 5-year Range of River and Meteorological Conditions

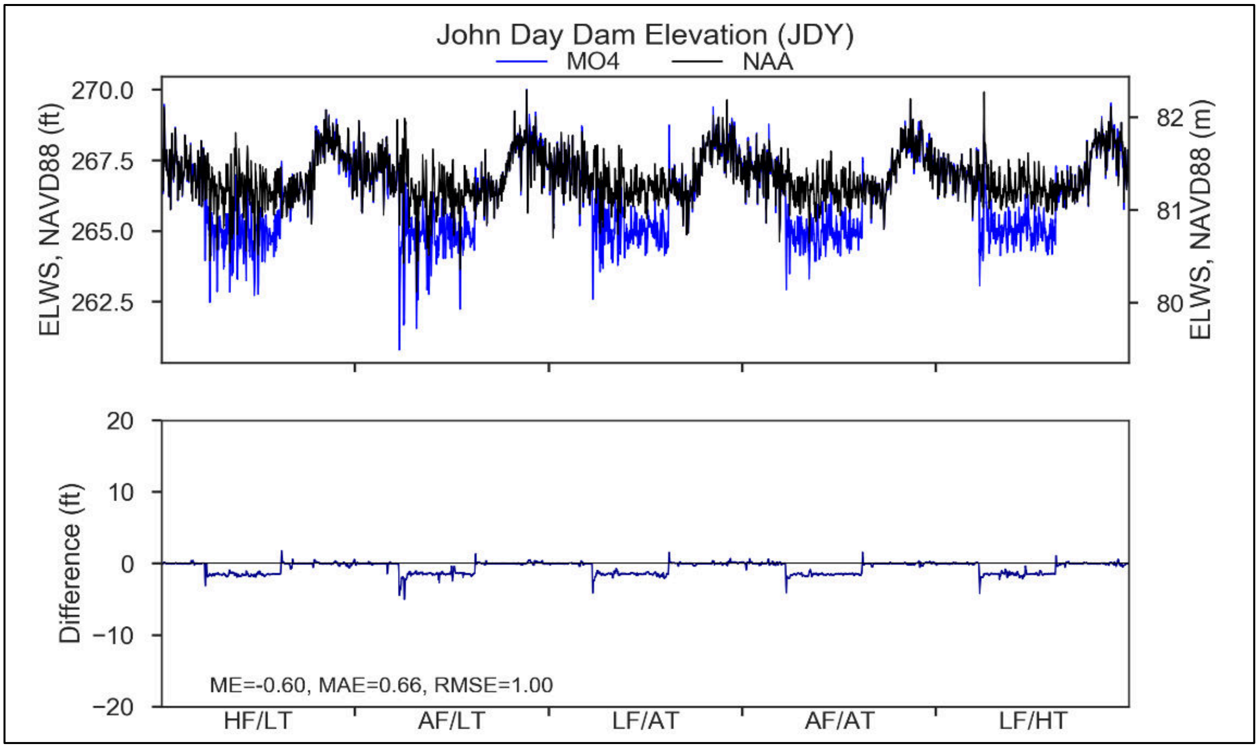


Figure 7-54. Modeled Forebay Elevation for Multiple Objective Alternative 4 at John Day Dam Under a 5-year Range of River and Meteorological Conditions

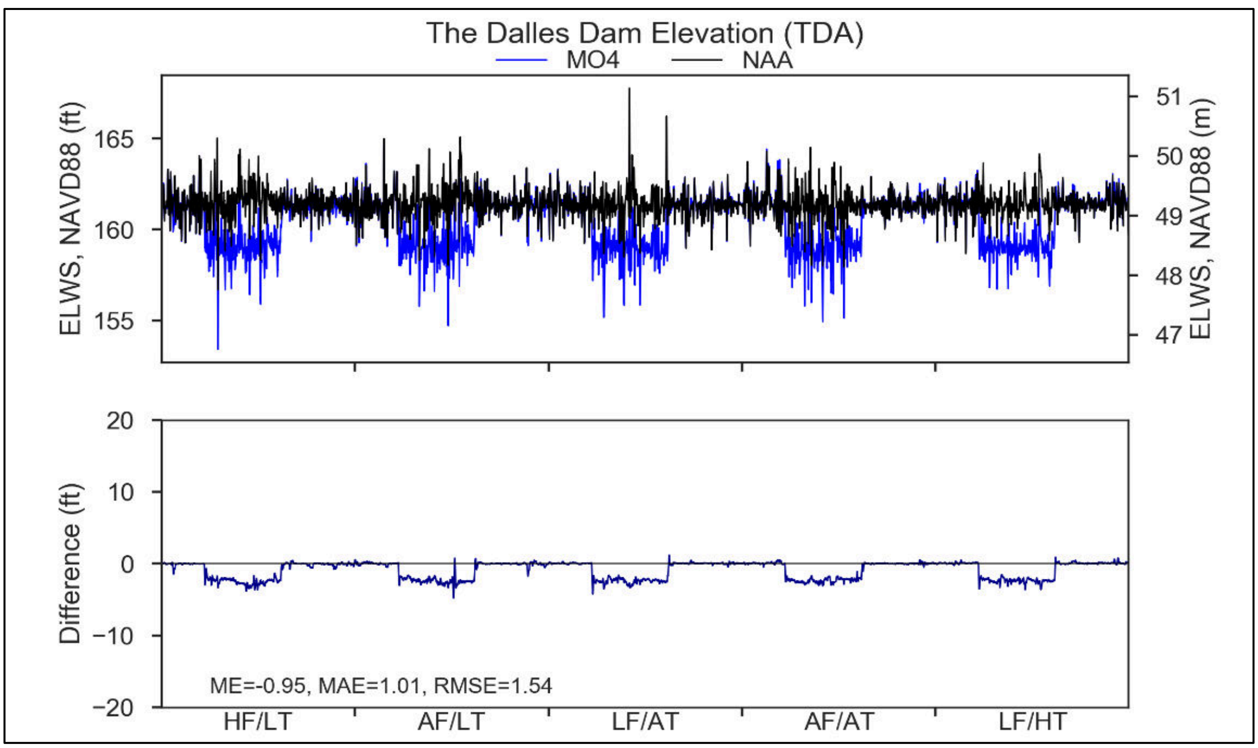


Figure 7-55. Modeled Forebay Elevation for Multiple Objective Alternative 4 at The Dalles Dam Under a 5-year Range of River and Meteorological Conditions

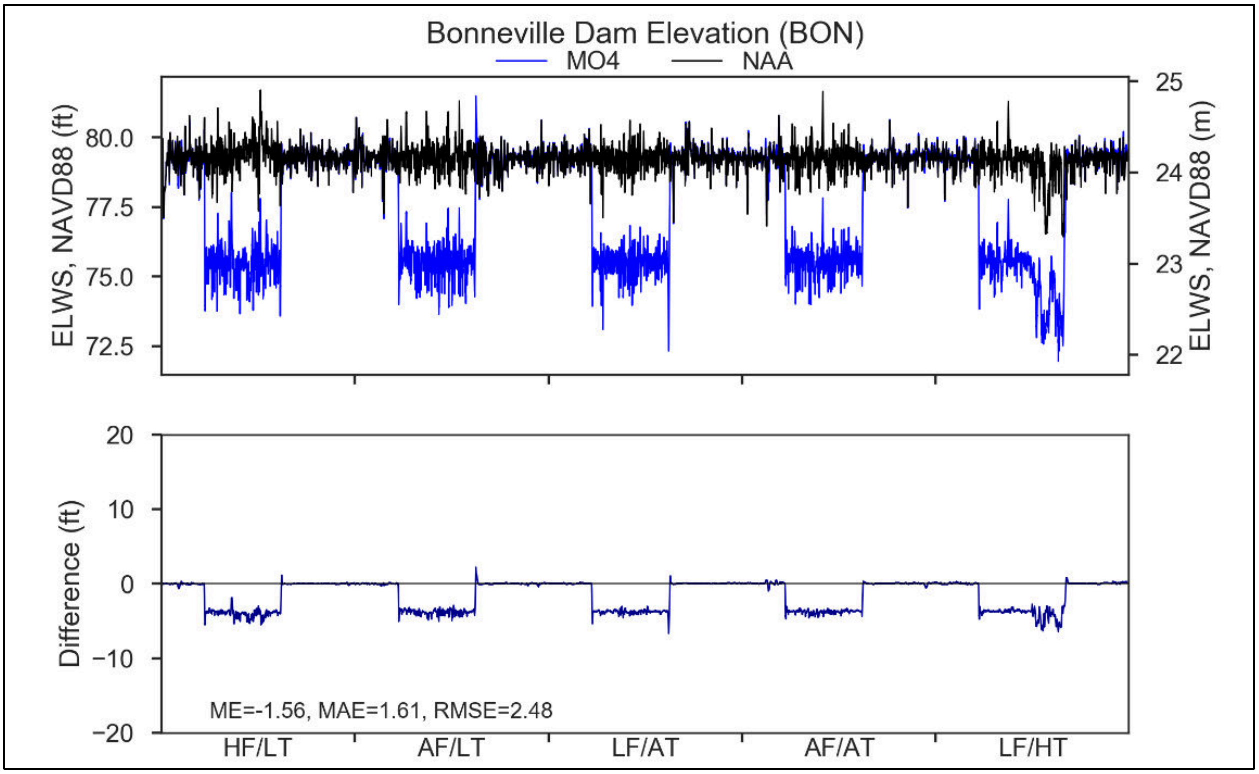


Figure 7-56. Modeled Forebay Elevation for Multiple Objective Alternative 4 at Bonneville Dam Under a 5-year Range of River and Meteorological Conditions

7.4 SEDIMENT PROCESSES

7.4.1 Sediment Sources

MO4 includes structural changes aimed at improving fish passage as well as hydropower operation; these proposed measures would not affect sediment sources or movement. The proposed operational changes include a wide range of hydropower and fish related measures; many of the operational changes do not affect sediment sources or movement. Increasing the irrigation volume to authorized levels could cause changes in sediment sources for the upper Columbia River. Sediment sources for the upper Columbia River Basin include erosion from bare lands (deforested or fallow agricultural lands) and landslides due to fluctuating water levels, especially in Lake Roosevelt. Since MO4 includes providing up to the authorized volume of irrigation water, the alternative would potentially increase agricultural land acreage and would likely increase erosion from agricultural land (simply because there would be more of it.) Increased irrigation from Lake Roosevelt would result in many thousands of additional acres of irrigable land for agricultural development. An additional 90,000 acre-feet of water from Hungry Horse reservoir has no specific purpose identified but could be used for either irrigation or municipal purposes. Increased irrigation from Chief Joseph would allow for an additional several thousand acres of land for agricultural development. Agricultural erosion could contain nutrients and pesticides that would affect sediment quality. The use of additional water from Lake Roosevelt could cause water level fluctuations which could exacerbate landslide conditions along the shores. These changes would affect the upper Columbia River portion of the project, however the changes in sediment sources would not be felt through the entire system since sediment downstream movement is disrupted by dams. The measures included in MO4 would not cause changes to land use near the lower Columbia River and Snake River projects including upland recreation, flood management, agricultural, timber, or mining activities, and would not be expected to change population growth patterns in those areas. Overall, sediment loading to Lake Roosevelt, Chief Joseph Reservoir, and Hungry Horse Reservoir could be increased due to the increased irrigation proposed in MO4.

7.4.2 Chemicals of Concern

No change is predicted to the list of sediment chemicals of concern, compared to the existing conditions and under the No Action Alternative. Higher loading of agriculturally sourced pollutants may occur on the upper Columbia River due to the increase in irrigated agricultural lands. Changes in reservoir water levels due to changes in operations could affect the mobility and bioavailability of some pollutants such as mercury (Willacker et al. 2016). Throughout the basin, the contaminants of concern would remain metals, polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), pesticides and pesticide degradation products, PCBs, dioxins, and nutrients (ammonia).

7.5 CONCEPTUAL SITE MODEL

The conceptual site model for dredging under MO4 is the same as the conceptual site model(s) for the existing conditions and under the No Action Alternative. Areas that are currently not dredged (such as Chief Joseph Reservoir) would not be dredged in the future, in spite of potential changes in sediment loading in the upper Columbia River Basin, since there are no navigational features maintained by dredging. Sediment management operations in the Snake and lower Columbia Rivers would remain as they currently are since sediment sources for those reaches are not affected. Where dredging is needed (such as at the confluence of the Snake and Clearwater Rivers), it is assumed that dredged materials would be of sufficient quality for either in-water or upland beneficial use, as habitat creation areas or as upland fill. Sediment characterization following the Sediment Evaluation Framework (RSET 2018) or other applicable guidance would continue to be required for any new dredging or sediment related projects.

7.6 WATER AND SEDIMENT QUALITY CONCLUSIONS

The most notable MO4 measures that affect water quality are as follows:

- *Spillway Weir Notch Inserts* and *Spill for Adult Steelhead*: Modify spillway weir with notch gate inserts at Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, and John Day; provide 2 kcfs of spill for steelhead and kelt downstream passage; October to November
- *Spill to 125% TDG*: Set juvenile fish passage spill not to exceed 125 percent TDG as measured in the tailrace at all lower Snake River and lower Columbia River projects

- *McNary Flow Target*: Maintain 220/200-kcfs spring spill objectives at McNary through use of water in upper Columbia River Basin storage projects
- *Hungry Horse Additional Water Supply, Lake Roosevelt Additional Water Supply, Chief Joseph Dam Project Additional Water Supply*: Modify operations to meet existing contractual water supply obligations
- *Modified Draft at Libby, December Libby Target Elevation, Update System FRM Calculation, Winter System FRM Space*: Modify operations for FRM at Libby and Grand Coulee
- *Grand Coulee Maintenance Operation*: Perform major maintenance at Grand Coulee

7.6.1 Multiple Objective Alternative 4 Results – Water Temperature

In general, MO4 would result in little to no change to water temperature downstream of Hungry Horse Dam. Some minor changes in water temperatures could be expected at Libby, Albeni Falls, Grand Coulee, and Chief Joseph Dams and Reservoirs, as compared to the No Action Alternative. Higher winter reservoir elevations at Libby from the change in the end-of-December draft target measure (*December Libby Target Elevation*), followed by higher outflows (aggressive drafting) in late winter/early spring, could result in warmer water temperatures downstream of the dam in the winter and colder downstream water temperatures in the early spring and summer as compared to under the No Action Alternative. This could result in various negative impacts to resident fish species. The largest changes in flow from the No Action Alternative to MO4 on the Pend Oreille River downstream of Albeni Falls Dam would occur in June and September during lower flow years, both of which months are associated with changes in Albeni Falls Dam operations for McNary Dam augmentation (*McNary Flow Target*). This is expected to result in warmer downstream water temperatures in the summer months. The *McNary Flow Target* measure combined with the Winter System FRM and the spring FRM system operations at Grand Coulee Dam (*Update System FRM Calculation* and *Planned Draft Rate at Grand Coulee*), result in lower Lake Roosevelt elevations year-round. These reductions in storage would result in warmer water temperatures downstream of Grand Coulee Dam in the spring and summer and cooler water temperatures in the fall and winter, which would be passed down and through Chief Joseph Dam.

Negligible impacts in water temperature are expected at Dworshak Dam and Reservoir or in the lower Snake and Columbia Rivers under MO4, with the exception of McNary, which could experience some warming due to the *McNary Flow Target* measure (Figure 7-57 to Figure 7-59).

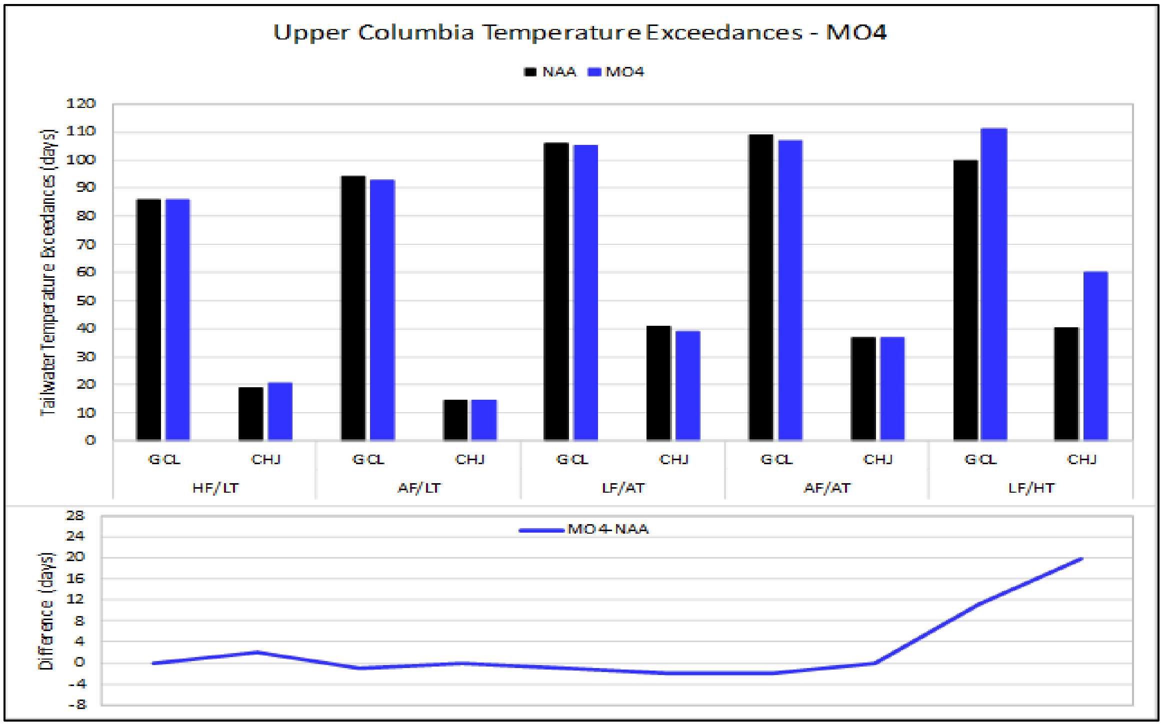


Figure 7-57. Modeled Tailwater Temperature Exceedances for the No Action Alternative and Multiple Objective Alternative 4 at Grand Coulee and Chief Joseph Dams Under a 5-Year Range of River and Meteorological Conditions

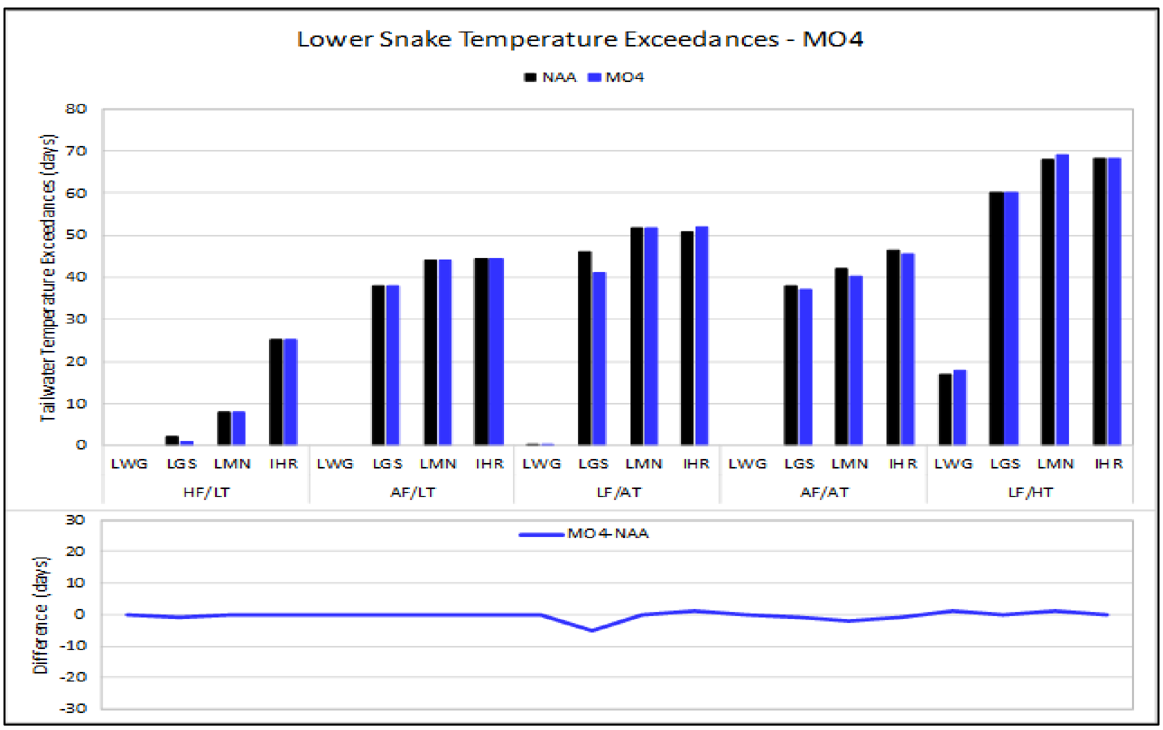


Figure 7-58. Modeled Tailwater Temperature Exceedances for the No Action Alternative and Multiple Objective Alternative 4 at Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams Under a 5-Year Range of River and Meteorological Conditions

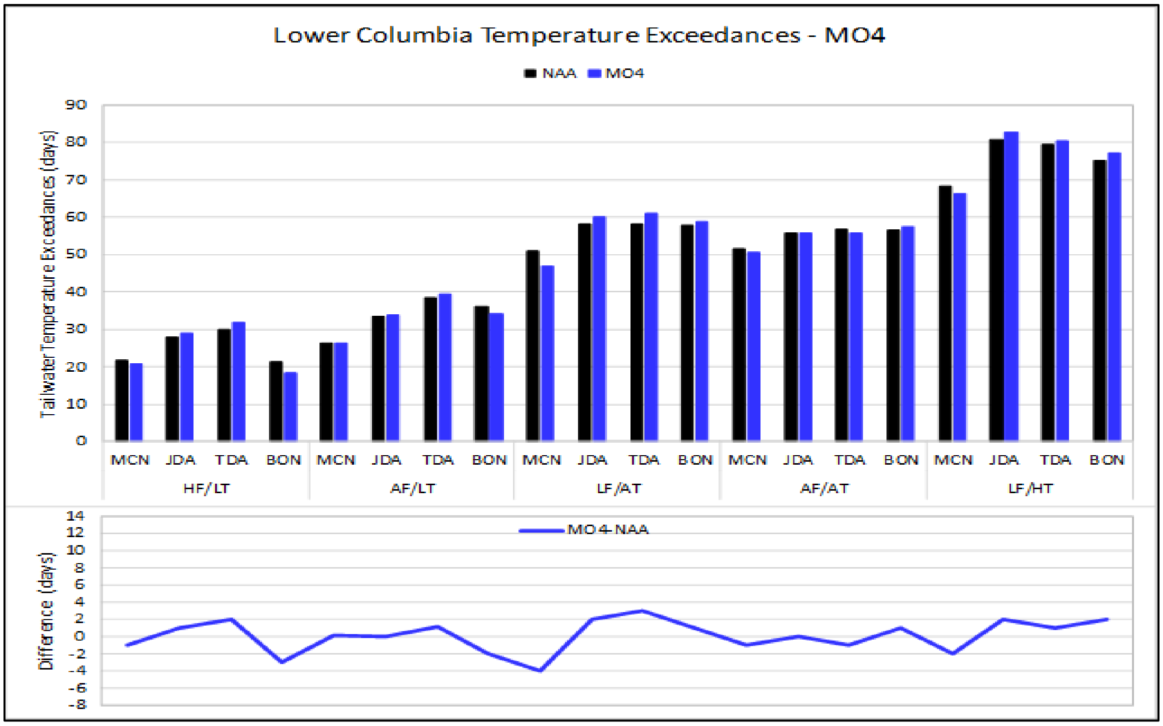


Figure 7-59. Modeled Tailwater Temperature Exceedances for the No Action Alternative and Multiple Objective Alternative 4 at McNary, John Day, The Dalles, and Bonneville Dams Under a 5-Year Range of River and Meteorological Conditions

7.6.2 Multiple Objective Alternative 4 Results – Total Dissolved Gas

There are no anticipated impacts to TDG expected downstream of Hungry Horse or Albeni Falls under MO4. For Libby, negligible increases to TDG are expected in the spring due to higher flows from aggressive drafting of Libby Reservoir following the *December Libby Target Elevation measure*. TDG effects downstream of Grand Coulee and Chief Joseph Dams are anticipated to be negligible (Figure 7-60). Under MO4, TDG would be higher at the lower Snake and Columbia River dams due to the *Spill to 125% TDG* measure, which sets tailwater TDG limits to 125 percent TDG with no forebay TDG limit. This results in higher TDG production as compared to under the No Action Alternative, which has TDG limits of 115 percent in the forebay and 120 percent in the tailrace. Overall, major increases in TDG are anticipated in the lower Snake River (Figure 7-61) and moderate increases in TDG are anticipated in the lower Columbia River (Figure 7-62).

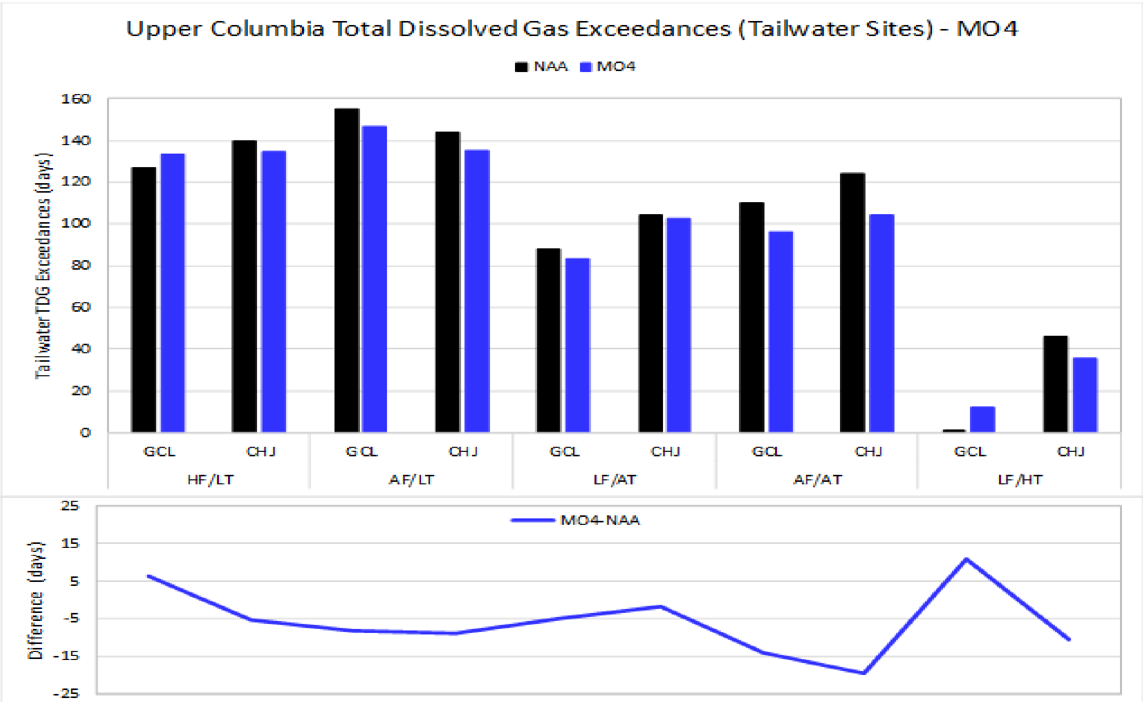


Figure 7-60. Modeled Tailwater Total Dissolved Gas Exceedances for the No Action Alternative and Multiple Objective Alternative 2 at Grand Coulee and Chief Joseph Under a 5-Year Range of River and Meteorological Conditions

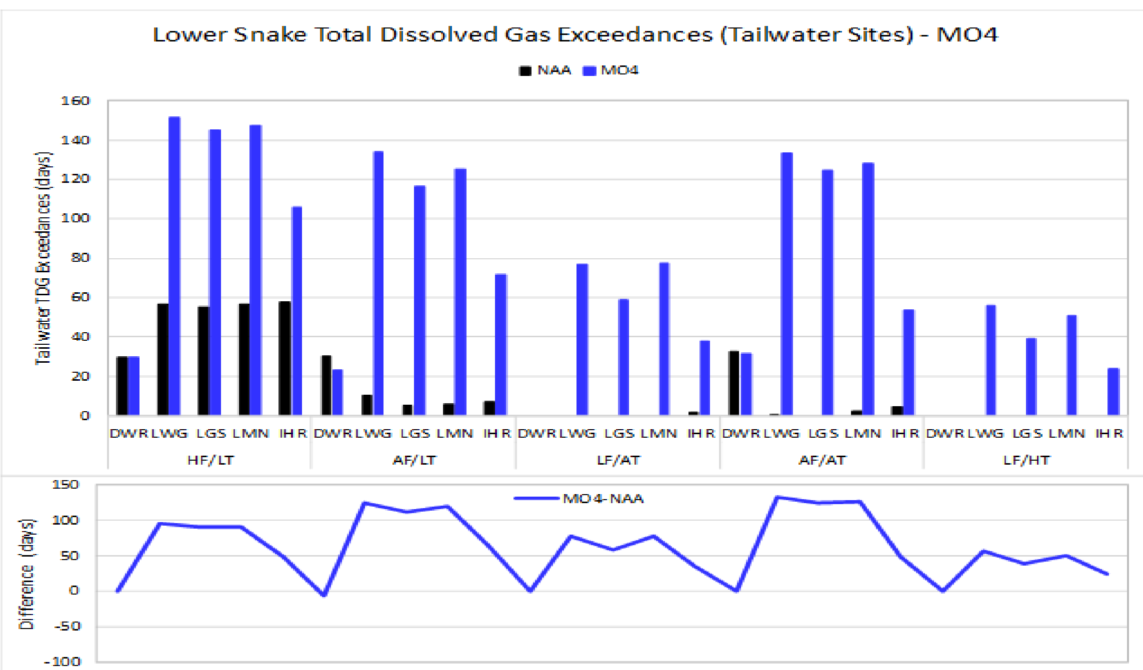


Figure 7-61. Modeled Tailwater Total Dissolved Gas Exceedances for the No Action Alternative and Multiple Objective Alternative 2 at Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams Under a 5-Year Range of River and Meteorological Conditions

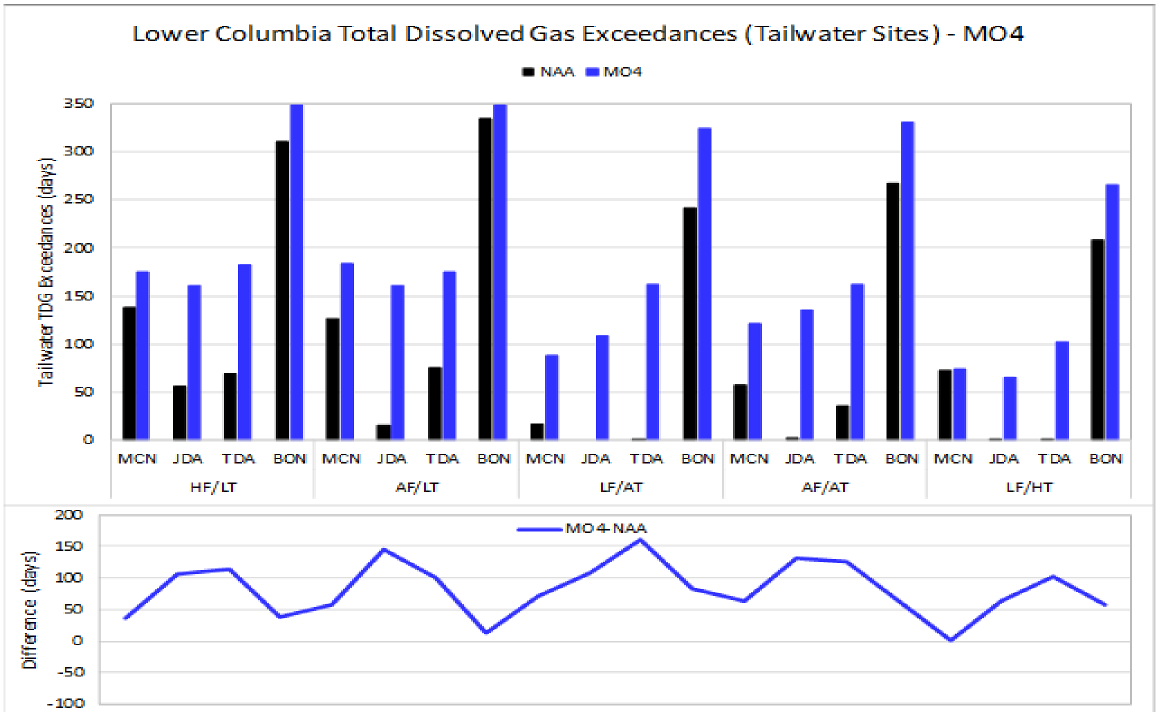


Figure 7-62. Modeled Tailwater Total Dissolved Gas Exceedances for the No Action Alternative and Multiple Objective Alternative 2 at McNary, John Day, The Dalles, and Bonneville Dams Under a 5-Year Range of River and Meteorological Conditions

7.6.3 Multiple Objective Alternative 4 Results – Other Water Quality Impacts

In general, MO4 would result in little to no change on other water quality parameters at most CRSO projects as compared to the No Action Alternative. The exceptions include potential changes at Libby and Grand Coulee. Due to higher winter reservoir elevations at Libby, resulting from the change in the *December Libby Target* measure, followed by higher outflows (aggressive drafting) in late winter/early spring due to the *Modified Draft at Libby* measure, operations could reduce overall lake productivity, effecting the growth rate in fish within and downstream of the reservoir. At Grand Coulee, the deeper draft of the reservoir elevation, associated with the carryover effects of the *McNary Flow Target,* the *Winter System FRM Space,* the system FRM operations at Grand Coulee *(Update System FRM Calculation* and *Planned Draft Rate at Grand Coulee)* and the *Lake Roosevelt Additional Water Supply* could lead to increased mercury methylation due to prolonged sediment exposure. The *Planned Draft Rate at Grand Coulee* measure would slow the reservoir draft rate to 0.8 feet/day, which could result in a decrease in bank erosion, sloughing, and overall turbidity in the reservoir.

7.6.4 Multiple Objective Alternative 4 Results – Sediment Quality

MO4 is not expected to affect land use throughout the Columbia River Basin, including upland recreation, flood management, agricultural, timber, or mining activities, and is not expected to change population growth patterns in the area of any of the affected reservoirs. Overall, MO4 is not expected to affect sediment movement within the system.

CHAPTER 8 - PREFERRED ALTERNATIVE

The Preferred Alternative (PA) includes a complete description of measures that would be implemented to operate the CRS to better meet the Purpose and Need and objectives of the study. Several measures, from the alternatives in Chapter 2, were refined or added for inclusion into the Preferred Alternative. Operations, maintenance and programs that were ongoing or planned as of 2016 are carried forward into the Preferred Alternative unless described otherwise. Ongoing operations and maintenance measures are described in more detail in Chapter 2.3.2.1. Further details regarding the Preferred Alternative measures can be found in Chapter 7.

8.1 UPPER COLUMBIA RIVER BASIN

8.1.1 Water Temperature

8.1.1.1 Libby and Hungry Horse Dams and Reservoirs

The PA would modify Libby Dam's draft and refill operations after December 31. The *Modified Draft at Libby* measure results in mid-April reservoir elevations lower than the No Action Alternative when the water supply forecast is less than 6.9 Maf (median to low water supply forecast). Refill operations would be adjusted for the water supply forecast with peak reservoir elevations being achieved in late July or August. Peak reservoir elevations under the PA would be about 1 to 5 feet higher than under the No Action Alternative depending on the water year. A summary hydrograph for Lake Koocanusa, representing the probability of the reservoir elevation on any given day under PA and the No Action Alternative, is shown in Figure 8-1. Under the PA, median elevations in Lake Koocanusa are similar to the No Action Alternative elevations from October through the end of January, about 5 feet lower by mid-April, slightly higher by the end of July, and held at similar elevations in August and September. In years with high water supply forecasts (represented by the 75 percent and 99 percent non-exceedance lines in Figure 8-1) mid-April draft elevations are similar but the reservoir is refilled and held slightly higher (1 to 4 feet) in August and September. In years with low water supply forecasts (the 25 percent and 1 percent non-exceedance lines in Figure 8-1), the PA drafts the reservoir deeper than the No Action Alternative by about 5 to 8 feet, and the reservoir is refilled at a more rapid rate and held higher by about 5 feet in August and September.

Historical temperature data suggests that holding the pool higher in the winter results in colder spring and summer reservoir temperatures and difficulty for the SWS to achieve downstream temperatures objectives. When the pool is drafted deeper in the winter, as is the case under the PA, the pool volume is less, thereby allowing for greater warming in the spring from warmer inflows and ambient air temperatures. Hence, the SWS has a greater ability to achieve desired water temperatures downstream in the Kootenai River.

In general, the PA impacts Libby Dam outflows and Kootenai River flows from January through April and again in June, July, and August (Figure 8-2). When compared to the No Action Alternative, median PA outflows are similar from October through December; 19, 26, and 18 percent greater in January, February, and March, respectively; 14 percent less in April; and about 5 to 8 percent greater from June through September. High water year flows (1 and 25 percent exceedance flows) do not follow the same pattern, and are 11 to 40 percent greater than the No Action Alternative in October and November, similar from December through June, and 1 to 12 percent less from June through September. Low water year flows (75 and 99 percent exceedance flows) follow a similar pattern as median flows, except for a 15 and 43 percent decrease in May for the 75 and 99 percent flows, respectively, and an increase in the June through August period (9 to 14 percent) for the 99 percent flows.

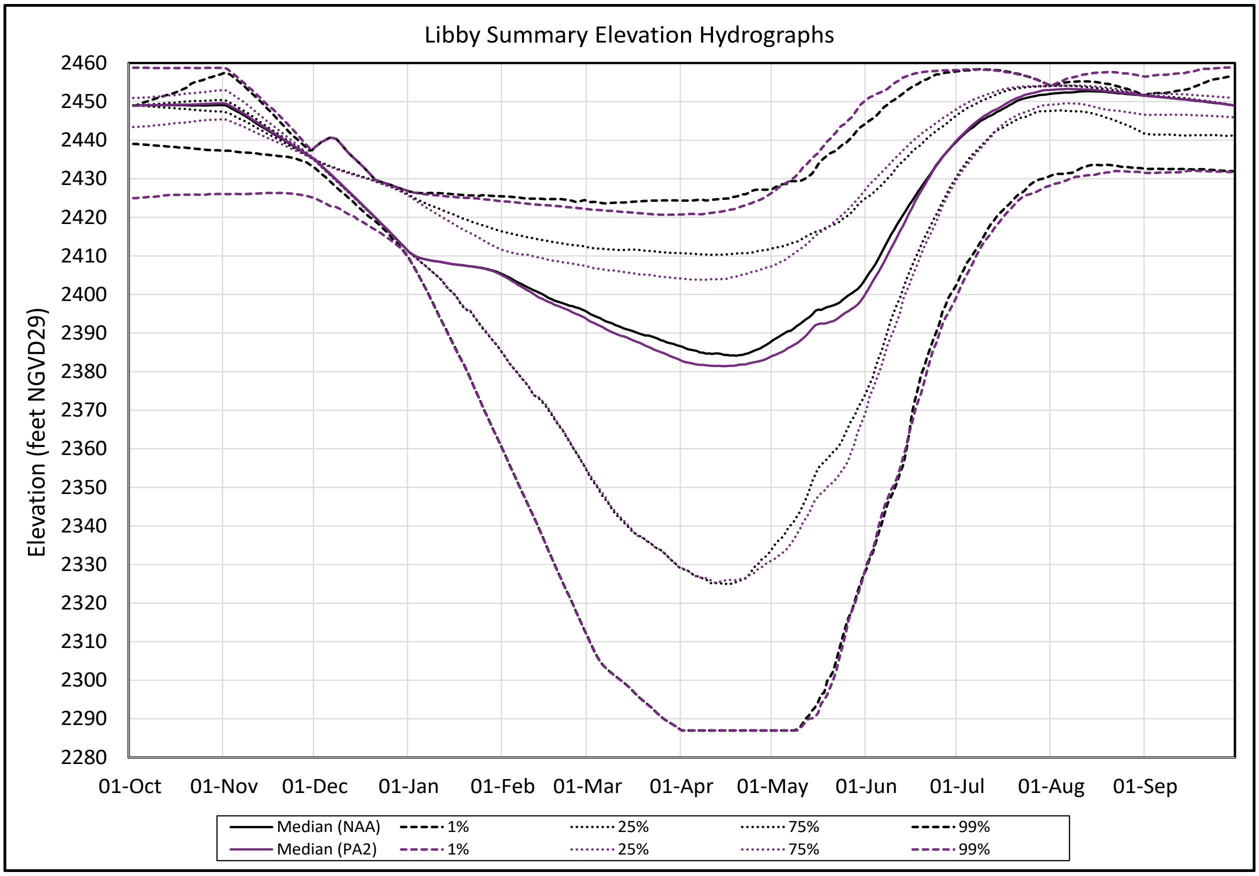


Figure 8-1. Libby Dam–Lake Koocanusa Summary Elevations for Preferred Alternative Versus No Action Alternative

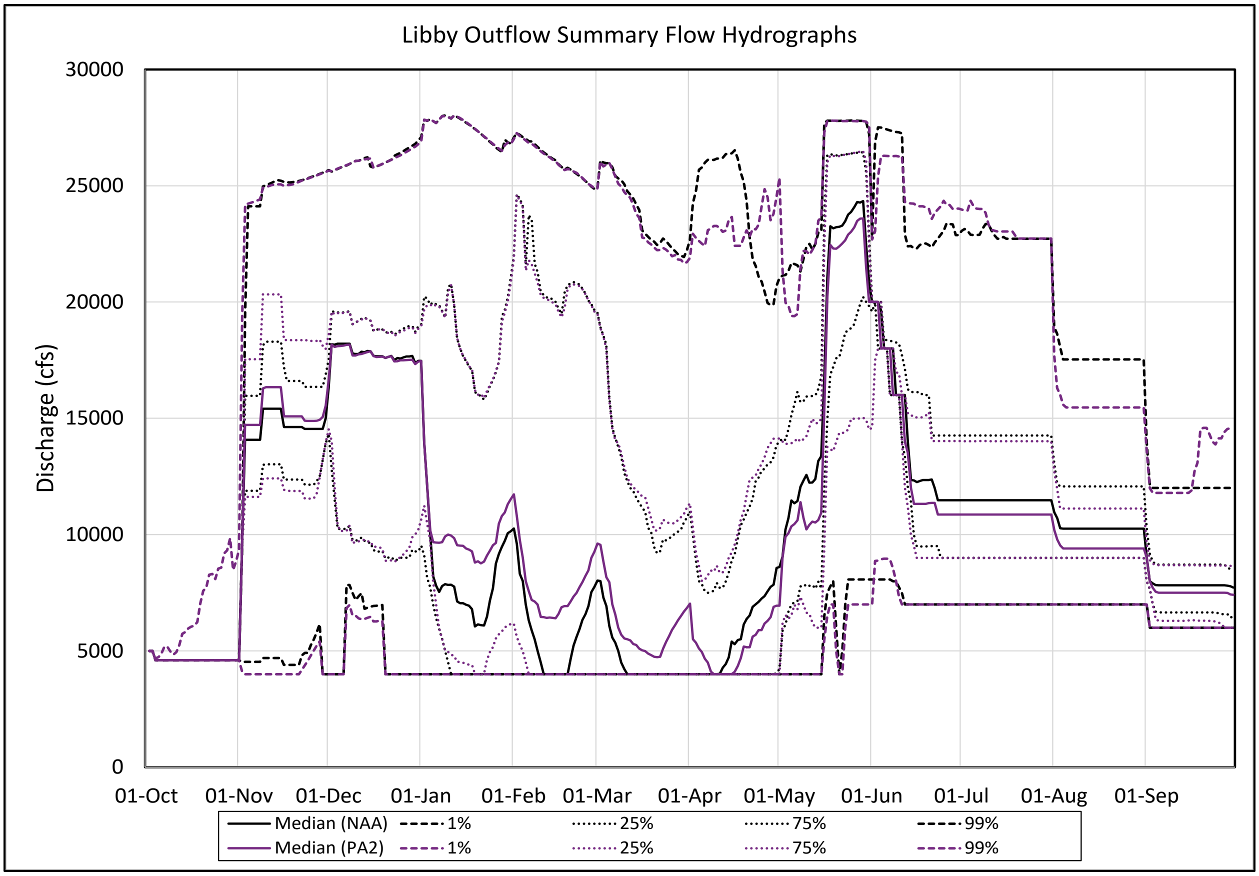


Figure 8-2. Libby Dam–Lake Koocanusa Summary Outflows for Preferred Alternative Versus No Action Alternative

Under the PA, Libby Dam's SWS provides some ability to adjust where in the water column water entering the powerhouse penstocks is drawn from. The range of the SWS bulkheads are from elevation 2,409 to 2,200 feet, NGVD29. Because SWS protocol maintains at least 30 feet of submergence over the top row of the bulkheads for hydraulic stability, the SWS has the ability to perform under the full range of possible PA operations with a similar efficiency as under the No Action Alternative. Modeled forebay elevations under PA are predicted to be well within the operating range of the SWS and similar to the ranges observed in the historical years described in Section 3.1.1.1.

Changes in downstream temperatures from Libby Dam to Bonners Ferry may result from PA operations increasing the median monthly outflow from January through March to draft the reservoir deeper. During the cold winter months, Kootenai River water can cool by several degrees between Libby Dam and Bonners Ferry if flows are held low. By increasing winter flows to draw the pool down deeper, the PA may prevent the natural cooling of the river as it moves downstream. These higher winter temperatures in the Kootenai River may be an issue for certain fish species, such as burbot, which require near freezing river temperatures (<35°F or <2°C) to spawn. Overall, the PA is expected to results in negligible to minor changes in water temperature as compared to the No Action Alternative.

Under the PA, water temperatures in the South Fork of the Flathead River below Hungry Horse Dam would be similar to those under the No Action Alternative. Only one operational measure, *Sliding Scale and Libby and Hungry Horse*, applies to Hungry Horse. This measure would result in negligible changes to summer operations at Hungry Horse Dam in dry years; these changes are not anticipated to impact the ability of Hungry Horse to utilize the selective withdrawal structure and meet water temperature objectives downstream in the South Fork Flathead River. As presented in the Hungry Horse Selective Withdrawal System Evaluation Report (Reclamation 2006), temperatures between 50°F and 59°F (10°C and 15°C) are optimal for trout growth and the SWS has been successful in maintaining these water temperatures during the summer months. Epilimnion thickness and thermocline strength is relatively stable from year-to-year in the reservoir despite drastically different hydrological conditions (Reclamation, 2006).

8.1.1.2 Albeni Falls Dam and Reservoir

Under the PA, there are no changes to operations at Albeni Falls Dam. Any changes in flow from Hungry Horse Dam under PA that move downstream through the basin are insignificant by the time they enter the Pend Oreille River Basin. As such, there are no expected changes in Lake Pend Oreille elevations and only minor changes in Pend Oreille River flows between the PA and the No Action Alternative (Figure 8-3). Median and high water supply year outflows from Albeni Falls Dam under the PA are expected to be the same as the No Action Alternative, while low water supply years would be up to several hundred cfs lower. Model results show a negligible change in temperature at Albeni Falls Dam between the PA and No Action Alternative with the majority of temperature differences between the two alternatives of about ± 0.35 degree Fahrenheit (± 0.2 degree Celsius) (Figure 8-4 and Figure 8-5). Modeled temperatures under both the PA and the No Action Alternative would continue to exceed the IDEQ Pend Oreille River temperature criteria (1-Day Maximum of 71.6°F [22°C] and 1-Day Average of 66.2°F [19°C]) during the summer.

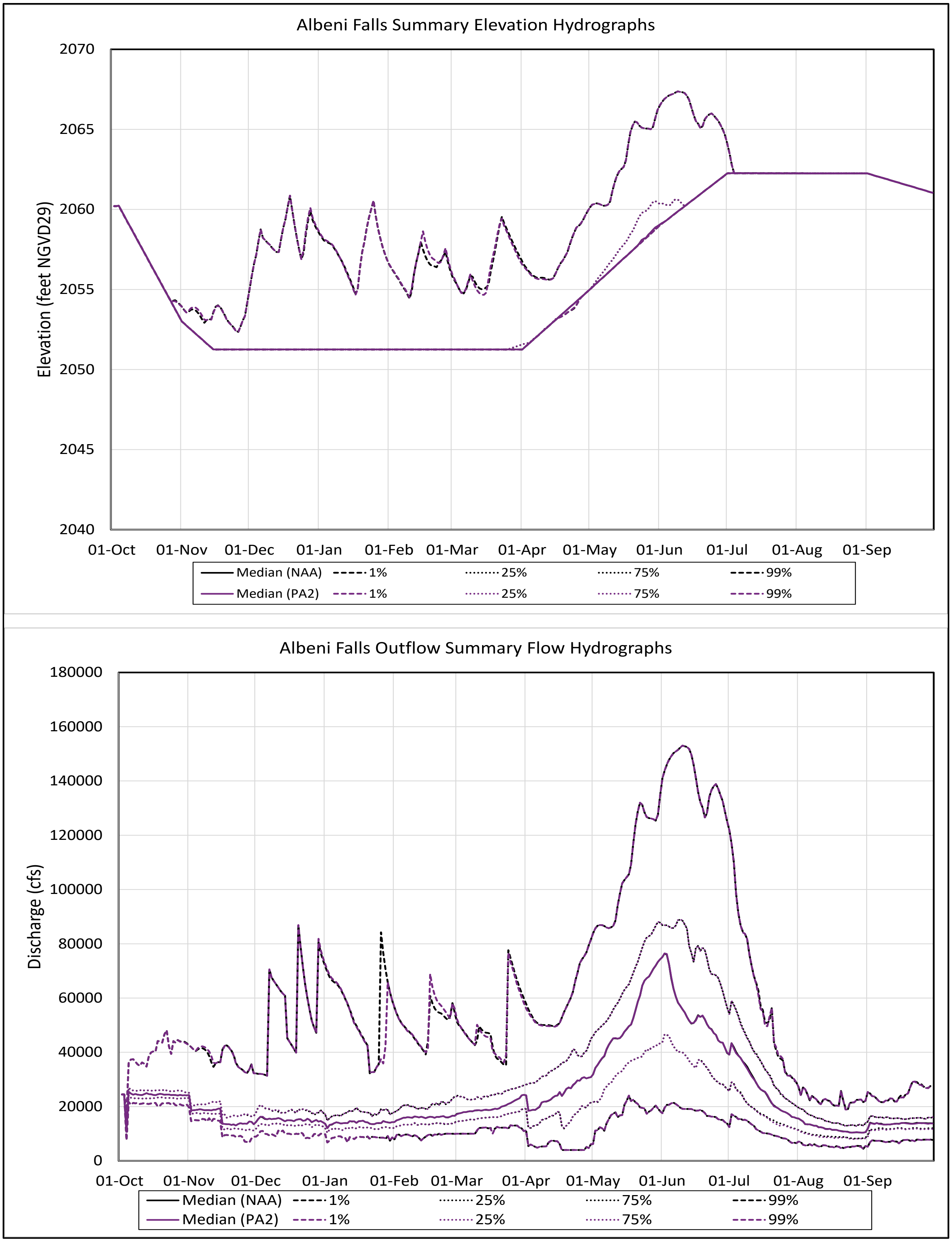


Figure 8-3. Albeni Falls Dam Summary Elevation Hydrographs and Outflows for Preferred Alternative Versus the No Action Alternative

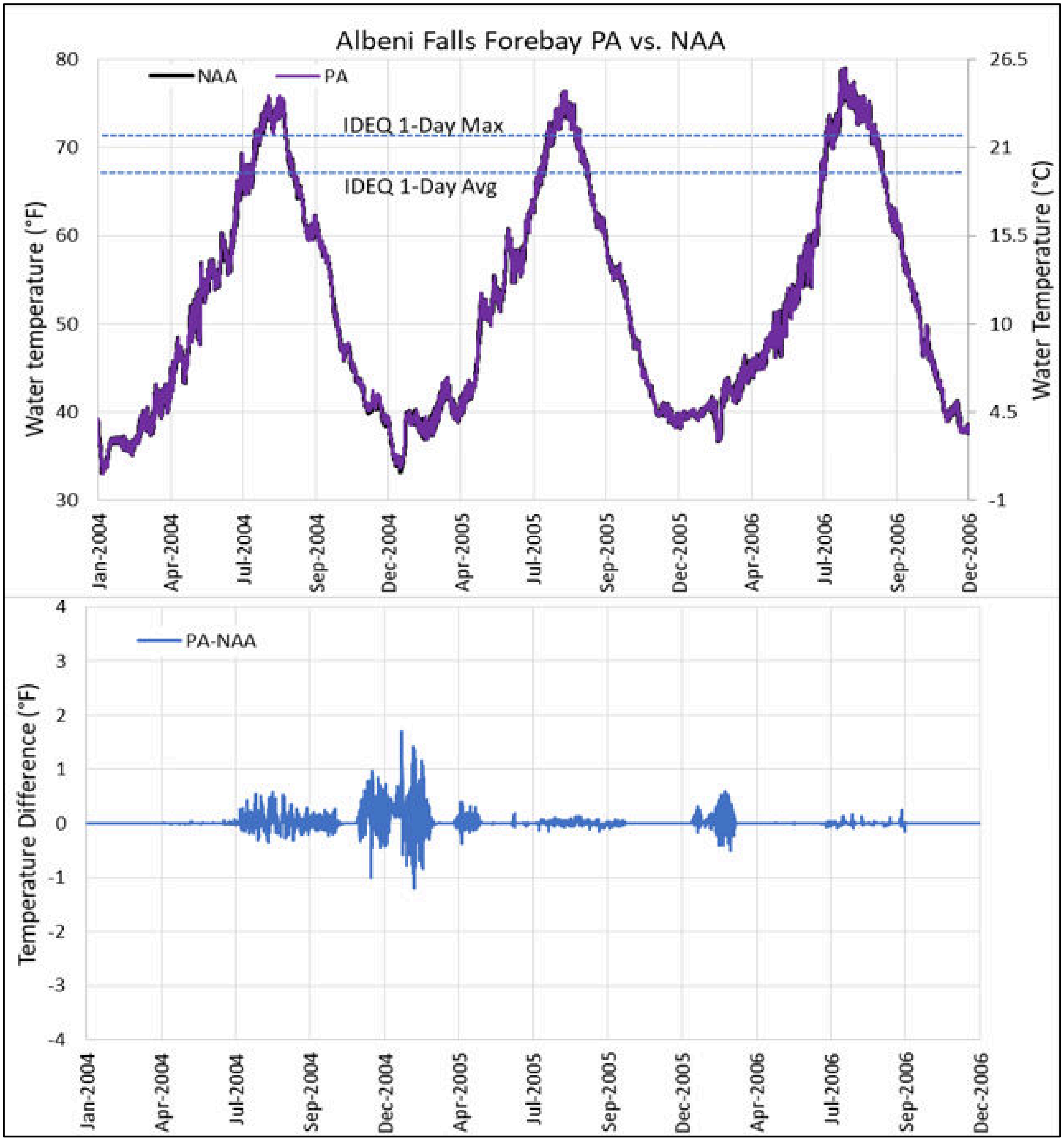


Figure 8-4. Modeled Forebay Temperatures for Preferred Alternative and No Action Alternative at Albeni Falls for 2004 to 2006

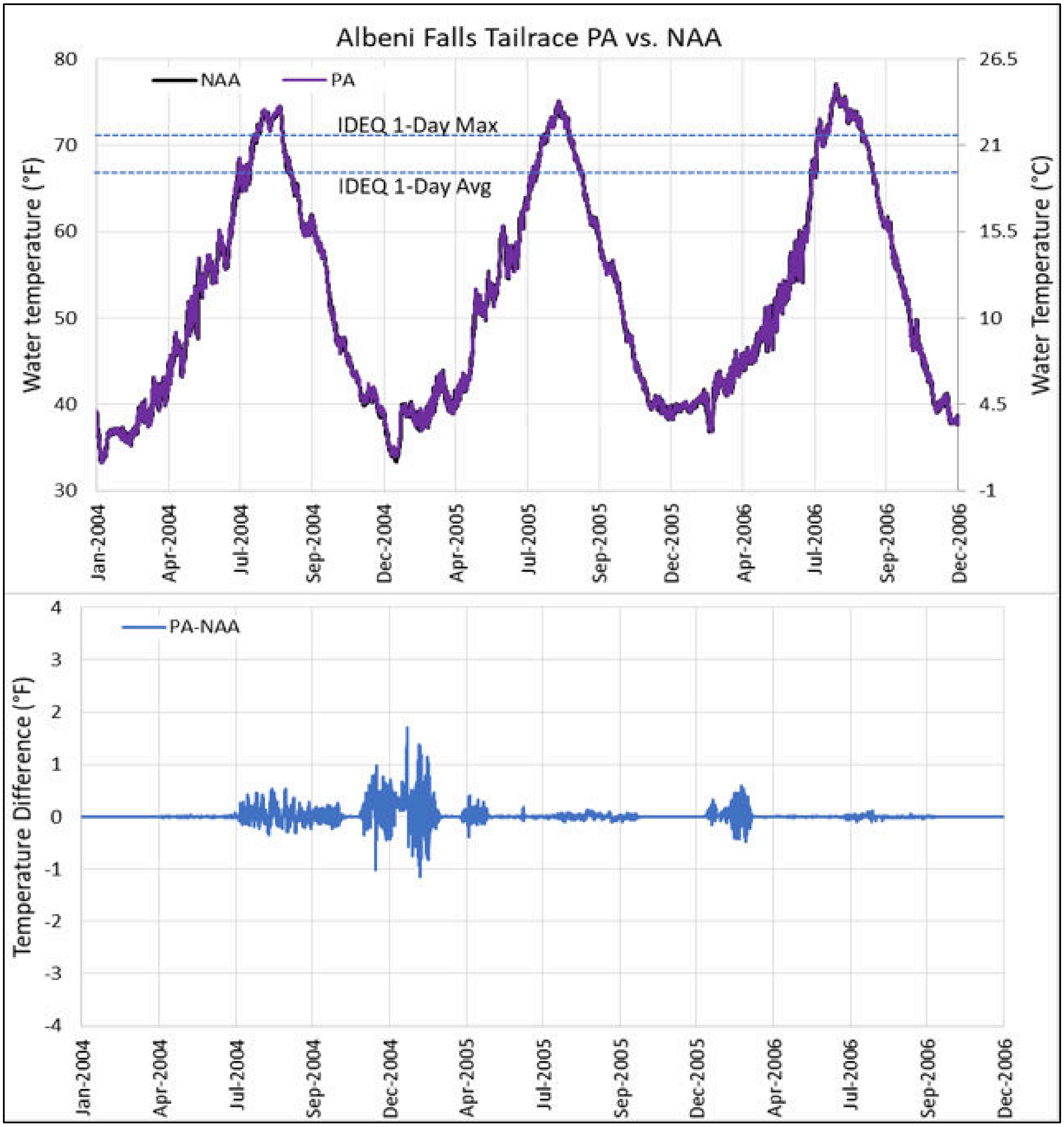


Figure 8-5. Modeled Tailwater Temperatures for Preferred Alternative and No Action Alternative at Albeni Falls for 2004–2006

8.1.1.3 Grand Coulee and Chief Joseph Dams and Reservoirs

Under the PA, the *Update System FRM Calculation, Planned Draft Rate at Grand Coulee, Fall Operational Flexibility for Hydropower (Grand Coulee),* and *Lake Roosevelt Additional Water Supply* measures relate directly to Grand Coulee Dam, and all of these (with the exception of *Lake Roosevelt Additional Water Supply*) would influence reservoir elevations at Lake Roosevelt. Operational changes in Region A upstream may also have a slight effect on Lake Roosevelt water levels. The *Grand Coulee Maintenance Operations* measure would not impact reservoir elevations or total outflows.

The changes in operations from these measures have negligible impacts to temperature. Figure 8-6 shows the PA versus the No Action Alternative modeled water temperatures below Grand Coulee Dam. As shown, the PA water temperatures are very similar to the No Action Alternative.

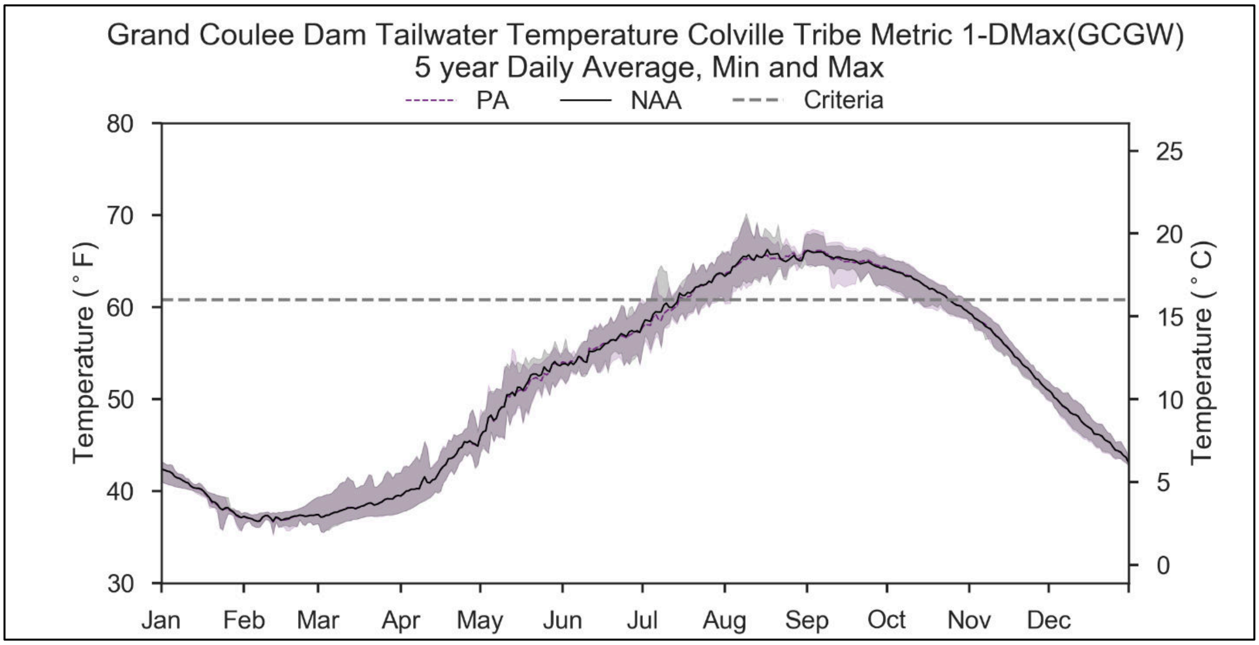


Figure 8-6. Modeled Range of Tailwater Total Dissolved Gas for the No Action Alternative and Multiple Objective Alternative 2 at Grand Coulee Dam Under a 5-Year Range of River and Meteorological Conditions

Model results predict little change in Rufus Woods Lake forebay elevations for the PA when compared to the No Action Alternative (Figure 8-7). Monthly outflows from Chief Joseph Dam are predicted to be similar to or about 1 percent less than the No Action Alternative for all types of water years (Figure 8-8). Consequently, modeled temperatures under the PA downstream of Chief Joseph Dam are similar to the No Action Alternative with the majority of temperature differences in the ±1 degree Fahrenheit range (Figure 4-8.). In general, temperatures modeled for PA are similar or slightly cooler than the No Action Alternative for most river and climate conditions. An exception is for the low flow/average temperature (LF/AT) scenario where river temperatures in the spring are expected to be up to 1 degree Fahrenheit greater under the PA alternative. Tailwater temperatures under both the PA and No Action Alternative are predicted to exceed the Washington State criterion of 63.5F (17.5°C) as measured by the 7-day average of the daily maximum temperature in August and September. Similar to the No Action Alternative, there is little difference in temperature between Grand Coulee Dam (Figure 8-6) and Chief Joseph Dam (Figure 8-9) under the PA (Table 8-1), showing that water temperatures released from Lake Roosevelt are passed through Rufus Woods Lake unchanged.

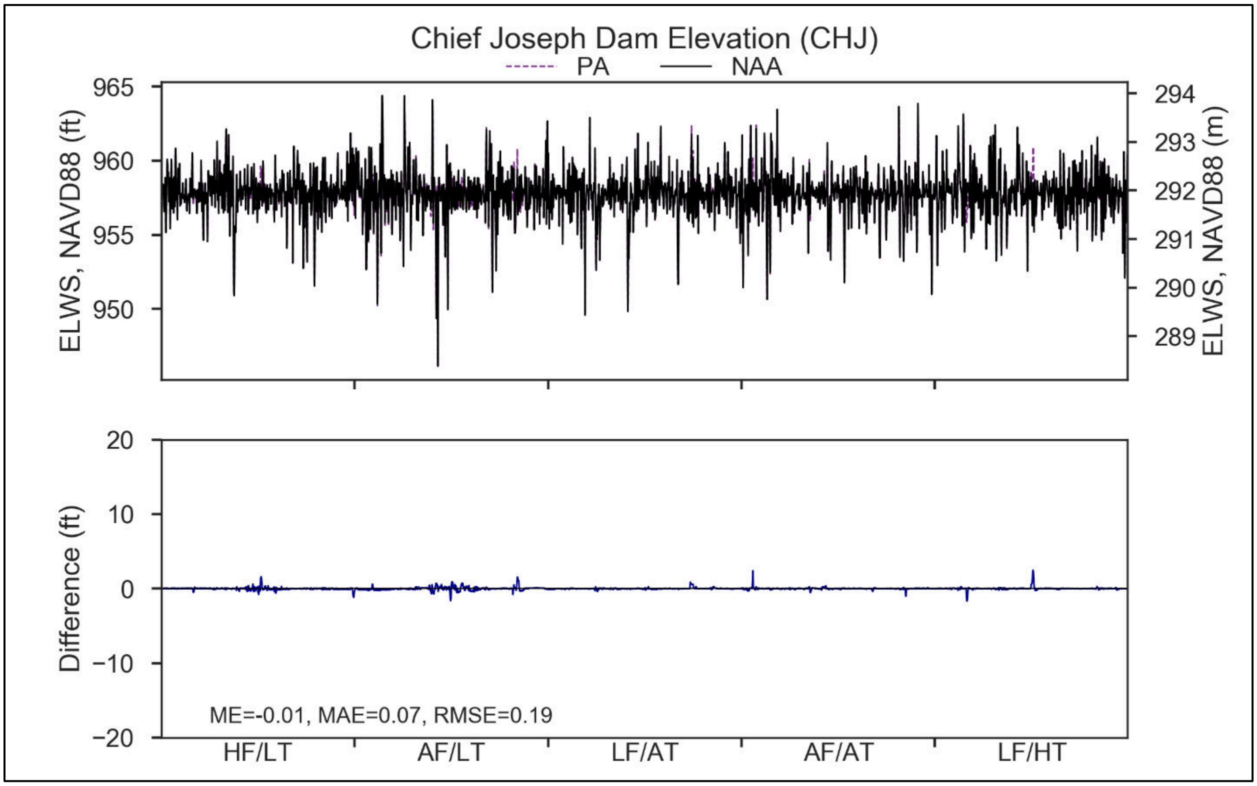


Figure 8-7. Chief Joseph Dam–Rufus Woods Lake Forebay Elevations for Preferred Alternative Versus No Action Alternative

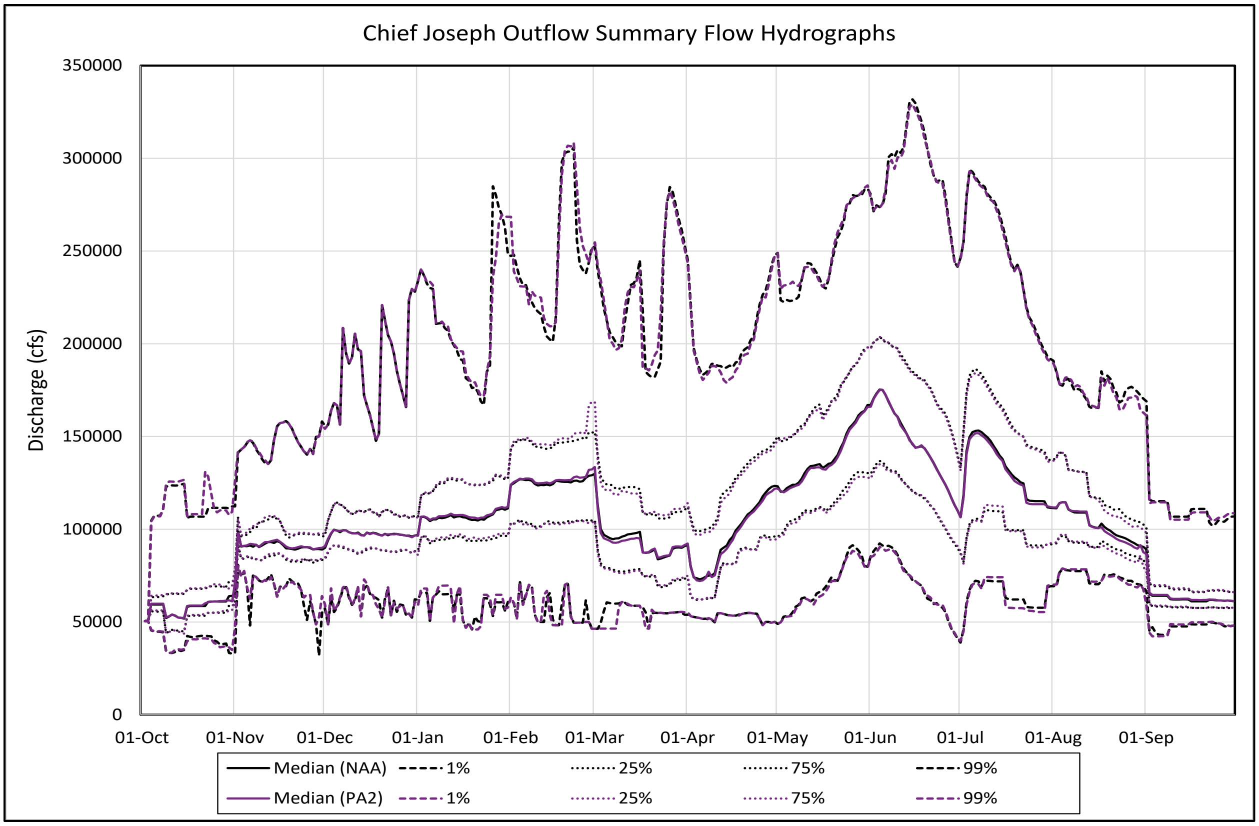


Figure 8-8. Chief Joseph Dam–Rufus Woods Lake Outflows for Preferred Alternative Versus No Action Alternative

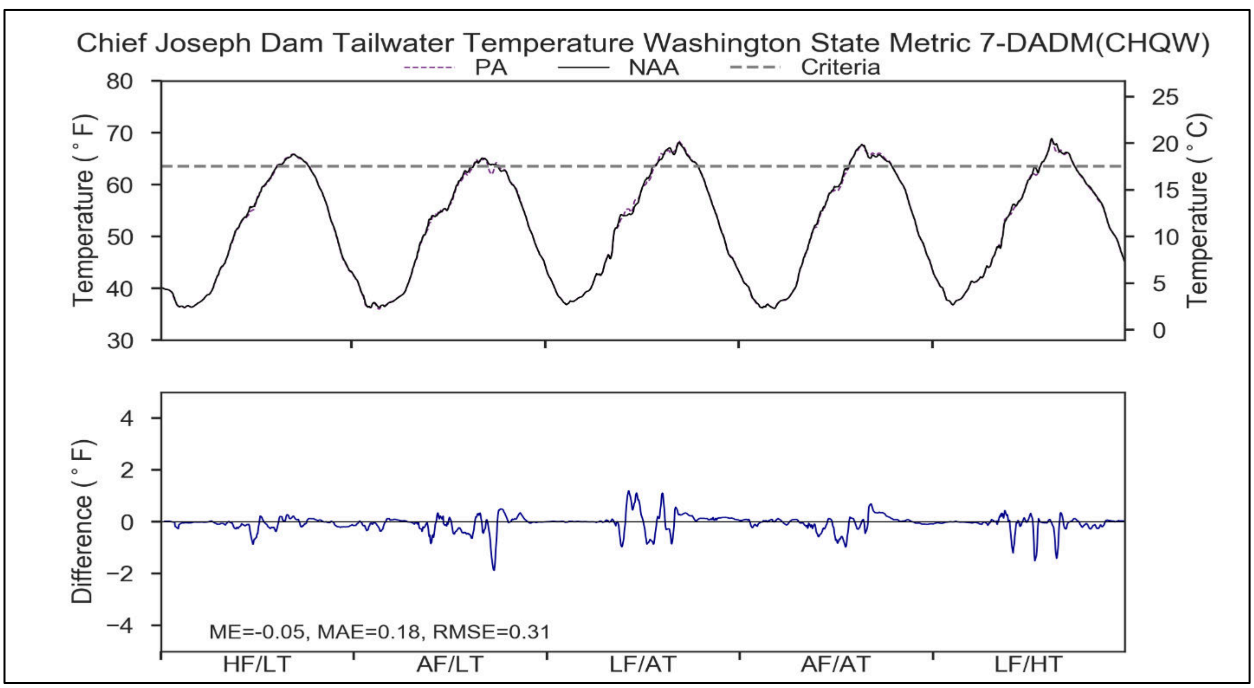


Figure 8-9. Modeled tailwater temperature for Preferred Alternative and No Action Alternative at Chief Joseph Dam Under a 5-year Range of River and Meteorological Conditions

Table 8-1. Difference in Number of Days the Temperature Criteria is Exceeded at the Tailwater Sites of Grand Coulee and Chief Joseph for the Preferred Alternative Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Grand Coulee	June	0	0	0	0	**1**
Grand Coulee	July	0	-3	-4	-2	-2
Grand Coulee	August	0	0	0	0	0
Grand Coulee	September	0	0	0	0	0
Grand Coulee	October	0	**1**	0	0	0
Chief Joseph	July	0	0	-2	0	0
Chief Joseph	August	**1**	**1**	0	0	0
Chief Joseph	September	0	-12	0	0	0
Chief Joseph	October	**1**	**3**	**1**	0	0

8.1.2 Total Dissolved Gas

8.1.2.1 Libby and Hungry Horse Dams and Reservoirs

Libby Dam is typically operated to minimize spill to minimize elevated TDG and related impacts. Under the PA, Libby Dam's draft and refill operations will be modified, resulting in an increase in the highest releases from the dam. This operational change is predicted to increase the chance of spill at Libby Dam. The 80-year period of record flows (1928 to 2008) were used to predict TDG, as presented in Figure 8-10. The model predicts 11 years with spill for PA versus only two years with spill for the No Action Alternative over the 80-year period. However, of those 11 years of spill, only 7 years were predicted to spill enough volume to increase tailwater TDG saturations to greater than 110 percent. The number of days exceeding 110 percent increased from 8 days for the No Action Alternative to 35 days for PA. Although spill from Libby Dam for the 80-year model period is predicted to increase under the PA, the frequency of spill with TDG exceeding 110 percent is still small and effects are considered negligible.

TDG below Hungry Horse Dam under the PA is expected to be relatively similar to the No Action Alternative in most years (Figure 8-11). Spill at Hungry Horse Dam, which is already infrequent, would increase slightly in a few years given the increase in carryover in some dry years due to the *Sliding Scale and Libby and Hungry Horse* measure, but the duration of spill would decrease in most years compared to the No Action Alternative. The PA would results in 64 days exceeding the criterion in a single year. On average, spill would exceed 110% approximately 10 days per year when including years with zero days of spill. Overall, the PA and No Action alternatives are similar in the number of exceedance days; the effects are considered negligible.

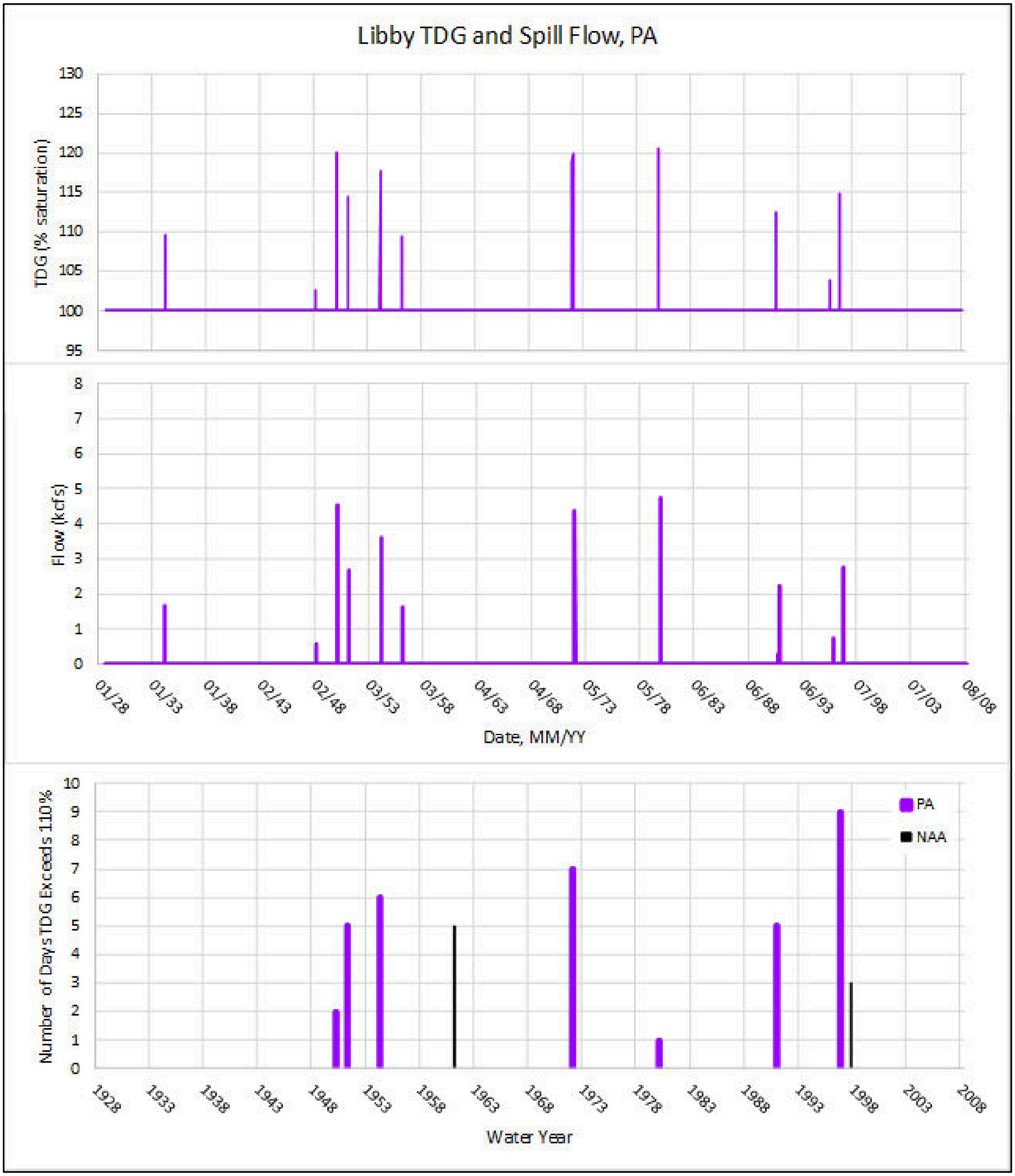


Figure 8-10. Modeled Tailwater Total Dissolved Gas and Spillway Flows for Preferred Alternative, and the Number of Exceedances for the Preferred Alternative and No Action Alternative at Libby Dam over an 80-year period

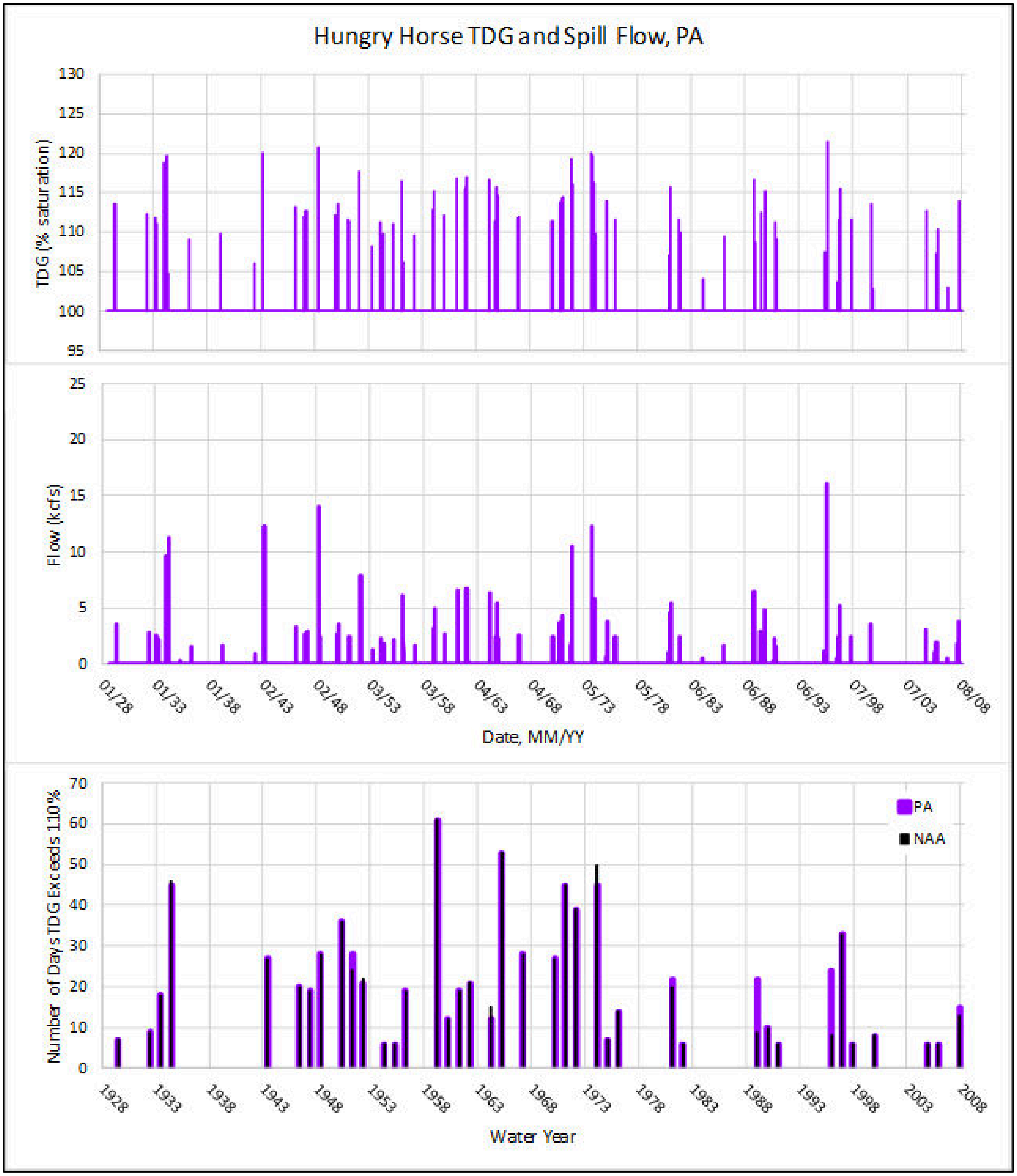
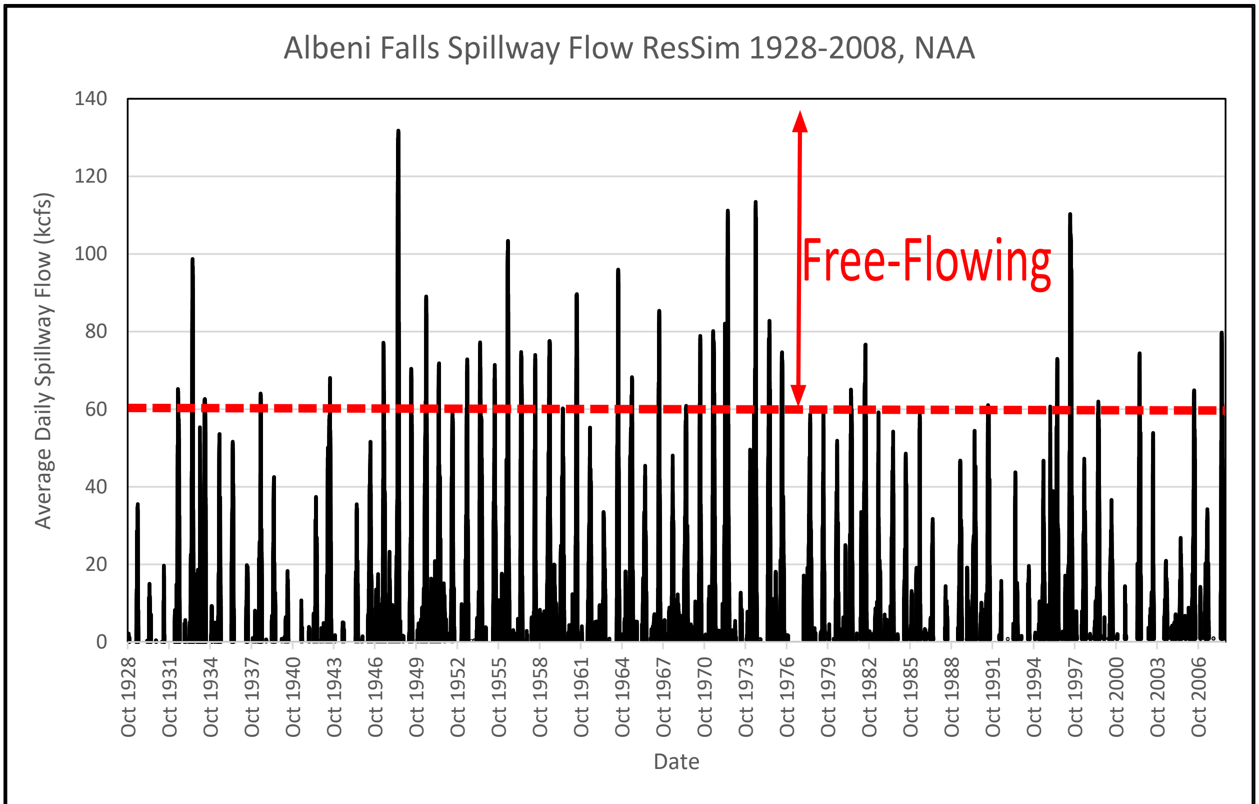


Figure 8-11. Modeled Tailwater Total Dissolved Gas and Spillway Flows for Preferred Alternative, and the Number of Exceedances for the Preferred Alternative and No Action Alternative at Hungry Horse Dam over an 80-year period

8.1.2.2 Albeni Falls Dam and Reservoir

TDG in the Pend Oreille River upstream of Albeni Falls Dam can be greater than 110 percent largely because of spillway releases from Cabinet Gorge Dam located on the Clark Fork River about 55 miles upstream of Albeni Falls Dam. During most years, Albeni Falls Dam spills during high-flow spring runoff. In general, when spill is spread evenly across the spillway, spillway discharges up to about 10 kcfs can increase TDG saturations over forebay levels by about 1 to 2 percent, while spill between 10 to 50 kcfs can increase TDG saturations downstream of Albeni Falls by about 5 to 9 percent. When Pend Oreille River flows exceed about 50 to 60 kcfs, Albeni Falls Dam powerhouse operations are suspended and the spillway gates are raised, allowing the river to flow relatively un-impounded across the dam. Under these high-flow conditions Albeni Falls Dam produces no TDG as the river is essentially free flowing. Spillway flows at Albeni Falls Dam were modeled under the PA and the No Action Alternative for the 80-year period from 1928 to 2008 (Figure 8-12). In general, there were no differences in spillway flows under the PA and the No Action Alternative. For both alternatives, spillway flows were predicted to range between 1 and 50 kcfs in nearly every year at Albeni Falls Dam, with many years having spill exceed about 60 kcfs, resulting in free-flowing conditions. The similar spillway flows under the PA and No Action Alternative are expected to result in no change in TDG saturations downstream of Albeni Falls Dam.



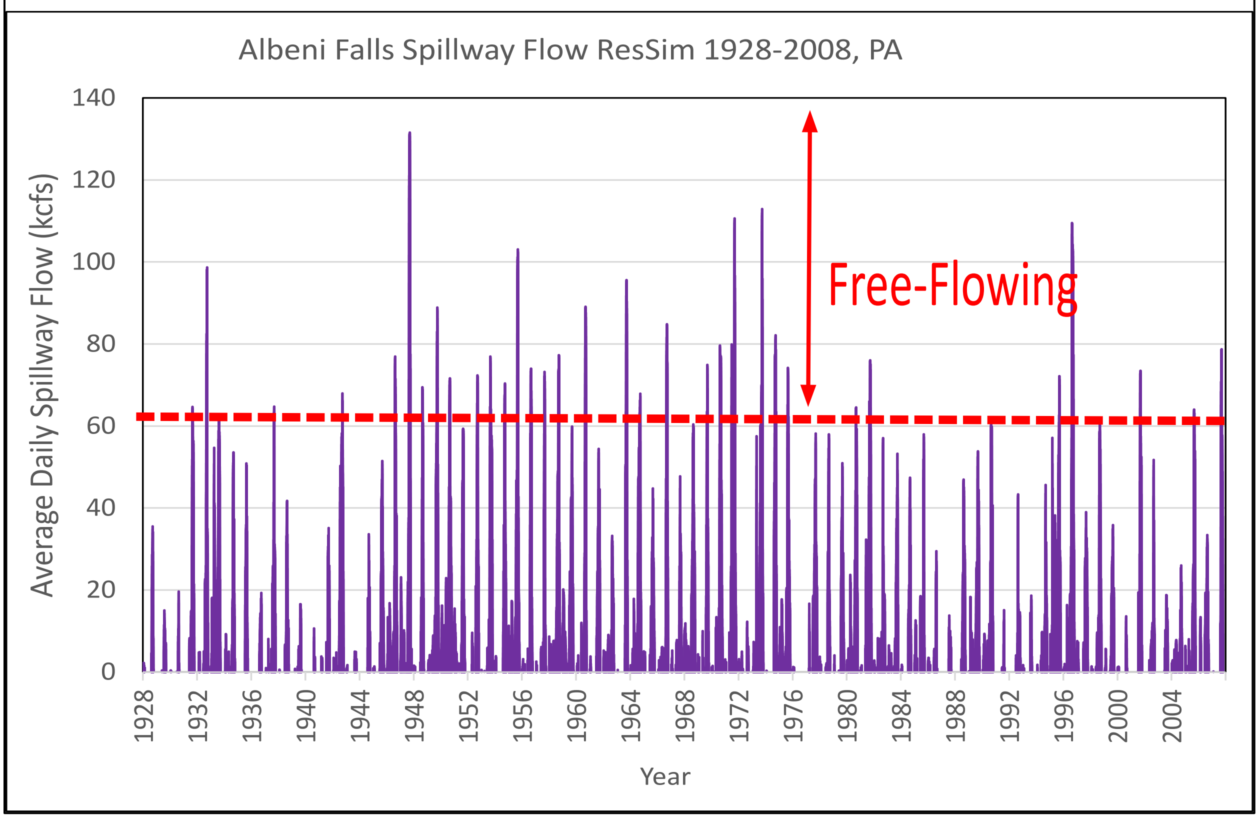


Figure 8-12. Modeled Tailwater Spillway Flows for Preferred Alternative and No Action Alternative at Albeni Falls Dam over an 80-year Period

8.1.2.3 Grand Coulee and Chief Joseph Dams and Reservoirs

The *Update System FRM Calculation, Planned Draft Rate at Grand Coulee, Fall Operational Flexibility for Hydropower (Grand Coulee),* and *Lake Roosevelt Additional Water Supply* measures relate directly to Grand Coulee Dam under the PA, and all of these (with the exception of *Lake Roosevelt Additional Water Supply*) would influence reservoir elevations at Lake Roosevelt. Operational changes in Region A (upstream) may also have a slight effect on Lake Roosevelt water levels. The *Grand Coulee Maintenance Operations* measure would not impact reservoir elevations or total outflows, but would affect power generation, frequency of spill, and potentially TDG generation.

Under the PA, TDG downstream of Grand Coulee Dam ranges from 95% to 125%; historically TDG in excess of 125% has been recorded and is still a possibility under the PA depending on inflowing TDG and flow conditions. The *Grand Coulee Maintenance Operations* and *Planned Draft Rate at Grand Coulee* measures, could affect TDG below the dam, but these measures tend to partially offset each other in this analysis. In general, these measure result in TDG very similar to the No Action Alternative (Figure 8-13). These differences are considered negligible.

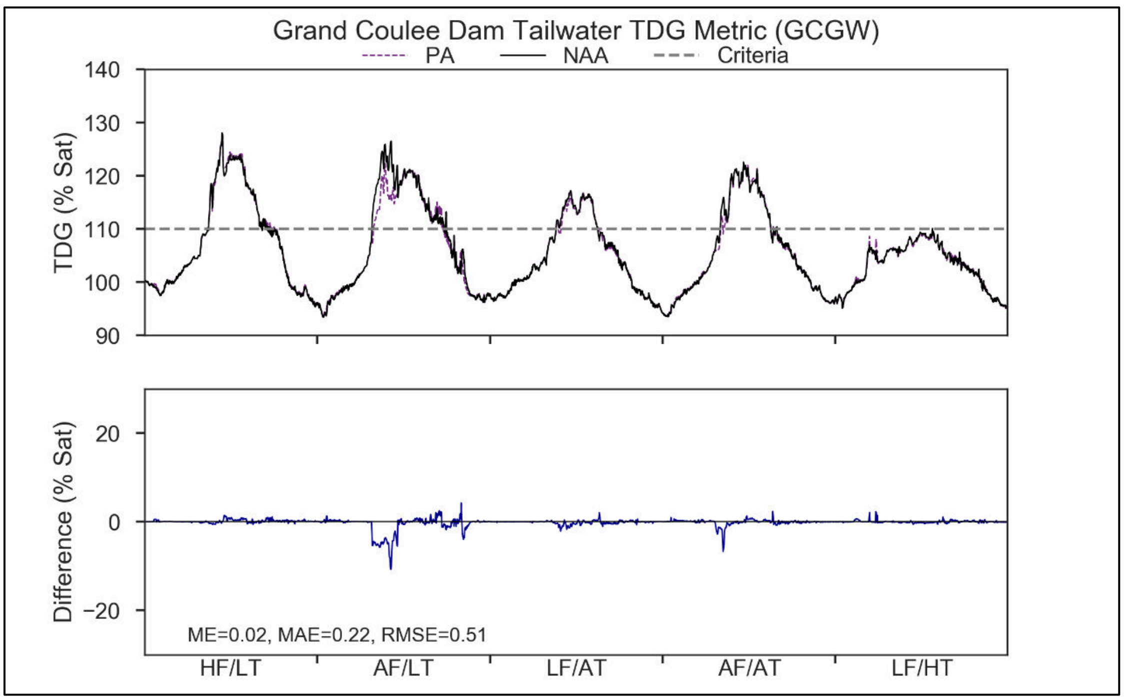


Figure 8-13. Modeled Tailwater Total Dissolved Gas saturations for Preferred Alternative and No Action Alternative at Grand Coulee Dam Under a 5-year Range of River and Meteorological Conditions

TDG at the forebay of Chief Joseph Dam is largely a function of the TDG released upstream from Lake Roosevelt and Grand Coulee Dam, because little degassing occurs in Rufus Woods Lake. High inflowing TDG to Lake Roosevelt from Canada, as well as spill from Grand Coulee Dam via the outlet tubes, can increase TDG saturations in Rufus Woods Lake at the Chief Joseph Dam forebay to over 130 percent. During periods when incoming TDG levels are above approximately 120 percent, spilling at Chief Joseph Dam over the spillway deflectors can degas the water and reduce downstream system TDG loading. Therefore, Chief Joseph Dam is often used to help manage overall system TDG production in the mainstem Columbia River. In addition, to avoid spilling through the outlet tubes at Grand Coulee Dam, spill is often shifted from Grand Coulee to Chief Joseph Dam to take advantage of the lower TDG produced by spilling over the deflectors. These operational strategies are expected to continue under the PA.

Chief Joseph Dam TDG saturations at the forebay and tailwater modeled under the PA for a range of flow and meteorological conditions were compared to the No Action Alternative Figure 8-14 and Figure 8-15). In general, predicted PA forebay TDG saturations are similar to the No Action Alternative for the different flow and air temperature conditions. Tailwater TDG saturations under the PA are predicted to be both lower and higher than the No Action Alternative depending on flow and meteorological conditions. The number of days the tailwater exceeds the 110 percent TDG criteria is predicted to be similar between the No Action Alternative and PA for all flow and meteorological conditions (Figure 8-16, Table 8-2, and Table 8-3). Decreased TDG saturations between the forebay and tailwater during high-flow and high-spill years (HF/LT) modeled under the No Action Alternative would continue under the PA. It is expected that under PA, Chief Joseph Dam would continue to decrease TDG during years when elevated TDG saturations occur in the forebay. TDG impacts at Chief Joseph Dam are expected to be negligible.

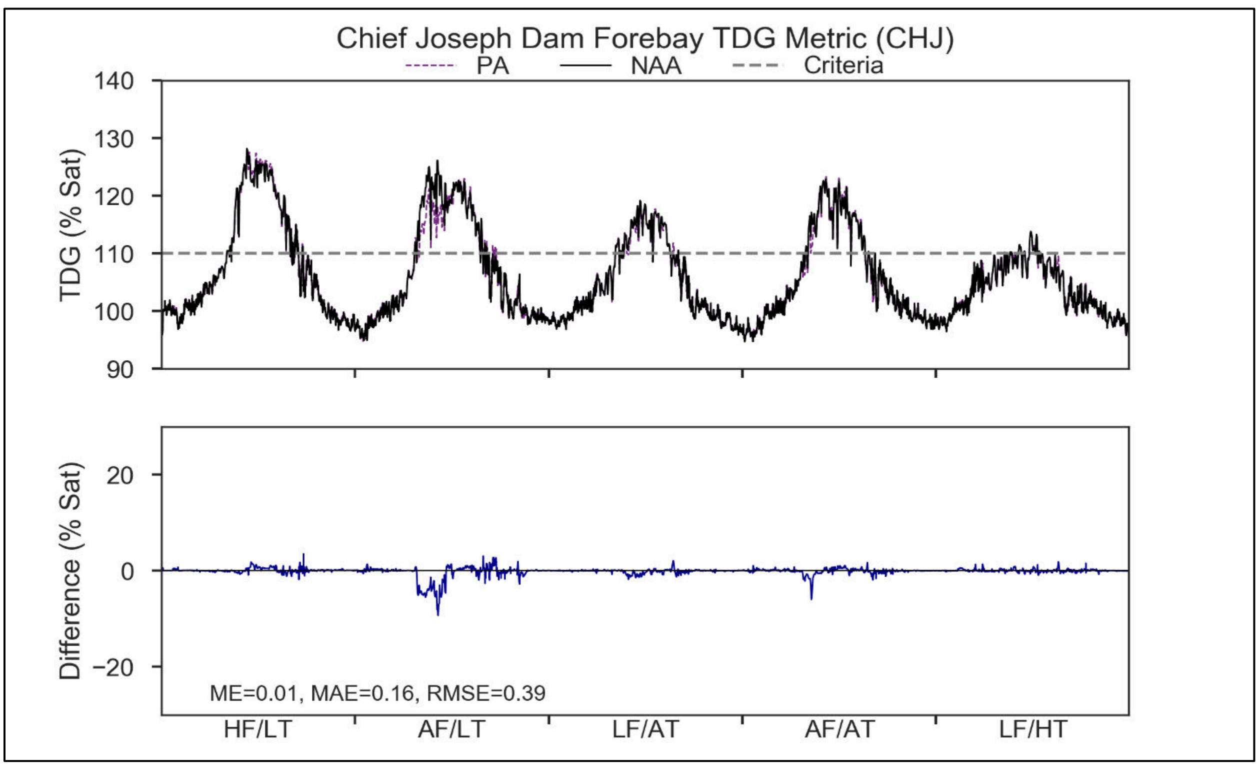


Figure 8-14. Modeled Forebay Total Dissolved Gas saturations for Preferred Alternative and No Action Alternative at Chief Joseph Dam Under a 5-year Range of River and Meteorological Conditions

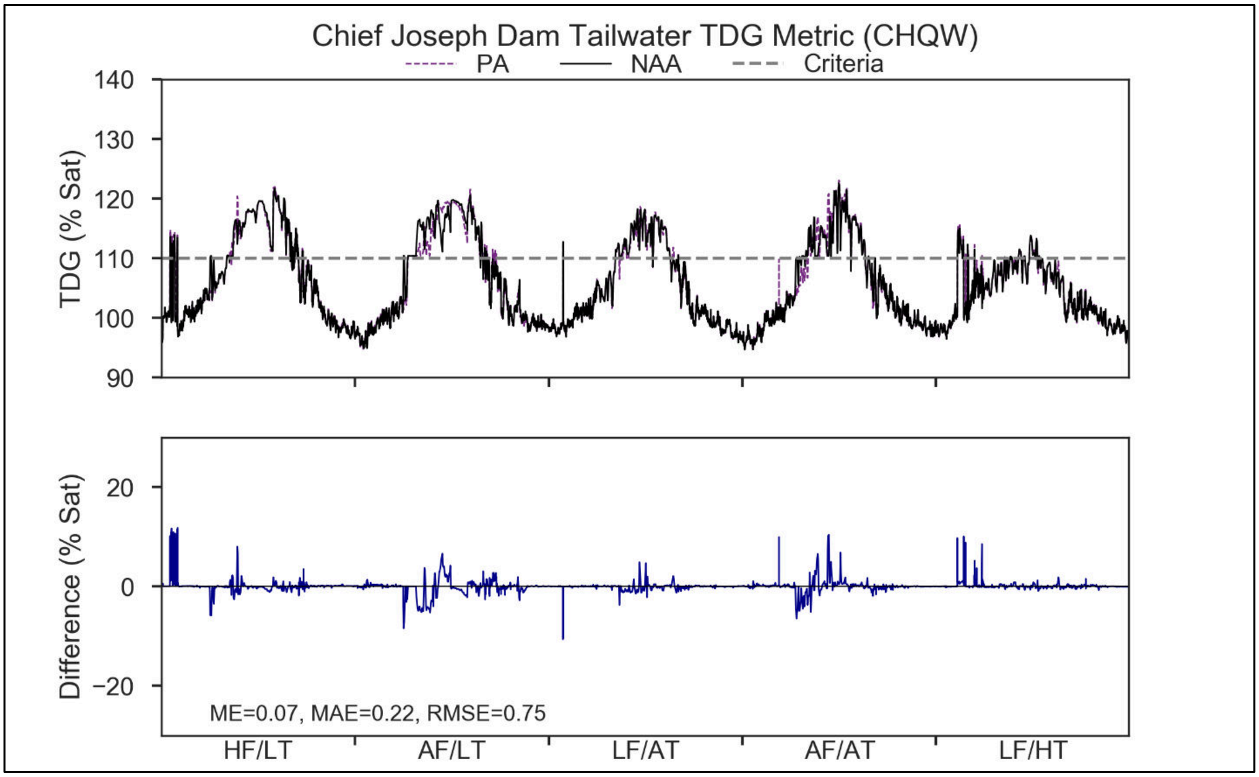


Figure 8-15. Modeled Tailwater Total Dissolved Gas saturations for Preferred Alternative and No Action Alternative at Chief Joseph Dam Under a 5-year Range of River and Meteorological Conditions

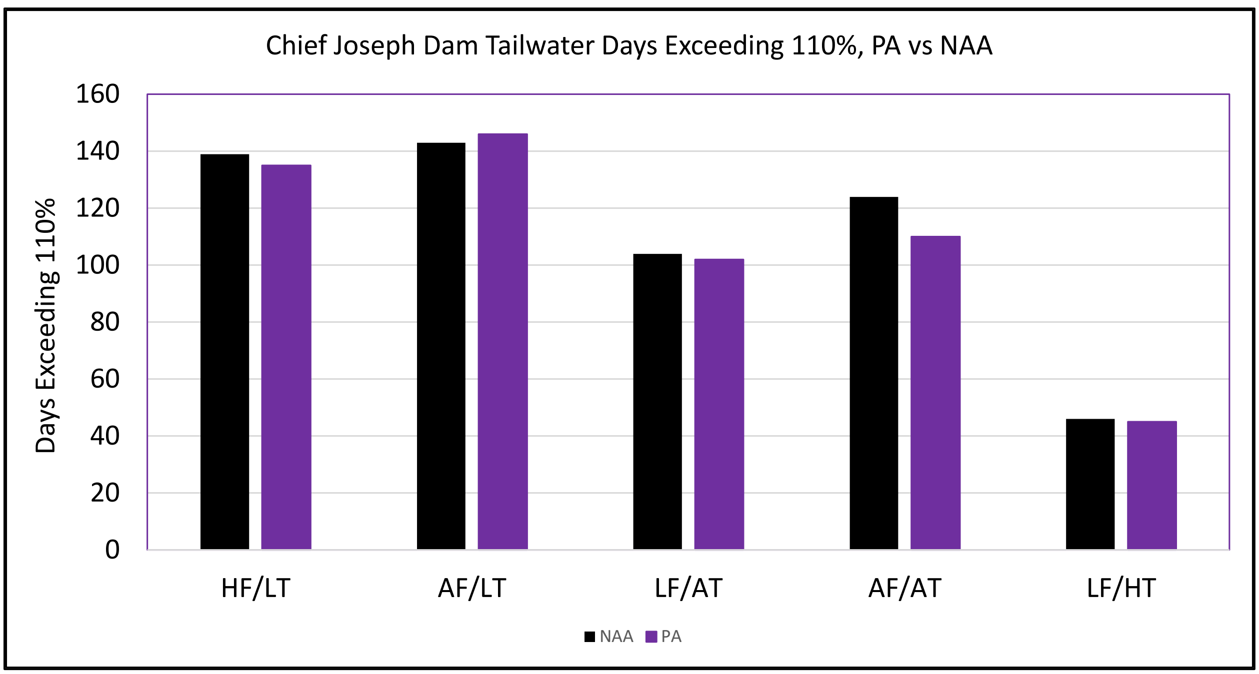


Figure 8-16. Days Exceeding the 110 percent Total Dissolved Gas Criteria for Preferred Alternative and No Action Alternative at Chief Joseph Dam Tailwater Under a 5-year Range of River and Meteorological Conditions

Table 8-2. Difference in Number of Days the TDG Criteria is Exceeded at the Forebay Sites of Grand Coulee and Chief Joseph for the Preferred Alternative Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Grand Coulee	April	0	**3**	0	0	0
Grand Coulee	May	**1**	**2**	0	0	0
Grand Coulee	June	-4	**1**	**2**	**3**	0
Grand Coulee	July	0	-4	**1**	**6**	0
Grand Coulee	August	**2**	**3**	0	0	0
Grand Coulee	September	0	0	0	0	0
Chief Joseph	April	0	-1	0	-1	0
Chief Joseph	May	0	-1	-3	-1	-1
Chief Joseph	June	0	0	0	0	-1
Chief Joseph	July	0	0	0	0	-2
Chief Joseph	August	0	0	**4**	-1	0
Chief Joseph	September	-1	**4**	0	0	0
Chief Joseph	October	0	0	0	0	0

Table 8-3. Difference in Number of Days the TDG Criteria is Exceeded at the Tailwater Sites of Grand Coulee and Chief Joseph for the Preferred Alternative Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Grand Coulee	April	0	-4	0	0	0
Grand Coulee	May	0	0	-5	-3	0
Grand Coulee	June	0	0	0	0	0
Grand Coulee	July	0	0	0	0	-1
Grand Coulee	August	0	0	**2**	-2	0
Grand Coulee	September	**6**	-2	0	0	0
Grand Coulee	October	**2**	0	0	0	0
Chief Joseph	January	**2**	0	0	0	0
Chief Joseph	February	0	0	0	0	1
Chief Joseph	March	0	0	0	0	**1**
Chief Joseph	April	-3	-2	0	-11	0
Chief Joseph	May	-1	0	-7	-2	-1
Chief Joseph	June	0	0	0	0	-1
Chief Joseph	July	0	0	0	0	-2

8.1.3 Other Physical, Chemical and Biological Processes

8.1.3.1 Libby and Hungry Horse Dams and Reservoirs

The PA modifies operations at Libby Dam resulting in changes in the drafting depth and refill elevations of Lake Koocanusa that may impact physical, chemical, and biological water quality parameters when compared to the No Action Alternative. The PA reservoir elevations and outflows during median and high water supply years will be relatively similar to the No Action Alternative, and water quality changes are not anticipated. However, for low water supply years, the reservoir would be drafted deeper with mid-April water elevations up to 8 feet lower in the driest 40 percent of years. Reservoir refill and summer pool elevations for all water supply years are improved over the No Action Alternative with the reservoir reaching full pool by the end of July and maintaining higher elevations (about 1 to 4 feet higher) in August and September. For water quality concerns, of particular interest are the 8 foot lower mid-April water elevations for low water supply years because they equate to less volume of water in Lake Koocanusa during the spring runoff and a shorter water retention time.

Retention time, which is the inverse of the flushing rate, refers to the length of time water remains in a waterbody. Water quality chemical and biological parameters of concern in Lake Koocanusa that may be impacted by changes in the reservoir elevation and retention times, under the PA, include suspended sediments, nutrients such as phosphorus and nitrogen, metals such as selenium, and phytoplankton such as cyanobacteria and diatoms. It is possible that shorter retention times may allow certain chemical constituents in inflowing waters to move farther down-reservoir toward the forebay and outflow before settling out or transforming.

Historical data show that Lake Koocanusa is a sink for phosphorus and sediments, with up to 93 percent of inflow total phosphorus retained in the reservoir (Yassien and Ward 2018). Under the PA, the lower reservoir elevations for the driest 40 percent of years may allow sediments and total phosphorus from the inflow to move farther down-reservoir. Conversely, Lake Koocanusa does not appear to be a sink for nitrogen with most of the inflow nitrate passing down-reservoir to the forebay and Kootenai River.

Increased nitrate loadings to Lake Koocanusa, largely due to coal mining operations in British Columbia, and low phosphorus concentrations have created a large imbalance in the nitrogen-to-phosphorus ratio resulting in strong phosphorus limitation. Despite rising nitrate concentrations in Lake Koocanusa, phytoplankton blooms appear to have been kept in check by the strong phosphorus limitation under existing conditions and the No Action Alternative. It is possible that the operational changes proposed for the PA may increase total phosphorus concentrations in Lake Koocanusa, which could result in changes in phytoplankton densities and functional types. However, these changes in retention times are small and only occur during more extreme water years (low water supply), which likely would reduce potential nutrient and phytoplankton impacts from PA on Lake Koocanusa.

Increasing selenium concentrations over the next 25 years in Lake Koocanusa from coal mining operations in British Columbia are a concern and were previously discussed for the No Action Alternative. Although there does not yet appear to be an increasing trend in water column selenium concentrations in the reservoir, there is concern that without water quality treatment, the continued selenium loadings to Lake Koocanusa may lead to additional selenium contamination. It is possible that the lower mid-April reservoir elevations for the driest 40 percent of years under PA may alter the movement, cycling, and transformation of selenium in the reservoir and downstream in the Kootenai River, possibly resulting in water and sediment quality impacts.

Low water year reservoir elevations under the PA would be up to 8 feet lower in the spring, but mid-June through September growing season reservoir elevations would be 1 to 4 feet higher as compared to the No Action Alternative. As such, Lake Koocanusa should not experience substantial changes to in-lake productivity under the PA. Additionally, changes in the median average monthly outflows from Libby Dam during the mid-June through September time frame are relatively minor (reduction of 5 to 8 percent when compared to the No Action Alternative), which result in only about a 0.3-foot decrease in median monthly elevation in the Kootenai River downstream of Libby Dam, and should not greatly impact the varial (periodically wetted) zone productivity. Overall, changes to water quality in Lake Koocanusa are anticipated to be negligible under the PA.

As previously stated, there no known sources of contamination in Hungry Horse Reservoir or in the South Fork of the Flathead River. Based on the very minor changes to operations at Hungry Horse there are no anticipated changes to water quality conditions anticipated under the PA as compared to the No Action Alternative.

8.1.3.2 Albeni Falls Dam and Reservoir

Under the PA, there are no changes to operations at Albeni Falls Dam. The physical, chemical, and biological water quality of Lake Pend Oreille and the Pend Oreille River described under the No Action Alternative are expected to remain unchanged.

8.1.3.3 Grand Coulee and Chief Joseph Dams and Reservoirs

Turbidity from mass wasting, such as small local landslides, within Lake Roosevelt, is correlated to the rate of drawdown and refill at Grand Coulee Dam. The operational measure to decrease the *Planned Draft Rate at Grand Coulee* changes the target maximum drawdown from 1.0 ft/day to a target of 0.8 ft/day. A slower drawdown rate may result in lower turbidity throughout the reservoir.

Water level fluctuations in Lake Roosevelt may have an impact on mercury cycling within the reservoir, especially when the lowest lake levels occur from April through June. As previously stated, studies have suggested that methylmercury has a greater probability of entering the food web. Under the PA, the *Update System FRM Calculation*, *Planned Draft Rate at Grand Coulee*, and *Fall Operational Flexibility for Hydropower* measures are all predicted to influence

Lake Roosevelt water surface elevations. However, as shown in Figure 8-17, changes in water surface elevation are small and are not predicted to impact mercury cycling. Overall, impacts to water quality within Lake Roosevelt are anticipated to be negligible as compared to the No Action Alternative.

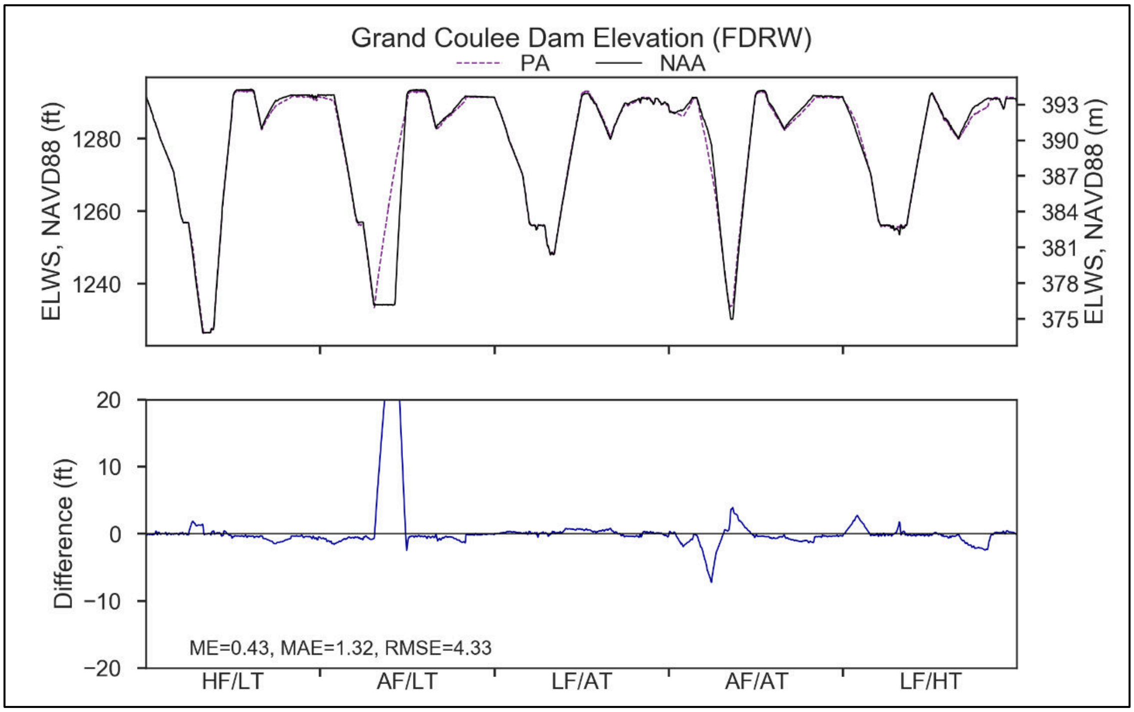


Figure 8-17. Modeled Forebay Elevations for the No Action Alternative and the Preferred Alternative at Grand Coulee Dam Under a 5-Year Range of River and Meteorological Conditions

Under the PA, only minor changes to operations, reservoir elevations, and flows at Chief Joseph Dam are expected. Given this, the physical, chemical, and biological water quality of Rufus Woods Lake and the Columbia River downstream of Chief Joseph Dam under the PA are expected to remain relatively unchanged from the No Action Alternative. The harmful algae blooms at this location, as described in the No Action Alternative (Section 3.1.3), would continue in the future under the PA.

8.2 LOWER SNAKE RIVER BASIN

Under the PA, a slightly deeper draft in the Dworshak Dam reservoir would occur between January and March during years with a higher flow forecast. Additional spill up to 125% would occur at the four lower Snake River projects from the beginning of April through the third week of June. Structural measures that include adult fish trap modifications at Lower Granite Dam and installation of entrance weir caps at each of the four lower Snake River dams are not anticipated to affect water quality conditions in the river.

The reservoir elevation differences that would occur at Dworshak Reservoir under the PA are shown in Figure 8-18. The largest difference would occur during January and February of a HF/LT (high flow/lower air temperature) year when the reservoir would be lower by a maximum of about 9 feet. Average January and February differences during the same flow and air temperature conditions would be 7.1 and 4.9 feet, respectively. The maximum and average differences during the other four flow and air temperature conditions would only range from 0.0 to 0.3 feet. Smaller elevation changes would occur during March ranging from a maximum of 1.2 to 1.6 feet during HF/LT, AF/LT, and LF/HT conditions. Average differences during the same month and conditions would range from 0.1 to 0.5 feet. Maximum and average conditions during LF/AT and AF/LT would be zero.

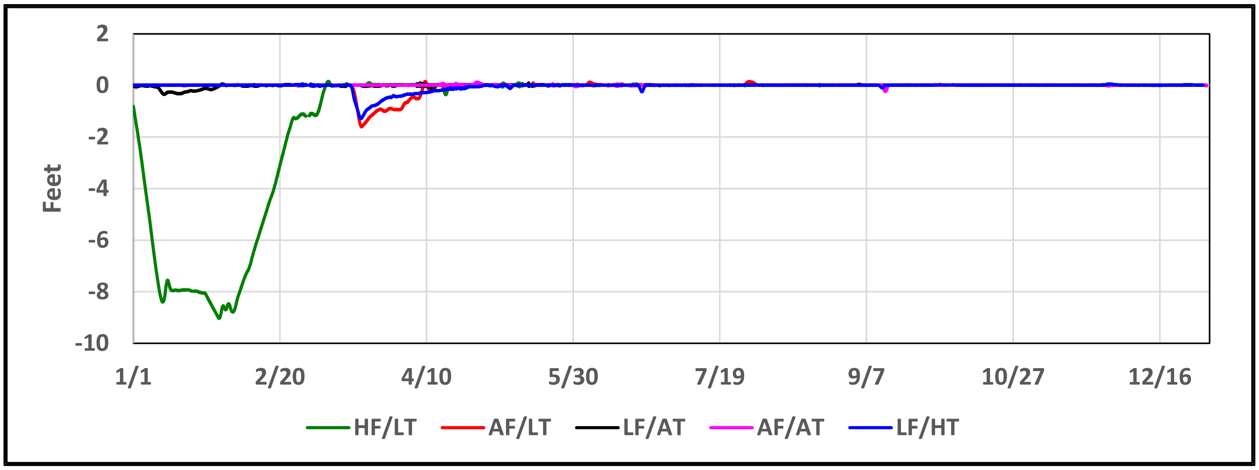


Figure 8-18. Differences Between Dworshak Reservoir Pool Elevations for the Preferred Alternative and the No Action Alternative for the 5-Year Range of Flow and Meteorological Conditions Modeled

8.2.1 Water Temperature

8.2.1.1 Dworshak Dam and Reservoir

Outflow water temperatures from Dworshak Dam under the PA would be very similar to No Action Alternative conditions (Figure 8-19). Daily average and maximum temperatures would be less than 52°F throughout the year. The average monthly temperature differences between January and September would not exceed 0.1°F (Table 8-4). Maximum daily differences could reach 1.7°F during February of a HF/LT year and 0.8°F during February, March, and April of a AF/AT year, but each of these events would only last one day.

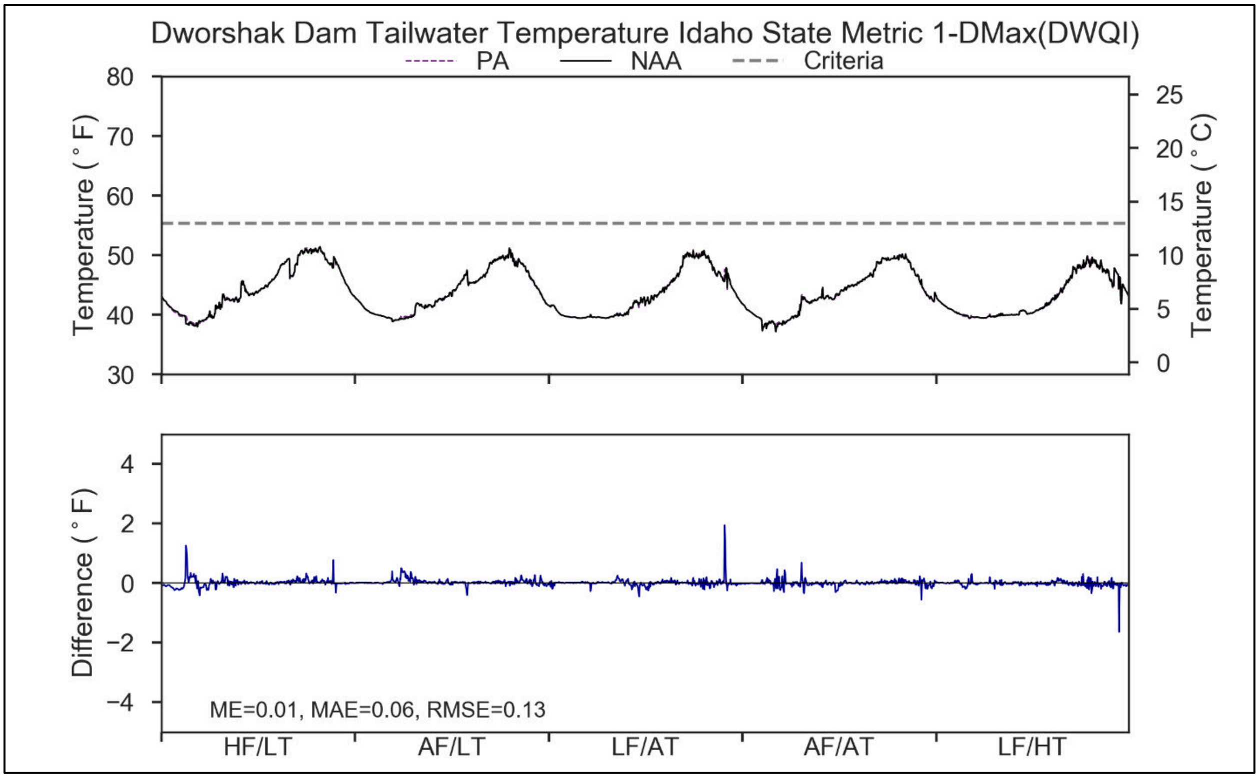


Figure 8-19. Modeled Tailwater Temperature for the Preferred Alternative and No Action Alternative at Dworshak Dam Under a 5-year Range of River and Meteorological Conditions

Table 8-4. Monthly Average Temperature Differences (°F) Between the Preferred Alternative and the No Action Model Results at Dworshak Dam for Five Flow and Meteorological Conditions

MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
January	**-0.1**	0.0	0.0	0.0	0.0
February	0.1	0.0	0.0	0.0	0.0
March	**-0.1**	**0.1**	0.0	0.0	0.0
April	0.0	**0.1**	0.0	0.0	0.0
May	0.0	0.0	**0.1**	0.0	0.0
June	0.0	0.0	**-0.1**	0.0	0.0
July	0.0	0.0	-0.1	0.0	0.0
August	0.0	0.0	0.0	0.0	**0.1**
September	**0.1**	0.0	0.0	0.0	0.0

8.2.1.2 Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams and Reservoirs

Water temperatures in the lower Snake River under the PA would be very similar to the No Action Alternative (Figure 8-20 through Figure 8-23). Maximum daily temperatures would be less than 68°F most of the time between April and September downstream of Lower Granite Dam. The two exceptions would occur during LF/AT and LF/HT conditions when maximum temperatures would reach 68.8°F and 70.2°F, respectively. Maximum daily temperatures would increase downstream and range from 70.1°F to 73.4°F during July and August. However, the average monthly differences under the PA would be cooler than the No Action Alternative at all four projects with the largest differences occurring in July and August (Figure 8-24). The number of days when water temperatures would exceed 68°F would be similar under the PA as compared to the No Action Alternative (Table 8-5). Overall, water temperature impacts are expected to be negligible under the PA.

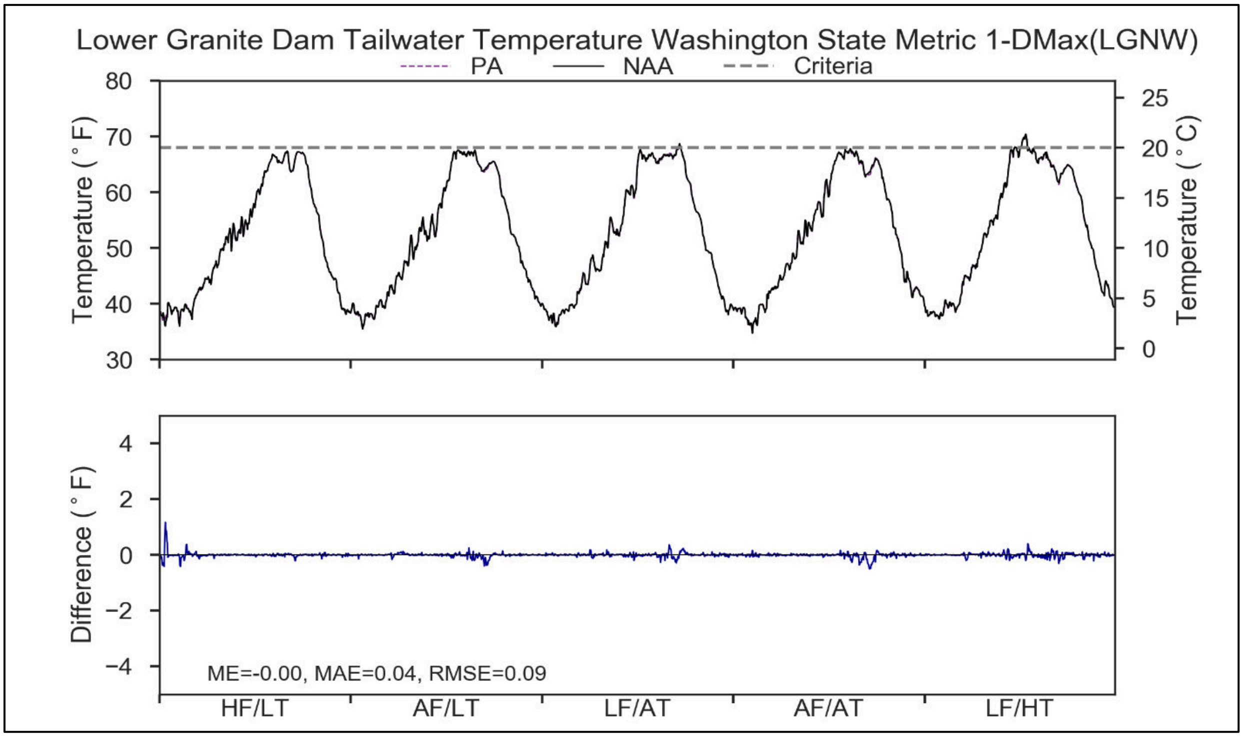


Figure 8-20. Modeled Tailwater Temperatures for the Preferred Alternative and No Action Alternative at Lower Granite Dam Under a 5-year Range of River and Meteorological Conditions

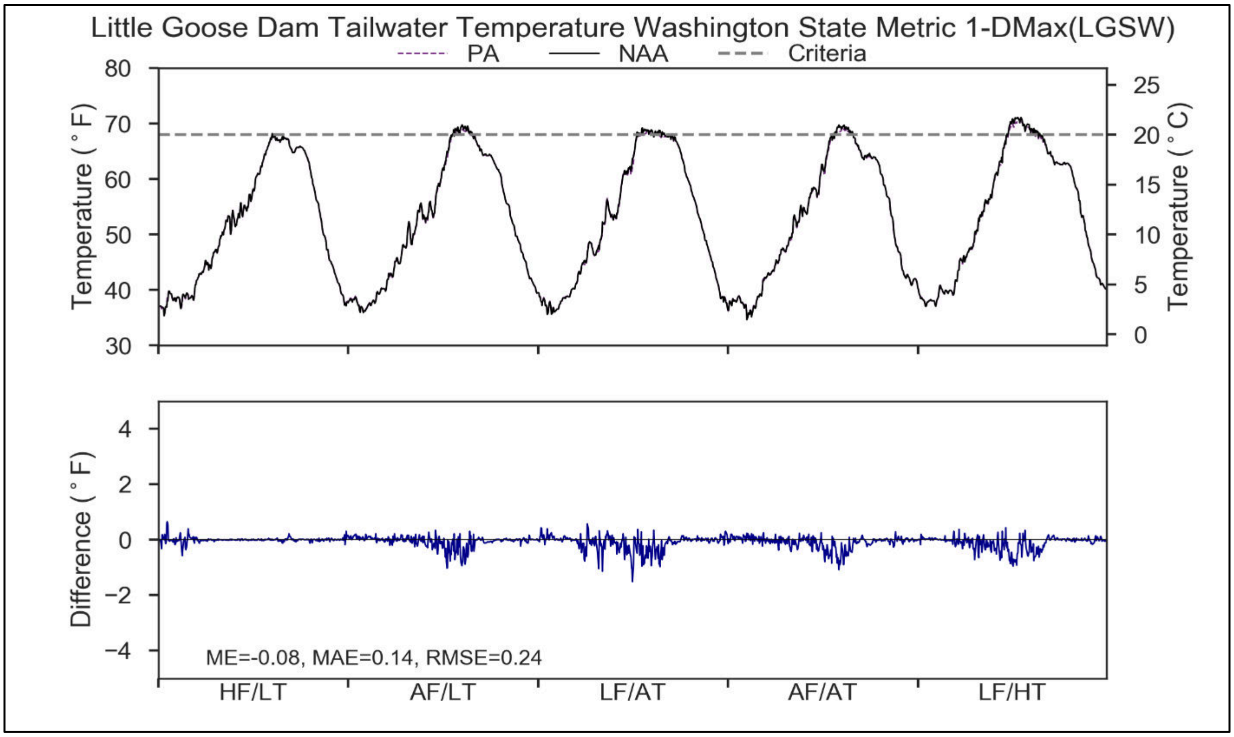


Figure 8-21. Modeled Tailwater Temperatures for the Preferred Alternative and No Action Alternative at Little Goose Dam Under a 5-year Range of River and Meteorological Conditions

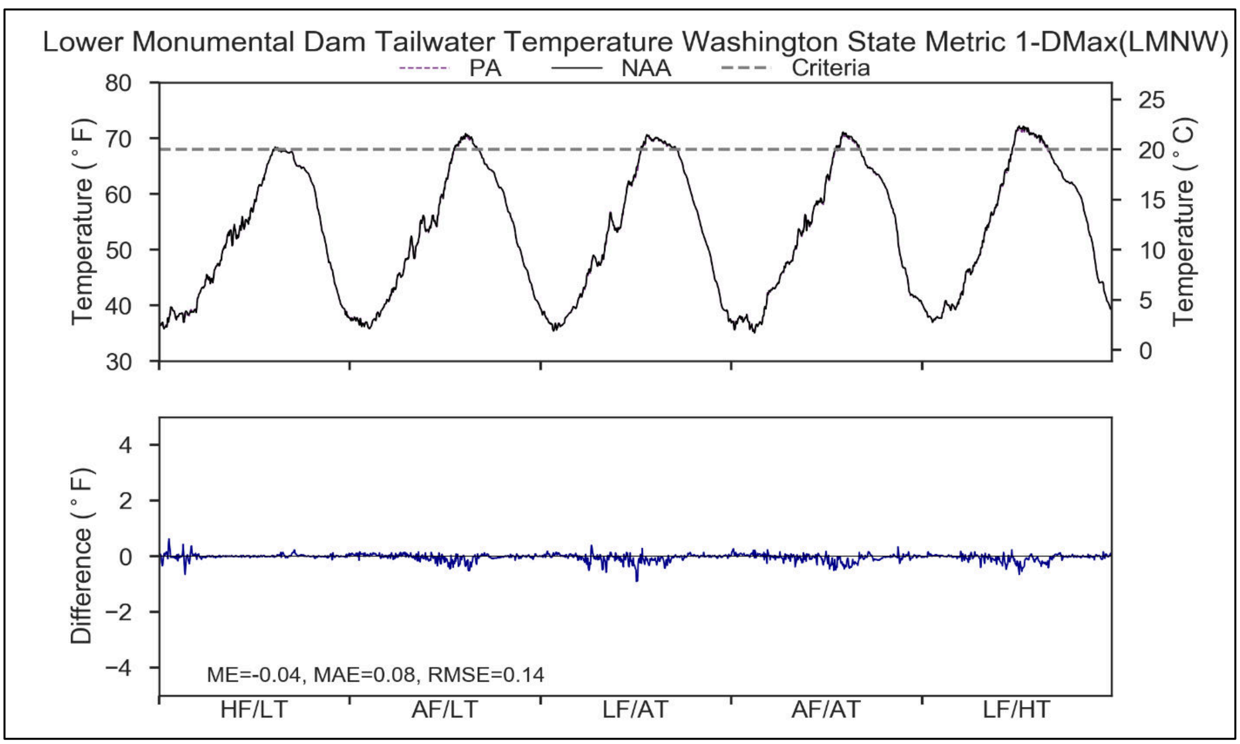


Figure 8-22. Modeled Tailwater Temperatures for the Preferred Alternative and No Action Alternative at Lower Monumental Dam Under a 5-year Range of River and Meteorological Conditions

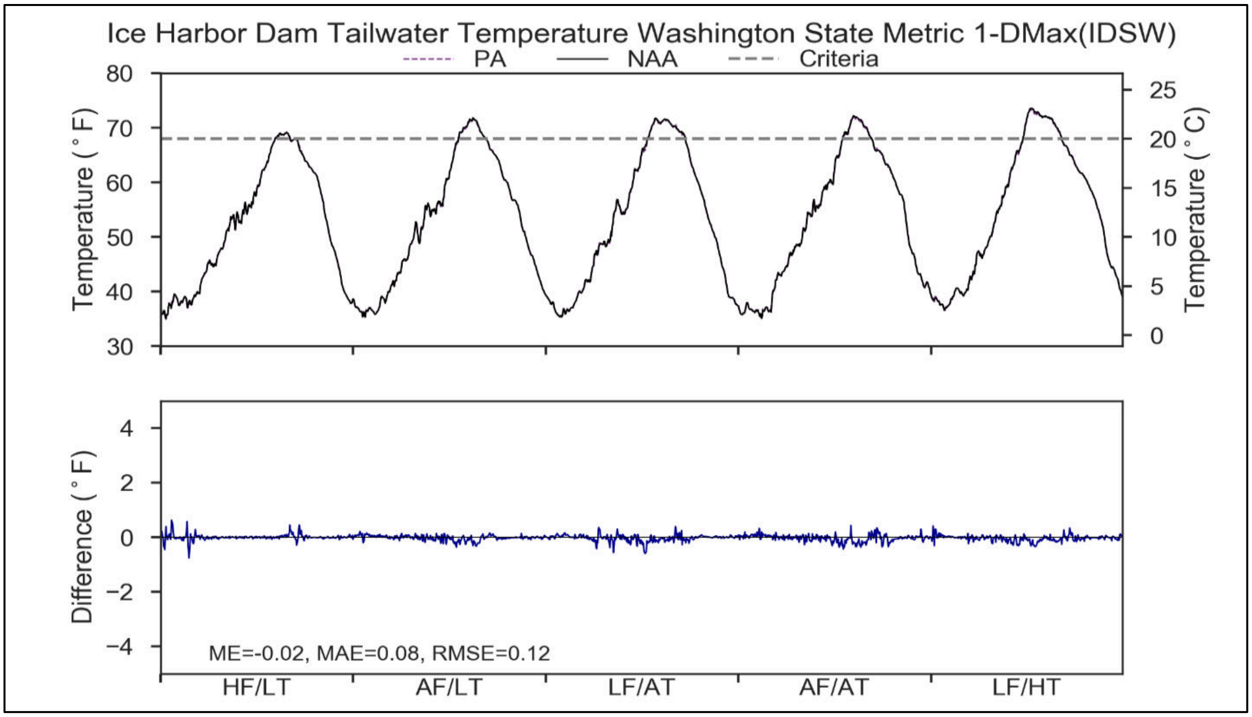


Figure 8-23. Modeled Tailwater Temperatures for the Preferred Alternative and No Action Alternative at Ice Harbor Dam Under a 5-year Range of River and Meteorological Conditions

Table 8-5. Difference in Number of Days the Temperature Criteria is Exceeded at the Tailwater Sites of Lower Granite, Little Goose, Lower Monumental, and Ice Harbor for the Preferred Alternative Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Lower Granite	June	0	0	0	0	0
Lower Granite	July	0	0	0	0	**2**
Lower Granite	August	0	0	0	0	0
Lower Granite	September	0	0	-1	0	0
Little Goose	June	0	0	0	0	-1
Little Goose	July	0	-1	-4	-4	0
Little Goose	August	0	-2	-16	-1	-5
Little Goose	September	0	0	0	0	0
Lower Monumental	June	0	0	0	0	0
Lower Monumental	July	0	-2	0	-2	0
Lower Monumental	August	**1**	0	0	0	0
Lower Monumental	September	0	**1**	0	0	-1
Ice Harbor	June	0	0	0	0	0
Ice Harbor	July	0	0	-1	-1	0
Ice Harbor	August	0	0	0	0	0
Ice Harbor	September	0	**1**	-1	**2**	0

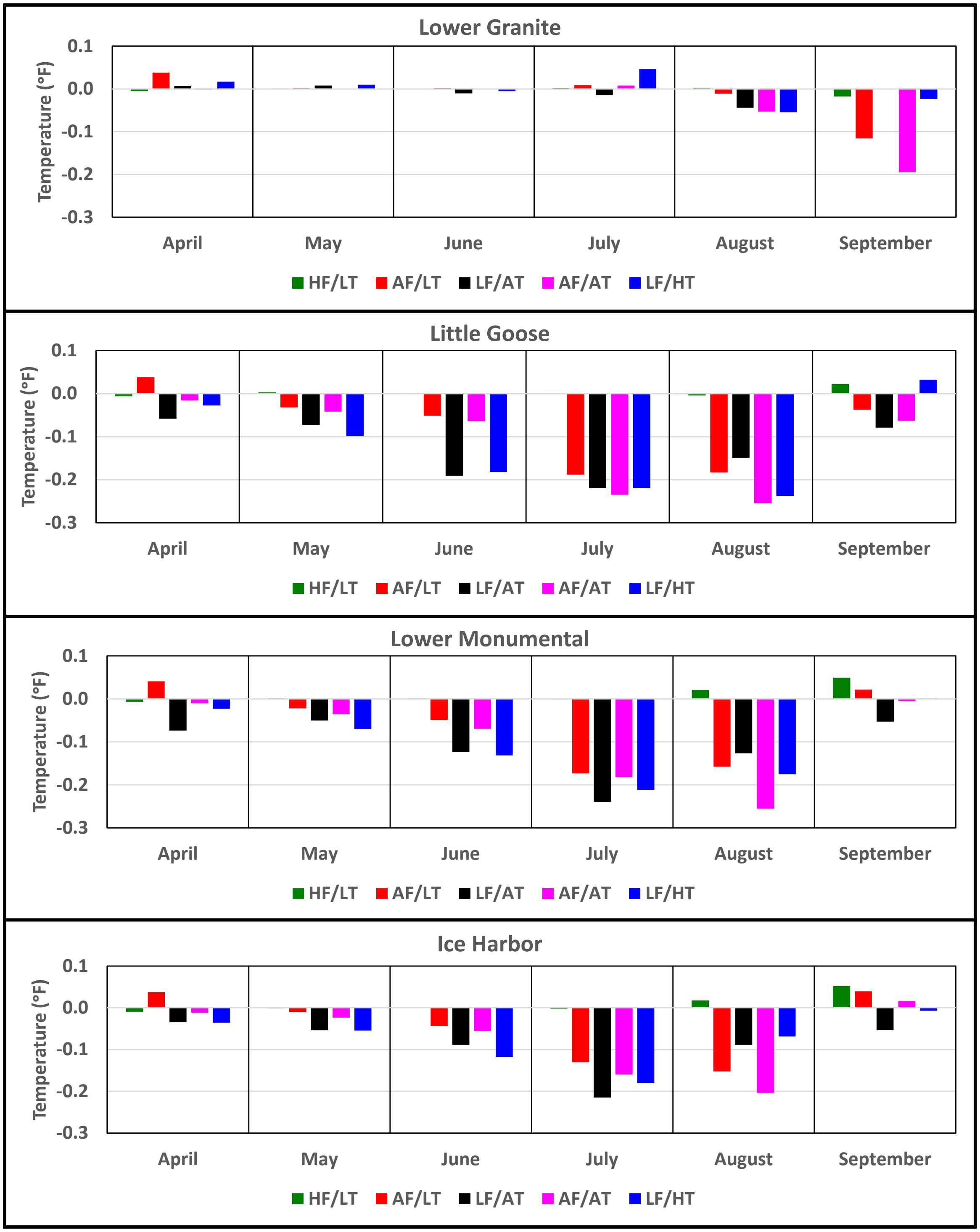


Figure 8-24. Average Temperature Differences Between the Preferred Alternative and the No Action Alternative for April Through September at the Four Lower Snake River Dam Tailwater Locations for the Five Flow and Air Temperature Conditions

8.2.2 Total Dissolved Gas

The PA contains the *Juvenile Fish Passage Spill* measure, which is based on the results of the spring 2019 Flexible Spill Test Operation and analyses of the four MO Alternatives. The *Juvenile Fish Passage Spill* measure would be implemented during the spring juvenile salmonid migration season at the lower Snake River and involve 16 hours of spill operations up to the 125% TDG gas cap at most projects for juvenile outmigration. For the remaining 8 hours, the projects would spill at a lower level (this level is referred to as performance criterion spill). These performance criterion spill levels are slightly variable depending on the project, and may be slightly higher or lower depending on river conditions and the opportunity to spill. This operation would allow hydropower generation during times of peak demand, while still providing for high spill for fish when it is expected to be most important (generally in the evenings and very early morning hours). These operations would be implemented during the spring juvenile migration, which at the lower Snake River projects occurs from April 3 through June 20. When *Juvenile Fish Passage Spill* ceases, the projects would transition to summer spill operations.

8.2.2.1 Dworshak Dam and Reservoir

TDG downstream from Dworshak Dam under the PA would be very similar to the No Action Alternative model results (Figure 8-25 and Figure 8-26). TDG would remain below the 110 percent criterion the majority of the time for each of the five flow and air temperature combinations. Gas saturation greater than 120 percent would still occur during April under HF/LT, AF/LT, and AF/AT conditions. However, the percent of time that TDG would be greater than 120 percent under the PA would not differ from the No Action Alternative under HF/LT and AF/AT conditions (Table 8-6). During April of AF/LT conditions, there would be a 6.4 percent decrease in the amount of time TDG would be greater than 120 percent. Finally, the additional release of water during January of HF/LT conditions would increase downstream TDG by up to 1.5 percent, but TDG in the river would still be less than 110 percent. Overall, TDG impacts downstream of Dworshak Dam are negligible.

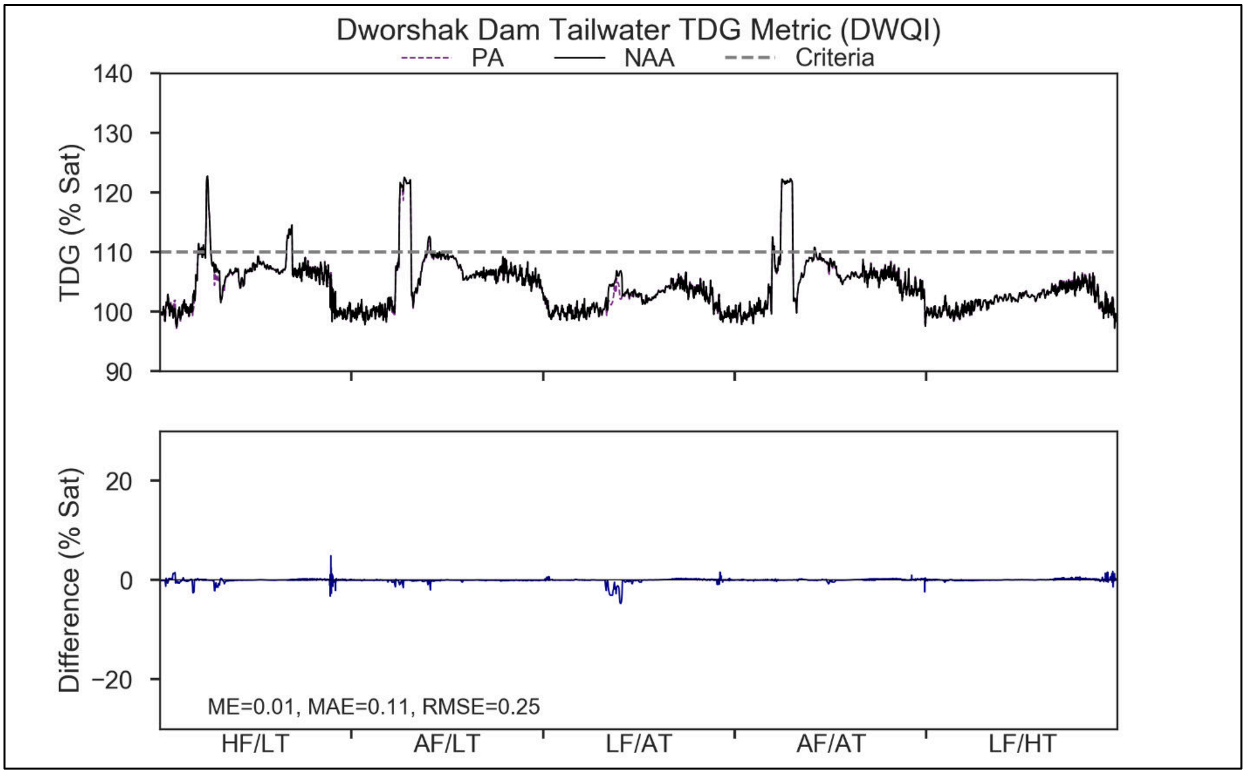


Figure 8-25. Modeled Tailwater Total Dissolved Gas for the Preferred Alternative and No Action Alternative at Dworshak Dam Under a 5-Year Range of River and Meteorological Conditions

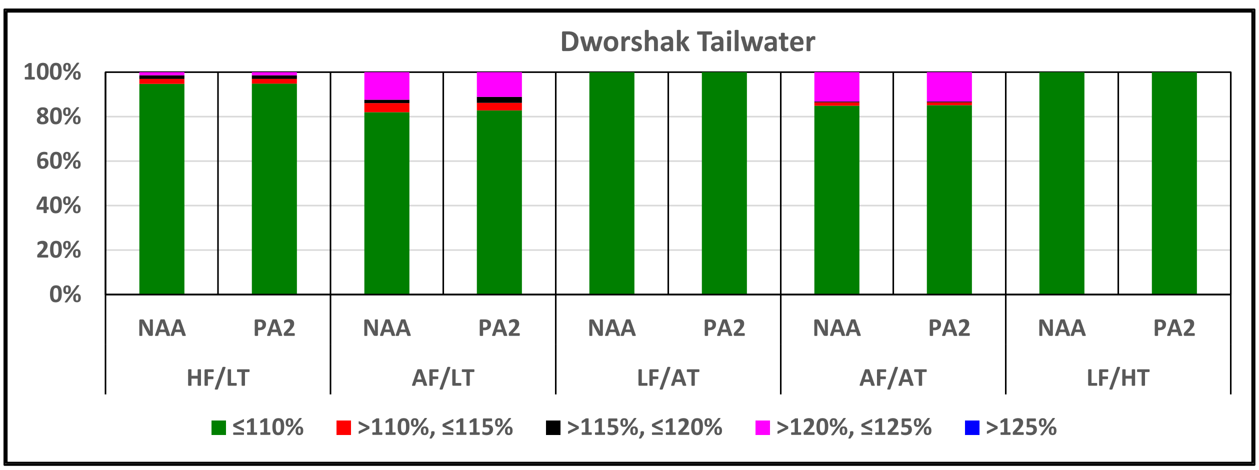


Figure 8-26. Frequency Distributions for Dworshak Tailwater Total Dissolved Gas for the No Action Alternative and Preferred Alternative for April through August during the five flow and air temperature conditions

Table 8-6. Changes in the percent of time Dworshak Tailwater TDG saturation would occur within selected ranges if PA would be implemented compared to the NAA for the five flow and air temperature conditions by month

Month	Percent Range	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
MARCH	≤ 110%	**-1.3**	0.0	0.0	0.0	0.0
MARCH	> 110%, ≤ 115%	**1.3**	0.0	0.0	0.0	0.0
MARCH	> 115%, ≤ 120%	0.0	0.0	0.0	0.0	0.0
MARCH	> 120%, ≤ 125%	0.0	0.0	0.0	0.0	0.0
APRIL	≤ 110%	**0.1**	**0.3**	0.0	0.0	0.0
APRIL	> 110%, ≤ 115%	**-0.1**	0.0	0.0	0.0	0.0
APRIL	> 115%, ≤ 120%	0.0	**6.1**	0.0	0.0	0.0
APRIL	> 120%, ≤ 125%	0.0	**-6.4**	0.0	0.0	0.0
MAY	≤ 110%	0.0	**2.3**	0.0	0.0	0.0
MAY	> 110%, ≤ 115%	0.0	**-2.3**	0.0	0.0	0.0
MAY	> 115%, ≤ 120%	0.0	0.0	0.0	0.0	0.0
MAY	> 120%, ≤ 125%	0.0	0.0	0.0	0.0	0.0
JUNE	≤ 110%	0.0	**1.1**	0.0	**1.3**	0.0
JUNE	> 110%, ≤ 115%	0.0	**-1.1**	0.0	**-1.3**	0.0
JUNE	> 115%, ≤ 120%	0.0	0.0	0.0	0.0	0.0
JUNE	> 120%, ≤ 125%	0.0	0.0	0.0	0.0	0.0

8.2.2.2 Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams and Reservoirs

Tailwater TDG would increase at the four lower Snake River projects under the PA due to the *Juvenile Fish Passage Spill* measure that would allow for spill up to 125% TDG 16 hours per day, from the beginning of April through the third week of June. Under the No Action Alternative, spill was limited to 120 percent TDG (Figure 8-27 through Figure 8-30). During the April through August fish passage season, there would be increases in the percent of time that TDG would be between 120 percent and 125 percent during each of the five flow and air temperature conditions modeled (Table 8-7).

The number of days during the month that TDG conditions would exceed 120 percent would increase, primarily during April, May and June, under the PA (Table 8-9). The changes in the number of days would be larger at the Lower Granite, Little Goose, and Lower Monumental projects. During April, the increases in the number of days exceeding 120 percent during HF/LT, AF/LT, and AT/AT conditions would range from 17 to 29. Changes during LF/AT and LF/HT conditions would be less, ranging from zero to an additional 6 days. TDG would be greater than 120 percent during May at Lower Granite and Mower Monumental dams 100 percent of the time during AF/LT and AF/AT conditions. The percent of time at this level during the same flow/air temperature conditions would be less at Little Goose Dam, but still range from 88 to 93 percent. TDG would drop off sharply in June under HF/LT and LF/HT conditions, resulting in only

1 to 4 additional days of exceedances. In contrast, the number of days of exceedances would still increase by 10 to 19 days during AF/LT, LF/AT, and AF/AT conditions.

The change in the number of days of exceedance that would occur downstream of Ice Harbor Dam would be smaller than at the three upstream projects since more degassing occurs in that reach. The model results show that for the majority of the time during AF/LT, LF/AT, AF/AT, and LF/HT conditions, 120 percent would not be exceeded. Under the PA, the largest changes at this project would be increases of 10 and 12 days during May of AF/LT and AT/AT conditions, respectively. This means that TDG would be greater than 120 percent for 23 to 35 percent of the time under the PA for that month and flow-air temperature conditions when no exceedances occur under the No Action Alternative. The remainder of the increases would be 8 days or less.

Maximum tailwater TDG would change under the PA (Figure 8-31). The highest TDG would still occur during HF/LT conditions, but the TDG under the PA would often be less than under the No Action Alternative conditions. TDG would peaks to 128 percent at Little Goose, Lower Monumental, and Ice Harbor during June and 131 percent at Lower Granite tailwater. However, these maximums, as well as the ones predicted for May, July, and August are the same, or often less than the No Action Alternative. The largest decreases, up to almost 3 percent, would occur at Lower Granite Dam followed by Little Goose Dam. TDG increases greater than 8 percent would occur at Lower Granite Dam during April of a LF/AT year as well as May and June of a LF/HT year. At Little Goose Dam, similar increases would occur during April of LF/AT and AF/AT conditions, May of LF/HT conditions, and June of LF/AT and LF/HT conditions. Remaining increases at the three upper projects between April and June would be 6 percent or less. April through June increases in gas saturation downstream from Ice Harbor Dam would be less than at the upstream projects, typically ranging from zero to less than 3 percent. Maximum TDG during July and August would either not change, decrease by up to 2 percent, or in the case of LF/HT conditions increase by up to 1 percent.

Overall, moderate changes to TDG in the lower Snake River would occur under the PA as compared to the No Action Alternative due to the *Juvenile Fish Passage Spill* measure.

Since the water entering Lower Granite forebay travels through free-flowing reaches before entering the reservoir, forebay TDG would remain less than 110 percent most of the time (Figure 8-32). The only exceptions would occur during a HF/LT year when TDG would be greater than 110 percent about 1 percent of the time during May and July, and 8 percent of the time in June. These occurrences, however, are not substantially different from the No Action Alternative.

Since tailwater TDG would be increased to 125 percent under the PA, downstream forebay TDG would also increase at the lower Snake River projects when compared to the No Action Alternative (Figure 8-32 through Figure 8-35; Table 8-8 and Table 8-9). The general downstream trend from Lower Granite Dam would be a primary increase in the amount of time TDG would be in the 115 to 120 percent range at Little Goose Dam, an increase in the 115 to 120 percent range at Lower Monumental Dam, and an increase in the 120 to 125 percent range at Ice Harbor Dam (Table 8-8).

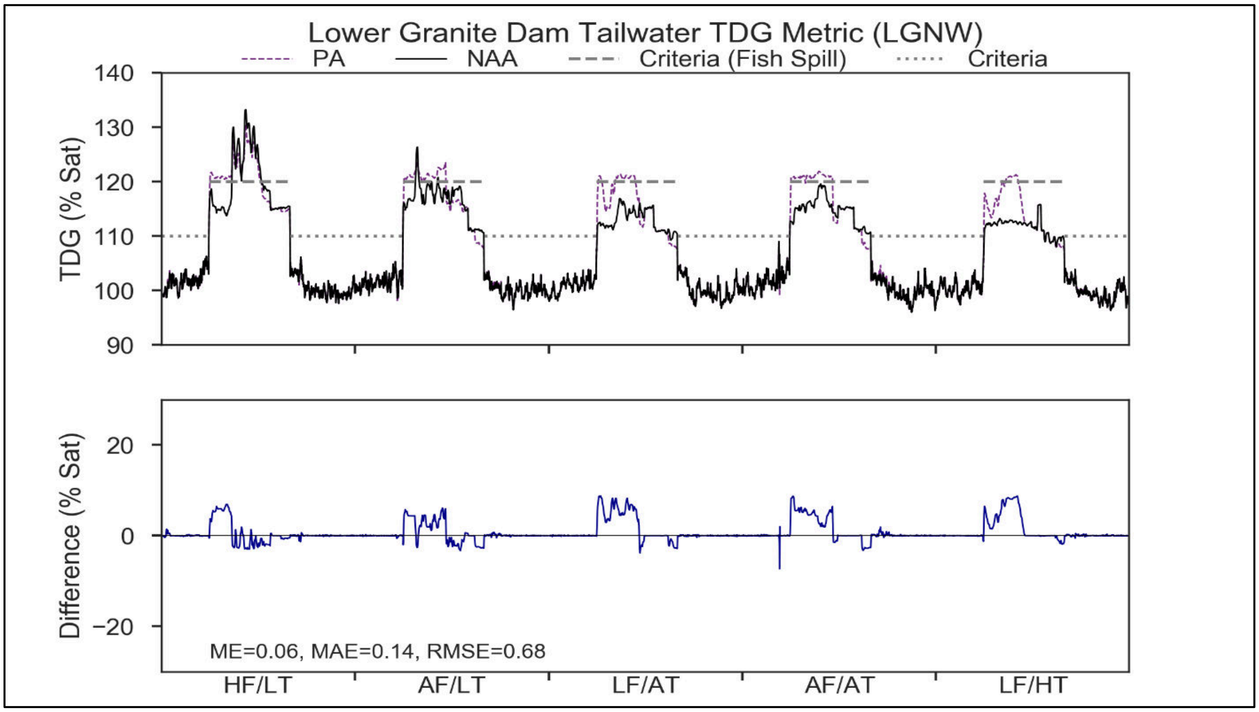


Figure 8-27. Modeled Tailwater Total Dissolved Gas for the Preferred Alternative and No Action Alternative at Lower Granite Dam Under a 5-year Range of River and Meteorological Conditions

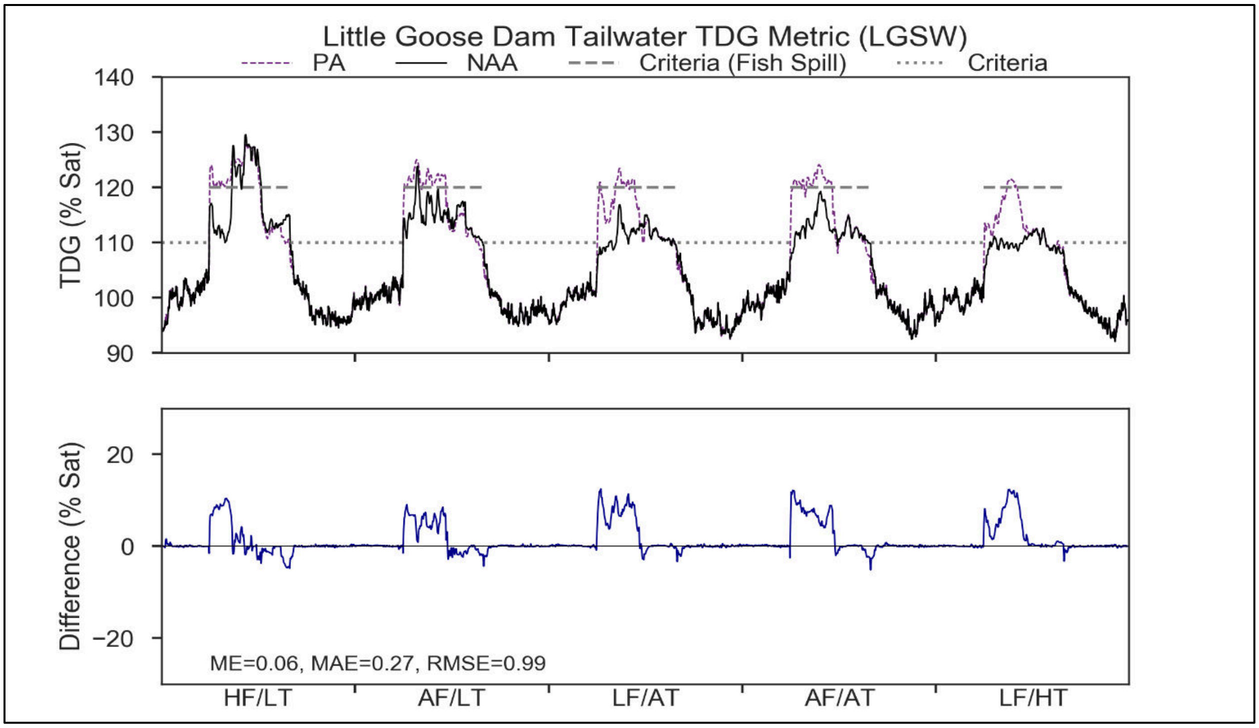


Figure 8-28. Modeled Tailwater Total Dissolved Gas for the Preferred Alternative and No Action Alternative at Little Goose Dam Under a 5-year Range of River and Meteorological Conditions

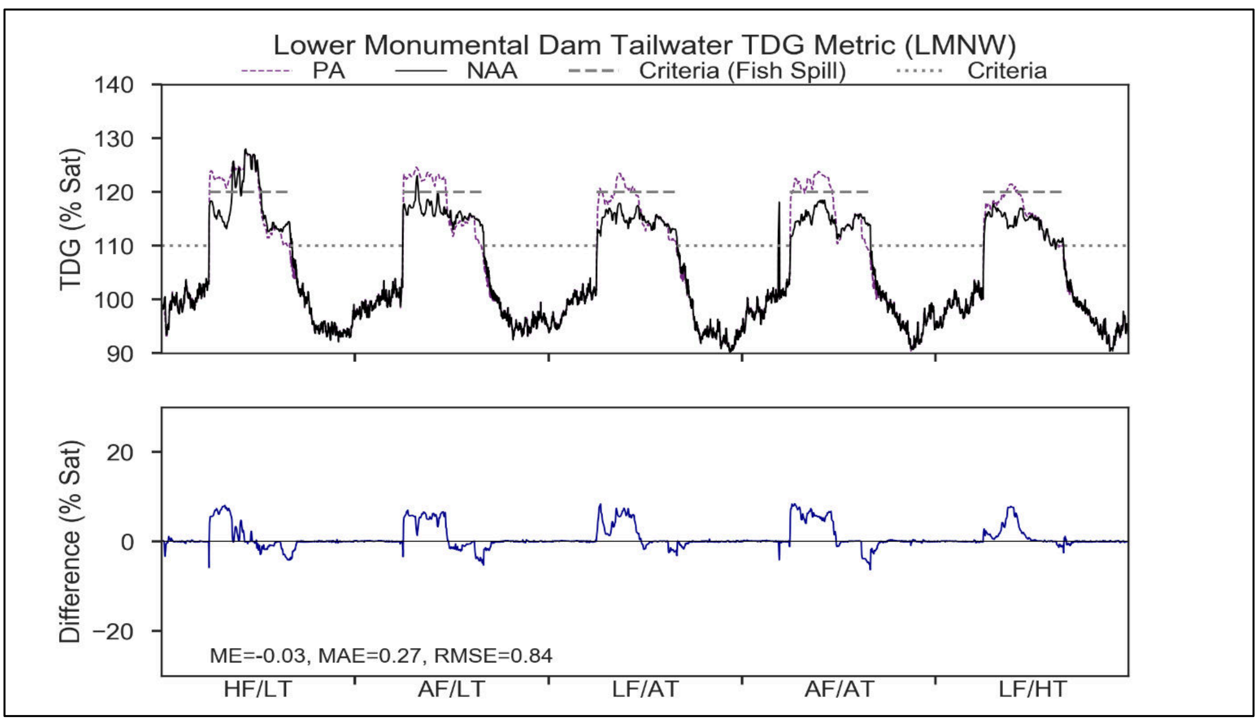


Figure 8-29. Modeled Tailwater Total Dissolved Gas for the Preferred Alternative and No Action Alternative at Lower Monumental Dam Under a 5-year Range of River and Meteorological Conditions

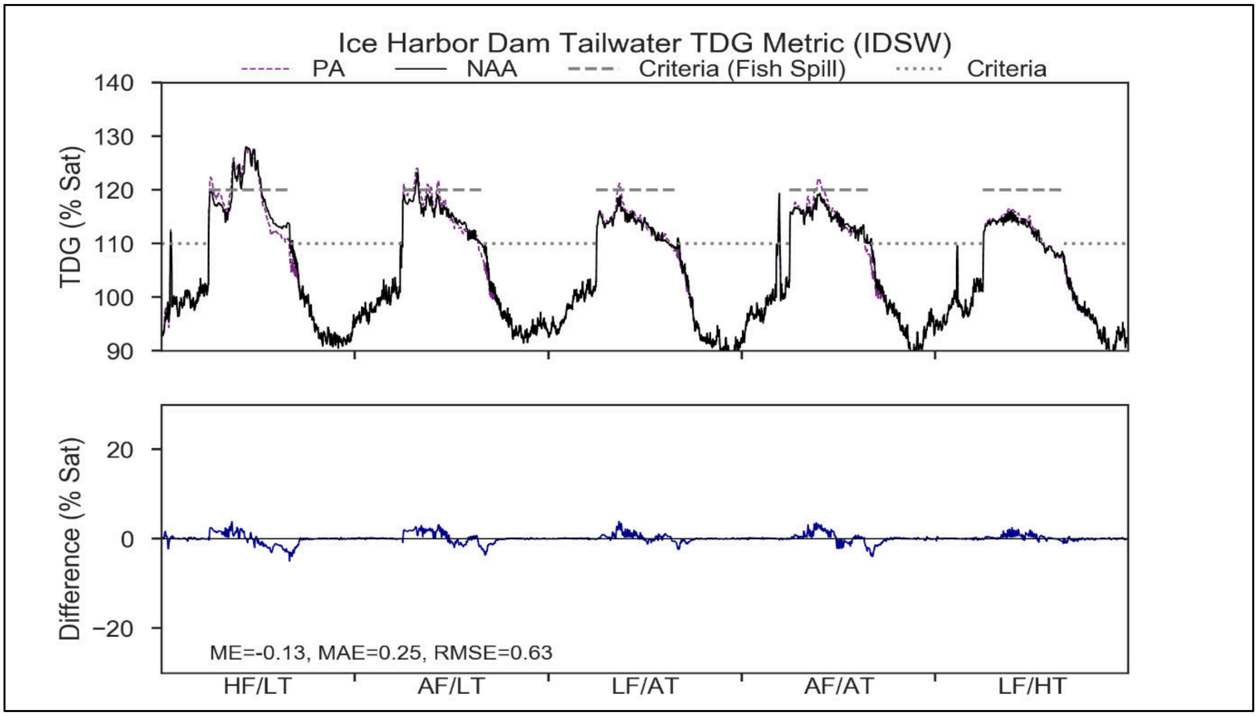


Figure 8-30. Modeled Tailwater Total Dissolved Gas for the Preferred Alternative and No Action Alternative at Ice Harbor Dam Under a 5-year Range of River and Meteorological Conditions

Table 8-7. Differences of the Frequency of the Total Dissolved Gas that Would Occur Within Selected Ranges During Juvenile Spill Season (April-August) if the Preferred Alternative is Implemented when Compared to the No Action Alternative at the Four Lower Snake River Dam Tailwater Locations Under a 5-Year Range of River and Meteorological Conditions

SITE	TDG Range (% Sat)	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Lower Granite	<=110	0.00%	10.97%	7.74%	10.97%	0.65%
Lower Granite	>110,<=115	-3.23%	-10.97%	-43.87%	-22.58%	-40.00%
Lower Granite	>115,<=120	-22.58%	-44.52%	6.45%	-38.71%	21.94%
Lower Granite	>120,<=125	33.55%	46.45%	29.68%	50.32%	17.42%
Lower Granite	>125	-7.74%	-1.94%	0.00%	0.00%	0.00%
Little Goose	<=110	0.00%	5.81%	-19.35%	2.58%	-39.35%
Little Goose	>110,<=115	-20.65%	-21.94%	-18.71%	-42.58%	10.97%
Little Goose	>115,<=120	-5.81%	-27.74%	13.55%	-5.16%	16.13%
Little Goose	>120,<=125	25.16%	43.23%	24.52%	45.16%	12.26%
Little Goose	>125	1.29%	0.65%	0.00%	0.00%	0.00%
Lower Monumental	<=110	1.29%	3.23%	0.00%	5.16%	5.16%

SITE	TDG Range (% Sat)	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Lower Monumental	>110,<=115	-7.10%	14.19%	-17.42%	-25.16%	-25.16%
Lower Monumental	>115,<=120	-21.29%	-65.81%	-11.61%	-28.39%	6.45%
Lower Monumental	>120,<=125	27.10%	48.39%	29.03%	48.39%	13.55%
Lower Monumental	>125	0.00%	0.00%	0.00%	0.00%	0.00%
Ice Harbor	<=110	1.29%	1.94%	-1.94%	7.10%	-2.58%
Ice Harbor	>110,<=115	1.29%	-0.65%	-12.26%	-11.61%	-13.55%
Ice Harbor	>115,<=120	-7.74%	-15.48%	10.32%	-3.87%	16.13%
Ice Harbor	>120,<=125	5.16%	14.19%	3.87%	8.39%	0.00%
Ice Harbor	>125	0.00%	0.00%	0.00%	0.00%	0.00%

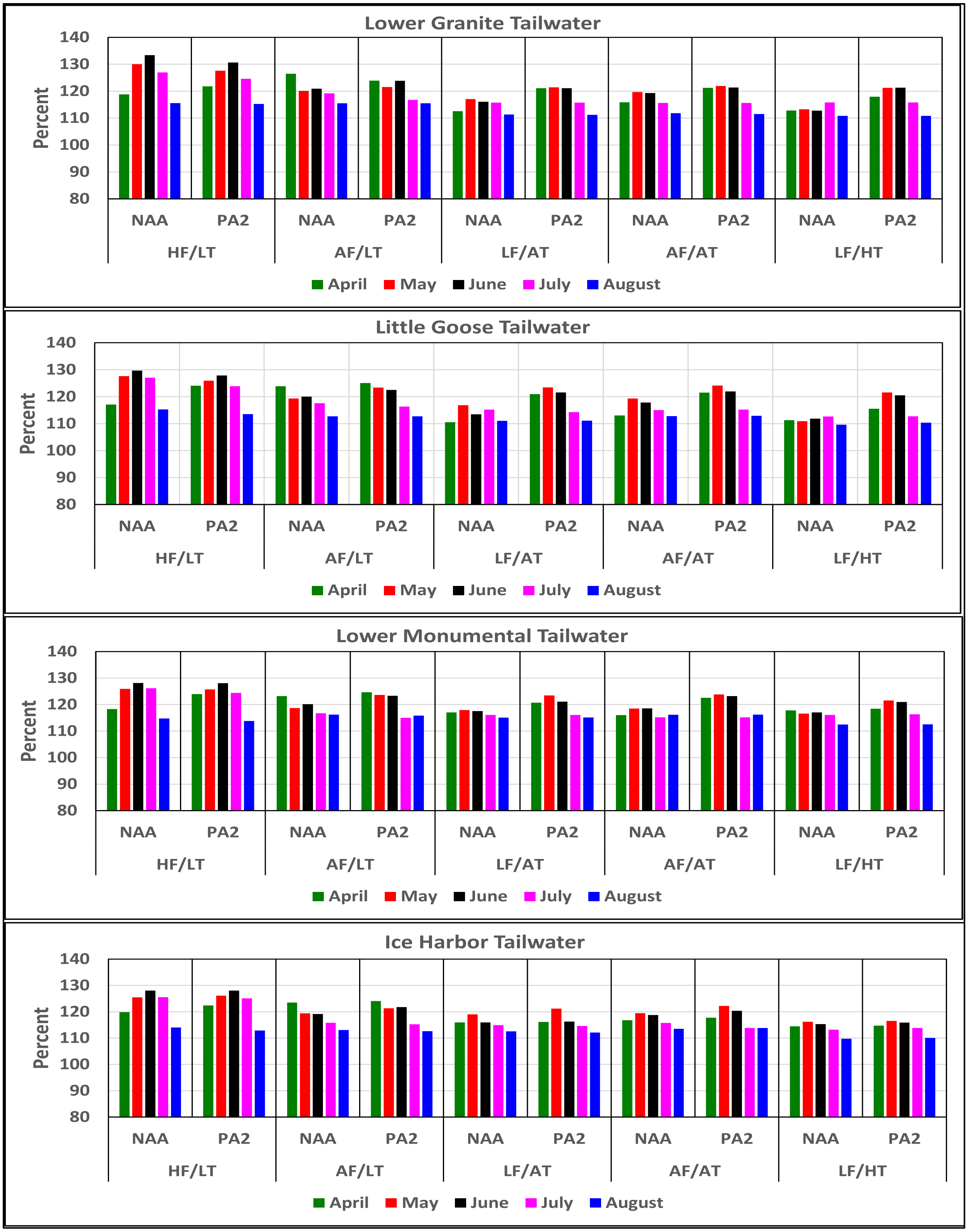


Figure 8-31. Maximum monthly tailwater TDG modeled for the No Action and Preferred Alternatives for the 5 flow and air temperature conditions

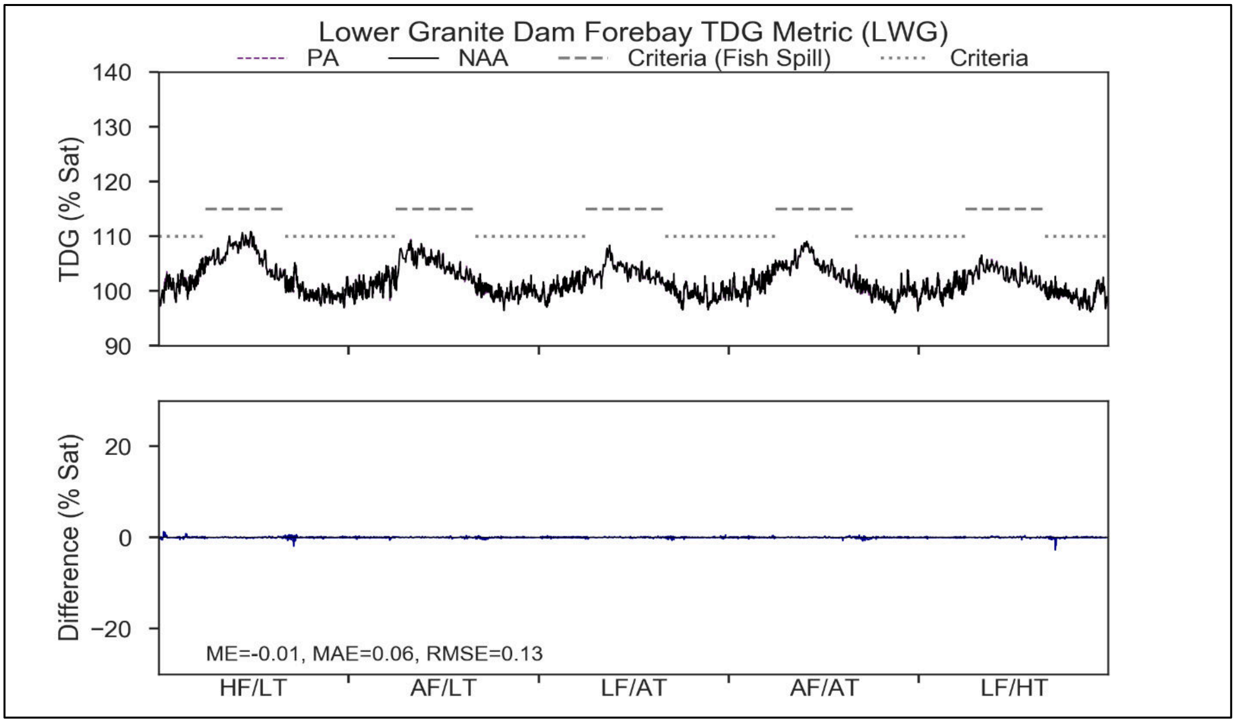


Figure 8-32. Modeled Forebay Total Dissolved Gas for the Preferred Alternative and No Action Alternative at Lower Granite Dam Under a 5-year Range of River and Meteorological Conditions

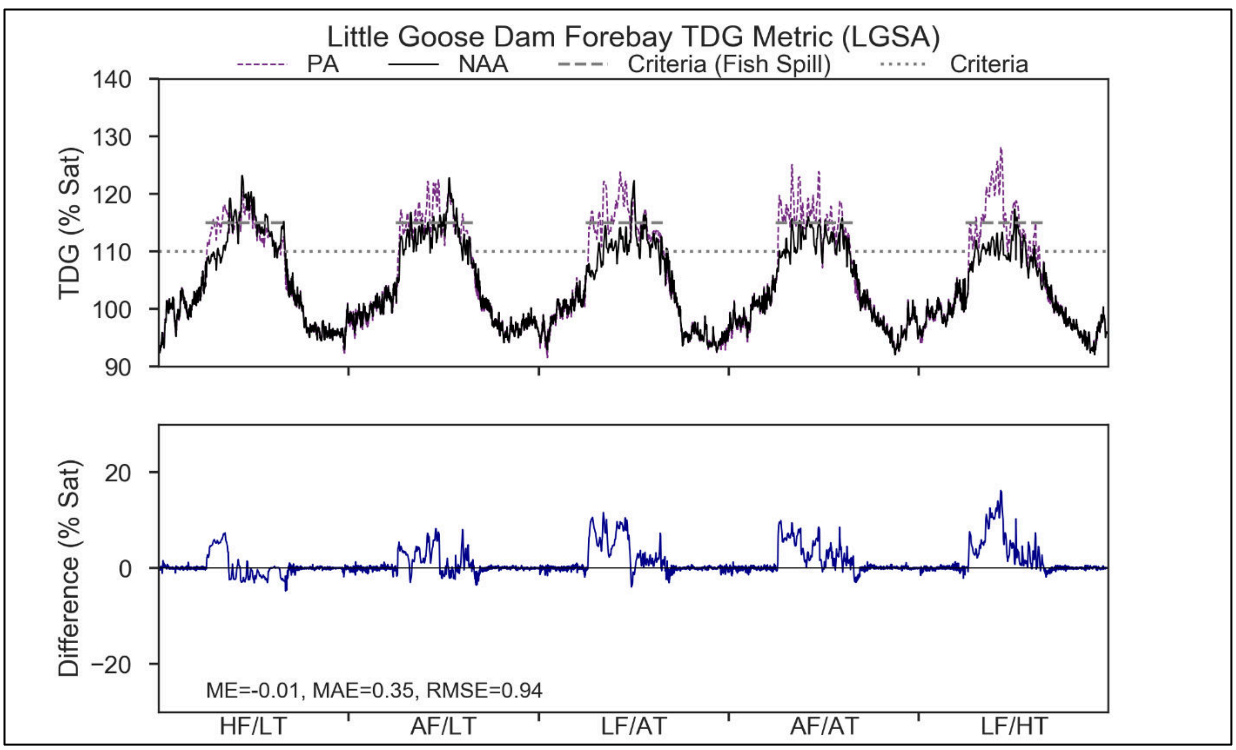


Figure 8-33. Modeled Forebay Total Dissolved Gas for the Preferred Alternative and No Action Alternative at Little Goose Dam Under a 5-year Range of River and Meteorological Conditions

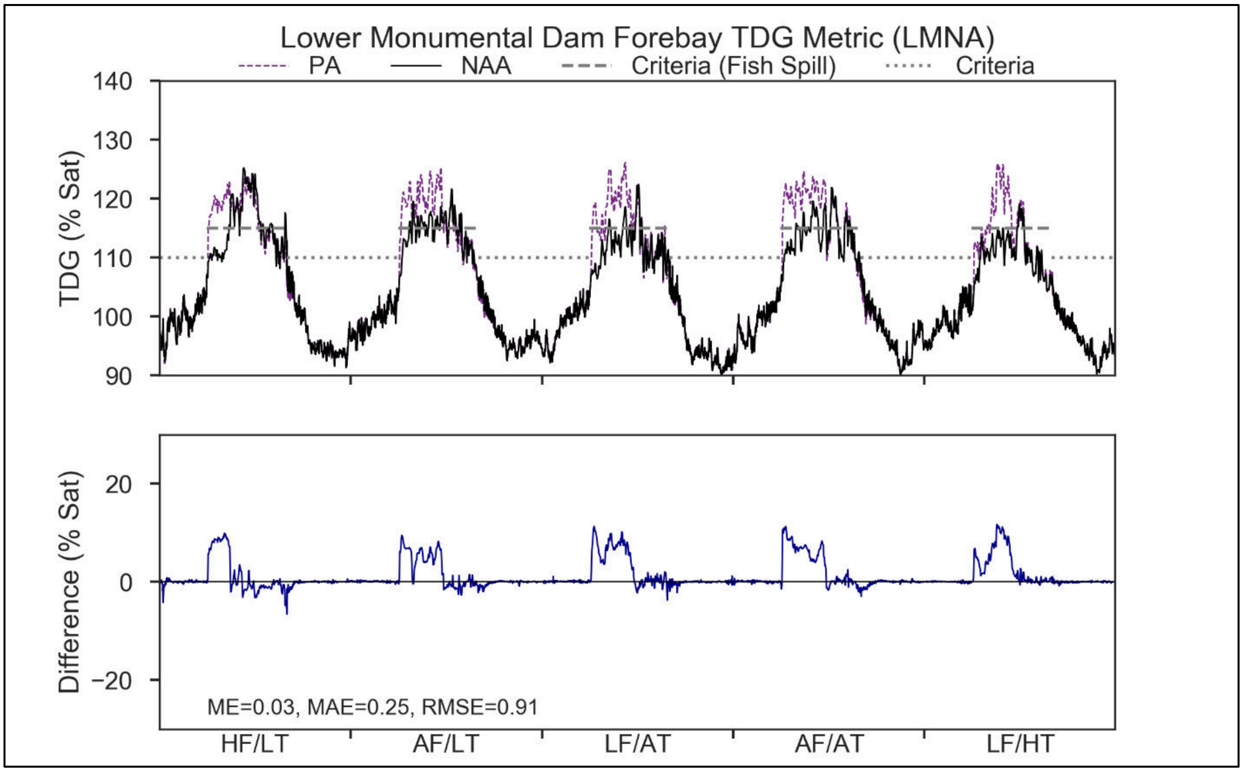


Figure 8-34. Modeled Forebay Total Dissolved Gas for the Preferred Alternative and No Action Alternative at Lower Monumental Dam Under a 5-year Range of River and Meteorological Conditions

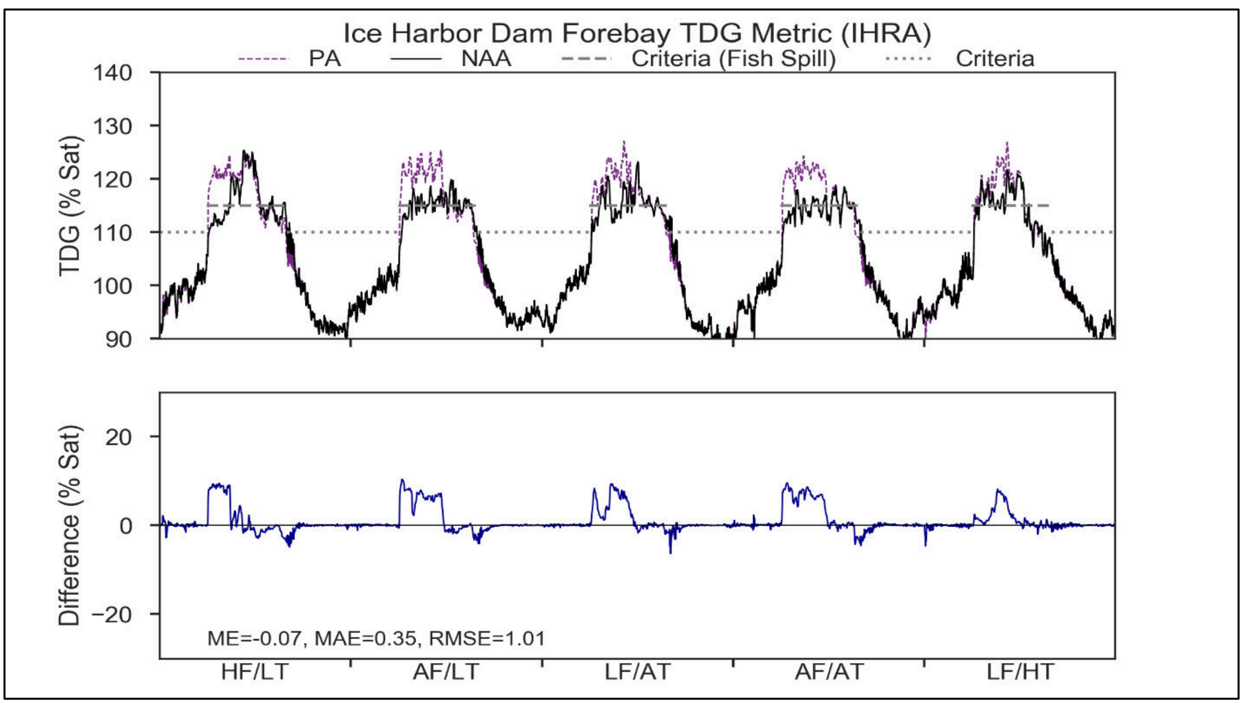


Figure 8-35. Modeled Forebay Total Dissolved Gas for the Preferred Alternative and No Action Alternative at Ice Harbor Dam Under a 5-year Range of River and Meteorological Conditions

Table 8-8. Differences of the Frequency of the Total Dissolved Gas that Would Occur Within Selected Ranges During Juvenile Spill Season (April-August) if the Preferred Alternative is Implemented when Compared to the No Action Alternative at the Four Lower Snake River Dam Forebay Locations Under a 5-Year Range of River and Meteorological Conditions

TDG Range (% Sat)	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Lower Granite Forebay					
<=110	0.00%	0.00%	0.00%	0.00%	0.00%
>110,<=115	0.00%	0.00%	0.00%	0.00%	0.00%
>115,<=120	0.00%	0.00%	0.00%	0.00%	0.00%
>120,<=125	0.00%	0.00%	0.00%	0.00%	0.00%
>125	0.00%	0.00%	0.00%	0.00%	0.00%
Little Goose Forebay					
<=110	0.12%	0.00%	0.29%	0.00%	0.00%
>110,<=115	-0.12%	0.00%	-0.29%	0.00%	0.00%
>115,<=120	0.00%	0.00%	0.00%	0.00%	0.00%
>120,<=125	0.00%	0.00%	0.00%	0.00%	0.00%
>125	0.00%	0.00%	0.00%	0.00%	0.00%
Lower Monumental Forebay					
<=110	0.16%	0.00%	0.02%	0.00%	0.00%
>110,<=115	-0.16%	0.00%	-0.02%	0.00%	0.00%
>115,<=120	0.00%	0.00%	0.00%	0.00%	0.00%
>120,<=125	0.00%	0.00%	0.00%	0.00%	0.00%
>125	0.00%	0.00%	0.00%	0.00%	0.00%
Ice Harbor Forebay					
<=110	0.61%	0.00%	1.85%	0.39%	0.00%
>110,<=115	-0.61%	0.00%	-1.85%	-0.39%	0.00%
>115,<=120	0.00%	0.00%	0.00%	0.00%	0.00%
>120,<=125	0.00%	0.00%	0.00%	0.00%	0.00%
>125	0.00%	0.00%	0.00%	0.00%	0.00%

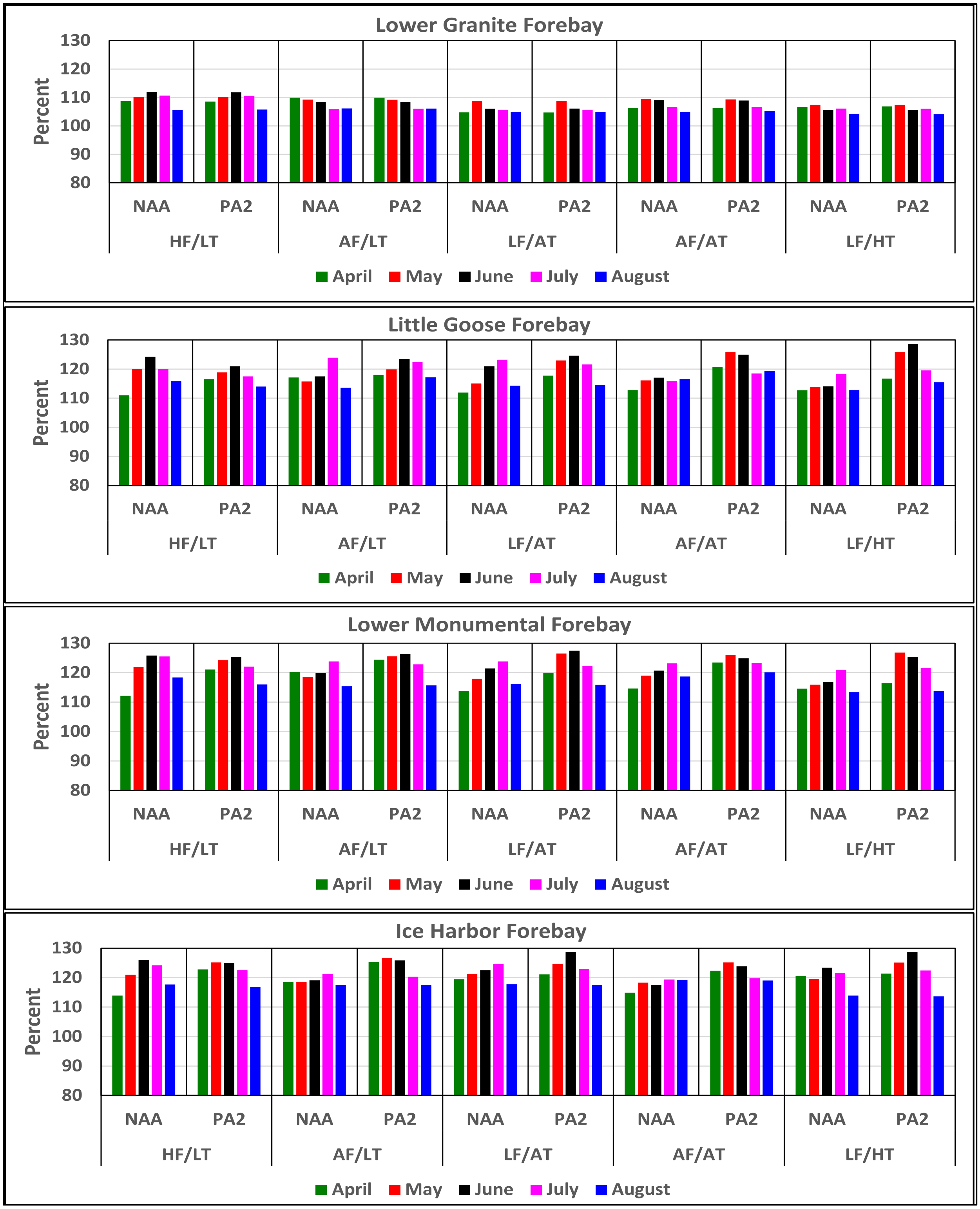


Figure 8-36. Maximum monthly forebay TDG modeled for the No Action and Preferred Alternatives for the 5-Year Range of River and Meteorological Conditions at the Four Lower Snake River Forebay Locations

Table 8-9. Difference in Number of Days the Total Dissolved Gas Criteria is Exceeded at the Forebay Sites of Little Goose, Lower Monumental, and Ice Harbor for the Multiple Objective 3 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Little Goose	March	0	0	0	0	0
Little Goose	April	**6**	**5**	**10**	**22**	**2**
Little Goose	May	**6**	**12**	**20**	**19**	**31**
Little Goose	June	**1**	**12**	**24**	**20**	**20**
Little Goose	July	-12	-6	**4**	**11**	**10**
Little Goose	August	-2	**3**	0	**5**	0
Little Goose	September	0	0	-1	0	0
Lower Monumental	March	0	0	0	0	0
Lower Monumental	April	**25**	**18**	**12**	**26**	**1**
Lower Monumental	May	**14**	**10**	**25**	**19**	**26**
Lower Monumental	June	**1**	**7**	**13**	**9**	**16**
Lower Monumental	July	-11	-5	**1**	0	**1**
Lower Monumental	August	-6	0	**1**	**1**	0
Lower Monumental	September	0	0	0	0	0
Ice Harbor	March	0	0	0	0	0
Ice Harbor	April	**27**	**20**	**13**	**26**	**4**
Ice Harbor	May	**14**	**12**	**22**	**21**	**7**
Ice Harbor	June	0	**4**	**4**	**8**	**4**
Ice Harbor	July	-5	-2	0	-1	**3**
Ice Harbor	August	-6	-1	**1**	**3**	0
Ice Harbor	September	-1	0	-4	-1	0

Table 8-10. Difference in Number of Days the Total Dissolved Gas Criteria is Exceeded at the Tailwater Sites of Lower Granite, Little Goose, Lower Monumental, and Ice Harbor for the Multiple Objective 3 Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Lower Granite	February	0	0	0	0	0
Lower Granite	March	0	0	0	0	0
Lower Granite	April	**28**	**22**	**7**	**27**	0
Lower Granite	May	**13**	**29**	**26**	**31**	**22**
Lower Granite	June	0	**18**	**13**	**20**	**5**
Lower Granite	July	-1	0	0	0	0
Little Goose	March	0	0	0	0	0
Little Goose	April	**28**	**19**	**3**	**21**	0
Little Goose	May	**13**	**29**	**25**	**30**	**15**
Little Goose	June	**1**	**20**	**10**	**19**	**4**
Little Goose	July	-1	0	0	0	0
Little Goose	September	0	0	0	0	0
Lower Monumental	February	0	0	0	0	0
Lower Monumental	March	0	0	0	0	0
Lower Monumental	April	**29**	**24**	**6**	**24**	0
Lower Monumental	May	**15**	**31**	**26**	**31**	**18**
Lower Monumental	June	**1**	**20**	**13**	**20**	**3**
Lower Monumental	July	-3	0	0	0	0
Lower Monumental	September	-3	0	0	0	0
Ice Harbor	January	0	0	0	0	0
Ice Harbor	February	0	0	0	0	0
Ice Harbor	March	0	0	0	0	0
Ice Harbor	April	**7**	**8**	0	0	0
Ice Harbor	May	**2**	**10**	**6**	**12**	0
Ice Harbor	June	0	**4**	0	**1**	0
Ice Harbor	July	-1	0	0	0	0
Ice Harbor	September	-1	0	-2	-1	0

8.2.3 Other Physical, Chemical and Biological Processes

8.2.3.1 Dworshak Dam and Reservoir

The other physical, chemical and biological conditions in Dworshak Reservoir are not expected to change under the PA as compared to the No Action Alternative.

8.2.3.2 Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams and Reservoirs

The other physical, chemical and biological conditions in the lower Snake River Reservoirs are not expected to change under the PA as compared to the No Action Alternative.

8.3 LOWER COLUMBIA RIVER

8.3.1 Water Temperature

There are no specific structural or operational measures in the PA that are expected to influence water temperatures in the lower Columbia River. Details are provided below.

8.3.1.1 McNary, John Day, The Dalles, and Bonneville Dams and Reservoirs

The tailwater temperatures for the PA at McNary, John Day, The Dalles, and Bonneville Dams were modeled under a 5-year range of river and meteorological conditions, and compared to the modeled results for the No Action Alternative (Figure 8-37 through Figure 8-40). Just as with the No Action Alternative model results, the PA model results show that tailwater temperatures can exceed 68°F at all four dams during any of the years and conditions presented, and maximum water temperatures and the frequency of water temperature violations of state water quality criteria would be higher during a year when river flows are lower than normal and summer ambient air temperatures are higher (as in LF/HT). The average frequency of water temperature violations of the state water quality criteria would be nearly identical for the No Action Alternative and the PA for all four lower Columbia River dams (Figure 8-41 and Table 8-11). Generally, the differences in tailwater temperatures under the No Action Alternative and the PA are negligible.

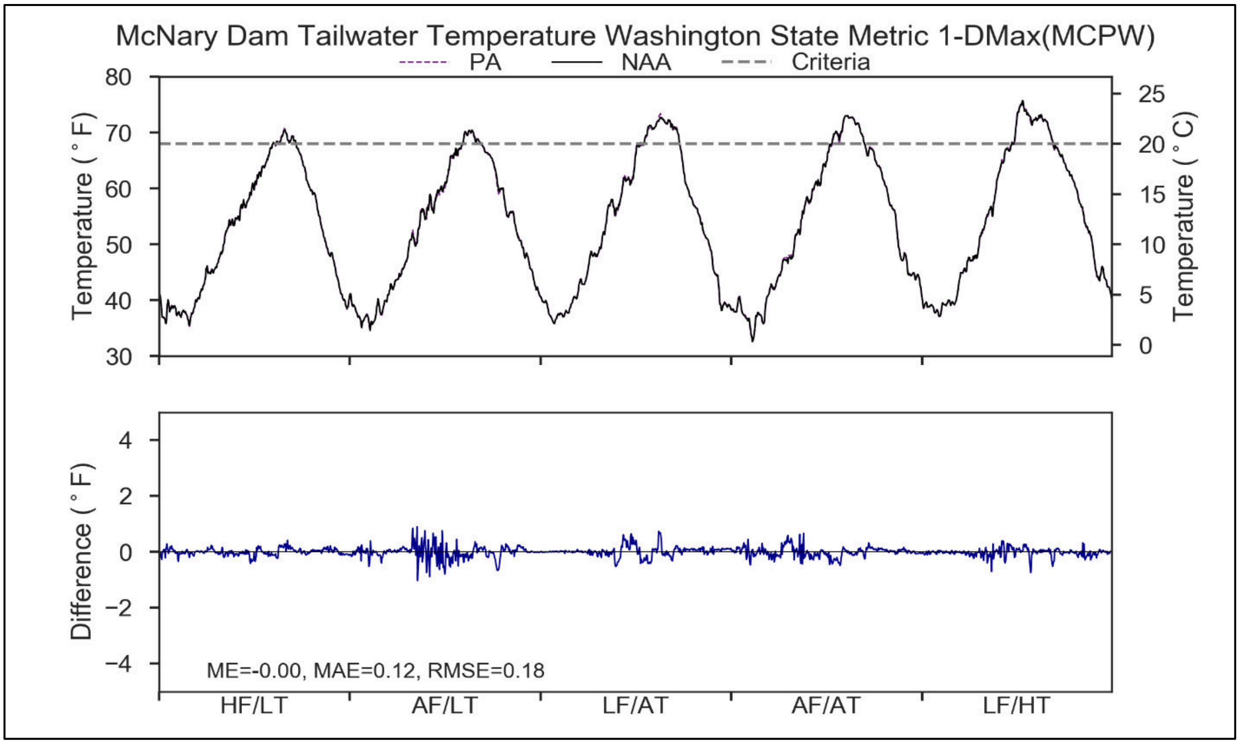


Figure 8-37. Modeled Tailwater Temperature for the Preferred Alternative at McNary Dam Under a 5-year Range of River and Meteorological Conditions

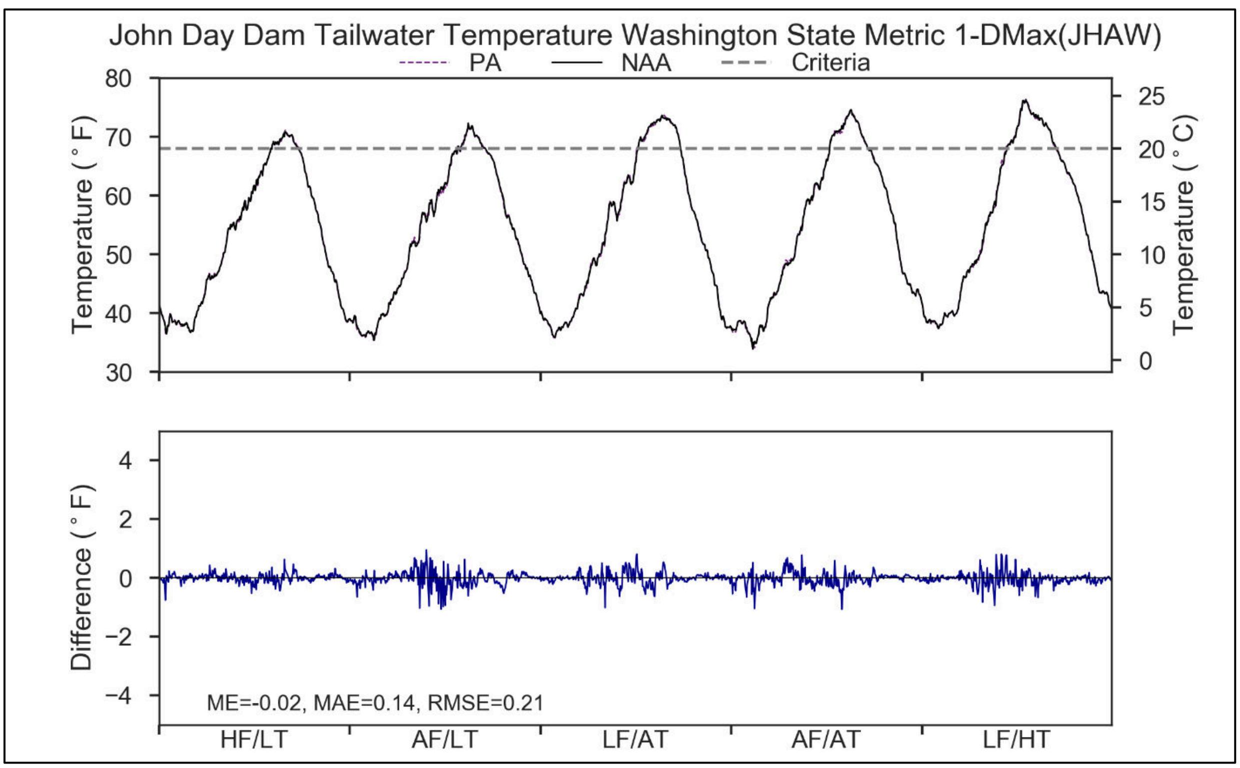


Figure 8-38. Modeled Tailwater Temperature for the Preferred Alternative at John Day Dam Under a 5-year Range of River and Meteorological Conditions

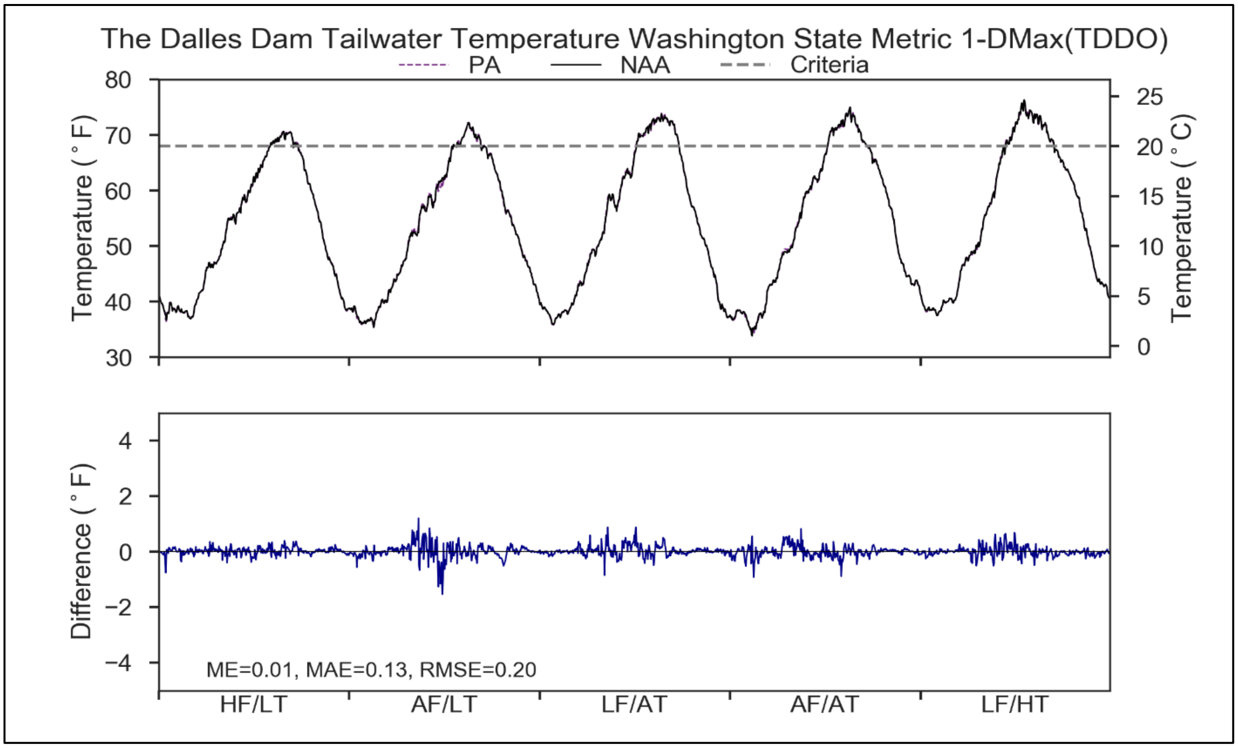


Figure 8-39. Modeled Tailwater Temperature for the Preferred Alternative at The Dalles Dam Under a 5-year Range of River and Meteorological Conditions

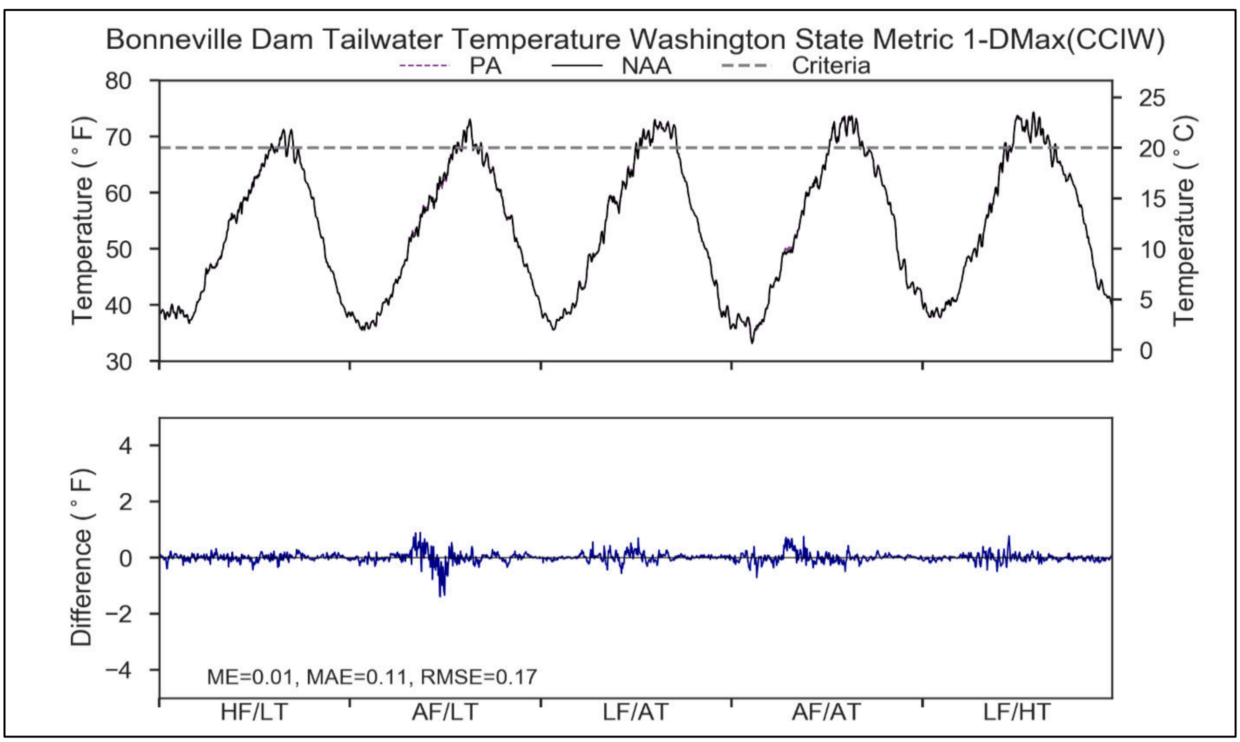


Figure 8-40. Modeled Tailwater Temperature for the Preferred Alternative at Bonneville Dam Under a 5-year Range of River and Meteorological Conditions

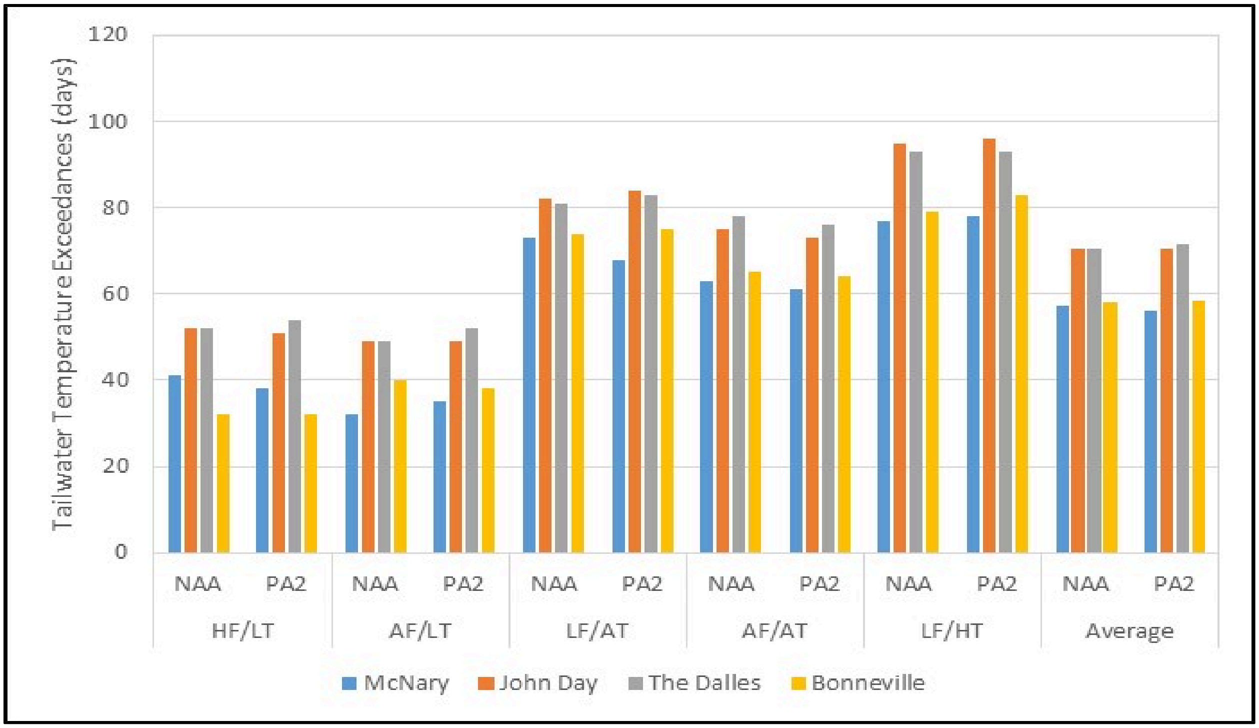


Figure 8-41. Frequency of Modeled Tailwater Temperature Violations of State Water Quality Criteria the Preferred Alternative and No Action Alternative at McNary, John Day, The Dalles, and Bonneville Dams Under a 5-year Range of River and Meteorological Conditions

Table 8-11. Difference in Number of Days the Temperature Criteria is Exceeded at the Tailwater Sites of McNary, John Day, The Dalles, and Bonneville for the Preferred Alternative Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary	June	0	0	0	0	**3**
McNary	July	0	0	-5	-2	0
McNary	August	-3	0	0	0	0
McNary	September	0	**3**	0	0	-2
John Day	June	0	0	0	0	**2**
John Day	July	0	**1**	**2**	0	0
John Day	August	0	0	0	0	0
John Day	September	-1	-1	0	-2	-1
The Dalles	June	0	0	0	0	**1**
The Dalles	July	0	**2**	**2**	-1	0
The Dalles	August	0	0	0	0	0
The Dalles	September	**2**	**1**	0	-1	-1
Bonneville	June	0	0	0	0	**4**
Bonneville	July	0	**1**	**1**	0	0
Bonneville	August	0	-2	0	0	0
Bonneville	September	0	-1	0	-1	0

8.3.2 Total Dissolved Gas

The PA contains the *Juvenile Fish Passage Spill* measure, which is based on the results of the spring 2019 Flexible Spill Test Operation and analyses of the four MO Alternatives. The *Juvenile Fish Passage Spill* measure would be implemented during the spring juvenile salmonid migration season at the lower Snake River and lower Columbia River Projects. In a 24-hr period, the *Juvenile Fish Passage Spill* measure would involve 16 hours of spill operations up to the 125% TDG gas cap at most projects for juvenile outmigration. For the remaining 8 hours, the projects would spill at a lower level (this level is referred to as performance criterion spill). These performance criterion spill levels are slightly variable depending on the project, and may be slightly higher or lower depending on river conditions and the opportunity to spill. This operation would allow hydropower generation during times of peak demand, while still providing for high spill for fish when it is expected to be most important (generally in the evenings and very early morning hours). These operations would be implemented during the spring juvenile migration, which at the lower Columbia River projects occurs April 10 through June 16. When Flex spill ceases, the projects would transition to summer spill operations.

Differences in forebay and tailwater TDG saturations and exceedances between the PA and the No Action Alternative can be attributed to the *Juvenile Fish Passage Spill* measure. Details are provided below.

8.3.2.1 McNary, John Day, The Dalles, and Bonneville Dams and Reservoirs

Forebay TDG saturations under the PA at McNary, John Day, The Dalles, and Bonneville Dams were modeled under a 5-year range of river and meteorological conditions, and compared to the modeled results for the No Action Alternative (Figure 8-42 to Figure 8-45). The PA model results show that forebay TDG saturations can exceed 115 percent TDG at all four dams during all of the years and conditions presented. Maximum forebay TDG saturations would be higher during a year when river flows were higher than normal (as in 2011 [HF/LT]). Forebay TDG saturations would be similar under the PA and the No Action Alternative for McNary Dam during spill season. At John Day, The Dalles, and Bonneville, forebay TDG saturations would be similar under the PA as compared to the No Action Alternative, except for some periods in the early parts of fish spill season when TDG saturations under the PA would be higher than those for the No Action Alternative. The frequency of 110% TDG exceedances outside of current fish passage spill seasons would be similar under PA and the No Action Alternative (Table 8-12). At all four dam forebays, the frequency of TDG going above 115% TDG would be greater under the PA than the No Action Alternative for all modeled river and meteorological conditions, though the impact is most apparent at John Day and The Dalles (Table 8-13).

Modeled tailwater TDG saturations for the PA at McNary, John Day, The Dalles, and Bonneville Dams can be found in Figure 8-46 through Figure 8-49. The PA model results show that tailwater TDG saturations would be greater than 120 percent TDG at all four dams during most of the years and conditions presented. Exceptions include LF/AT conditions at John Day and LF/HT conditions at McNary, John Day, and The Dalles. Maximum tailwater TDG saturations would be higher during a year when river flows were higher than normal and summer ambient air temperatures were lower (as in 2011). Tailwater TDG saturations in the PA would be generally similar to those for the No Action Alternative for all four dams during the spill season, though there are periods during fish spill season where PA TDG saturations would be higher or lower than for the No Action Alternative. Generally, the frequency of 110% TDG exceedances outside of current fish passage spill seasons would be similar under the PA and the No Action Alternative (Table 8-14). During the current fish passage spill season, the frequency of TDG greater than 120% TDG at all four dams would be higher under PA than the No Action Alternative under most modeled river and meteorological conditions (Table 8-15). Exceptions include AF/LT conditions at Bonneville and a few other conditions where 120% would not be exceeded under either alternative (LF/HT conditions at McNary, John Day, and The Dalles and LF/AT conditions at John Day). Due to the assumed higher amount of lack of market spill in the No Action Alternative, model results do not show a notable differences in TDG in the PA as compared to the No Action Alternative. TDG effects are negligible (Table 8-16).

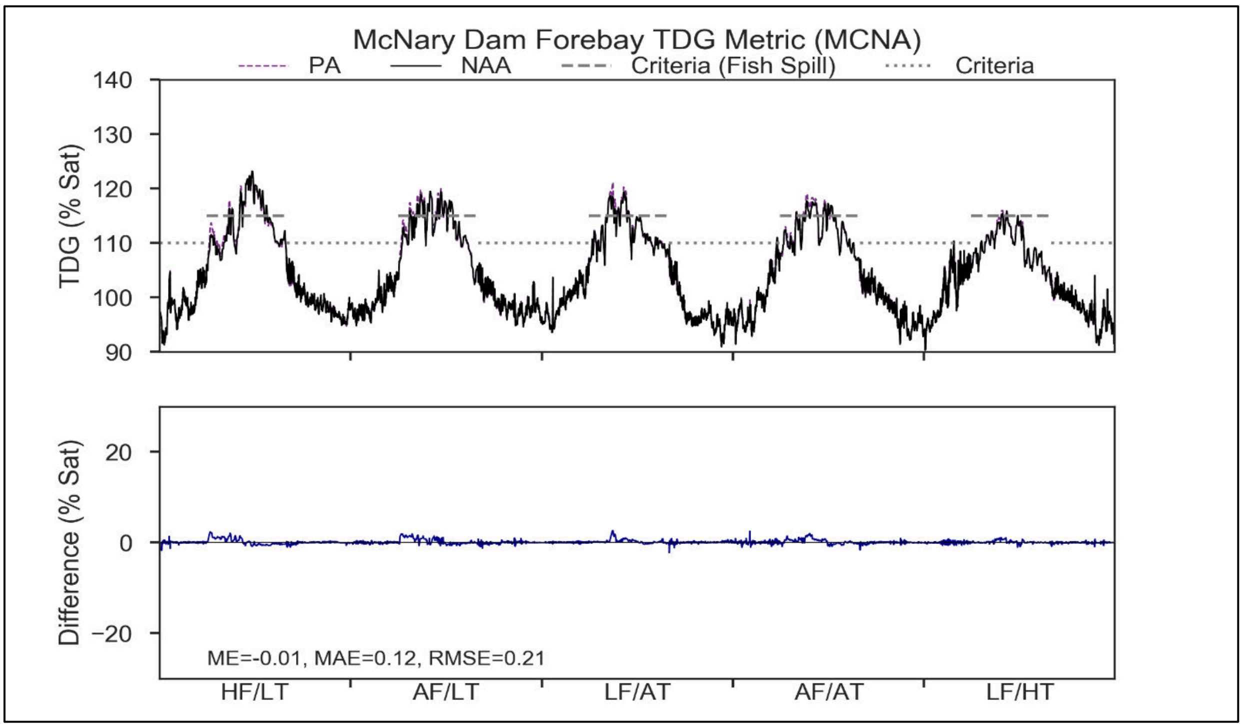


Figure 8-42. Modeled Forebay Total Dissolved Gas for the Preferred Alternative at McNary Dam Under a 5-year Range of River and Meteorological Conditions

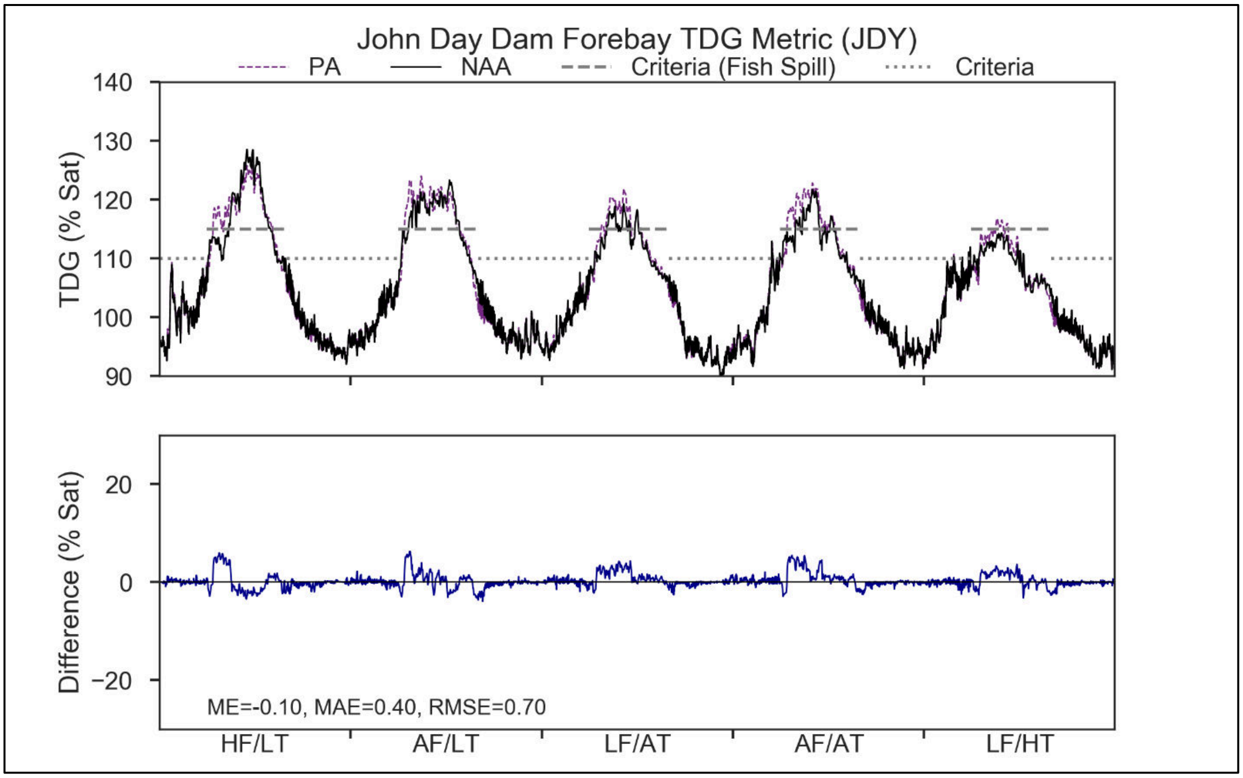


Figure 8-43. Modeled Forebay Total Dissolved Gas for the Preferred Alternative at John Day Dam Under a 5-year Range of River and Meteorological Conditions

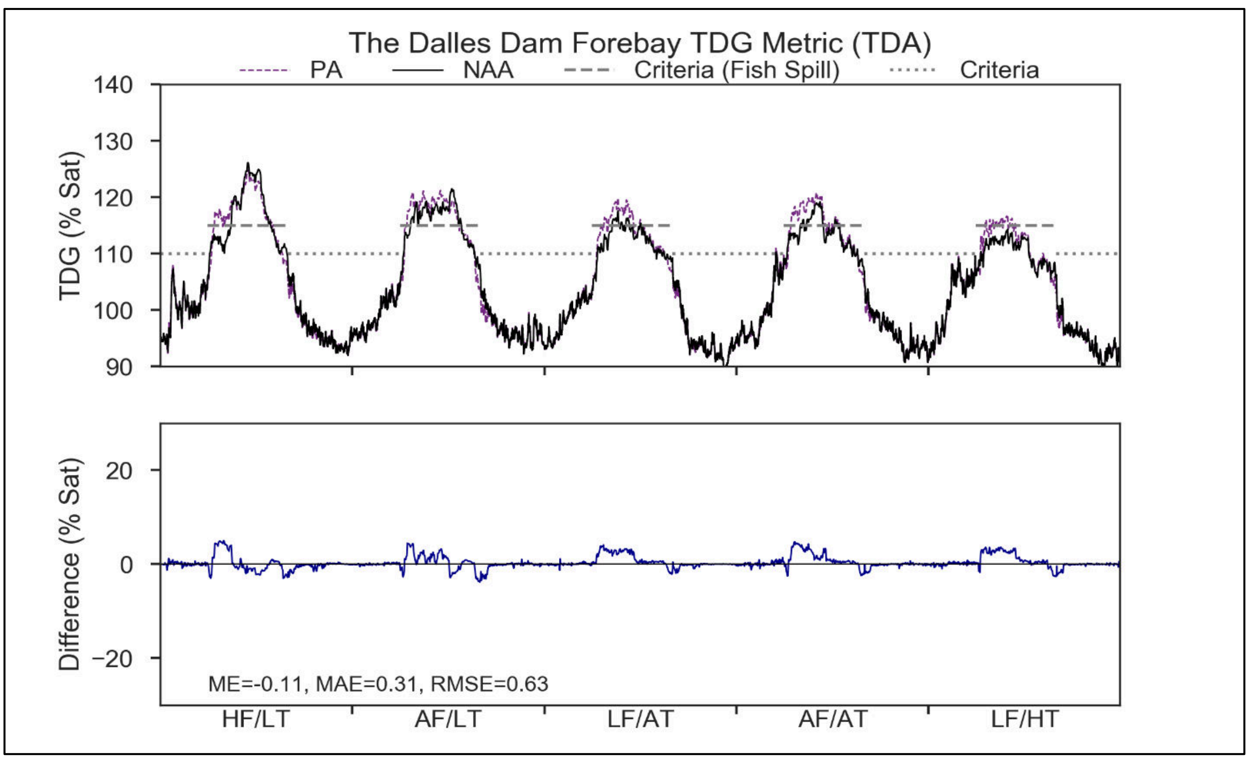


Figure 8-44. Modeled Forebay Total Dissolved Gas for Preferred Alternative at The Dalles Dam Under a 5-year Range of River and Meteorological Conditions

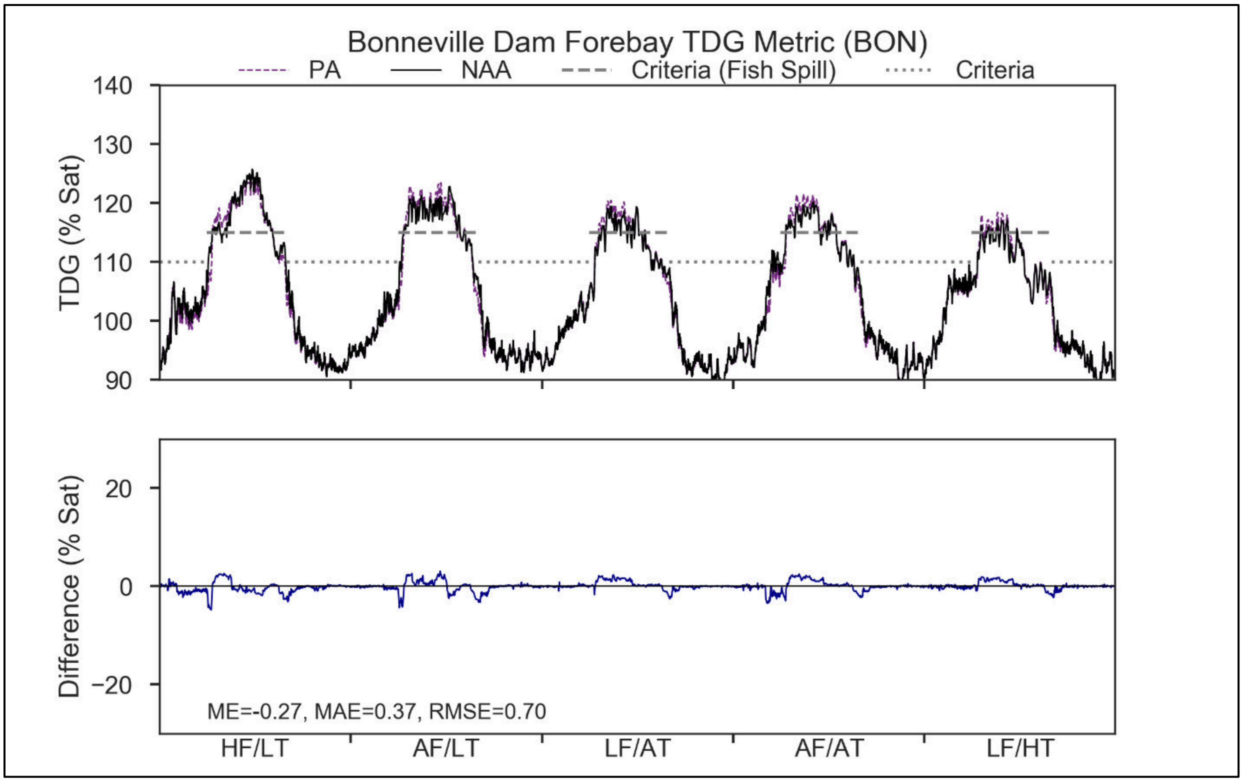


Figure 8-45. Modeled Forebay Total Dissolved Gas for the Preferred Alternative at Bonneville Dam Under a 5-year Range of River and Meteorological Conditions

Table 8-12. Differences of the Frequency of the Total Dissolved Gas that Would Occur Within Selected Ranges Outside of Juvenile Spill Season if the Preferred Alternative is Implemented when Compared to the No Action Alternative at the Four Lower Columbia River Dam Forebay Locations Under a 5-Year Range of River and Meteorological Conditions

SITE	TDG Range (% Sat)	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary	<=110	0.00%	0.00%	0.00%	-0.08%	0.02%
McNary	>110,<=115	0.00%	0.00%	0.00%	0.08%	-0.02%
McNary	>115,<=120	0.00%	0.00%	0.00%	0.00%	0.00%
McNary	>120,<=125	0.00%	0.00%	0.00%	0.00%	0.00%
McNary	>125	0.00%	0.00%	0.00%	0.00%	0.00%
John Day	<=110	0.00%	0.00%	0.00%	0.02%	-0.14%
John Day	>110,<=115	0.00%	0.00%	0.00%	-0.02%	0.14%
John Day	>115,<=120	0.00%	0.00%	0.00%	0.00%	0.00%
John Day	>120,<=125	0.00%	0.00%	0.00%	0.00%	0.00%
John Day	>125	0.00%	0.00%	0.00%	0.00%	0.00%
The Dalles	<=110	0.00%	0.00%	0.00%	-0.45%	0.00%
The Dalles	>110,<=115	0.00%	0.00%	0.00%	0.45%	0.00%
The Dalles	>115,<=120	0.00%	0.00%	0.00%	0.00%	0.00%
The Dalles	>120,<=125	0.00%	0.00%	0.00%	0.00%	0.00%
The Dalles	>125	0.00%	0.00%	0.00%	0.00%	0.00%
Bonneville	<=110	0.00%	0.00%	0.00%	3.56%	0.00%
Bonneville	>110,<=115	0.00%	0.00%	0.00%	-3.56%	0.00%
Bonneville	>115,<=120	0.00%	0.00%	0.00%	0.00%	0.00%
Bonneville	>120,<=125	0.00%	0.00%	0.00%	0.00%	0.00%
Bonneville	>125	0.00%	0.00%	0.00%	0.00%	0.00%

Table 8-13. Differences of the Frequency of the Total Dissolved Gas that Would Occur Within Selected Ranges During Juvenile Spill Season if the Preferred Alternative is Implemented when Compared to the No Action Alternative at the Four Lower Columbia River Dam Forebay Locations Under a 5-Year Range of River and Meteorological Conditions

SITE	TDG Range (% Sat)	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary	<=110	-5.88%	-2.61%	-1.96%	-2.61%	1.96%
McNary	>110,<=115	4.58%	-2.61%	-1.31%	-0.65%	-3.27%
McNary	>115,<=120	1.96%	5.23%	0.00%	3.27%	1.31%
McNary	>120,<=125	-0.65%	0.00%	3.27%	0.00%	0.00%
McNary	>125	0.00%	0.00%	0.00%	0.00%	0.00%
John Day	<=110	0.65%	-0.65%	-0.65%	1.31%	-3.27%
John Day	>110,<=115	-22.22%	-3.27%	-11.76%	-26.14%	-11.76%
John Day	>115,<=120	26.80%	-9.80%	1.96%	7.84%	15.03%
John Day	>120,<=125	11.11%	13.73%	10.46%	16.99%	0.00%
John Day	>125	-16.34%	0.00%	0.00%	0.00%	0.00%
The Dalles	<=110	9.80%	1.31%	-3.92%	-0.65%	-3.92%
The Dalles	>110,<=115	-30.72%	-4.58%	-18.95%	-20.92%	-20.92%
The Dalles	>115,<=120	26.14%	-1.31%	22.88%	16.99%	24.84%
The Dalles	>120,<=125	-3.27%	4.58%	0.00%	4.58%	0.00%
The Dalles	>125	-1.96%	0.00%	0.00%	0.00%	0.00%
Bonneville	<=110	5.23%	3.27%	-1.96%	1.96%	-1.31%
Bonneville	>110,<=115	-13.73%	-3.27%	-5.88%	-7.19%	-11.11%
Bonneville	>115,<=120	12.42%	-5.88%	3.27%	-9.15%	12.42%
Bonneville	>120,<=125	-1.31%	5.88%	4.58%	14.38%	0.00%
Bonneville	>125	-2.61%	0.00%	0.00%	0.00%	0.00%

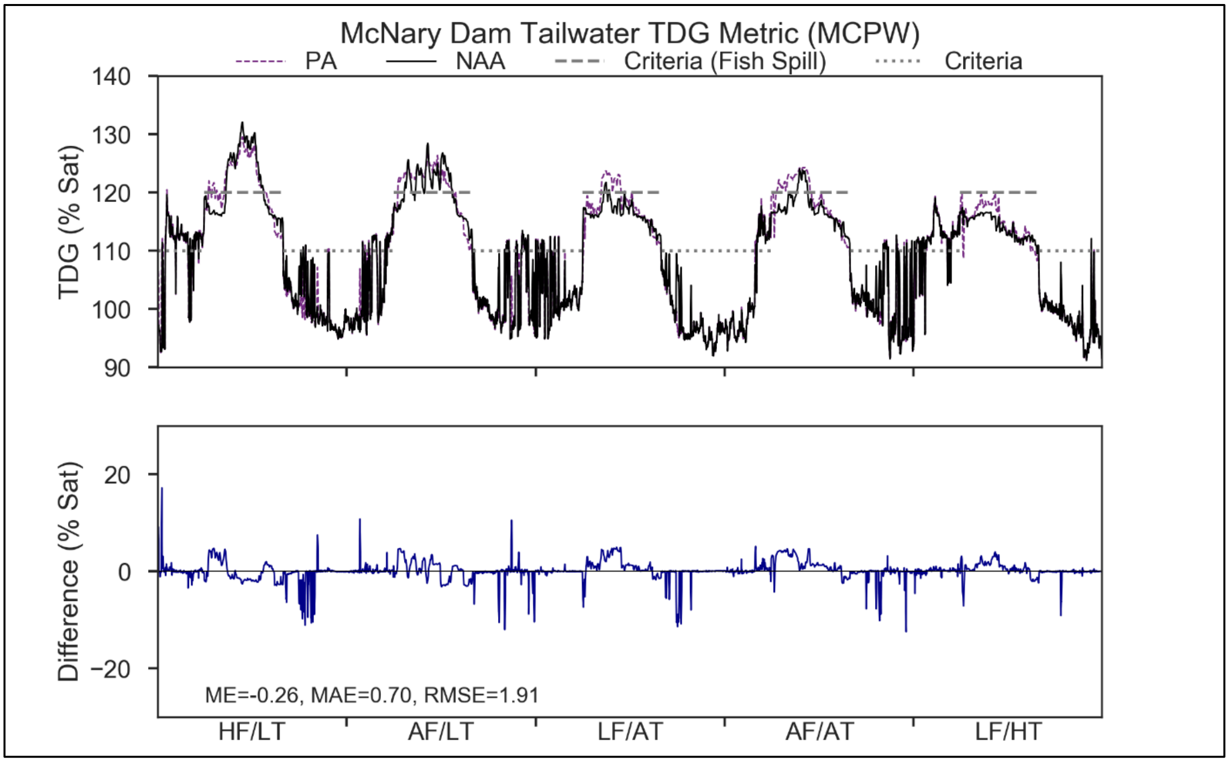


Figure 8-46. Modeled Tailwater Total Dissolved Gas for the Preferred Alternative at McNary Dam Under a 5-year Range of River and Meteorological Conditions

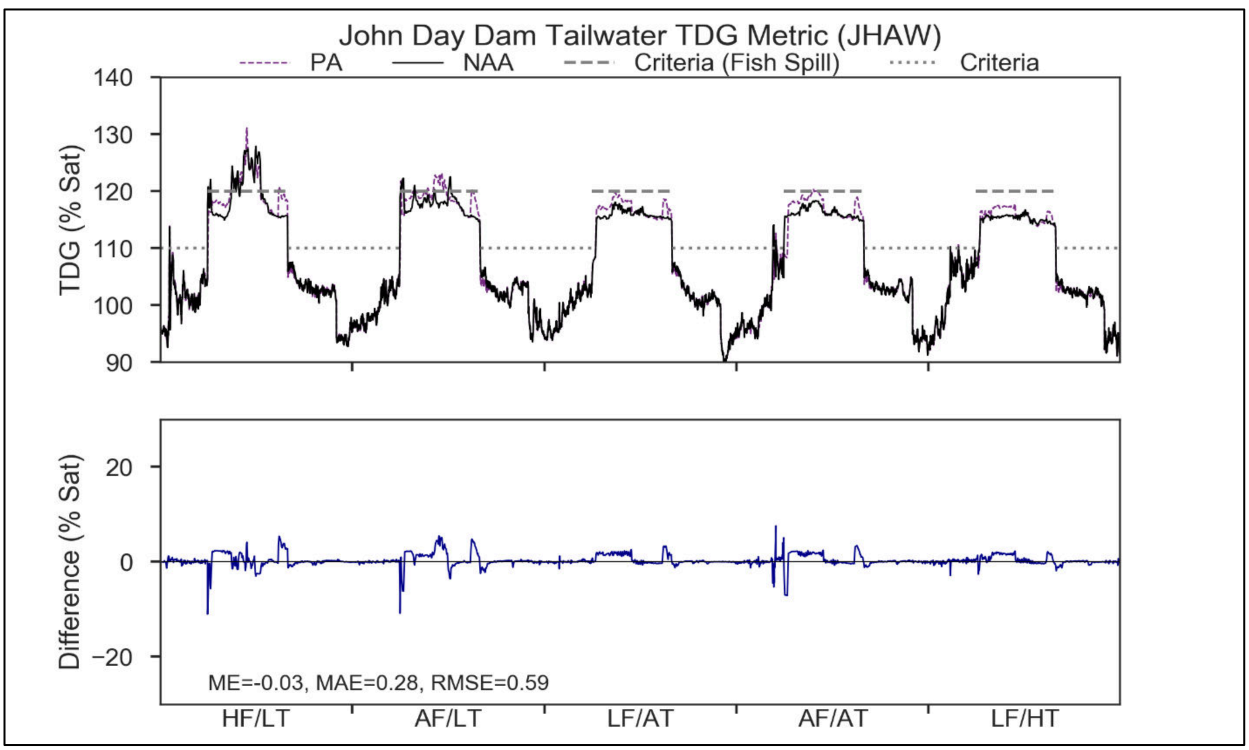


Figure 8-47. Modeled Tailwater Total Dissolved Gas for the Preferred Alternative at John Day Dam Under a 5-year Range of River and Meteorological Conditions

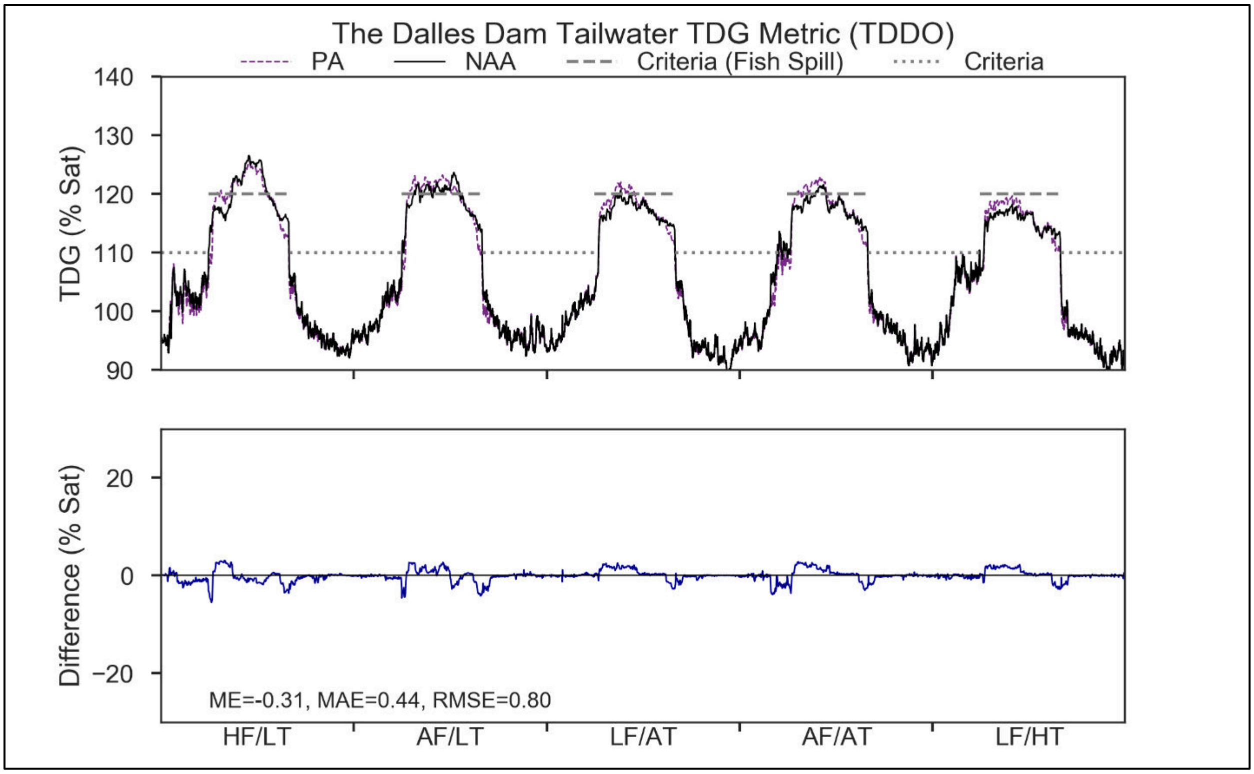


Figure 8-48. Modeled Tailwater Total Dissolved Gas for the Preferred Alternative at The Dalles Dam Under a 5-year Range of River and Meteorological Conditions

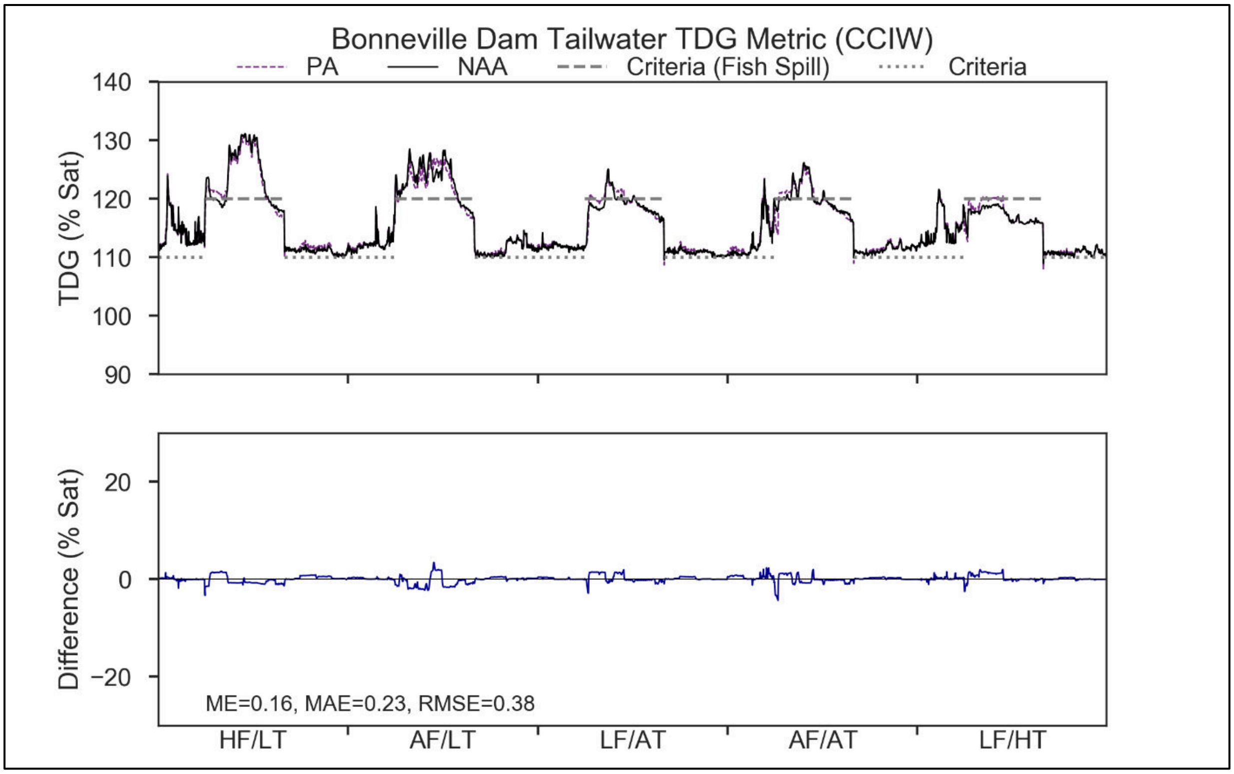


Figure 8-49. Modeled Tailwater Total Dissolved Gas for the Preferred Alternative at Bonneville Dam Under a 5-year Range of River and Meteorological Conditions

Table 8-14. Differences of the Frequency of the Total Dissolved Gas that Would Occur Within Selected Ranges Outside of Juvenile Spill Season if the Preferred Alternative is Implemented when Compared to the No Action Alternative at the Four Lower Columbia River Dam Tailwater Locations Under a 5-Year Range of River and Meteorological Conditions

SITE	TDG Range (% Sat)	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary	<=110	0.44%	-2.01%	-0.22%	-0.62%	0.14%
McNary	>110,<=115	-1.03%	2.01%	0.22%	-1.43%	-0.70%
McNary	>115,<=120	0.42%	0.00%	0.00%	2.04%	0.56%
McNary	>120,<=125	0.18%	0.00%	0.00%	0.00%	0.00%
McNary	>125	0.00%	0.00%	0.00%	0.00%	0.00%
John Day	<=110	-0.02%	0.00%	0.00%	0.08%	-0.06%
John Day	>110,<=115	0.02%	0.00%	0.00%	-0.08%	0.06%
John Day	>115,<=120	0.00%	0.00%	0.00%	0.00%	0.00%
John Day	>120,<=125	0.00%	0.00%	0.00%	0.00%	0.00%
John Day	>125	0.00%	0.00%	0.00%	0.00%	0.00%
The Dalles	<=110	0.00%	0.00%	0.00%	5.77%	0.10%
The Dalles	>110,<=115	0.00%	0.00%	0.00%	-5.77%	-0.10%
The Dalles	>115,<=120	0.00%	0.00%	0.00%	0.00%	0.00%
The Dalles	>120,<=125	0.00%	0.00%	0.00%	0.00%	0.00%
The Dalles	>125	0.00%	0.00%	0.00%	0.00%	0.00%
Bonneville	<=110	-0.10%	0.00%	0.04%	0.00%	-0.28%
Bonneville	>110,<=115	0.73%	-0.10%	-0.04%	-1.69%	-1.02%
Bonneville	>115,<=120	-0.81%	0.10%	0.00%	1.17%	0.82%
Bonneville	>120,<=125	0.18%	0.00%	0.00%	0.52%	0.48%
Bonneville	>125	0.00%	0.00%	0.00%	0.00%	0.00%

Table 8-15. Differences of the Frequency of the Total Dissolved Gas that Would Occur Within Selected Ranges During Juvenile Spill Season if the Preferred Alternative is Implemented when Compared to the No Action Alternative at the Four Lower Columbia River Dam Tailwater Locations Under a 5-Year Range of River and Meteorological Conditions

SITE	TDG Range (% Sat)	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary	<=110	0.00%	0.65%	1.94%	0.65%	9.03%
McNary	>110,<=115	8.39%	3.87%	-5.16%	-4.52%	-13.55%
McNary	>115,<=120	-21.29%	-20.65%	-17.42%	-26.45%	4.52%
McNary	>120,<=125	22.58%	20.65%	20.65%	30.32%	0.00%
McNary	>125	-9.68%	-4.52%	0.00%	0.00%	0.00%
John Day	<=110	0.65%	1.29%	0.00%	4.52%	0.00%
John Day	>110,<=115	0.00%	-2.58%	0.00%	-4.52%	-7.74%
John Day	>115,<=120	-3.87%	-12.90%	0.00%	-4.52%	7.74%
John Day	>120,<=125	11.61%	14.19%	0.00%	4.52%	0.00%
John Day	>125	-8.39%	0.00%	0.00%	0.00%	0.00%
The Dalles	<=110	4.52%	5.16%	1.29%	3.87%	1.29%
The Dalles	>110,<=115	7.74%	-1.29%	0.00%	-1.94%	-5.16%
The Dalles	>115,<=120	-14.84%	-16.13%	-21.94%	-24.52%	3.87%
The Dalles	>120,<=125	18.06%	12.26%	20.65%	22.58%	0.00%
The Dalles	>125	-15.48%	0.00%	0.00%	0.00%	0.00%
Bonneville	<=110	0.00%	0.00%	0.00%	0.00%	0.00%
Bonneville	>110,<=115	0.65%	0.00%	0.65%	2.58%	1.94%
Bonneville	>115,<=120	-10.32%	4.52%	-12.90%	-12.90%	-18.71%
Bonneville	>120,<=125	10.97%	3.23%	12.90%	16.77%	16.77%
Bonneville	>125	-1.29%	-7.74%	-0.65%	-6.45%	0.00%

Table 8-16. Difference in Number of Days the Total Dissolved Gas Criteria is Exceeded at the Forebay Sites of McNary, John Day, The Dalles and Bonneville for the Preferred Alternative Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary	April	0	**4**	0	0	0
McNary	May	**2**	**1**	**2**	**7**	**1**
McNary	June	**2**	**3**	**3**	**1**	**1**
McNary	July	-2	0	0	-3	0
John Day	February	0	0	0	0	**1**
John Day	March	0	0	0	0	0
John Day	April	**17**	**6**	**5**	**16**	0
John Day	May	**12**	**1**	**5**	**4**	**15**
John Day	June	0	0	**4**	**9**	**8**
John Day	July	0	-1	**5**	**9**	0
John Day	August	**4**	0	0	0	0
The Dalles	March	0	0	0	**1**	0
The Dalles	April	**15**	**7**	**7**	**16**	**4**
The Dalles	May	**14**	**1**	**13**	**9**	**24**
The Dalles	June	0	0	**12**	**7**	**10**
The Dalles	July	**1**	-3	**3**	**1**	0
The Dalles	August	**2**	0	0	0	0
Bonneville	March	0	0	0	-8	0
Bonneville	April	**7**	0	**7**	**2**	**5**
Bonneville	May	**6**	0	**1**	0	**12**
Bonneville	June	0	0	**1**	**6**	**2**
Bonneville	July	0	-1	**3**	0	0
Bonneville	August	0	**1**	0	0	0

Table 8-17. Difference in Number of Days the Total Dissolved Gas Criteria is Exceeded at the Tailwater Sites of McNary, John Day and The Dalles for the Preferred Alternative Under a 5-Year Range of River and Meteorological Conditions as Compared to the No Action Alternative

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
McNary	January	**1**	0	0	0	-1
McNary	February	0	**1**	0	0	0
McNary	March	-2	**1**	0	**1**	0
McNary	April	**15**	**12**	0	**20**	0
McNary	May	**3**	**8**	**16**	**20**	0
McNary	June	0	0	**15**	**7**	0
McNary	July	**2**	**5**	**1**	0	0
McNary	August	0	0	0	0	0
McNary	September	0	0	0	0	0
McNary	October	-1	0	0	0	0
McNary	November	0	**2**	0	0	0
McNary	December	0	0	0	0	0
John Day	January	0	0	0	0	0
John Day	February	0	0	0	0	0
John Day	March	0	-1	0	0	0
John Day	April	-3	-4	0	0	0
John Day	May	**4**	**5**	0	**3**	0
John Day	June	**2**	**23**	0	**4**	0
John Day	July	-1	-5	0	0	0
John Day	August	**3**	**3**	0	0	0
The Dalles	February	0	0	0	0	0
The Dalles	March	0	0	0	-13	0
The Dalles	April	**6**	**11**	0	**8**	0
The Dalles	May	**4**	**11**	**18**	**24**	0
The Dalles	June	0	0	**14**	**3**	0
The Dalles	July	-6	-3	0	0	0
The Dalles	August	0	0	0	0	0
The Dalles	September	0	0	0	0	0

Table 8-18. Difference in Number of Days the Total Dissolved Gas Criteria is Exceeded at the Tailwater Sites of Bonneville for the Preferred Alternative Under a 5-Year Range of River and Meteorological

SITE	MONTH	HF/LT	AF/LT	LF/AT	AF/AT	LF/HT
Bonneville	January	0	0	0	0	0
Bonneville	February	0	0	0	0	0
Bonneville	March	0	0	0	0	0
Bonneville	April	**9**	-4	**10**	**12**	0
Bonneville	May	**10**	0	**5**	**4**	**19**
Bonneville	June	0	0	**10**	**1**	**7**
Bonneville	July	-4	-3	-6	-1	0
Bonneville	August	0	0	0	0	0
Bonneville	September	0	0	0	0	0
Bonneville	October	0	0	0	0	**1**
Bonneville	November	0	0	0	0	0
Bonneville	December	0	0	0	0	0

8.3.3 Other Physical, Chemical and Biological Processes

8.3.3.1 McNary, John Day, The Dalles, and Bonneville Dams and Reservoirs

The Preferred Alternative contains optimized versions of three operational measures from the multiple objective alternatives that would affect the John Day reservoir elevation:

- *Predator Disruption Operations*: This measure would allow the Corps to manipulate the John Day reservoir elevation to decrease avian predation on ESA-listed juvenile salmon and steelhead in the lower Columbia River. The normal reservoir operating range of the John Day reservoir is up to elevation 266.5 feet (although it is authorized to operated up to 268 feet). This measure would include operating between 264.5 - 266.5 feet during the period of April 10 - June 15; operations may be initiated earlier, prior to the start of nesting by Caspian Terns, to avoid take. The results of this action would be monitoring and communicated with the USFWS and NOAA Fisheries.
- *Increased Forebay Range Flexibility*: This measure would provide operating flexibility during fish passage season (April 3 - August 31) by changing the operating elevation ranged restriction at John Day. The operating elevation range restriction at John Day would be MIP plus 2 feet (262.5 - 264.5 feet), except from April 1 - May 31 when the John Day forebay operating range would remain between elevations 263.5 and 265.5 feet. The operating range restrictions would end when spill is reduced or ends. Safety-related restrictions would continue, including but not limited to maintaining ramp rates for minimizing erosion and maintaining power grid reliability.

- *John Day Full Pool*: This measure would remove current restrictions on seasonal pool elevations at John Day, allowing more operating flexibility for hourly and daily shaping of hydropower generation. This measure would allow John Day to use the full normal operating range (262.0 - 266.5 feet) outside of fish-passage season except as needed for flood risk management.

These measures would generally lead to the John Day forebay elevation being higher for the PA than for the No Action Alternative, except from about June through August when the elevations for the PA and the No Action Alternative would be similar (Figure 8-50). Under the PA, the elevations would be lower from about June through August than the rest of the year presumably due to the operating range restriction described in the *Increased Forebay Range Flexibility* measure. No structural or operating measures are expected to impact the forebay elevations at McNary, The Dalles, and Bonneville; forebay elevations at these dams for both PA2 and the No Action Alternative would be similar.

Raising and/or lowering the water level could lead to an increase in total suspended solids (TSS) and associated impacts (increased turbidity, decreased light attenuation, and/or increased concentrations of chemicals that may be associated with TSS like nutrients, metals, and organics). However, the impact is expected to be negligible in the large John Day Reservoir.

Otherwise, the introduction of pollutants and excess nutrients from farming and industrial activities, as well as urban runoff, is expected to continue under the PA. As with the No Action Alternative, emerging contaminants such as pharmaceuticals and new pesticides will also likely become more prevalent. The lower Columbia River contains a variety of human-sourced compounds, including metals and organic contaminants. This condition is expected to remain generally unchanged, and it is expected that current water quality impairments would continue.

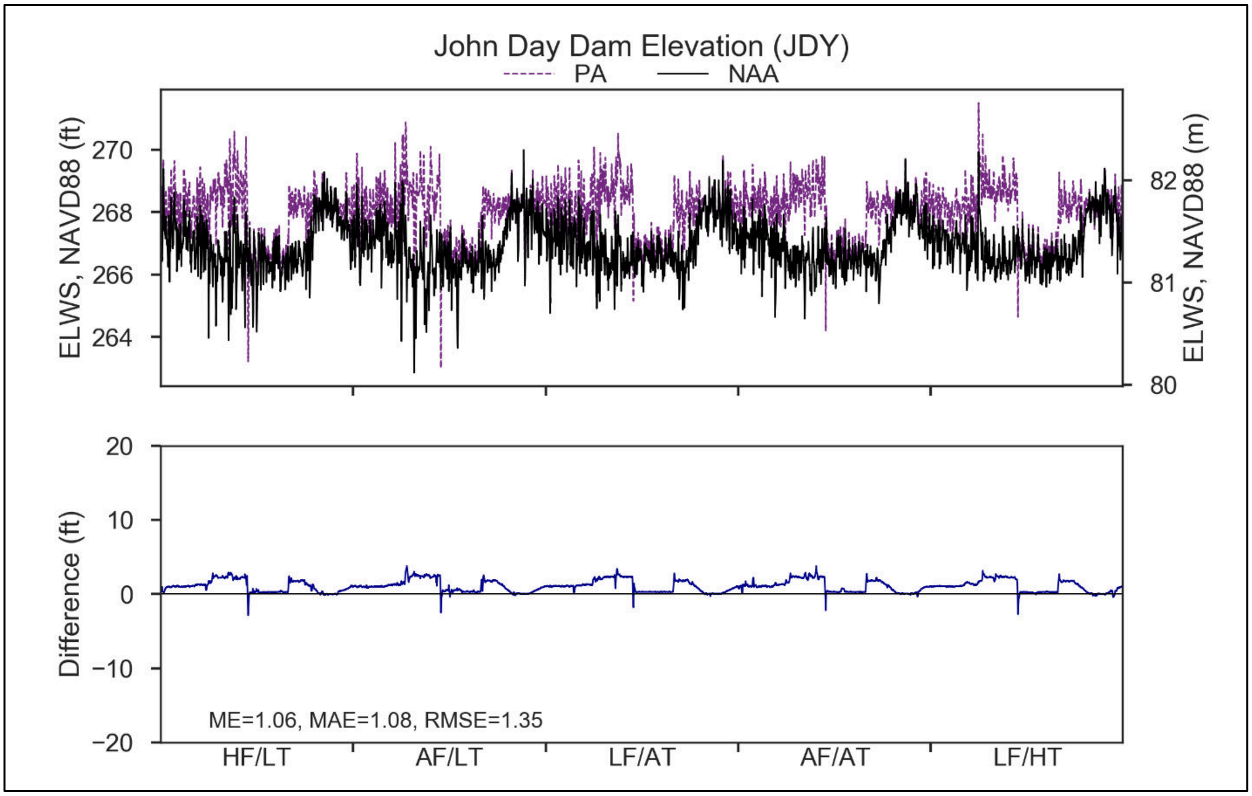


Figure 8-50. Modeled Forebay Elevation for the Preferred Alternative at John Day Dam Under a 5-year Range of River and Meteorological Conditions

8.4 SEDIMENT PROCESSES

8.4.1 Sediment Sources

The PA includes a wide range of structural, fish passage, water management, hydropower and other measures. These proposed measures would have negligible effects on sediment sources or movement. The measures included in the PA are not expected to cause changes to land use within the CRS including upland recreation, flood management, agricultural, timber, or mining activities, and would not be expected to change population growth patterns in those areas.

8.4.2 Chemicals of Concern

No change is predicted to the list of sediment chemicals of concern, compared to the existing conditions and under the No Action Alternative. Throughout the basin, the contaminants of concern would remain. These include metals, polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), pesticides and pesticide degradation products, PCBs, dioxins, and nutrients (ammonia).

8.5 CONCEPTUAL SITE MODEL

The conceptual site model for dredging under the preferred alternative is the same as the conceptual site model(s) for the existing conditions and under the No Action Alternative. Areas that are currently not dredged (such as Chief Joseph Reservoir) would not be dredged in the future, in spite of potential changes in sediment loading in the upper Columbia River Basin, since there are no navigational features maintained by dredging. Sediment management operations in the Snake and lower Columbia Rivers would remain as they currently are since sediment sources for those reaches are not affected. Where dredging is needed (such as at the confluence of the Snake and Clearwater Rivers), it is assumed that dredged materials would be of sufficient quality for either in-water or upland beneficial use, as habitat creation areas or as upland fill. Sediment characterization following the Sediment Evaluation Framework (RSET 2018) or other applicable guidance would continue to be required for any new dredging or sediment related projects

8.6 WATER AND SEDIMENT QUALITY CONCLUSIONS

The most notable PA measures that affect water quality are as follows:

- *Juvenile Fish Passage Spill Operations*: Set spill to the 125% TDG gas cap at most projects for 16 hours for juvenile outmigration. For the remaining 8 hours, the projects would spill to the performance criterion spill.
- *Modified Draft at Libby, Update System FRM Calculation, Planned Draft Rate at Grand Coulee, Sliding Scale at Libby and Hungry Horse*: Modify operations for FRM at Libby, Hungry Horse and Grand Coulee
- *Grand Coulee Maintenance Operation*: Perform major maintenance at Grand Coulee
- *Lake Roosevelt Additional Water Supply*: Modify operations to meet existing contractual water supply obligations
- *Slightly Deeper Draft for Hydropower*: Allow for a larger operating range at storage projects for hydropower flexibility at Dworshak.
- *Fall Operational Flexibility for Hydropower*: Allow for a larger operating range at storage projects for hydropower flexibility at Grand Coulee in the fall.

8.6.1 Preferred Alternative Results – Water Temperature

In general, the PA would result in little to no change in water temperature conditions at Hungry Horse, Albeni Falls, Grand Coulee, and Chief Joseph dams and reservoirs, as compared to the No Action Alternative (Figure 8-51). Due to PA higher winter outflows elevations at Libby Dam, resulting from the deeper mid-April draft targets, Kootenai River water temperatures could be warmer in the winter as compared to the No Action Alternative. This could result in negligible to minor negative impacts to resident fish species.

Negligible impacts to water temperature are expected at Dworshak Dam and Reservoir or in the lower Snake and Columbia Rivers under the PA (Figure 8-52 and Figure 8-53).

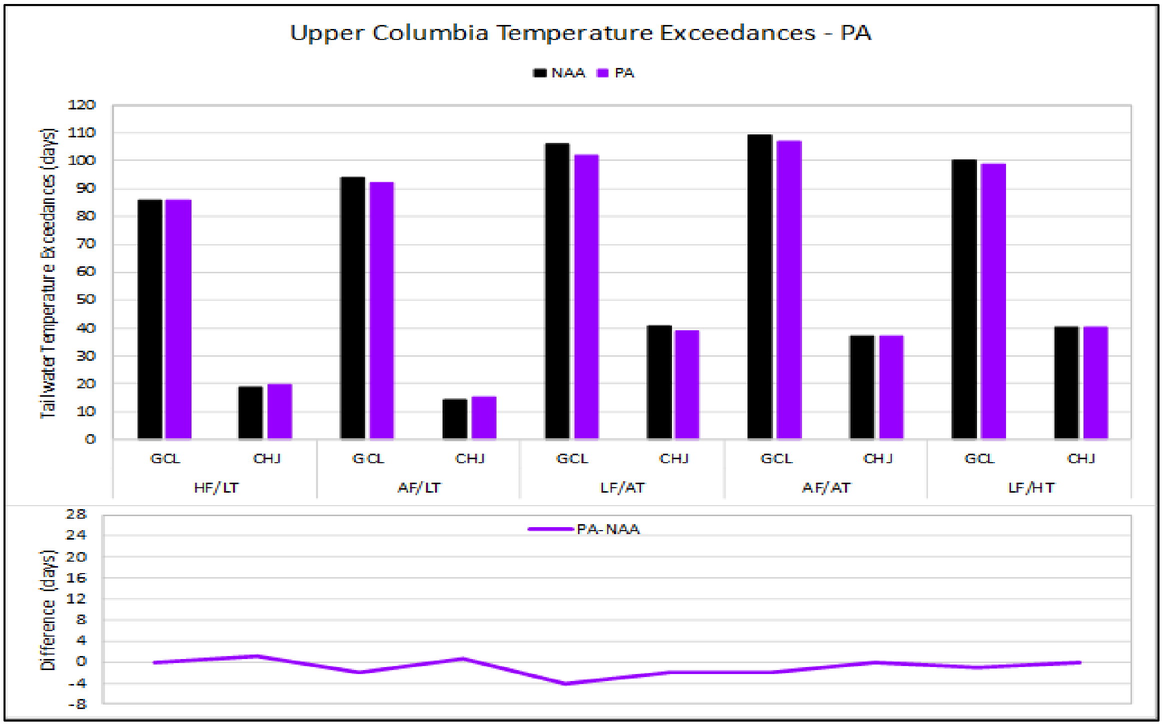


Figure 8-51. Modeled Tailwater Temperature Exceedances for the No Action Alternative and the Preferred Alternative at Grand Coulee and Chief Joseph Dams Under a 5-Year Range of River and Meteorological Conditions

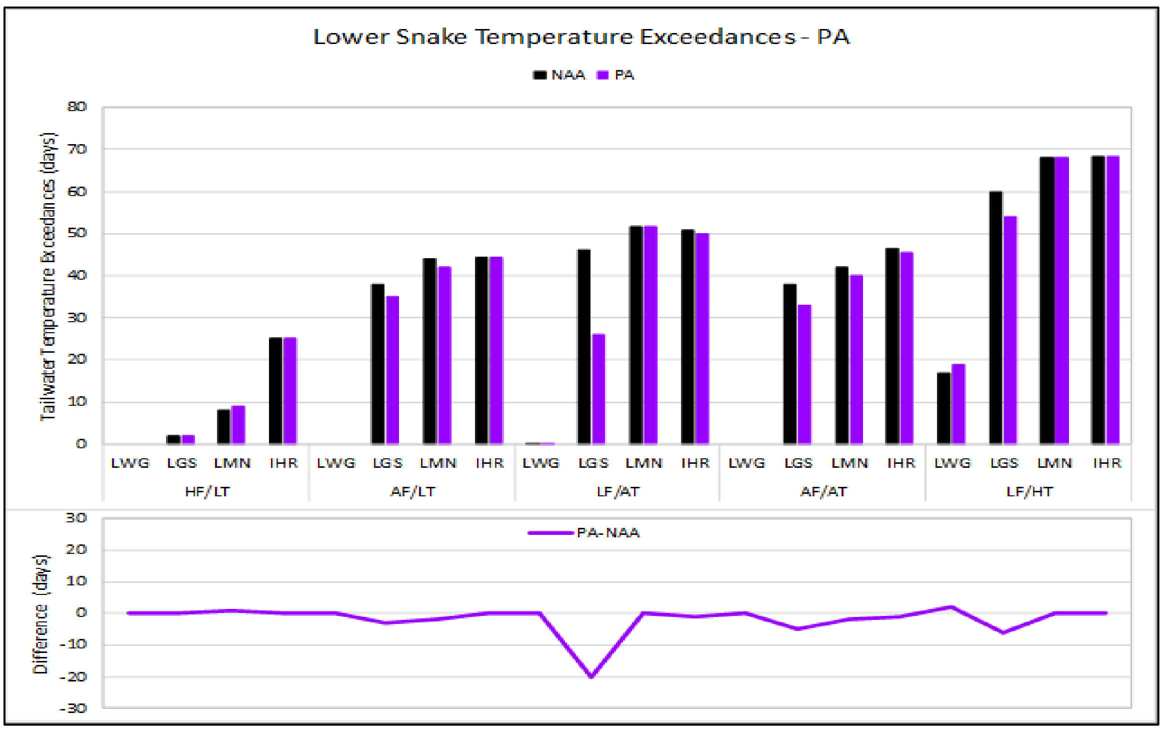


Figure 8-52. Modeled Tailwater Temperature Exceedances for the No Action Alternative and the Preferred Alternative at Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams Under a 5-Year Range of River and Meteorological Conditions

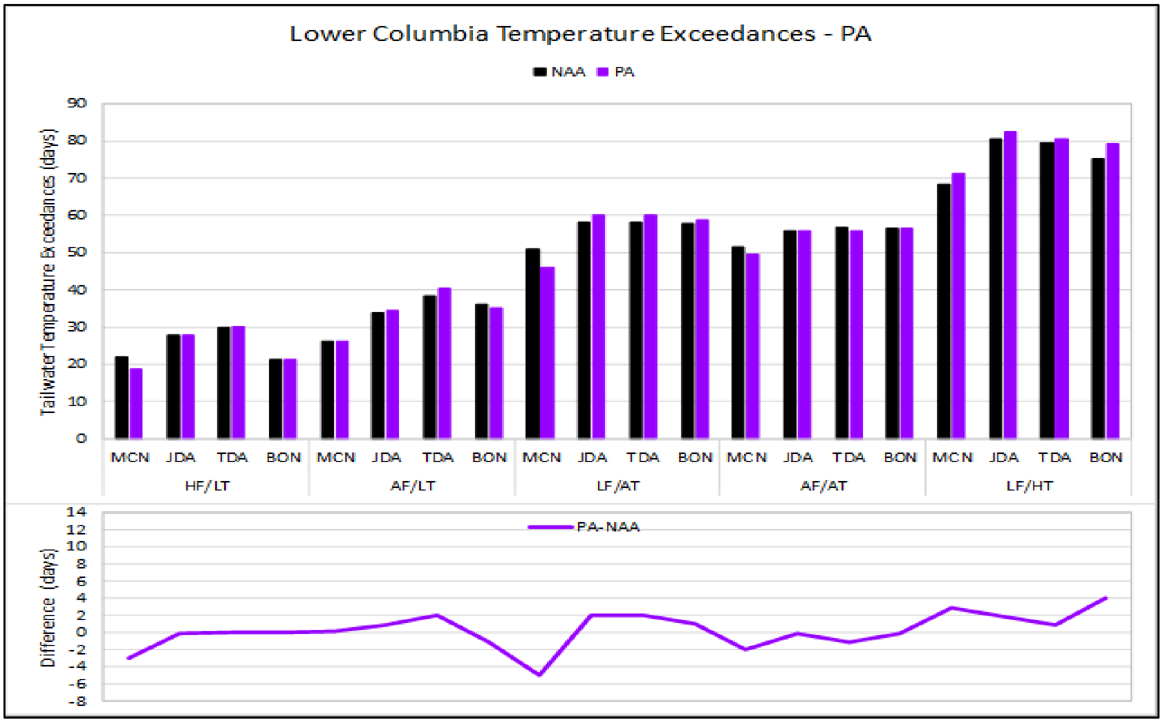


Figure 8-53. Modeled Tailwater Temperature Exceedances for the No Action Alternative and the Preferred Alternative at McNary, John Day, The Dalles, and Bonneville Dams Under a 5-Year Range of River and Meteorological Conditions

8.6.2 Preferred Alternative Results – Total Dissolved Gas

There are no anticipated impacts to TDG expected downstream of Albeni Falls under PA. Negligible changes in TDG are expected downstream of Libby, Hungry Horse, Grand Coulee or Chief Joseph Dams (Figure 8-54).

Under the PA, TDG would be higher in the lower Snake and Columbia River dams due to the *Juvenile Fish Passage Spill* measure, which sets tailwater TDG limits to 125 percent TDG with no forebay TDG limit (Figure 8-55 and Figure 8-56). This results in moderate increases in TDG in the lower Snake River. Due to the assumed higher amount of lack of market spill in the No Action Alternative, model results do not show a notable differences in TDG in the PA as compared to the No Action Alternative in the lower Columbia River. TDG effects are negligible in this reach.

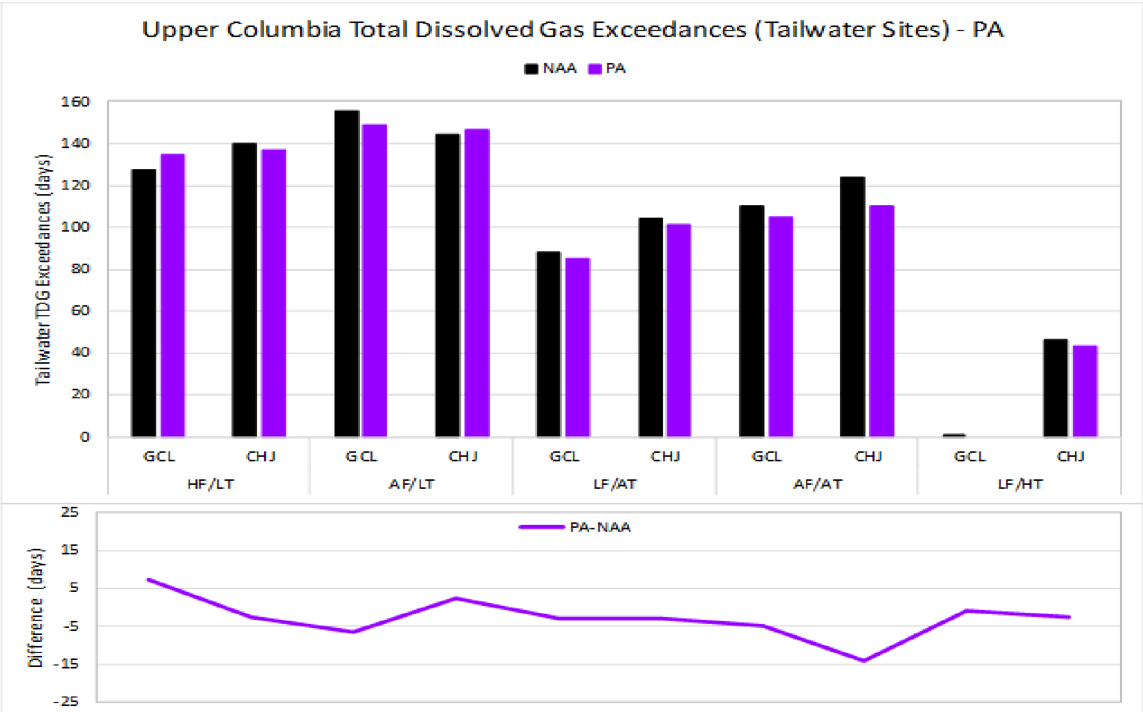


Figure 8-54. Modeled Tailwater Total Dissolved Gas Exceedances for the No Action Alternative and the Preferred Alternative at Grand Coulee and Chief Joseph Under a 5-Year Range of River and Meteorological Conditions

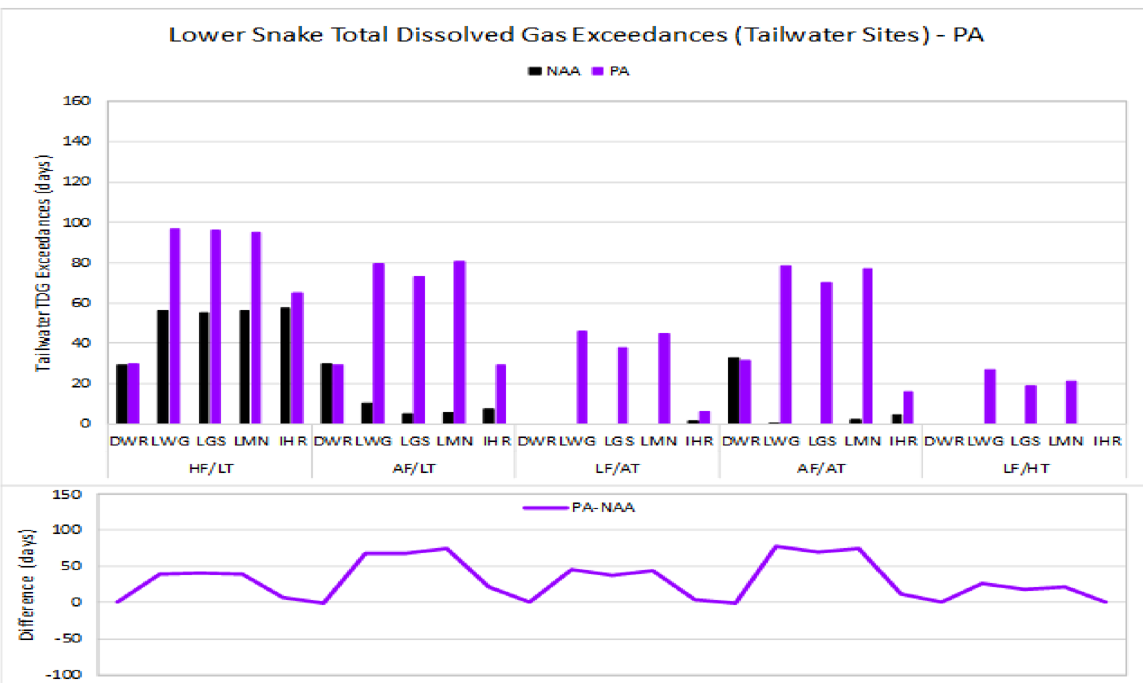


Figure 8-55. Modeled Tailwater Total Dissolved Gas Exceedances for the No Action Alternative and the Preferred Alternative at Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams Under a 5-Year Range of River and Meteorological Conditions

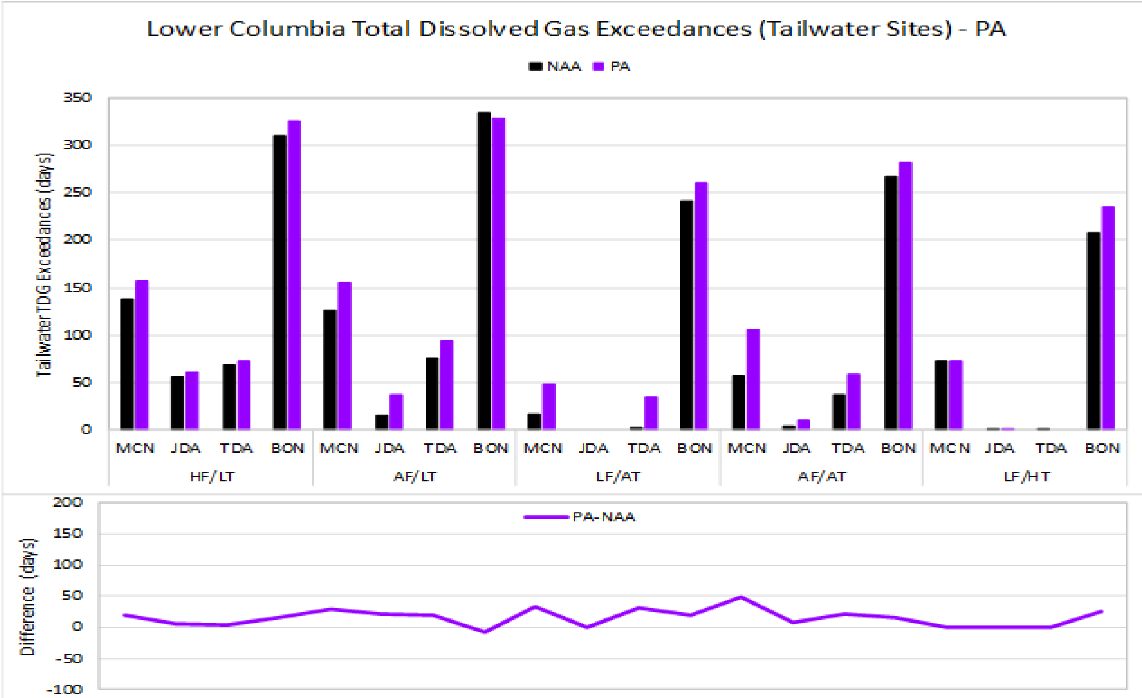


Figure 8-56. Modeled Tailwater Total Dissolved Gas Exceedances for the No Action Alternative and the Preferred Alternative at McNary, John Day, The Dalles, and Bonneville Dams Under a 5-Year Range of River and Meteorological Conditions

8.6.3 Preferred Alternative Results – Other Water Quality Impacts

In general, PA would result in negligible changes in other water quality parameters at all CRSO projects.

8.6.4 Preferred Alternative Results – Sediment Quality

Overall sediment distribution and quality within the entire system are expected to experience negligible impacts from the PA. The effects of the proposed changes on dredging requirements and the quality of dredged materials are expected to be negligible since existing transportation features (locks) are not changing and sediment sources are similarly un-impacted by the proposed measures.

CHAPTER 9 - CONCLUSIONS

The overall effects of the MOs and PA, as compared to the No Action for water temperature have been summarized for water temperature and TDG (Table 9-1 and Table 9-2). The metrics used (negligible, minor, moderate or major) in the summary tables describe the magnitude of change relative to the No Action Alternative and do not signify if the change was a negative or positive (improved or deteriorated water quality condition). The methodology used to summarize these effects can be found in Section 2.6.

Table 9-1. Summary of Water Temperature Effects by EIS Alternative

SITE	MO1	MO2	MO3	MO4	PA2
Libby	negligible	negligible	negligible	minor	negligible
Hungry Horse	negligible	negligible	negligible	negligible	negligible
Albeni Falls	negligible	negligible	negligible	minor	negligible
Grand Coulee	negligible	negligible	negligible	minor	negligible
Chief Joseph	negligible	negligible	negligible	minor	negligible
Dworshak	minor	minor	negligible	negligible	negligible
Lower Granite	major	moderate	major	negligible	negligible
Little Goose	negligible	minor	major	negligible	moderate
Lower Monumental	negligible	minor	major	negligible	negligible
Ice Harbor	minor	minor	major	negligible	negligible
McNary	minor	negligible	minor	minor	negligible
John Day	negligible	negligible	minor	negligible	negligible
The Dalles	negligible	negligible	minor	minor	negligible
Bonneville	negligible	negligible	minor	negligible	negligible

Note: The level of effect is the magnitude of change relative to the No Action Alternative.

Table 9-2. Summary of Tailwater Total Dissolved Gas Effects by EIS Alternative

SITE	MO1	MO2	MO3	MO4	PA2
Libby	negligible	negligible	negligible	minor	negligible
Hungry Horse	negligible	negligible	negligible	negligible	negligible
Albeni Falls	negligible	negligible	negligible	minor	negligible
Grand Coulee	minor	negligible	negligible	negligible	negligible
Chief Joseph	negligible	negligible	negligible	negligible	negligible
Dworshak	negligible	negligible	negligible	negligible	negligible
Lower Granite	negligible	minor	NA	major	minor
Little Goose	negligible	negligible	NA	major	major
Lower Monumental	negligible	minor	NA	major	moderate
Ice Harbor	negligible	minor	NA	moderate	negligible
McNary	negligible	minor	minor	negligible	negligible
John Day	negligible	minor	minor	major	minor
The Dalles	negligible	moderate	negligible	moderate	negligible
Bonneville	negligible	negligible	negligible	negligible	negligible

Note: The level of effect is the magnitude of change relative to the No Action Alternative.

Based on findings from the CRSO EIS water quality analysis, some broad conclusions regarding the operation and maintenance of CRSO projects can be made. These include:

9.1 UPPER COLUMBIA RIVER BASIN

- Water temperatures in Lake Roosevelt and below Grand Coulee Dam are influenced by the changes in operations including changes to storage timing (winter drafts for FRM in the *Winter System FRM Space* measure), reductions in reservoir volume due to the McNary Flow Target, by decreasing outflows for Lake Roosevelt Additional Water Supply, and by changes upstream that changes to inflows. Additionally, changes to spill levels and predicted outlet use and power plant operations influence modeled water temperatures and introduce some uncertainty.
- Changes to operations (elevations and flows), reservoir temperatures, retention time, and potentially simplifying modeling assumptions resulted in changes to dissolved oxygen in the Spokane Arm of Lake Roosevelt. The results in MO2 and MO4 for LF/HT years predicted that a larger portion of the water column would have low dissolved oxygen.
- Even though the major maintenance measure did not result in impacts to downstream water quality, it is anticipated that a reduction in power plant capacity could result in higher TDG during years with large water supplies requiring high discharges. Because the capacity to pass the water through the power plants would be reduced, additional spill would be required, increasing downstream TDG.

9.2 LOWER SNAKE RIVER BASIN

- Results suggest that it is critical to begin Dworshak water temperature management operations in early July to "get ahead" of warming in the lower Snake River. The proposed operational changes in the MOs either did not make a significant difference or resulted in higher temperatures, i.e., McNary Flow target and Modified Dworshak Summer Draft in the lower Snake River.
- Reductions in spill operations on the lower Snake River during the late summer do not result in a reduction in water temperature.
- Meeting TDG limits of 110 percent are typically not achievable due to minimum spill requirements, involuntary spill, and lack of market conditions.
- Meeting TDG limits of 125 percent TDG are difficult to achieve throughout the juvenile downstream fish passage spill season in low flow years due to a lack of total river flow.
- Dam breaching
  - Elevated river TDG due to dam spill operations will not occur. However, TDG above 110 percent would still occur during breaching and is expected to be geographically localized and would occur much less frequently and for shorter durations under normative river conditions.
  - Water temperatures would be similar to what they were before the dams were built; daily maximums would exceed 68°F during the summer, daily fluctuations would be greater, and more rapid heating would occur in spring, followed by earlier cooling in the fall.
    - Re-suspension of sediments following dam breaching could result in:
      - Exposure of chemical contaminants that have been contained in reservoir sediment. Chemicals of concern include total DDT, dioxin, manganese, and un-ionized ammonia. DDT could potentially affect the biological system, and un-ionized ammonia concentrations may exceed EPA water quality criteria for the protection of aquatic life.
      - Low, and even anoxic, oxygen concentrations for up to several weeks during the breaching process, which would create harmful conditions for aquatic organisms.
      - Initial reduction of primary and secondary production while suspended solids concentrations and turbidity are elevated.
      - Damage to irrigation pumps and adverse effects to irrigated crops.
    - Phytoplankton and zooplankton would become minor components of the food web. Attached benthic algae and macroinvertebrates would dominate primary and secondary productivity after a new equilibrium is established.

9.3 LOWER COLUMBIA RIVER

- Results suggest that lower Columbia River water temperatures are not influenced by upstream structural and/or operational changes. This includes breaching of the lower Snake River dams.
- Meeting TDG limits of 110 percent are typically not achievable due to minimum spill requirements, involuntary spill, and lack of market conditions.
- Meeting TDG limits of 125 percent TDG are difficult to achieve throughout the juvenile downstream fish passage spill season in low flow years due to a lack of total river flow.

CHAPTER 10 - REFERENCES

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Columbia River System Operations
Final Environmental Impact Statement

Annex A
Lower Snake River Multiple Objective Alternative 3
Model Development Report

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ACRONYMS AND ABBREVIATIONS

#OBS	number of observations
°C	degrees Celsius
°F	degrees Fahrenheit
AME	absolute mean error
ANA	Anatone, Idaho
ANQW	Anatone River station
cfs	cubic feet per second
Corps	U.S. Army Corps of Engineers
CRSO	Columbia River System Operations
DENI	Dent Acres, Idaho, weather station
DWQI	North Fork Clearwater River at Ahsahka, Idaho, station
DWR	Dworshak Dam
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
ft^2/s	square feet per second
HEC	Hydrologic Engineering Center
HEC-RAS	Hydrologic Engineering Center River Analysis System
IHR	Ice Harbor Dam
LEGW	Legrow, Washington, station
LEWI	Lewiston, Idaho, station
LGS	Little Goose Dam
LMN	Lower Monumental Dam
LSR	Lower Snake River (model)
LWG	Lower Granite Dam
m	meters
m/s	meters per second
MAE	mean absolute error
MCN	McNary Dam
ME	mean error
mmHg	millimeters mercury
MO	Multiple Objective Alternative
MO3	Multiple Objective Alternative 3
ORFI	Clearwater River at Orofino, Idaho, station
PEK	Peck, Idaho
ResSim	reservoir simulation model (power/flood model)
RM	river mile
RBM10	River Basin Model-10
RMSE	root mean square error
SILW	Silcott Island, Washington, station
SPD	Spalding, Idaho
SWSolar W/m^2	short wave solar radiation

TMDL	total maximum daily load
W2	water quality model CE-QUAL-W2
WQ team	Columbia River System Operations water quality modeling team

CHAPTER 1 - LOWER SNAKE RIVER MULTIPLE OBJECTIVE ALTERNATIVE 3 MODEL

1.1 INTRODUCTION

The Lower Snake River (LSR) Multiple Objective Alternative 3 (MO3) model was developed to evaluate water quality impacts from breaching of all four dams on the lower Snake River. Analysis was performed using a 5-year period, spanning 2011 through 2015, to understand impacts under a wide range of flow and meteorological conditions. MO3 has several notable measures (Chapter 2), the most significant of which is the removal of the lower Snake River dams, which would occur over a 2-year period with Lower Granite and Little Goose Dams breached in the first year, Lower Monumental and Ice Harbor Dams breached the second year. Unlike the other Multiple Objective Alternatives (MOs), for MO3, the lower Snake River reach is represented by a one-dimensional Hydrologic Engineering Center River Analysis System (HEC-RAS) model with dam breach bathymetry. This geometry represents the channel at sediment movement equilibrium and is a stable geometry. Other MOs used the two-dimensional CE-QUAL-W2 (W2) model that represents the existing dam configuration.

1.2 SELECTION

Given the Columbia River System Operations (CRSO) project timeline, available resources, and product quality, the CRSO water quality modeling team (WQ team) considered using either W2 or HEC-RAS to represent temperature under the dam breach alternative. HEC-RAS is a depth-averaged one-dimensional hydraulic model designed for free-flowing riverine conditions, whereas W2 is designed primarily for stratified lakes and becomes unstable with a sloped water surface and higher velocities. There are distinct advantages of both of these models.

The advantages of W2 are as follows:

- Use of calibrated parameterization identical to that of other CRSO models

The advantages of HEC-RAS are as follows:

- Stable hydraulics
- More precise cross-section and channel slope representation
- Bathymetry file for dam breach conditions already developed in HEC-RAS format

The water quality modeling team used past experiences and professional judgment to come to a consensus decision and use HEC-RAS to represent the lower Snake River dam breach. Although riverine models using W2 do exist, the amount of effort required to set up a stable model and test a variety of parameter sets was not within the project constraints. There are several instabilities that occur when developing a W2 riverine model, many of which involve unstable water surface elevations due to having a sloped channel. Given this and past unsuccessful efforts to set up a W2 riverine model on the Clearwater River due to stability issues over the observed annual hydrograph, the WQ team chose to move forward by pursing the development of a one-dimensional model.

The WQ team used the following strategies to minimize the uncertainty introduced by not using parameters that had been calibrated to an existing condition:

- When possible, use a similar parameterization to the calibrated W2 model or published values.
- Utilize the same meteorology and solar radiation inputs as the calibrated W2 model.
- When the HEC-RAS heat balance representation needed different parameters than W2, utilize the parameters from the calibrated Clearwater River HEC-RAS model.
- Use Edinger values for wind coefficients since the W2 calibration wind parameters represent wind differently (Edinger, et. al. 1974; reported in Cole and Wells 2018).
- Perform a test of the parameterization utilizing the current hydraulics (with dams) and comparing results to 2011 – 2015 measured water temperature.
- Perform a sensitivity analysis of the chosen parameterization to ensure that temperature predictions are ideal.
- Compare the predictions of MO3 to other dam breach modeling efforts.

1.3 LOWER SNAKE RIVER MULTIPLE OBJECTIVE ALTERNATIVE 3 MODEL DEVELOPMENT

The LSR-MO3 model simulates water temperature using the newly developed HEC-RAS geometry to represent dam breach. The software program HEC-RAS Version 5.0.3 and appropriate system improvements and modifications were used for the MO3 model development. A depiction of the full CRSO MO3 model is shown below in Figure 1-1; however, this report focuses solely on the lower Snake River portion of the model development, which is shown in Figure 1-2.

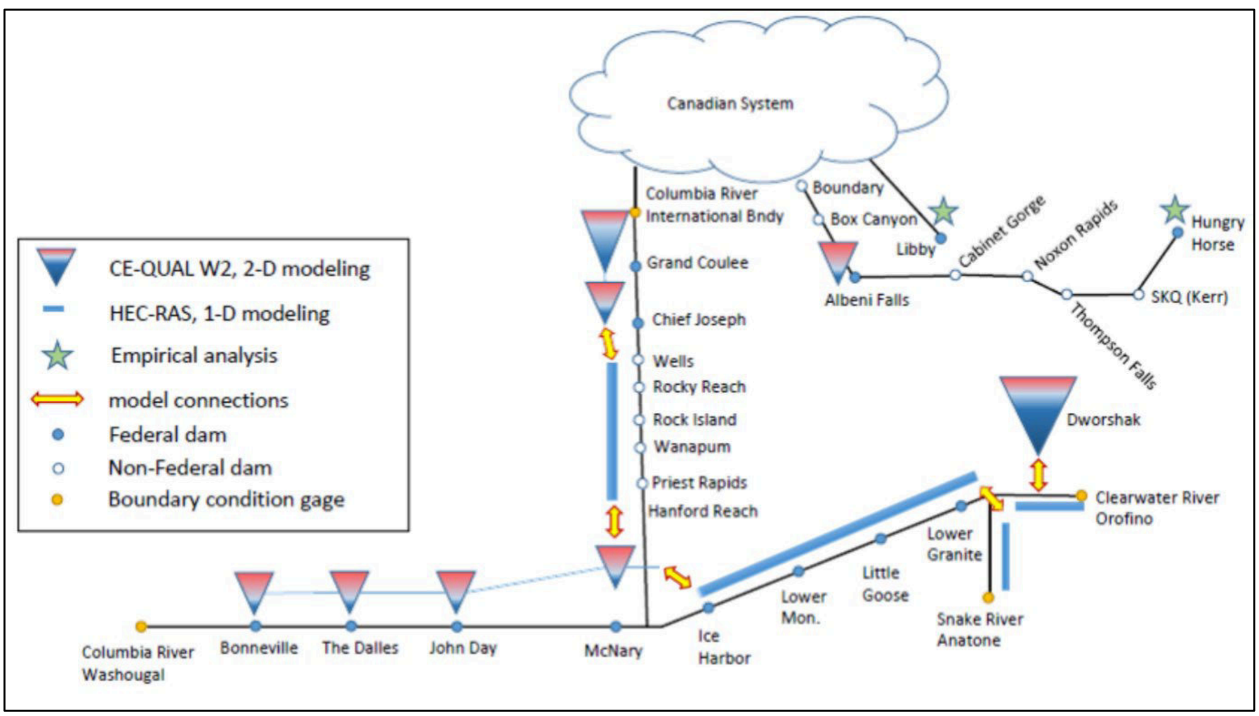

Figure 1-1. Columbia River System Operations Multiple Objective 3 Model Schematic

Figure 1-2. Lower Snake River Multiple Objective Alternative 3 Model Geometry
Note: IHR = Ice Harbor, LMN = Lower Monumental, LGS = Little Goose, LWG = Lower Granite, ORFI = Clearwater River at Orofino station, ANA = Anatone station on the Snake River.

1.3.1 Model Geometry

An in-depth sediment transport model was developed for the lower Snake River reach to characterize sediment movement through the system from the breaching of the four lower Snake River dams. A one-dimensional quasi-unsteady mobile bed model of the Clearwater River, lower Snake River, and McNary Reservoir was employed using the HEC-RAS Version 5.0.6 software to inform on the scour, transport, and fate of materials stored in the lower Snake River system. Once sediment equilibrium was achieved, the resulting channel was compared to the 1934 river terrain and yielded similar characteristics. A channel geometry calibrated to the 1934 channel geometry was developed and provided for water quality analysis. Modifications to the geometry include the addition of the dam structure remnants and configured flow bypasses. The final channel geometry presented by the CRSO river mechanics team may be different than the 1934 representation used in the water quality analysis. Additional refinement of the sediment movement study and resulting channel geometry will not likely yield noticeable differences in water temperature.

The geometry obtained from the CRSO river mechanics was updated with edits specific to the Columbia River System Operations (CRSO) modeling so that impacts from MO3 could be directly compared to the No Action Alternative (NAA). Geometry updates include the following:

1. The Snake and Clearwater River channels were extended further upstream to match the CRSO model. The Orofino Creek reach was added and the North Fork Clearwater River was extended to link with the upstream Dworshak W2 model. Cross sections from the CRSO

model were added as part of this extension. Channel slopes and downstream lengths were verified during the updates. Cross sections along the Clearwater and Snake Rivers were compared to identify major changes in channel geometries between the No Action and MO3 models. Figure 1-3 shows two locations on the Clearwater River, cross sections 7.8160 and 7.0348. Similarly, Figure 1-4 shows the Snake River cross sections 147.85 and 140.40662. These cross sections are located at the upstream end of the 1934 geometry where the cross sections transition to the CRSO existing condition geometry. The black line represents the 1934 geometry with dam bypass and the pink line represents the CRSO No Action Alternative geometry. Above the Snake and Clearwater Rivers confluence, all cross sections were compared between geometry sets. In general, the Clearwater River reach shows good agreement between datasets at most locations. However, the Snake River is noticeably variable.

2. Bridges and bounding cross sections were copied over from the CRSO geometry and corresponding reach lengths were adjusted. Downstream distances were adjusted based on assigned river mile station.
3. Snake River bridges at river miles (RM) 136, 138, and 140 and Clearwater cross section 0.591 were imported into the 1934 geometry from the CRSO geometries. Bridge and pier stationing were compared and shifted to best represent thalweg location within the channel. Snake River cross section 138.7972 was copied as 138.633 to define an adjacent cross section, as needed for bridge computation. Reach length distances and channel elevations were adjusted base on channel slope to provide a smooth representation of the channel. Figure 1-5 through Figure 1-7 compare bridge cross sections for the Clearwater and Snake Rivers, respectively. It is important to note that cross section layout and distance from the bridge varies between geometries. It should also be noted that the sediment study did not include existing bridges and therefore does not consider bridge-related scour and deposition potential in the MO3 1934 geometry.
4. Interpolated cross sections along Clearwater River were added to the MO3 1934 geometry for stability. Interpolated cross sections were not necessary throughout the other reaches.

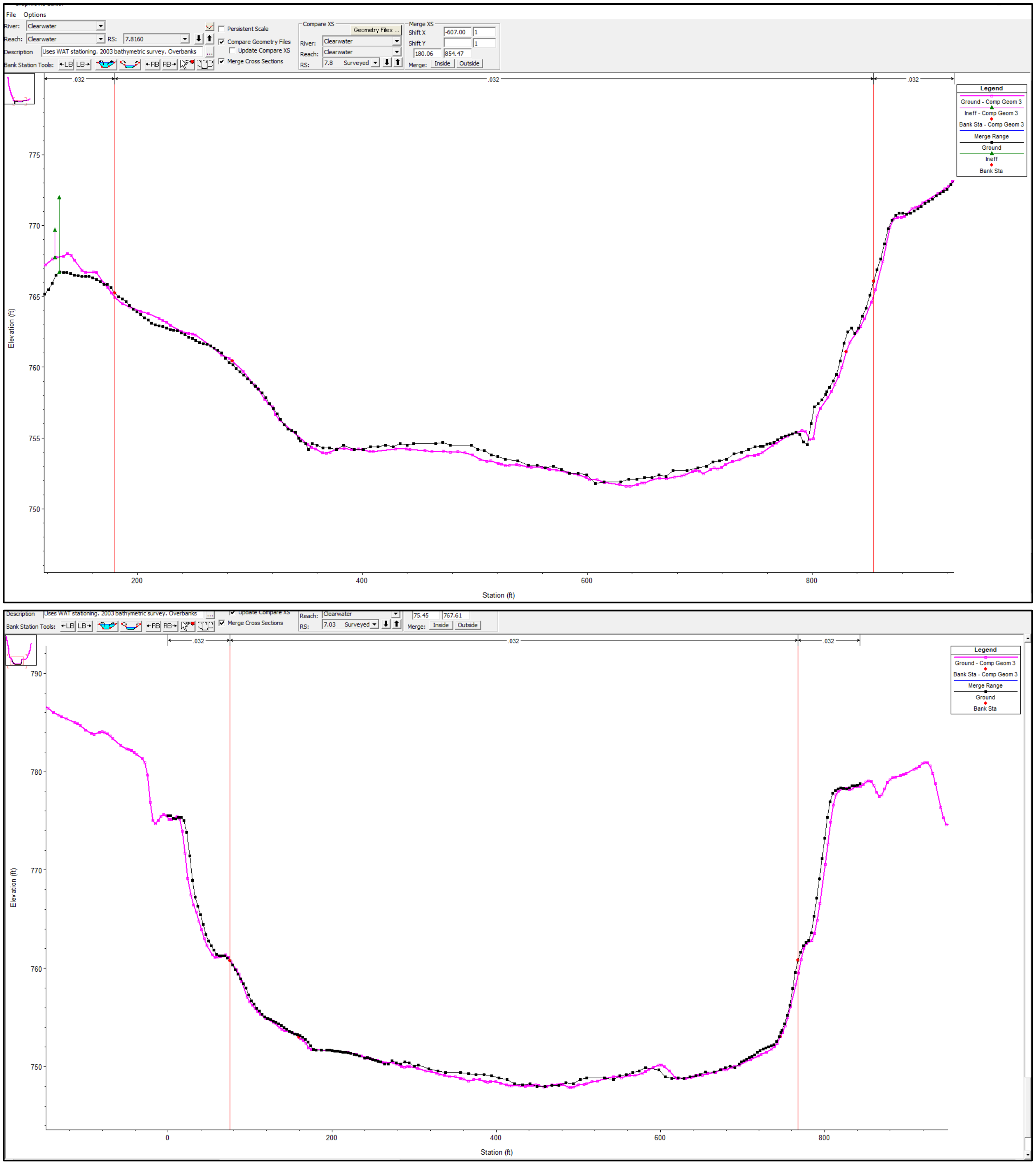

Figure 1-3. Overlapping Clearwater Cross Section 7.8160 (top) and Cross Section 7.0348 (below)

Note: MO3 1934 geometry is shown in black; CRSO No Action Alternative is shown in pink.

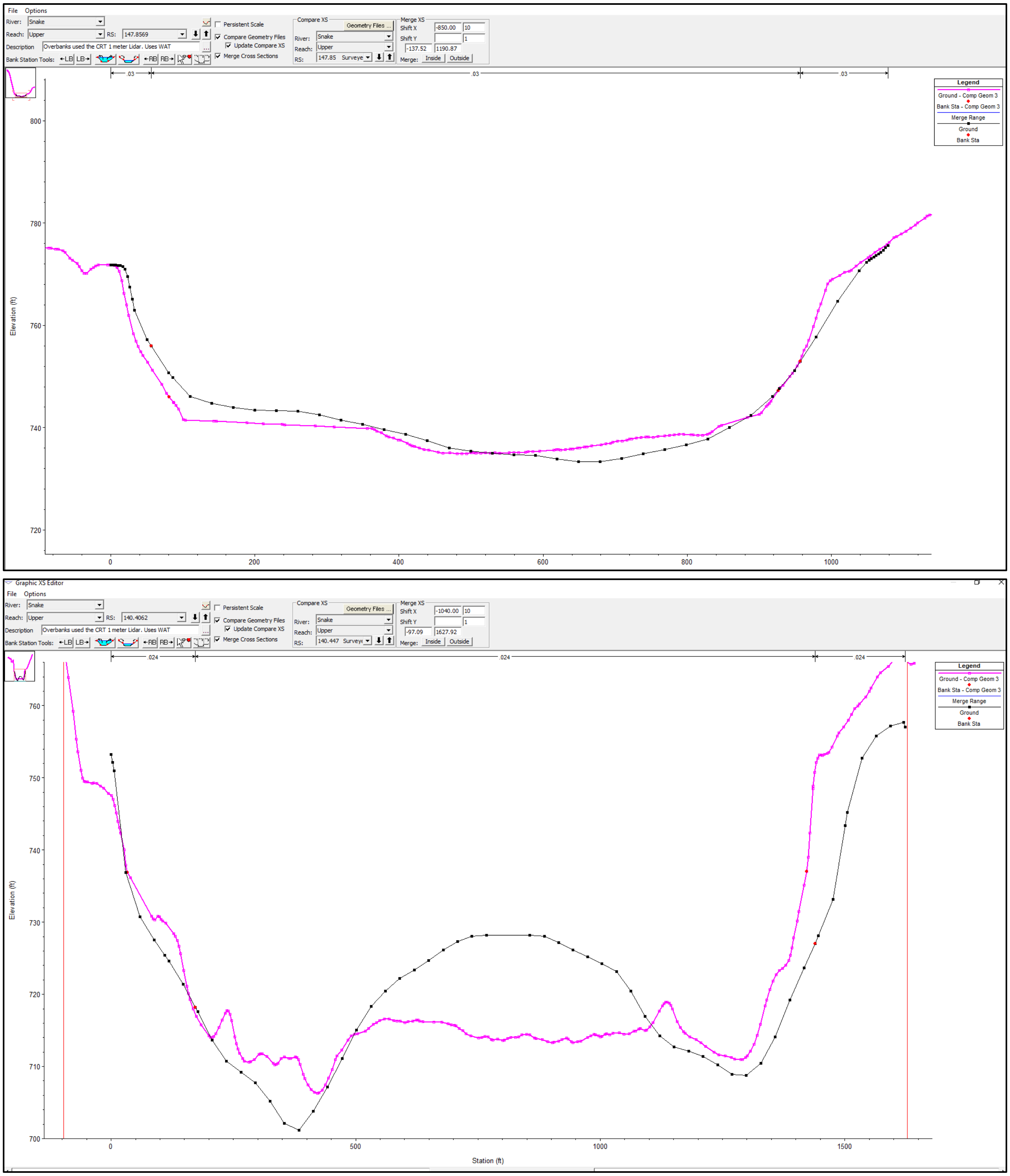

Figure 1-4. Overlapping Cross Sections of the Snake River, Cross Section 147.85 (top) and Cross Section 140.40662 (bottom)

Note: MO3 1934 geometry is shown in black; CRSO No Action Alternative is shown in pink.

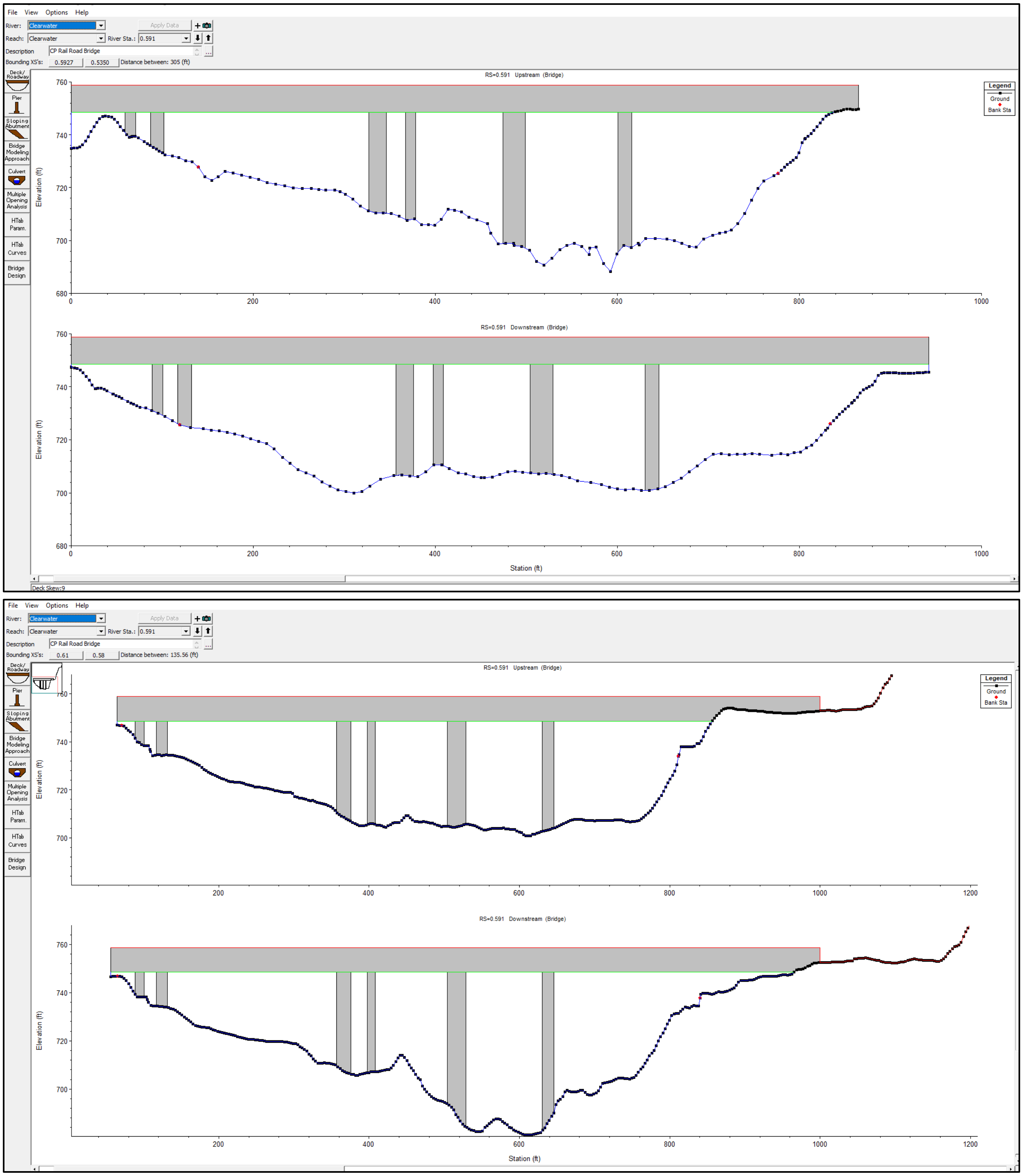

Figure 1-5. Bridge Geometry and Upstream and Downstream Cross Sections at the Railroad Bridge (Clearwater River Mile Cross Section 0.591)

Note: MO3 bridge is shown on the left and the CRSO No Action Alternative bridge is on the right.

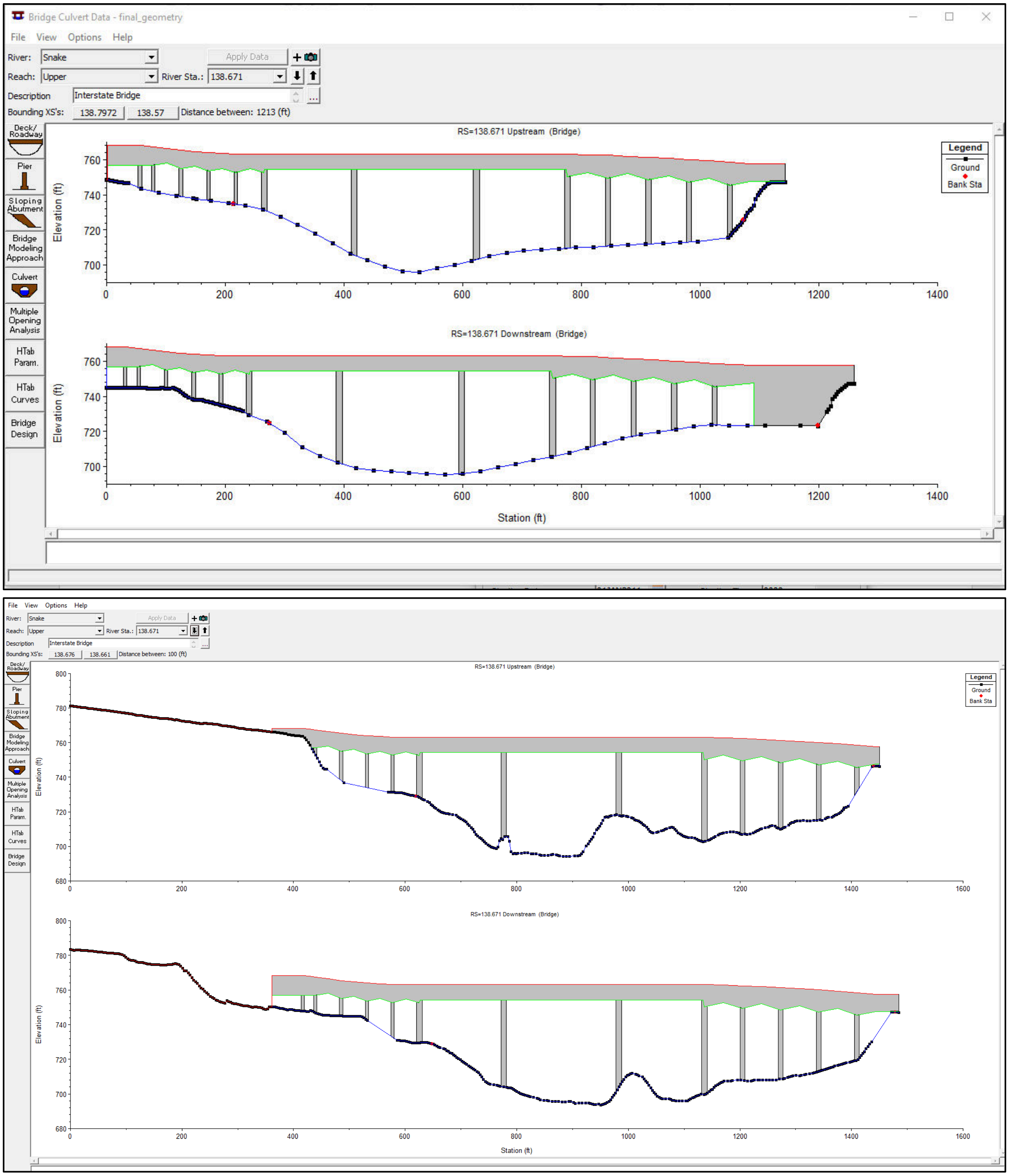

Figure 1-6. Bridge Geometry and Upstream and Downstream Cross Sections at the Interstate Bridge (Snake River Mile Cross Section 138.671)

Note: MO3 bridge is shown on the left and the CRSO No Action Alternative bridge is on the right.

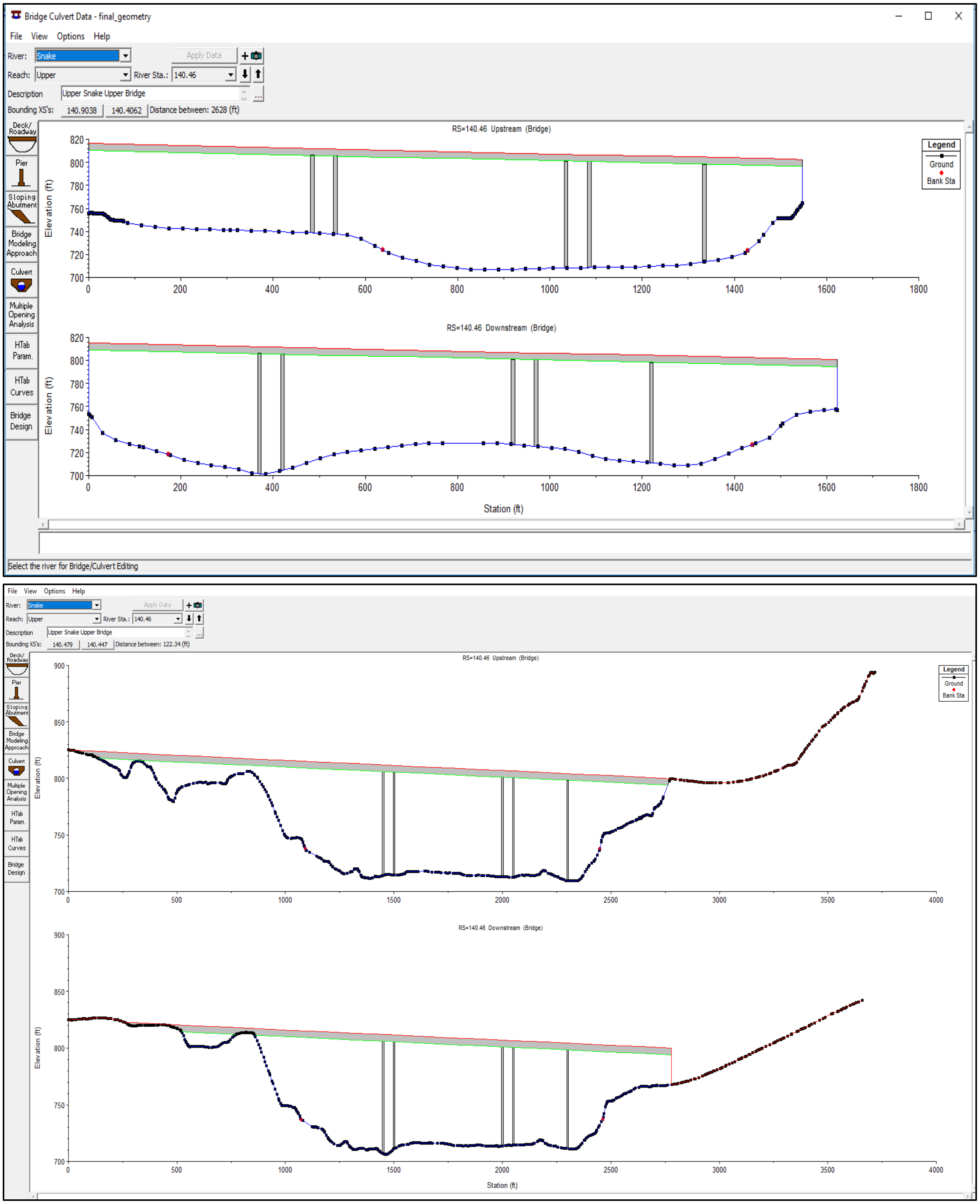

Figure 1-7. Bridge Geometry and Upstream and Downstream Cross Sections at the Upper Snake Upper Bridge (Snake River Mile Cross Section 140.46)

Note: MO3 bridge is shown on the left and the CRSO No Action Alternative bridge is on the right.

1.3.2 Model Flows

A DSS file for discharge time series was generated by the CRSO hydrology team using the HEC reservoir simulation (ResSim) model for MO3, and data was extracted for locations in the model system. The DSS was linked to a flow file identifying flow change locations and inflow boundaries and is shown in Table 1-1; Figure 1-8 shows a plot of the major upstream flow boundaries. Flow comparisons were made at each dam bypass location and indicated additional flow balance was not needed. Figure 1-9 through Figure 1-12 show the modeled ResSim values in black and the resulting HEC-RAS flows in red. Tributaries are not included in the model between Lower Granite and Ice Harbor Dams.

Table 1-1. DSS File Paths for Each Flow and Stage Boundary

Flow	Station	Dam Location	Inflow Tributaries	DSS pathname
Major Inflows	1.329	NF Clearwater	(DWR) North Fork	//DWORSHAK-POOL/FLOW-OUT/01JAN2007/1DAY/FLOODMODEL1/
	1675	Orofino_Cr	Orofino (100 cfs)	Constant 100 cfs
	45.502	Clearwater	Upper Main	//OROFINO/FLOW/01JAN2007/1DAY/FLOODMODEL1/
	178.27	Snake	Upper	//SNAKE+GRANDE RONDE/FLOW/01JAN2007/1DAY/FLOODMODEL1/
Flow Balance	138.13–118.8	Snake	Lower	Constant 100 cfs (uniform lateral inflow)
Flow Checks	106.994	Snake	Lower	//LOWER GRANITE-POOL/FLOW-OUT/01JAN2007/1DAY/FLOODMODEL1/
	69.689	Snake	Lower	//LITTLE GOOSE-POOL/FLOW-OUT/01JAN2007/1DAY/FLOODMODEL1/
	41.384	Snake	Lower	//LOWER MONUMENTAL-POOL/FLOW-OUT/01JAN2007/1DAY/FLOODMODEL1/
	9.526	Snake	Lower	//ICE HARBOR-POOL/FLOW-OUT/01JAN2007/1DAY/FLOODMODEL1/

Note: cfs = cubic feet per second; DWR = Dworshak.

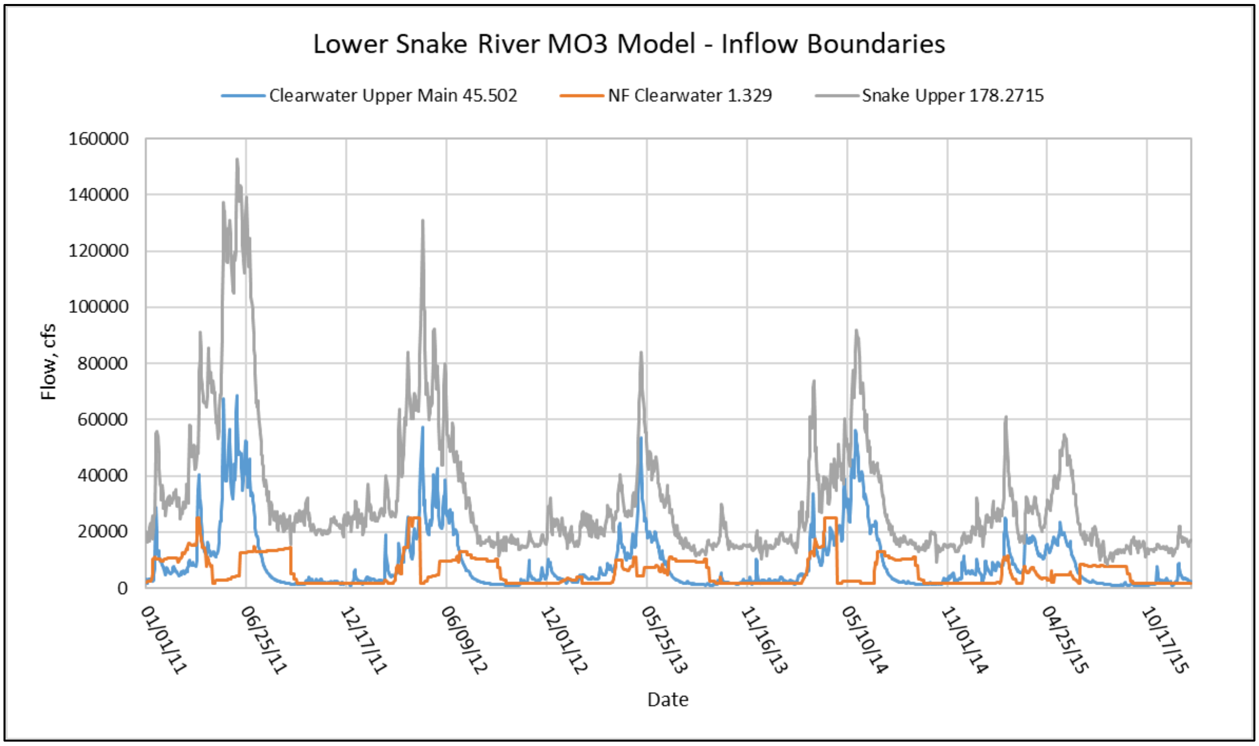

Figure 1-8. Lower Snake River Multiple Objective Alternative 3 Model Main Flow Boundaries

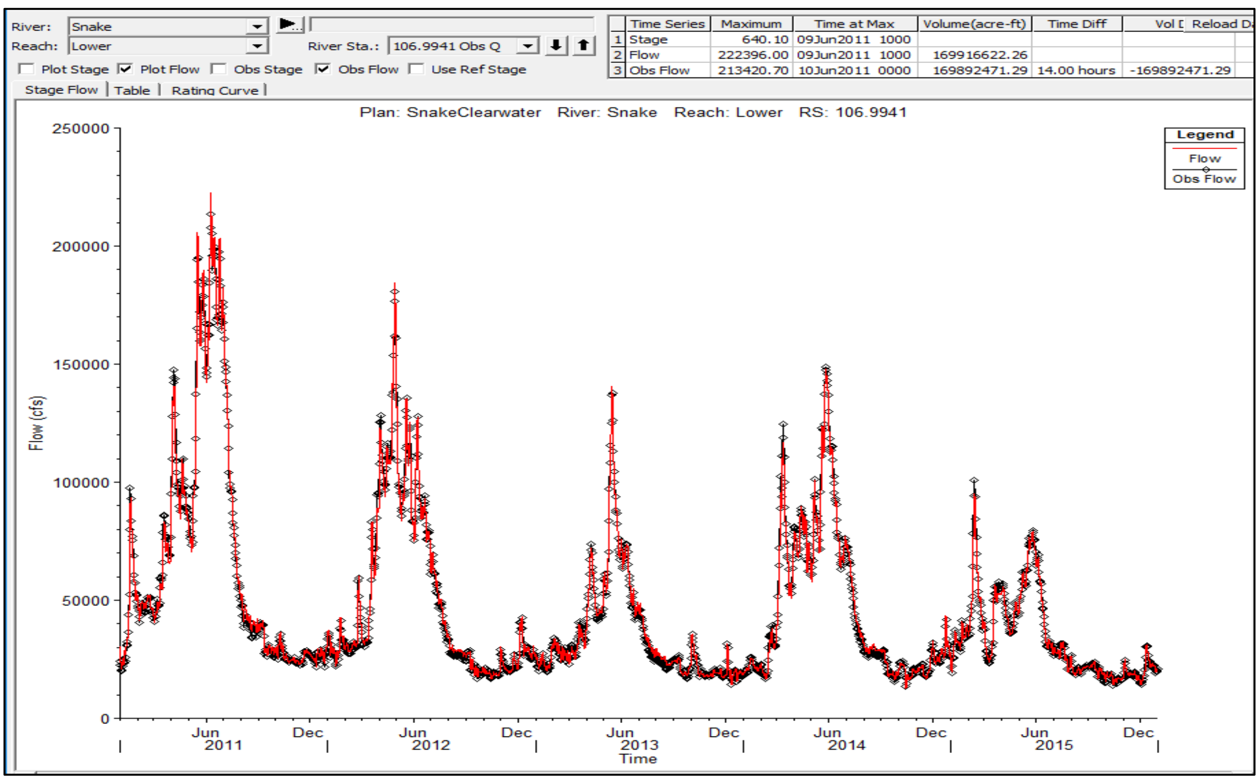

Figure 1-9. ResSim (black) and HEC-RAS (red) Flows at Lower Granite Dam Bypass

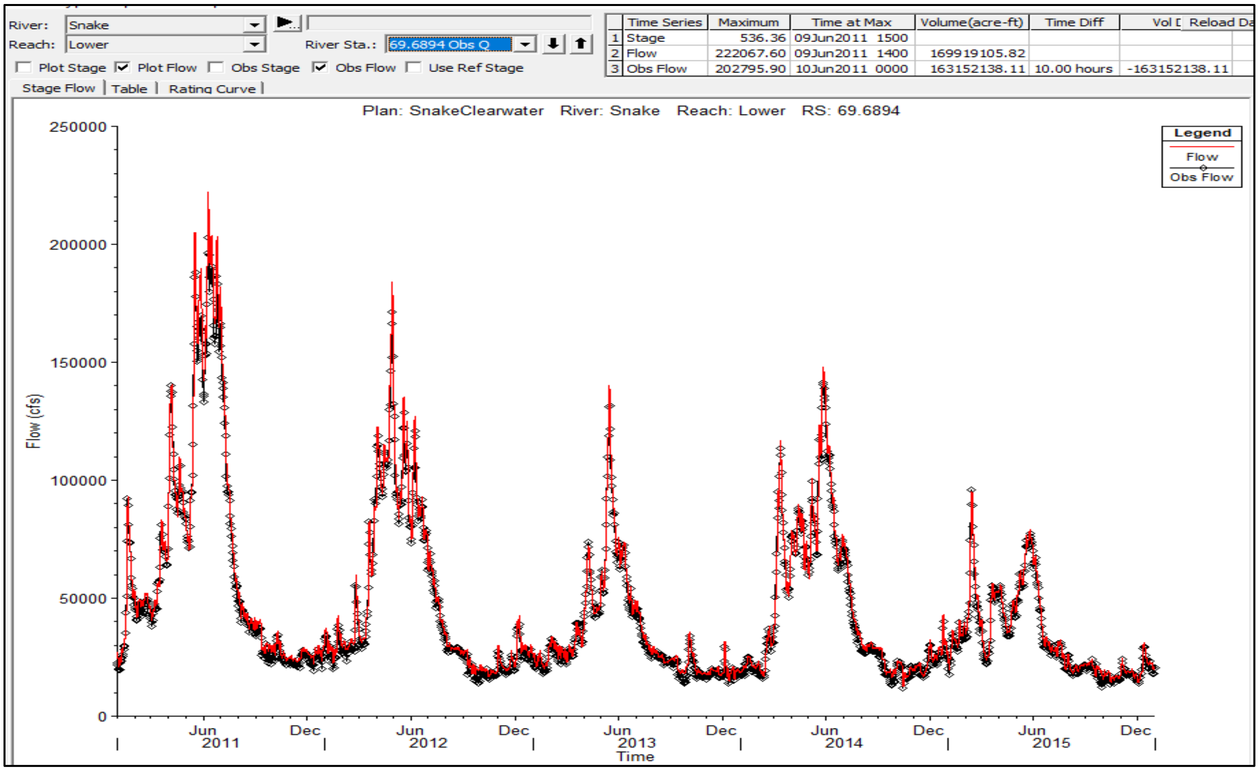

Figure 1-10. ResSim (black) and HEC-RAS (red) Flows at Little Goose Dam Bypass

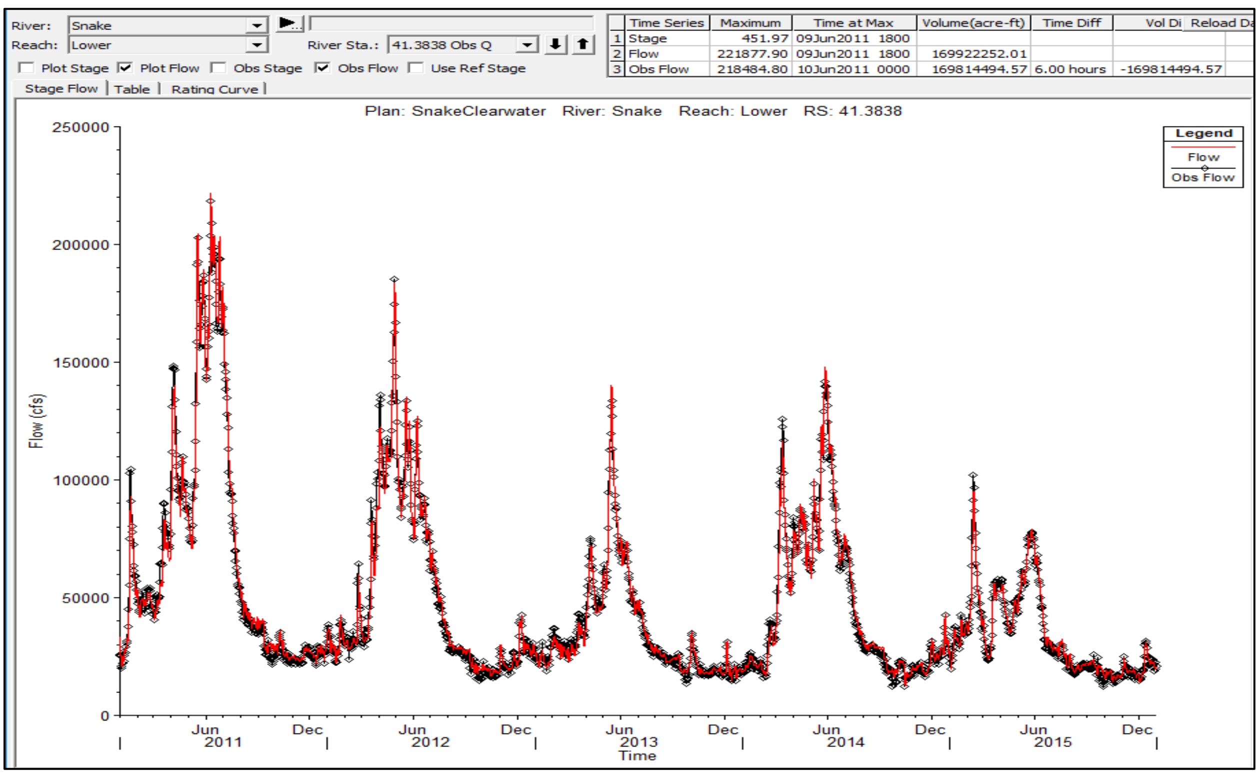

Figure 1-11. ResSim (black) and HEC-RAS (red) Flows at Lower Monumental Dam Bypass

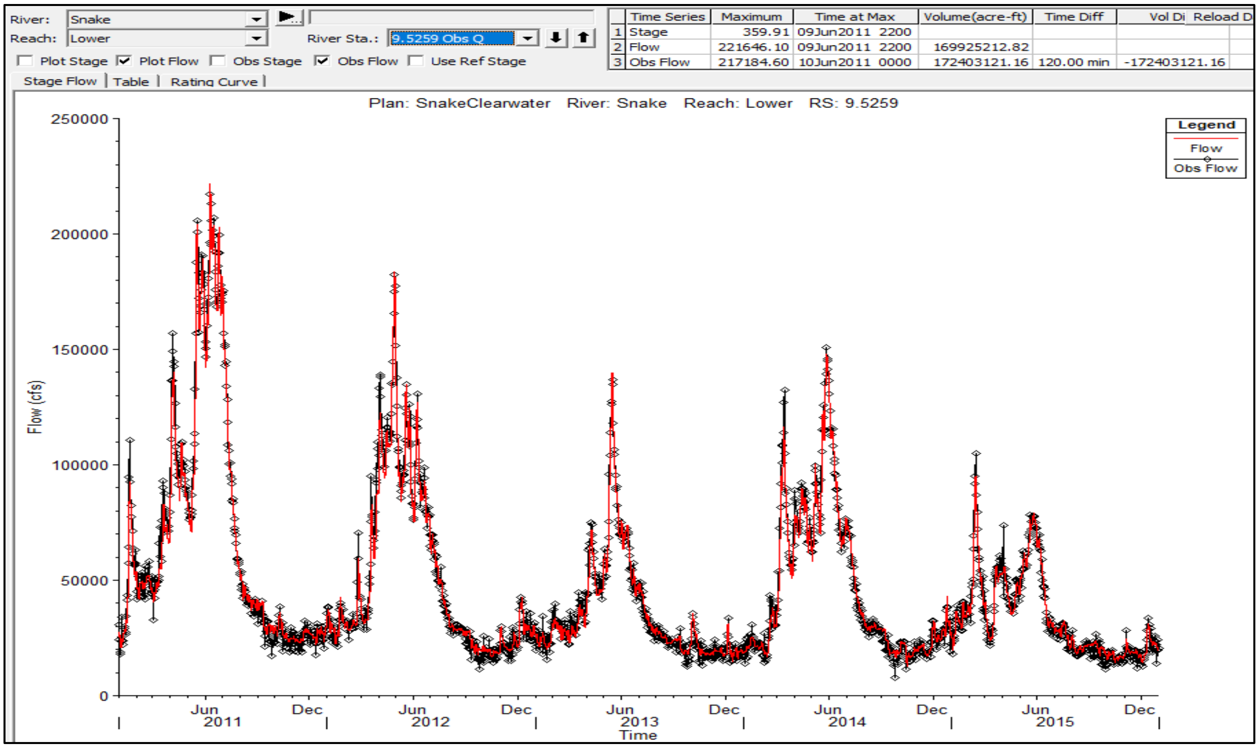

Figure 1-12. ResSim (black) and HEC-RAS (red) Flows at Ice Harbor Dam Bypass

1.3.3 Water Temperature

Upstream inflow temperatures and meteorological conditions are the biggest contributing factors to temperature calibrations. Table 1-2 shows the DSS pathname used in the MO3 model for temperature boundary and initial conditions; a plot is shown in Figure 1-13. During the development of the HEC-RAS dam breach model, the following corrections were made to the 2011–2015 calibration of the Clearwater-Upper Snake HEC-RAS Model (called “Version 2”):

1. The Silcott Island, Washington (SILW), station data provided as DSS was 8 hours off when compared to measured station data.
2. Station data representing the inputs from the W2 model was used. Using the W2 datasets ensured calculated data for missing points was consistent between the No Action Alternative and MO3 models.
3. A correction to the No Action Alternative inflow boundary temperatures was made. The temperature at Orofino was incorrectly linked in the DSS file. This was updated in the CRSO MO3 model; the same correction was made to the CRSO No Action Alternative run (called v2) and results were compared.
4. Wind heights for all meteorological stations were set to non-standard height of 3 m.

Meteorology data was obtained from the W2 meteorological files as air temperature (degrees Celsius [°C]), dew temperature (°C), atmospheric pressure (millimeters mercury [mmHg]), short wave solar radiation (SWSolar W/m^2), cloudiness (fraction), and wind speed (meters per second [m/s]) and put into DSS format. This guaranteed that this MO3 model was consistent with the No Action Alternative model in terms of meteorological data. Missing data was at most 1.0 day and linearly interpolated. Data was linked to each dam as a separate meteorological station, as pressure was calculated unique to each dam location. Figure 1-14 shows the geographic domain for each meteorological station used for the LSR-MO3 model.

Table 1-2. DSS File Paths for Each Temperature Boundary and Initial Conditions

Temperature Boundary	Station	Location	Inflow Tributaries	DSS Pathname
Boundary Temperatures, Inflows	1.329	NF Clearwater	(DWR) North Fork	DWR_2011-2015_W2_Output.dss/DWR_DAM_W2_OUTPUT/TEMPERATURE/T/01DEC2010/1HOUR/TEMPERATURE/
	1675	Orofino_Cr	Orofino (100 cfs)	Orofino_water_temps.dss/USGS-ORFI/ORFI/T/01DEC2010/1HOUR/WATER_TEMP/
	45.502	Clearwater	Upper Main	Orofino_water_temps.dss/USGS-ORFI/ORFI/T/01DEC2010/1HOUR/WATER_TEMP/
	178.27	Snake	Upper	RAS_WQ.dss /GOES-REV/ANQW/TEMP-WATER/01SEP2010/1HOUR/MODIFIED/
	0.05	Snake	Lower	McNary Temps – not used
Boundary Temperatures, Uniform lateral flow	138.13 – 118.8	Snake	Lower	RAS_WQ.dss /GOES-REV/ANQW/TEMP-WATER/01SEP2010/1HOUR/MODIFIED/
Initial Conditions	45.502	Clearwater, Upper Main	1.5	Unchanged from NAA
	45.21	Clearwater, Middle	1.5	Unchanged from NAA
	40.658	Clearwater	1.5	Unchanged from NAA
	1.329	NF Clearwater	6	Unchanged from NAA
	1675	Orofino_Cr	1.5	Unchanged from NAA
	178.27	Snake	3	Unchanged from NAA
	138.329	Snake	3	Unchanged from NAA
Dispersion	Clearwater River: 10-500 ft^2/s, RAS calculated to be 500ft^2/s Snake River: 10-1000 ft^2/s, RAS calculated to be 1000ft^2/s Sensitivity was performed at 10-1000ft^2/s; RAS calculated to be 1000 ft^2/s			

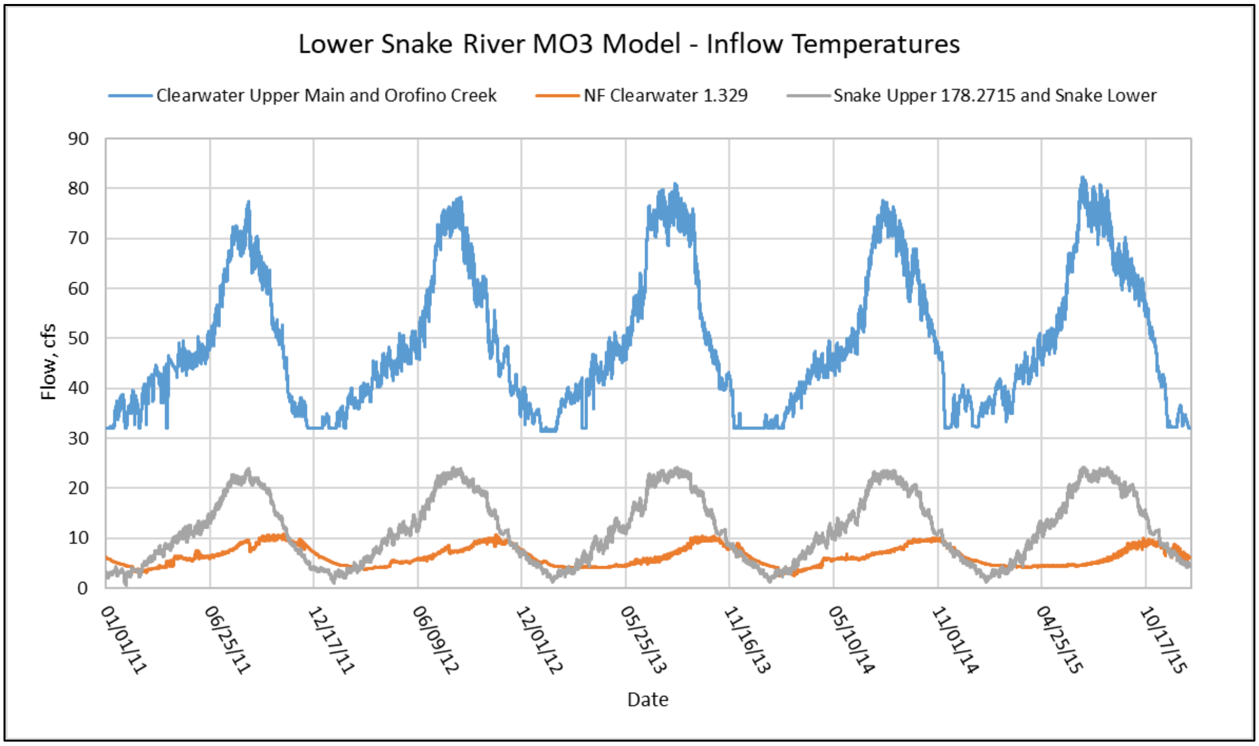

Figure 1-13. Lower Snake River Multiple Objective Alternative 3 Model Main Temperature Boundaries

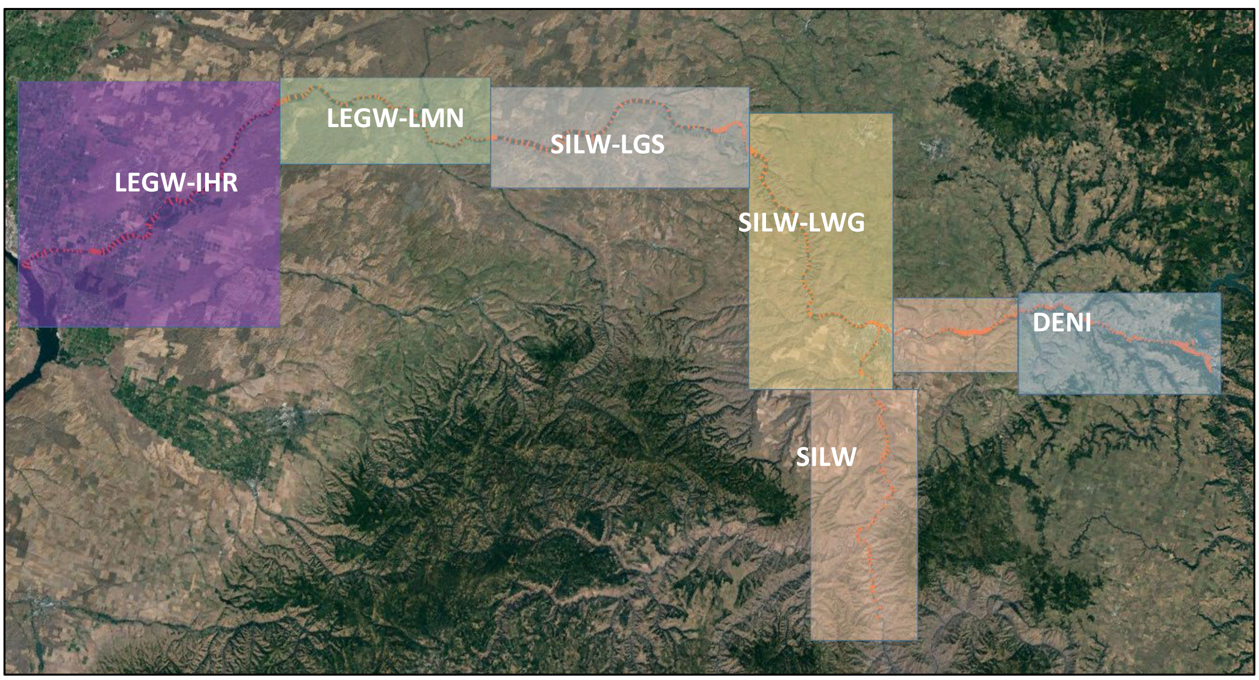

Figure 1-14. Lower Snake River Multiple Objective Alternative 3 Meteorological Stations

Note: LEGW = Legrow, Washington, station; SILW = Silcott Island, Washington, station; LGS = Little Goose; LWG = Lower Granite, LMN = Lower Monumental, DENI = Dent Acres, Idaho, station, IHR = Ice Harbor.

1.3.4 Heat Flux and Model Parameterization Discussion

Evaporation heat flux is typically the most uncertain part of the heat balance equation that a model uses to predict water temperature. Calibration typically varies the coefficients (within that heat balance equation) that relate measured wind speed to evaporation (i.e., heating and cooling), so that a model can accurately predict water temperature. The WQ team was not successful calibrating HEC-RAS under existing conditions on the lower Snake River (i.e., dams in place). The root mean square error (RMSE) could not be minimized in HEC-RAS to a level consistent with the W2 calibration: 0.65°C, at Ice Harbor (Corps, 2019). We hypothesize that the one-dimensional model of the lower Snake River impoundments cannot be calibrated with seasonally consistent coefficients (as in W2). A one-dimensional model does not account for water temperature variation with depth, which leads to an oversimplified depiction of surface water temperature. Three heat fluxes depend on the temperature of the water surface: back radiation, evaporative heat loss, and surface heat conduction. Despite the mild and short-duration stratification in these impoundments, there can be notable differences between the surface and middle depth temperature in the lower Snake River. For example, in July 2015, at Ice Harbor, there was a 2.5°C difference between the temperature at 0.5 m and 20 m with 36 hourly measurements exceeding a 5.0°C difference. The HEC-RAS model does not have an option of changing the evaporation coefficient seasonally without code modification. W2 was able to reproduce measurements within acceptable error using constant wind coefficients on the lower Snake River. The WQ team hypothesizes that the one-dimensional model is not able to accurately reproduce the heat budget in the existing lower Snake River (i.e., current conditions) but could produce meaningful results under a dam breach bathymetry, with no stratification.

Additionally, the W2 NAA models used wind sheltering coefficients of: Lower Granite = 1.2, Little Goose = 0.9, Lower Monumental = 1.2, and Ice Harbor = 1.2. No adjustments were made for wind speed in HEC-RAS to account for this because HEC-RAS does not explicitly model wind sheltering.

Ultimately, the model parameter set chosen for HEC-RAS was based on the published values (Edinger et. al. 1974; reported in Cole and Wells 2018), calibrated W2 modeling, HEC-RAS modeling for an upstream reach, and default parameters (Table 1-3). The parameter set was tested by running the model with an existing (i.e., with dams) bathymetry and comparing to measurements. Generally, the HEC-RAS representation of the current system overpredicts mid-summer temperatures and underpredicts winter temperatures but is believed to corroborate the HEC-RAS heat balance routines and the parameter set for a one-dimensional representation of a dam breach bathymetry.

Table 1-3. Calibration Coefficients Used in the Lower Snake River No Action Alternative (HEC-RAS and W2) and MO3 (HEC-RAS) Models

Category	(Met Station)	Units	HEC-RAS Default	NAA	MO3
Initial Temperature		°C	–	0.1–6.2 [3/]	0.1–6.2
Dispersion Coefficients – Upper Limit		ft^2/s	–	500 (CLWR) [3/] 1,000 (SNK) [3/]	500 (CLWR) 1,000 (SNK)
Dispersion Coefficients – Lower Limit		ft^2/s	–	100 [3/]	100
Meteorological Coefficients					
Atmospheric Pressure – DENI		mmHg	–	DWQI [3/]	DWQI
Atmospheric Pressure – SILW		mmHg	–	LWG Trendline [3/]	LWG Trendline
Dust Coefficient	DENI	–	0.06	– [2,3/]	– [2/]
	SILW	–	0.06	– [2,3/]	– [2/]
Wind – a coefficient	DENI	–	1	1[3/]	1
	SILW	–	1	1	1
	SILW-LWG	–	1	9.0 (W2) [4/]	9.2
	SILW-LGS	–	1	9.0 (W2)	9.2
	LEGW-LMN	–	1	9.0 (W2)	9.2
	LEGW-IHR	–	1	9.0 (W2)	9.2
Wind – b coefficient	DENI	–	1	0.3 [3/]	0.3
	SILW	–	1	0.5	0.5
	SILW-LWG	–	1	0.4 (W2)	0.46
	SILW-LGS	–	1	0.4(W2)	0.46
	LEGW-LMN	–	1	0.4 (W2)	0.46
	LEGW-IHR	–	1	0.4 (W2)	0.46
Wind – c coefficient	DENI	–	1	1	1
	SILW	–	1	0.5	0.5
	SILW-LWG	–	1	1.9 (W2)	2
	SILW-LGS	–	1	1.9 (W2)	2
	LEGW-LMN	–	1	1.9 (W2)	2
	LEGW-IHR	–	1	1.9 (W2)	2
Richardson # Used	DENI	–	False	True	True
	SILW	–	False	True	True
	SILW-LWG	–	False	–	True
	SILW-LGS	–	False	–	True
	LEGW-LMN	–	False	–	True
	LEGW-IHR	–	False	–	True
Kh/Kw (Diffusivity ratio)	DENI	–	1	0.9 [3/]	0.9
	SILW	–	1	1	1
	SILW-LWG	–	1	–	1
	SILW-LGS	–	1	–	1
	LEGW-LMN	–	1	–	1
	LEGW-IHR	–	1	–	1

Category	(Met Station)	Units	HEC-RAS Default	NAA	MO3
Anemometer (Wind gage) Height (m)	DENI	m	2	3	3
	SILW	m	2	3	3
	SILW-LWG	m	2	3 (W2)	3
	SILW-LGS	m	2	3 (W2)	3
	LEGW-LMN	m	2	3 (W2)	3
	LEGW-IHR	m	2	3 (W2)	3

Note: CLWR = Clearwater River; DWQI = Ahsahka, Idaho, station; m = meter; SNK = Snake River.
2/ Solar radiation is read in from W2 No Action Alternative model input. Dust coefficient is not needed in this case.
3/ This value was updated after the original No Action Alternative due to an error in upstream boundary temperatures discovered during the MO3 modeling. No Action Alternative Version 2 is used for comparison to MO3 but differs from the documented calibration.
4/ W2 indicates a parameter from the W2 NAA.

1.3.5 Evaluation of HEC-RAS parameterization

The WQ team tested the parameterization of the HEC-RAS LSR-MO3 model (above) under existing bathymetry/hydraulics (i.e., with dams) with 2011–2015 observed weather and hydrology. This test provides the WQ team with an additional level of confidence that this model can be directly applied to the MO3 model.

The one-dimensional, existing conditions model was set up using the same geometry as used in the USACE's Columbia River Basin modeling schematic and was updated to include all of the existing conditions for 2011–2015 at all boundary conditions. All figures are available from the WQ team[1], but only results at Lower Granite and Ice Harbor will be presented in this report. As shown in Figure 1-15 through Figure 1-18, the Lower Granite model, the uppermost reservoir on the lower Snake, underpredicts water temperature consistently throughout the year except during the summer, at which time the temperature is overpredicted. These differences are even more pronounced at Ice Harbor. The WQ team believes these results corroborate the HEC-RAS heat balance routines and the parameter set for a one-dimensional representation of dam breach of the lower Snake River.

[1] \\nww-netapp1.nww.ds.usace.army.mil\Common\Planning Programs and Project Management\CRSO-EIS\Water Quality\Models\zzz_Sensitivity\LSR_CLW_Existing_RAS_v2\post_processing

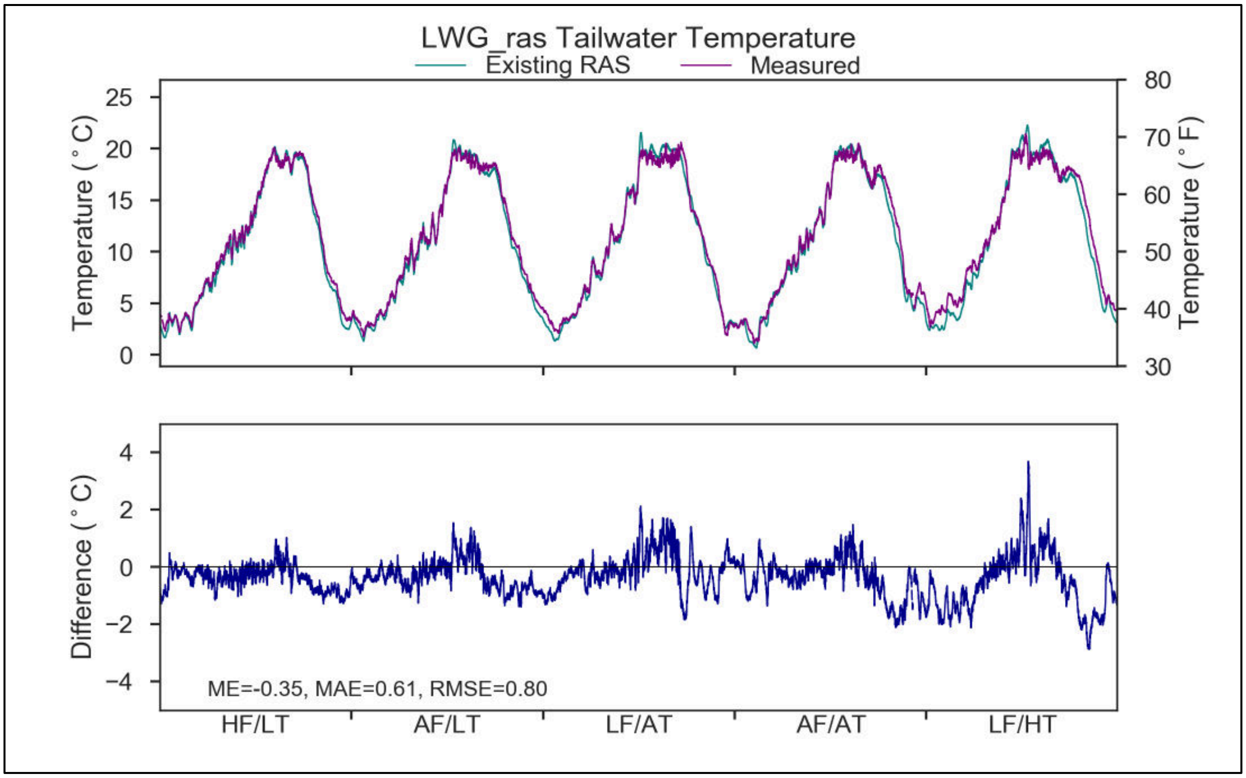

Figure 1-15. Hourly Temperature Comparison of HEC-RAS Existing Conditions Representation to Measurements at Lower Granite Dam Tailwater

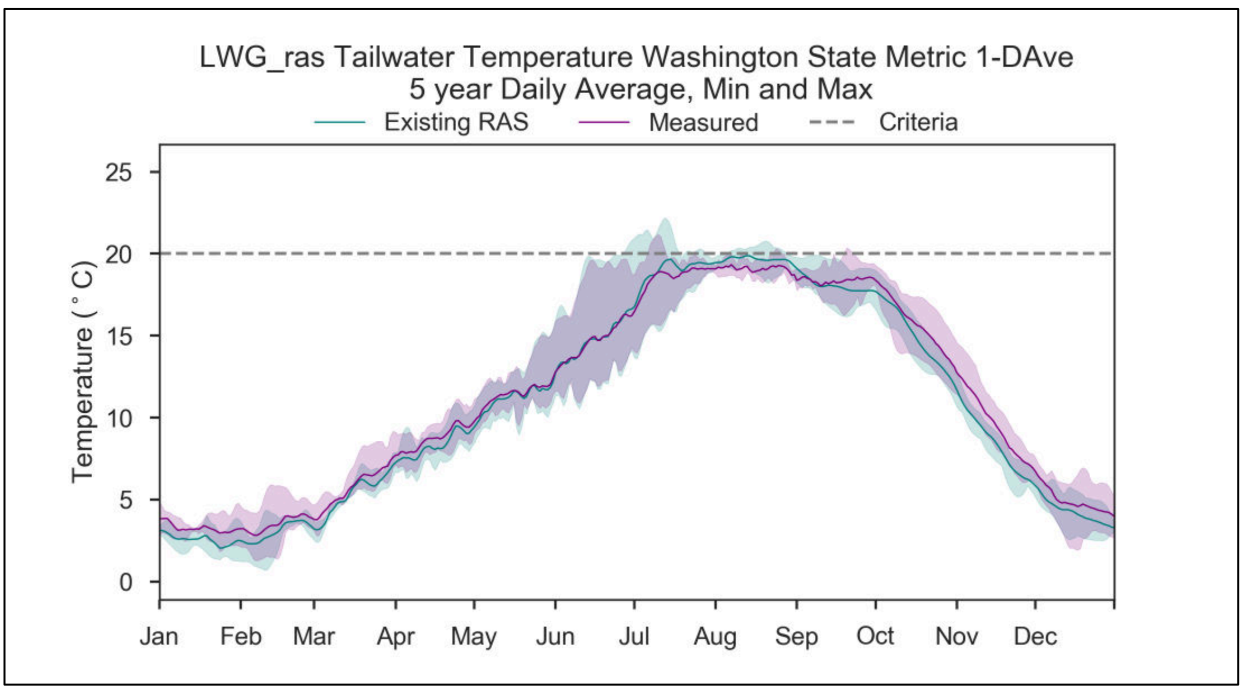

Figure 1-16. Daily Average Temperature Comparison of HEC-RAS Existing Conditions Representation to Measurements at Lower Granite Dam Tailwater

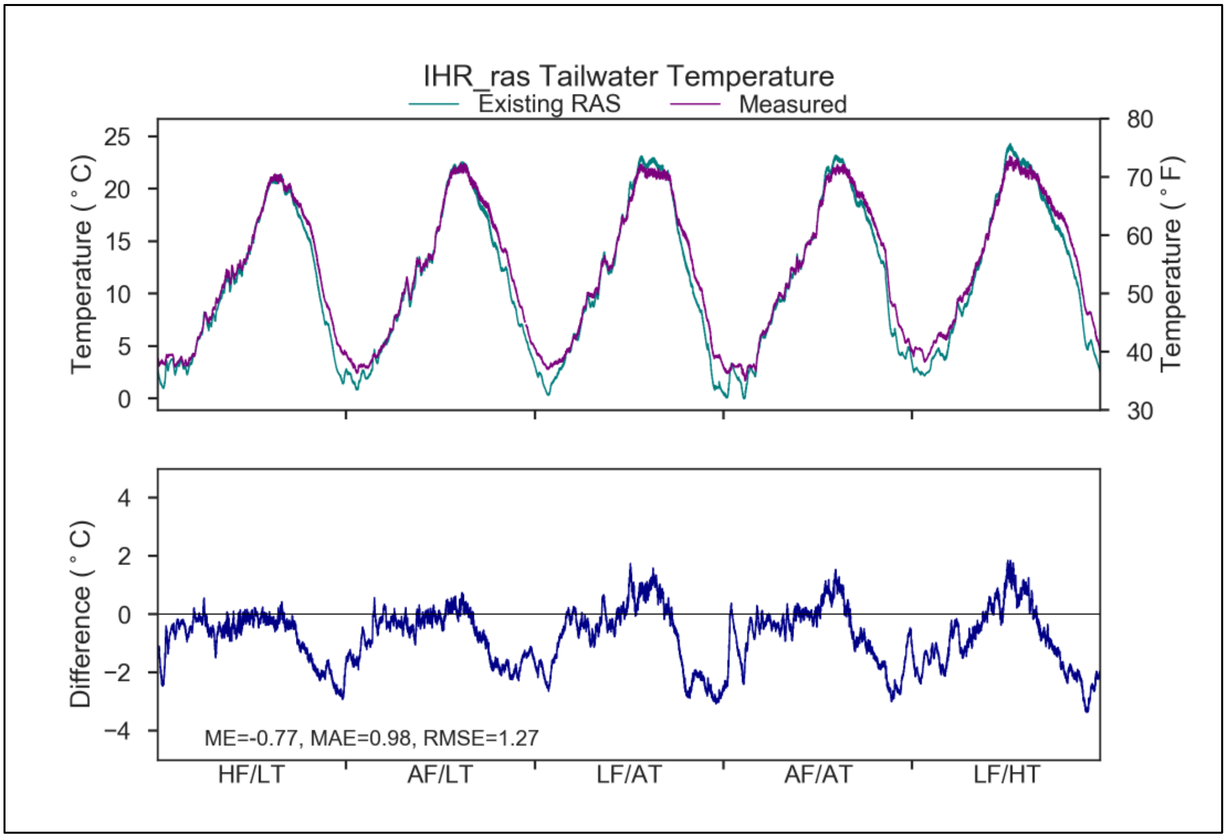

Figure 1-17. Hourly Temperature Comparison of HEC-RAS Existing Conditions Representation to Measurements at Ice Harbor Dam Tailwater

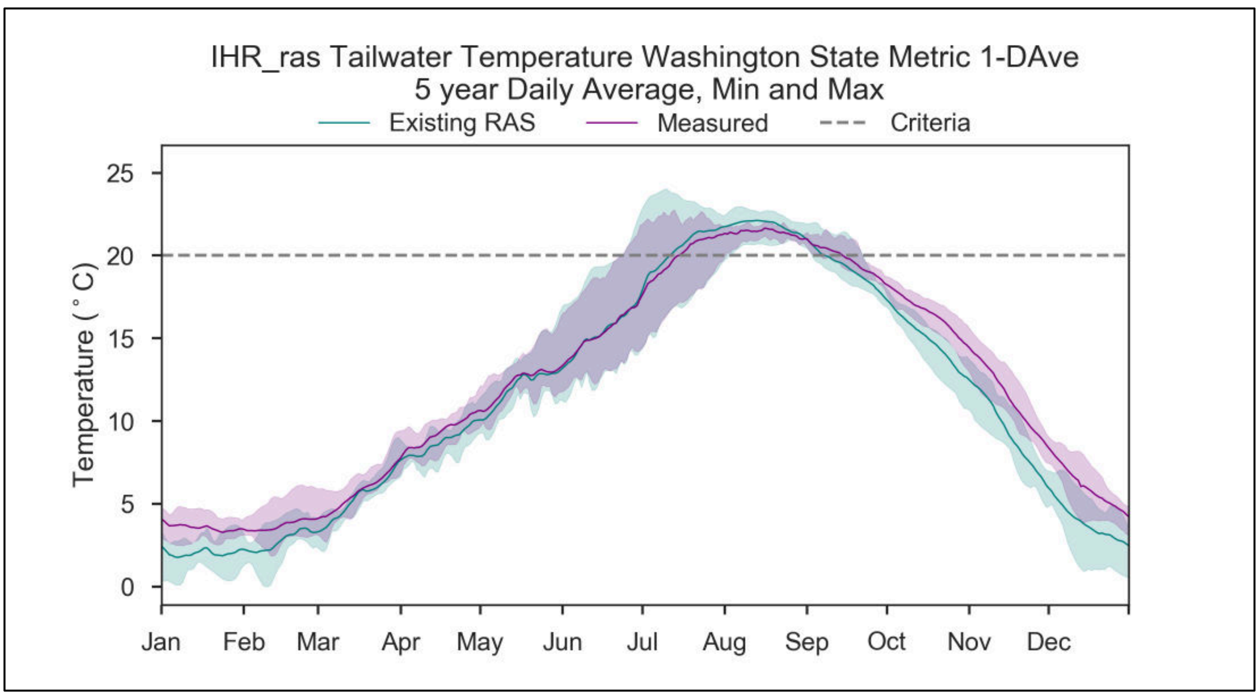

Figure 1-18. Daily Average Temperature Comparison of HEC-RAS Existing Conditions Representation to Measurements at Ice Harbor Dam Tailwater

1.3.6 Model Sensitivity to Vertical Stratification

The largest assumption made is that the use of the one-dimensional model will produce similar results as the two-dimensional model under the same conditions, which may not necessarily be valid in every month/season. The one-dimensional existing conditions simulation produces temperatures that are slightly warmer in the winter and early spring and cooler in summer and fall as compared to the W2 two-dimensional model. A comparison of temperatures at Ice Harbor is shown in Figure 1-19. Figure 1-20 shows the comparison of the MO3 predicted temperature at IHR compared to the actual observed temperature profile. Since W2 is a 2D model and the water can be released from different outlets to optimize the desired temperature, one can see from the image that the depth averaged value may skew the results in either direction depending on surface temperatures and dam operations.

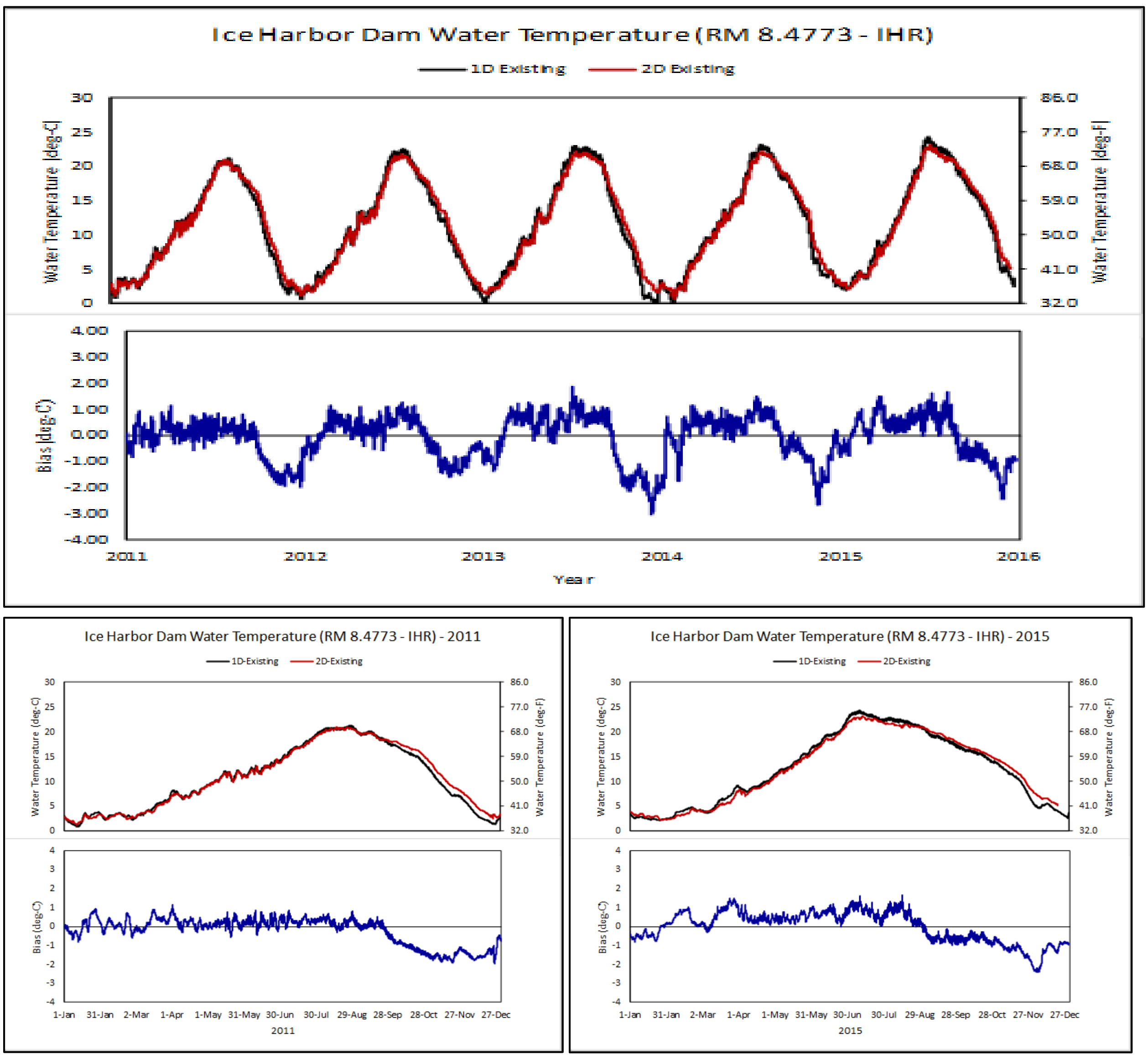

Figure 1-19. Comparison of One-dimensional Existing Conditions and Two-dimensional Existing Conditions at Ice Harbor Dam

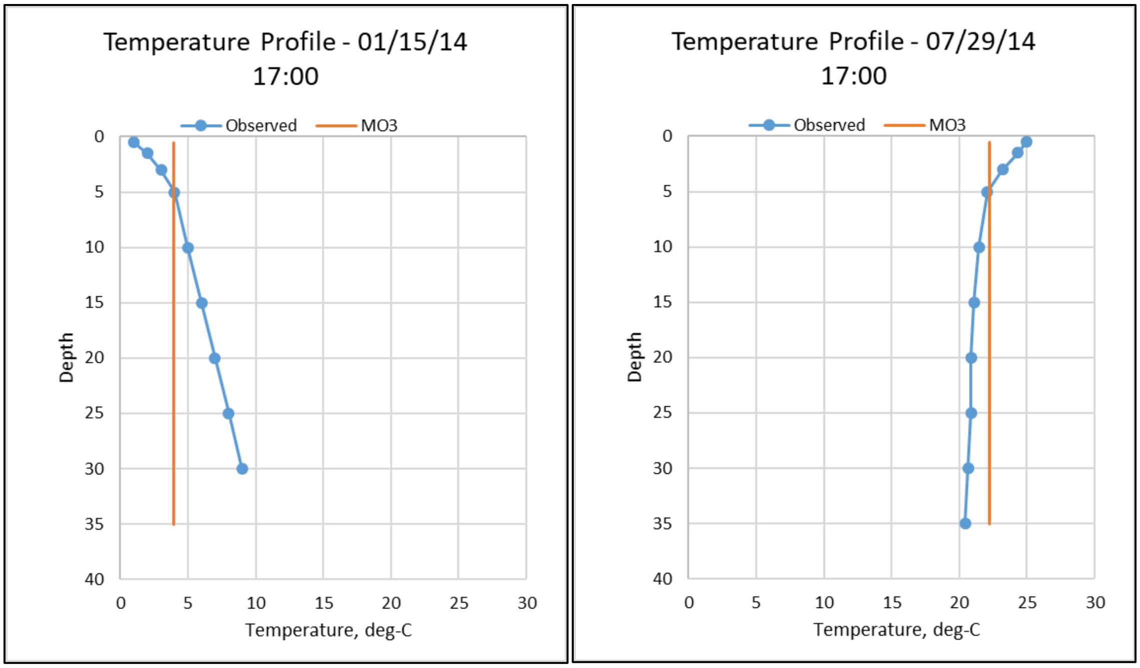

Figure 1-20. Observed Temperature Profile at Ice Harbor Dam in mid-January and late June Compared to Multiple Objective Alternative 3 Predicted Temperature

1.3.7 Model Sensitivity to parameters

For the sensitivity model, the 2014 No Action Alternative flow and weather conditions were chosen to represent a base condition with parameters and model setup described above with dam breach bathymetry (Table 1-4 through Table 1-9). A single parameter was changed by a specified amount and the change in error statistics from the base condition is reported. The focus was on the lower Snake River, since there was not a typical calibration performed.

Table 1-4. Sensitivity to Increased Dispersion Coefficient

Parameter:	Initial Value:	Tested Value:			
Dispersion	10–500 ft^2/s	1,000 ft^2/s			
		(°C)			
STATION		#OBS	ME	AME	RMSE
(ANQW 166.656)		8,737	0.000	0.005	0.007
Spalding (SPDI 11.745)		8,737	-2.193	2.205	4.842
Lewiston (LEWI 3.944)		8,737	-2.164	2.175	4.776
LWG Tailwater (106.28)		8,737	-0.765	0.771	1.748
LGS Tailwater (68.84)		8,737	-0.648	0.654	1.474
LMN Tailwater (39.78)		8,737	-0.571	0.593	1.299
IHR Tailwater (5.722)		8,737	-0.494	0.502	1.117

Note: #OBS = number of observations; AME = absolute mean error; ME = mean error; RMSE = root mean square error.

Table 1-5. Sensitivity to Increased Roughness Coefficient

Parameter:	Initial Value:	Tested Value:			
Manning's N	Range	All N values increased by 0.0079			
		(°C)			
STATION		#OBS	ME	AME	RMSE
(ANQW 166.656)		8,737	0.007	0.031	0.040
Spalding (SPDI 11.745)		8,737	0.059	0.105	0.389
Lewiston (LEWI 3.944)		8,737	0.076	0.127	0.390
LWG Tailwater (106.28)		8,737	0.029	0.145	0.200
LGS Tailwater (68.84)		8,737	0.027	0.184	0.242
LMN Tailwater (39.78)		8,737	0.025	0.210	0.270
IHR Tailwater (5.722)		8,737	0.025	0.234	0.299

Note: Change in roughness value was based on guidance for roughness uncertainty as described in EM 1110-2-1619, Risk-Based Analysis for Flood Damage Reduction Studies (U.S. Army Corps of Engineers [Corps] 1996).

Table 1-6. Sensitivity to Decreased Roughness Coefficient

Parameter:	Initial Value:	Tested Value:			
Manning's N	Range	All N values decreased by 0.0079			
		(°C)			
STATION		#OBS	ME	AME	RMSE
(ANQW 166.656)		8,737	0.000	0.000	0.000
Spalding (SPDI 11.745)		8,737	-0.044	0.087	0.217
Lewiston (LEWI 3.944)		8,737	-0.070	0.121	0.256
LWG Tailwater (106.28)		8,737	-0.018	0.036	0.072
LGS Tailwater (68.84)		8,737	-0.015	0.030	0.058
LMN Tailwater (39.78)		8,737	-0.014	0.027	0.049
IHR Tailwater (5.722)		8,737	-0.012	0.023	0.040

Note: Change in roughness value was based on guidance for roughness uncertainty as described in EM 1110-2-1619, Risk-Based Analysis for Flood Damage Reduction Studies (Corps 1996)

Table 1-7. Sensitivity to Increased Wind Coefficients

Parameter:	Initial Value:	Tested Value:
a	9.2	92
b	0.46	4.6
c	2.0	3.0
Kh/Kw	1.0	1.5

STATION	(°C)			
	#OBS	ME	AME	RMSE
(ANQW 166.656)	8,737	0.000	0.000	0.000
Spalding (SPDI 11.745)	8,737	0.000	0.000	0.000
Lewiston (LEWI 3.944)	8,737	0.000	0.000	0.000
LWG Tailwater (106.28)	8,737	-0.438	1.604	2.093
LGS Tailwater (68.84)	8,737	-0.378	1.719	2.163
LMN Tailwater (39.78)	8,737	-0.243	1.803	2.265
IHR Tailwater (5.722)	8,737	-0.262	1.759	2.241

Table 1-8. Sensitivity to Decreased Wind Coefficients

Parameter:	Initial Value:	Tested Value:			
a	9.2	0.92			
b	0.46	0.046			
c	2.0	1.0			
Kh/Kw	1.0	0.5			
STATION		(°C)			
		#OBS	ME	AME	RMSE
(ANQW 166.656)		8,737	0.000	0.000	0.000
Spalding (SPDI 11.745)		8,737	0.000	0.000	0.000
Lewiston (LEWI 3.944)		8,737	0.000	0.000	0.000
LWG Tailwater (106.28)		8,737	0.180	0.266	0.393
LGS Tailwater (68.84)		8,737	0.361	0.514	0.743
LMN Tailwater (39.78)		8,737	0.445	0.666	0.954
IHR Tailwater (5.722)		8,737	0.556	0.849	1.200

Table 1-9. Sensitivity to Richardson wind coefficient

Parameter:	Initial Value:	Tested Value:			
Richardson # Used	True	False			
STATION		(°C)			
		#OBS	ME	AME	RMSE
(ANQW 166.656)		8,737	0.000	0.000	0.000
Spalding (SPDI 11.745)		8,737	0.000	0.000	0.000
Lewiston (LEWI 3.944)		8,737	0.000	0.000	0.000
LWG Tailwater (106.28)		8,737	0.000	0.000	0.000
LGS Tailwater (68.84)		8,737	0.000	0.000	0.000
LMN Tailwater (39.78)		8,737	0.000	0.000	0.000
IHR Tailwater (5.722)		8,737	0.000	0.000	0.000

1.3.8 Model Sensitivity to Daily Heat Fluxes

During the evaluation of the model and comparison to River Basin Model 10 (RBM10) the WQ team felt it was necessary to evaluate the sensitivity of predicted temperature to daily average heat fluxes. HEC-RAS and W2 both calculate the heat balance using hourly data while RBM10 uses daily average data. This test was accomplished by daily averaging the solar radiation and weather inputs into the HEC-RAS model and comparing to the hourly input dam breach model run. There was an expected change in the daily ranges of temperatures but there was also an effect on the daily average predicted temperatures. The largest effect was observed at Ice Harbor. Daily averaging caused an overall average of 0.10°C warming of the model results with an RMSE of 0.33°C (Figure 1-21).

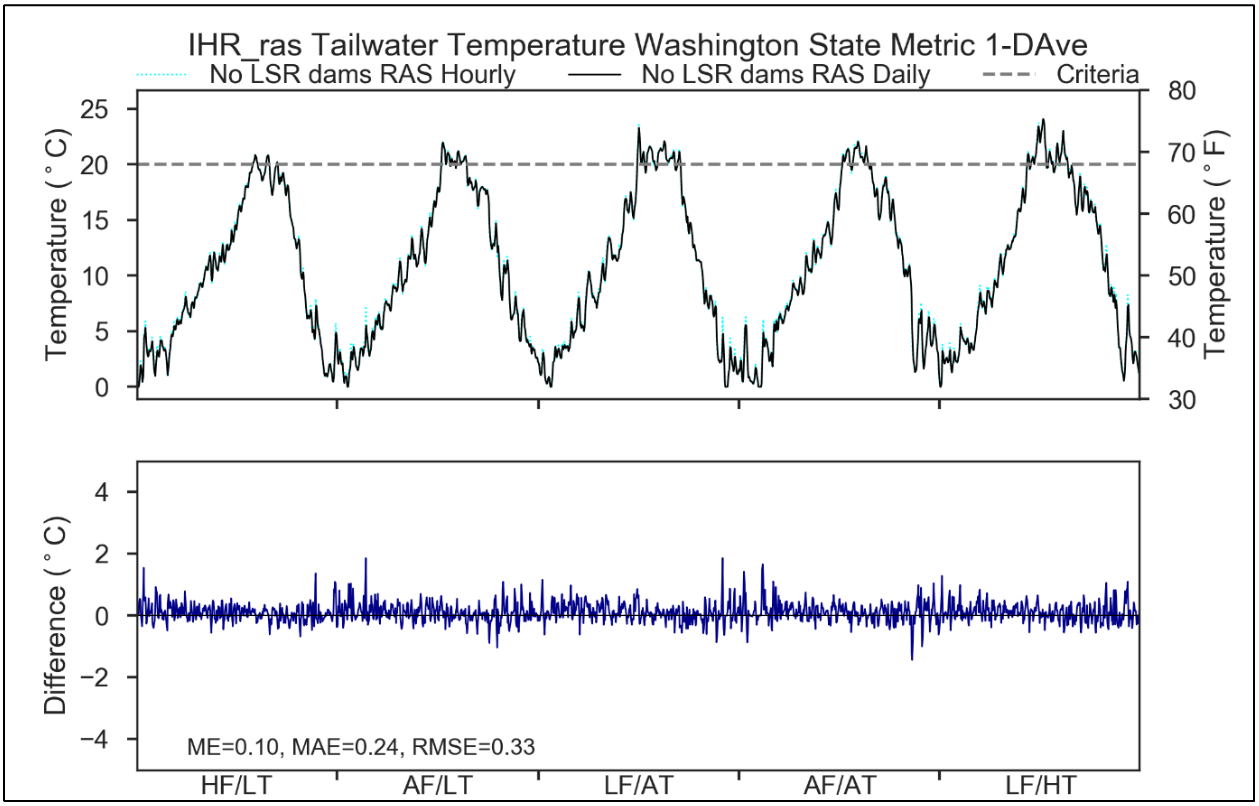

Figure 1-21. Comparison of Hourly versus Daily Model Inputs to Daily Average Temperature Predictions

1.3.9 Comparison to Other Model Predictions

The U.S. Environmental Protection Agency (EPA) is also developing a temperature model of the Columbia River system that will be used in the total maximum daily load (TMDL) and investigates the impact of dams on temperature. The EIS water quality model and the EPA model overlap geographically and temporally, so they are compared directly below. The Lower Snake River Juvenile Salmon Migration Feasibility Report/EIS (Corps 2002) documents historical temperature analysis and three distinct temperature modeling efforts that predict temperatures without dams. These modeling efforts are not directly comparable to the EIS effort because they use a different hydrology and flow, but are qualitatively discussed below.

1.3.9.1 U.S. Environmental Protection Agency's 2018 RBM10

The RBM10 model is a one-dimensional mathematical model of the thermal energy budget of the mainstem Columbia and Snake Rivers (Tetra Tech 2018). It simulates daily average water temperature under conditions of gradually varied flow. The 2018 RBM10 model simulates temperatures from 1970 through 2016. The Columbia River is represented from the U.S.-Canada border to the mouth; the Snake River from Anatone to its mouth; and the Clearwater River from Orofino to its mouth. The terms of the heat exchange are similar to W2 and HEC-RAS. The model was calibrated by seasonally and spatially varying one evaporation heat flux parameter to minimize error with tailrace temperature gages.

The EPA evaluated sources of temperature impairments on the Columbia and Snake Rivers using the 2018 RBM10 model (EPA 2018). To evaluate the dams within the model domain, EPA developed a "free-flowing" scenario in which the channel velocity, depth, and width is calculated as if the dams did not impound the river based on current, measured channel geometry. Other than the hydraulics, the free-flowing scenario uses the same 1970–2016 hydrology, weather, and temperature boundary conditions as the calibrated RBM10 model. The free-flowing scenario includes the temperature and flow inputs from 1970–2016 from Dworshak Dam, because it is outside of the model domain.

Table 1-10. RBM10 Estimated Monthly Impact of Dam Impoundments on Snake River Temperatures (August; 2011–2016)

Location	RBM10 Free Flowing		Cumulative Impact	
	°C	°F	°C	°F
LWG	18.7	65.6	0.8	1.4
LGS	19.1	66.3	1.2	2.2
LMN	19.1	66.4	1.5	2.7
IHR	19.7	67.5	1.7	3.1

Note: °F = degrees Fahrenheit; °C = degrees Celsius
Source: EPA 2018

There are differences between EPA's free-flowing scenario and the MO3 results that make it difficult to interpret a direct comparison of reported results:

- MO3 uses a daily maximum temperature as its primary metric while free-flowing uses a daily average temperature.
- MO3 summarizes results based a 5-year weather period (2011–2015) while free-flowing summarizes results from 6 years (2011–2016).

- MO3 uses a simulated flow and temperature from Dworshak representing operations based on the No Action Alternative with slight modifications, while free-flowing uses observed flows and temperatures from Dworshak Dam.
- MO3 computes a change in temperature from No Action Alternative temperatures that are estimated using the W2 calibrated model. Free-flowing computes a change in temperature from the calibrated RBM10 model. Neither of the scenarios are compared directly to observed historic data.

In order to more directly compare HEC-RAS to RBM10, an additional scenario was run in HEC-RAS meant to be as similar as feasible to free-flowing. This "no lower Snake River dams" scenario used the 1934 bathymetry but 2011–2015 measured flows and temperature inputs at Dworshak and other boundaries. The temperature results were summarized as daily averages, in degrees Celsius by month at Lower Granite and Ice Harbor (Table 1-11 and Table 1-12). The "predicted impact" for each model is based on the same measured temperatures. The RBM10 results are reported from 2011–2015 (Figure 1-22).

Table 1-11. Lower Granite Tailrace, Comparison of RBM10 and HEC-RAS Predictions of Temperature without Lower Snake River Dams, 2011–2015 Weather and Hydrology, Monthly Average

Month	Measured (°C)	No LSR Dams, RBM10 (°C)	RBM10 Predicted Impact of No LSR Dams (°C)	No LSR Dams, RAS (°C)	HEC-RAS Predicted Impact of No LSR Dams (°C)	No LSR Dam HEC-RAS - RBM10 (°C)
1	3.3	3.0	-0.3	2.5	-0.7	-0.5
2	3.5	3.8	0.3	3.2	-0.3	-0.6
3	5.7	6.3	0.6	5.6	-0.1	-0.7
4	8.7	8.3	-0.4	8.3	-0.4	0.0
5	11.4	11.3	-0.1	11.2	-0.2	-0.1
6	14.6	14.6	0.0	14.7	0.1	0.1
7	18.6	18.2	-0.3	18.5	0.0	0.3
8	19.1	18.8	-0.3	19.0	-0.1	0.2
9	18.4	18.0	-0.4	18.0	-0.4	0.0
10	15.8	13.8	-2.0	13.7	-2.1	-0.1
11	9.6	7.3	-2.4	7.6	-2.0	0.3
12	4.9	4.3	-0.6	4.3	-0.7	0.0

Table 1-12. Ice Harbor Tailrace, Comparison of RBM10 and HEC-RAS Predictions of Temperature without Lower Snake River Dams, 2011-2015 Weather and Hydrology, Monthly Average

Month	Measured (°C)	No LSR Ddams, RBM10 (°C)	RBM10 predicted impact of no LSR dams (°C)	No LSR dams, RAS (°C)	HEC-RAS predicted impact of no LSR dams (°C)	No LSR dam HEC-RAS - RBM10 (°C)
1	3.6	2.7	-0.9	2.1	-1.5	-0.6
2	3.7	3.9	0.2	3.2	-0.5	-0.7
3	5.7	6.8	1.1	6.1	0.4	-0.7
4	9.3	8.9	-0.4	8.8	-0.4	0.0
5	12.3	12.0	-0.3	12.0	-0.3	0.0
6	15.3	15.3	-0.1	15.6	0.3	0.4
7	20.0	19.2	-0.8	20.0	0.0	0.8
8	21.4	19.9	-1.5	20.4	-1.0	0.5
9	19.8	17.8	-1.9	17.9	-1.9	0.0
10	16.6	13.2	-3.4	13.1	-3.5	-0.1
11	11.5	6.6	-5.0	6.5	-5.0	0.0
12	6.0	3.7	-2.3	3.2	-2.9	-0.5

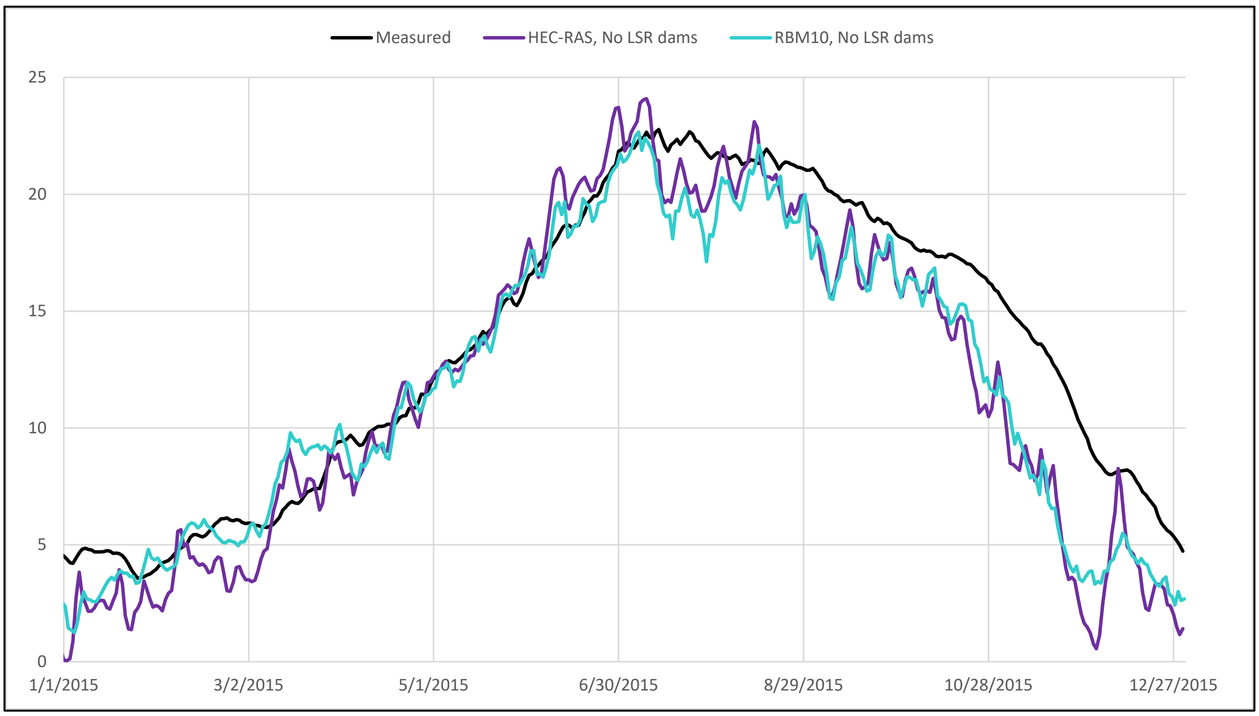

Figure 1-22. Ice Harbor tailrace, Comparison of 2015 Daily Average Temperature Prediction with No Lower Snake River Dams

1.3.9.2 2002 Feasibility Study

The 2002 Feasibility Study (Corps 2002) documents three different modeling efforts that estimate the impact of the lower Snake River dams: 1999 RBM10, WQRSS, and MASS1. The 1999 RBM10 results were quantified. Based on Table 4-4 in that report, near Ice Harbor Dam, a dam breach would reduce the number of days exceeding 20°C (68°F) from 62 days to 42 days per year based on averaging results from 1994, 1995, and 1997. The focus of the WQRSS model was biological productivity and temperature was mainly considered in context of productivity. MASS1 results of the dam breach were presented graphically. MASS1 predicted more temperature variability after a dam breach than existing conditions. Based on Figures 4-8 and 4-11 in the 2002 Feasibility Study, the MASS1 analysis near Ice Harbor Dam after a dam breach predicts a water temperature increase during July and August with more days exceeding 20°C and more rapid cooling during September. However, due to the uncertainties in the simulation model, the authors of the MASS1 study concluded that the results showed only small differences between the current and without dam river temperature regimes.

1.3.10 Model Results

The following section serves to present the results of the LSR-MO3 model and compares those results to the results from the No Action Alternative (Version 2). This ensures that we are comparing models with the same upstream boundary temperatures.

1.3.10.1 Flow Comparison to No Action Alternative

The upstream flows out of Dworshak and at Orofino remained unchanged as can be seen in Figure 1-23 and Figure 1-24. The upstream flow from Anatone, Idaho, did change slightly due to operational changes in MO3. This is shown in Figure 1-25. There are also very small changes seen on the Clearwater River at Peck and Spalding, Idaho, (Figure 1-26 and Figure 1-27), but the reason for this is uncertain. It could be due to the effects of dam breaching where water is moving through the system faster, or it could simply be due to the slightly different geometries used for the model since MO3 used the geometry from the sediment model. Flow changes, shown in Table 1-13, provide an overview of the model comparison between the No Action Alternative and MO3. Statistics are calculated using (No Action Alternative – MO3), so a positive number means the No Action Alternative prediction was higher than that of MO3. From Lower Granite and below, the major differences in flow can be attributed to a temporal shift forward in the timing of flow from the No Action Alternative (with dams) to MO3 (dams breached).

Table 1-13. 5-Year No Action Alternative versus Multiple Objective Alternative 3 Statistical Comparisons for Flow (cms)

	Average Flow		Min Flow		Max Flow		(NAA - MO3) Statistics		
	NAA	MO3	NAA	MO3	NAA	MO3	ME	MAE	RMSE
DWR	166.18	166.18	45.31	45.31	707.92	707.92	0.00	0.00	0.00
ORFI	259.91	259.91	25.49	25.49	1945.37	1945.37	0.00	0.00	0.00
PEK	428.93	428.93	73.83	73.81	2067.86	2068.74	-0.07	0.30	0.53
SPD	428.93	428.93	74.00	74.01	2060.55	2060.58	-0.02	0.09	0.24
ANA	897.47	897.47	239.65	239.59	4318.38	4318.41	-0.01	0.39	1.04
LWG	1328.95	1329.19	378.66	360.49	6043.37	6297.38	29.16	103.59	182.89
LGS	1276.22	1329.21	336.81	362.52	5742.37	6287.98	-23.14	126.43	193.35
LMN	1328.31	1329.24	343.17	364.09	6186.76	6282.73	96.83	142.57	248.00
IHR	1348.51	1329.26	216.98	365.56	6149.75	6275.89	94.48	162.87	259.64

Note: ANA = Anatone; MAE = mean absolute error; ME = mean error; RMSE = root mean square error; PEK = Peck; SPD = Spalding.

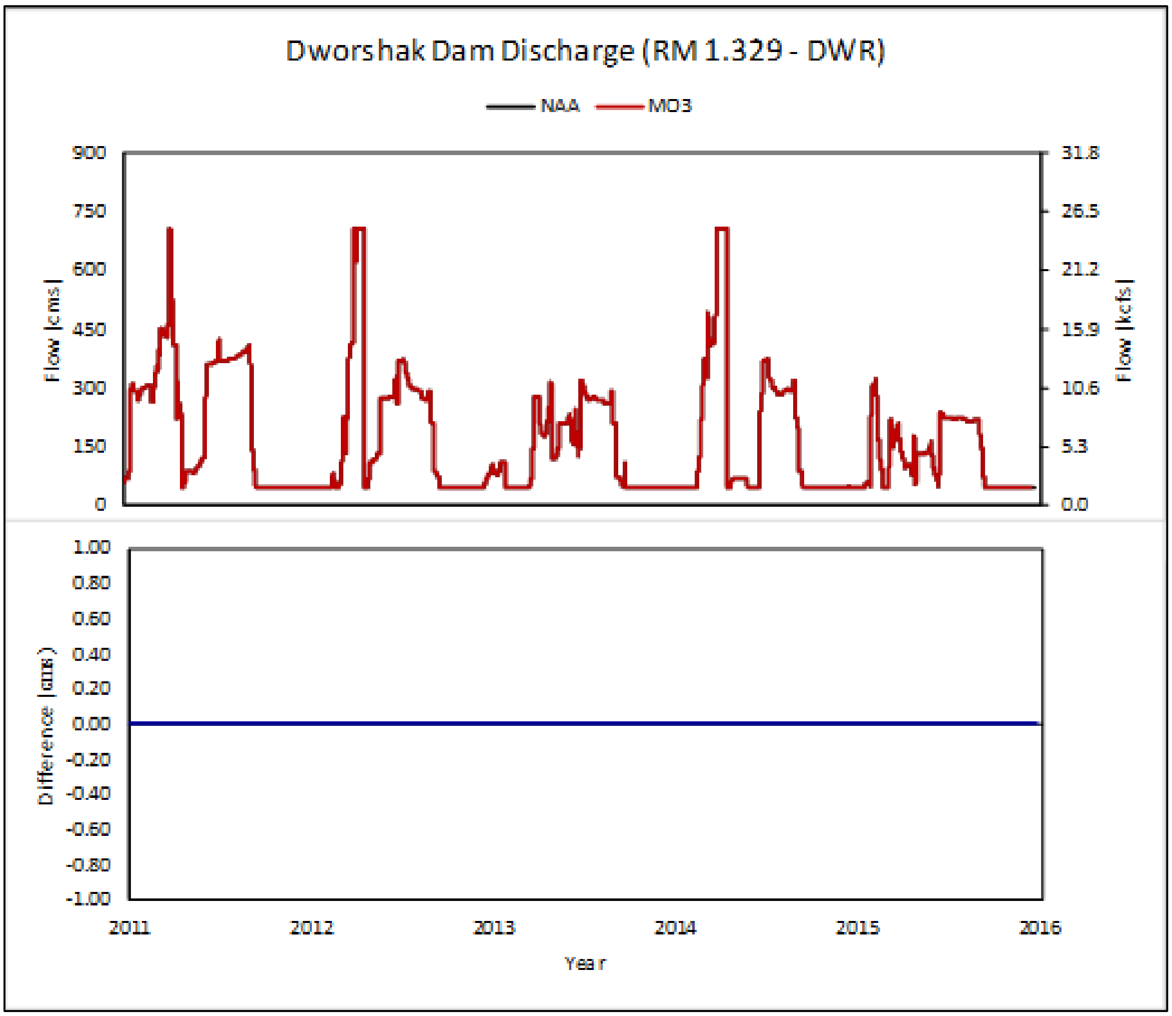

Figure 1-23. Discharge Comparison at Dworshak Dam

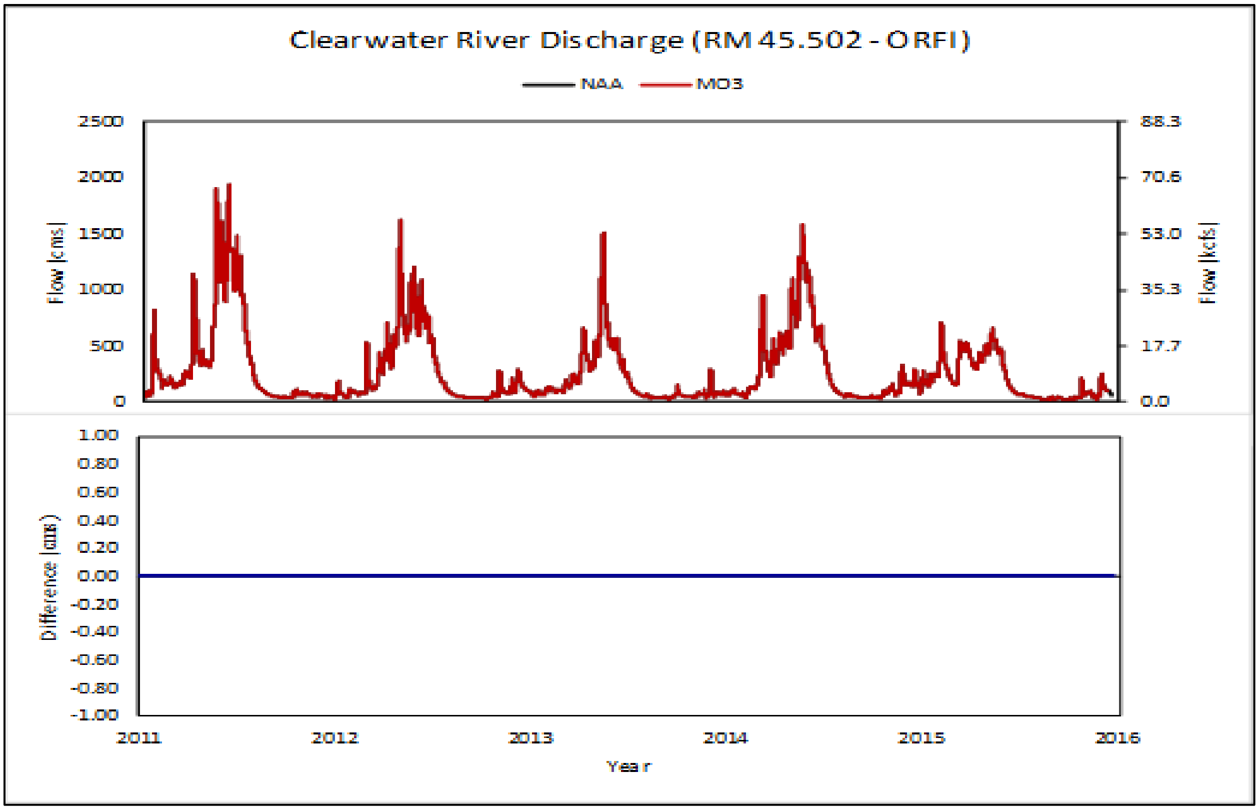

Figure 1-24. Discharge Comparison at the Clearwater River at Orofino, Idaho

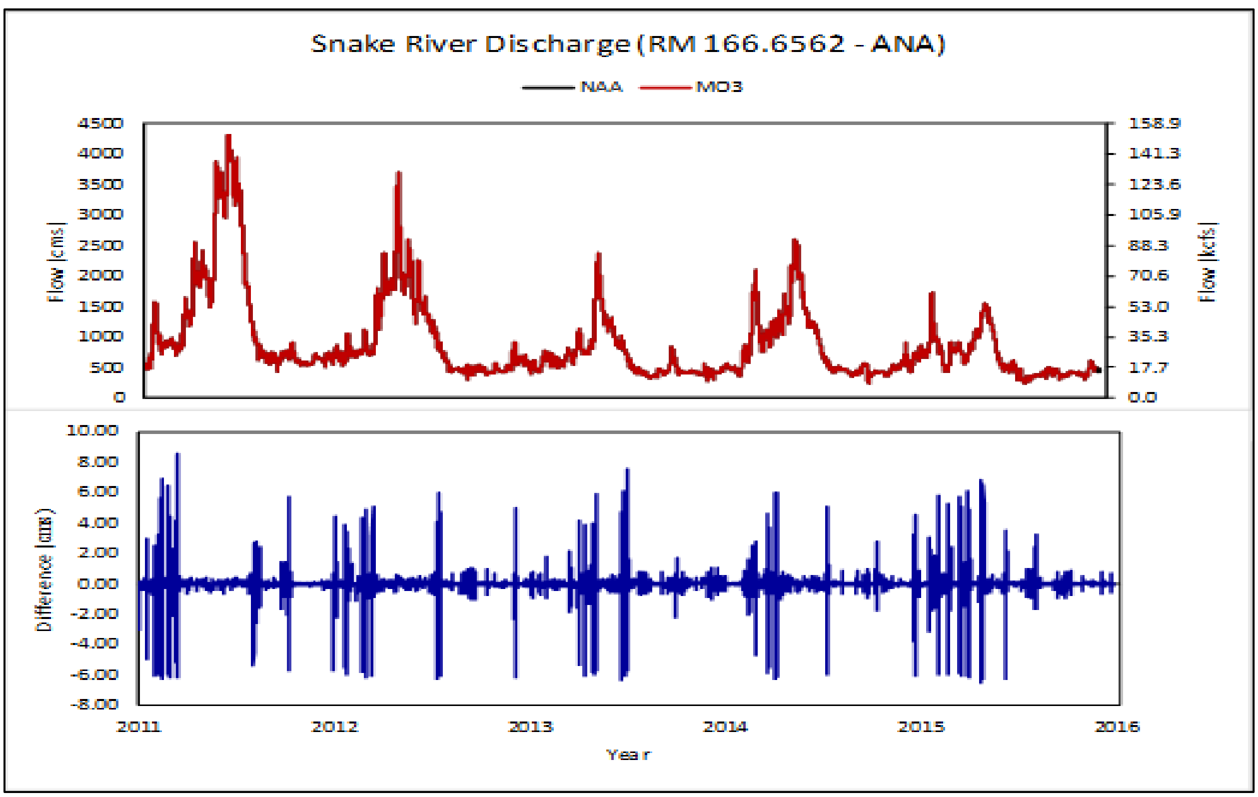

Figure 1-25. Discharge Comparison at the Snake River near Anatone, Idaho

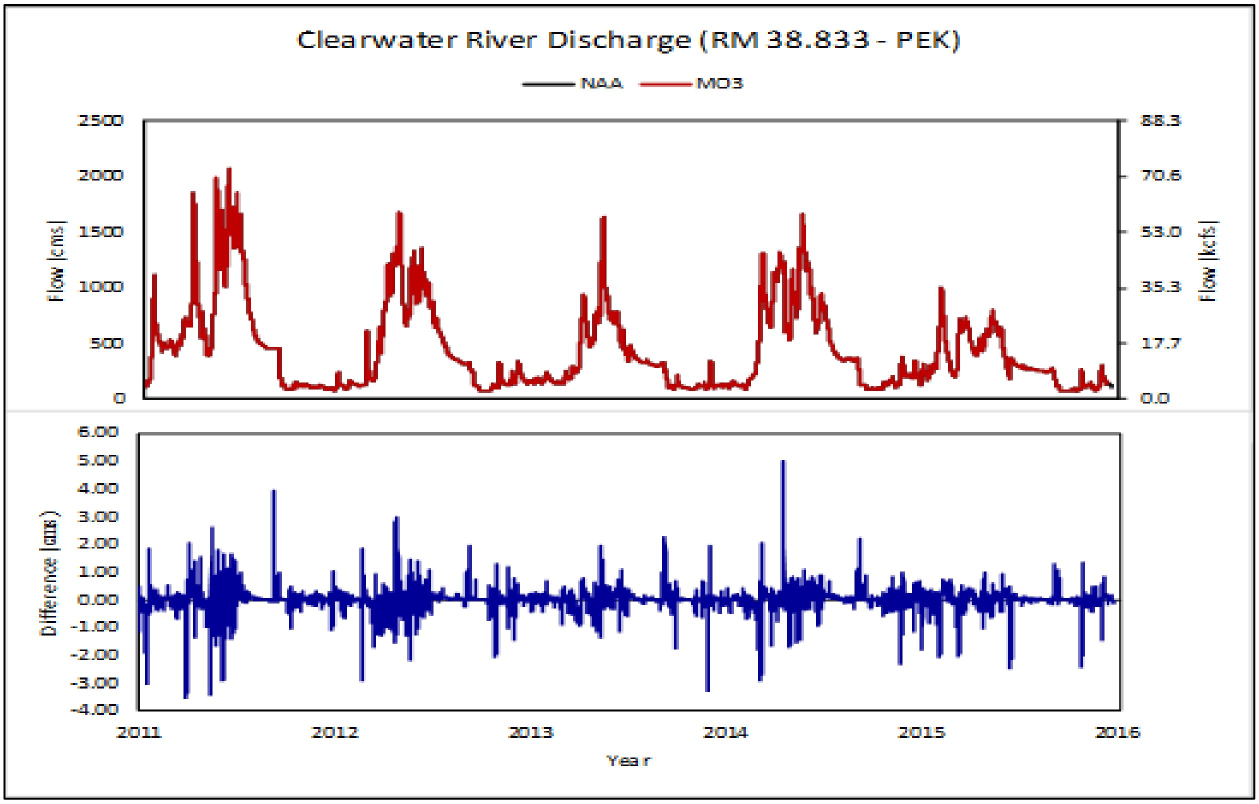

Figure 1-26. Discharge Comparison at the Clearwater River near Peck, Idaho

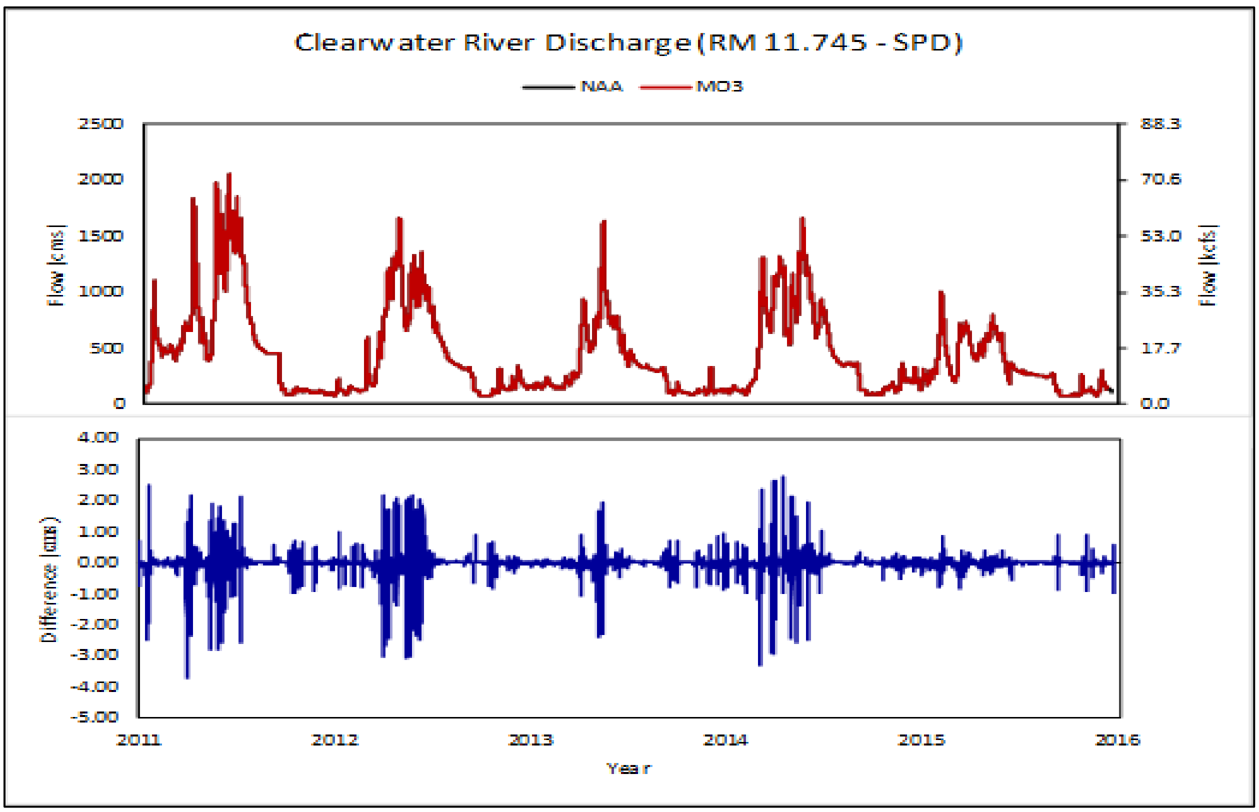

Figure 1-27. Discharge Comparison at the Clearwater River near Spalding, Idaho

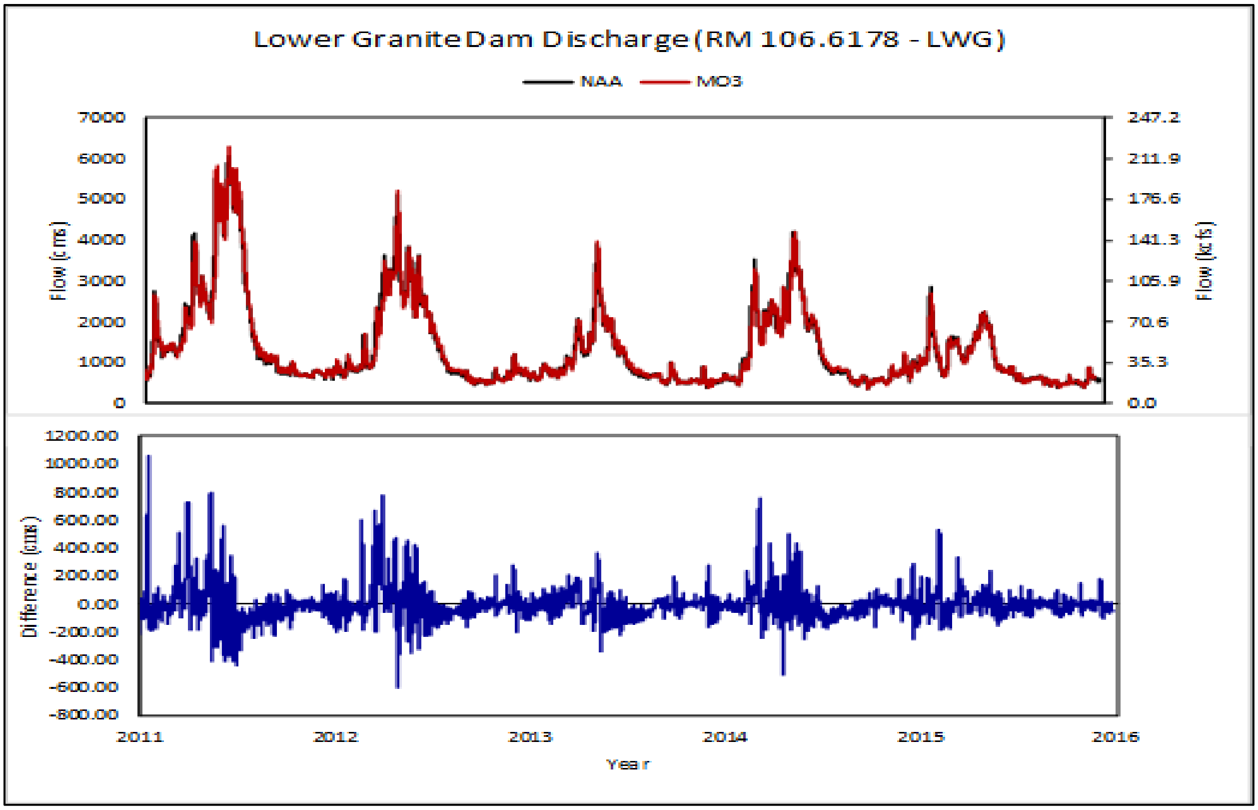

Figure 1-28. Discharge Comparison at Lower Granite Dam

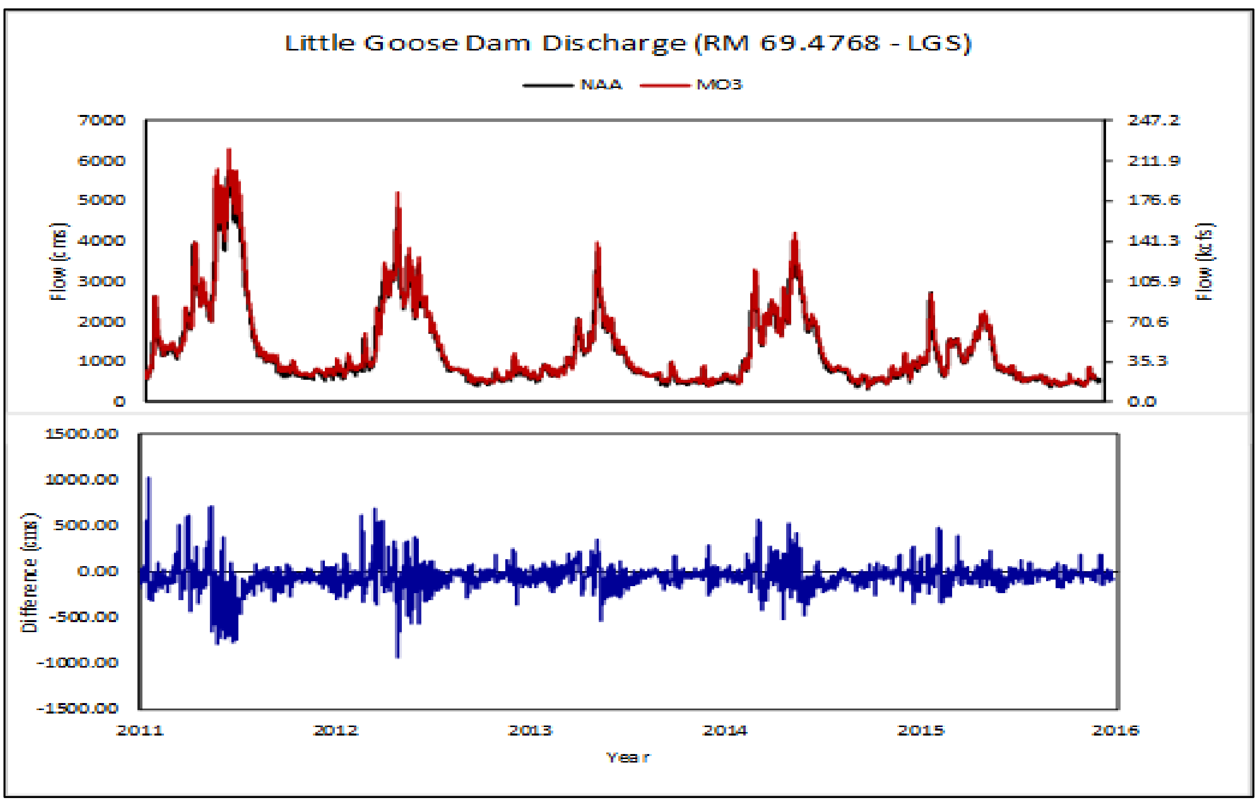

Figure 1-29. Discharge Comparison at Little Goose Dam

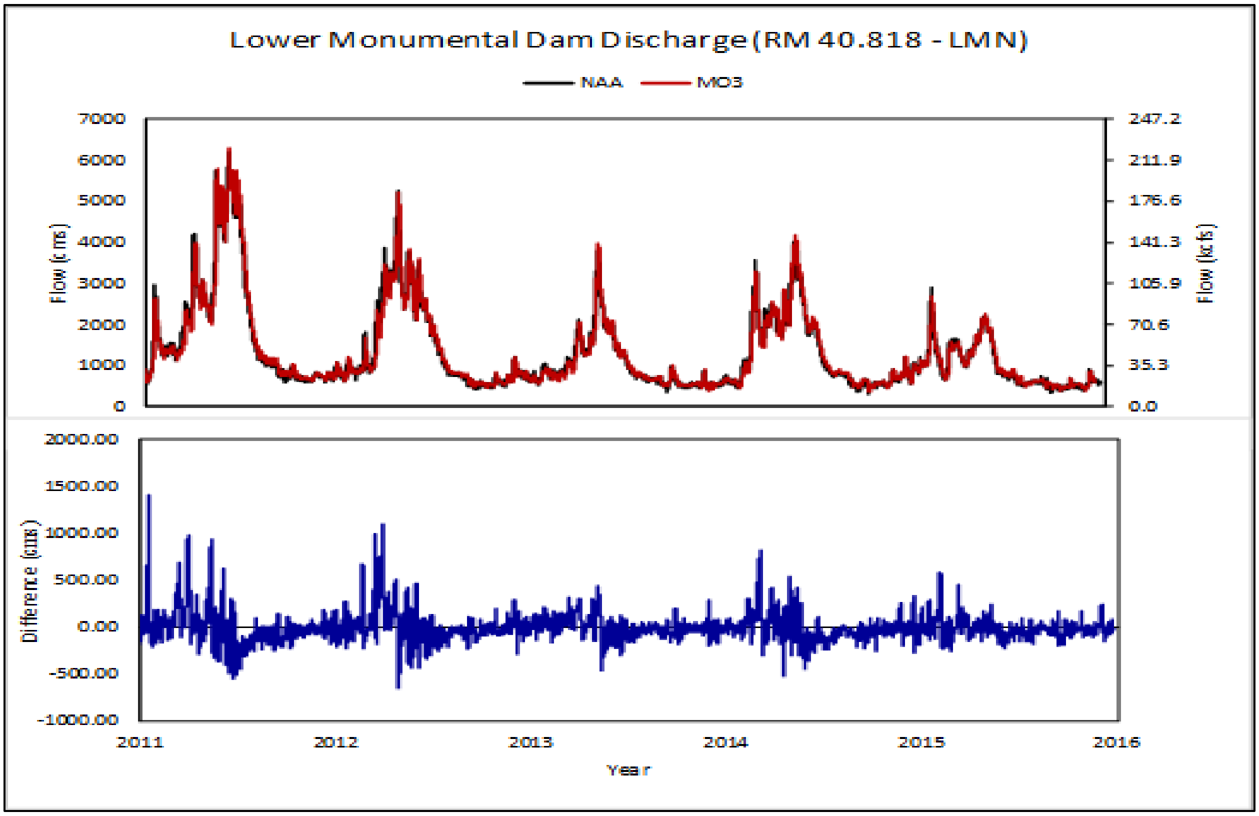

Figure 1-30. Discharge Comparison at Lower Monumental Dam

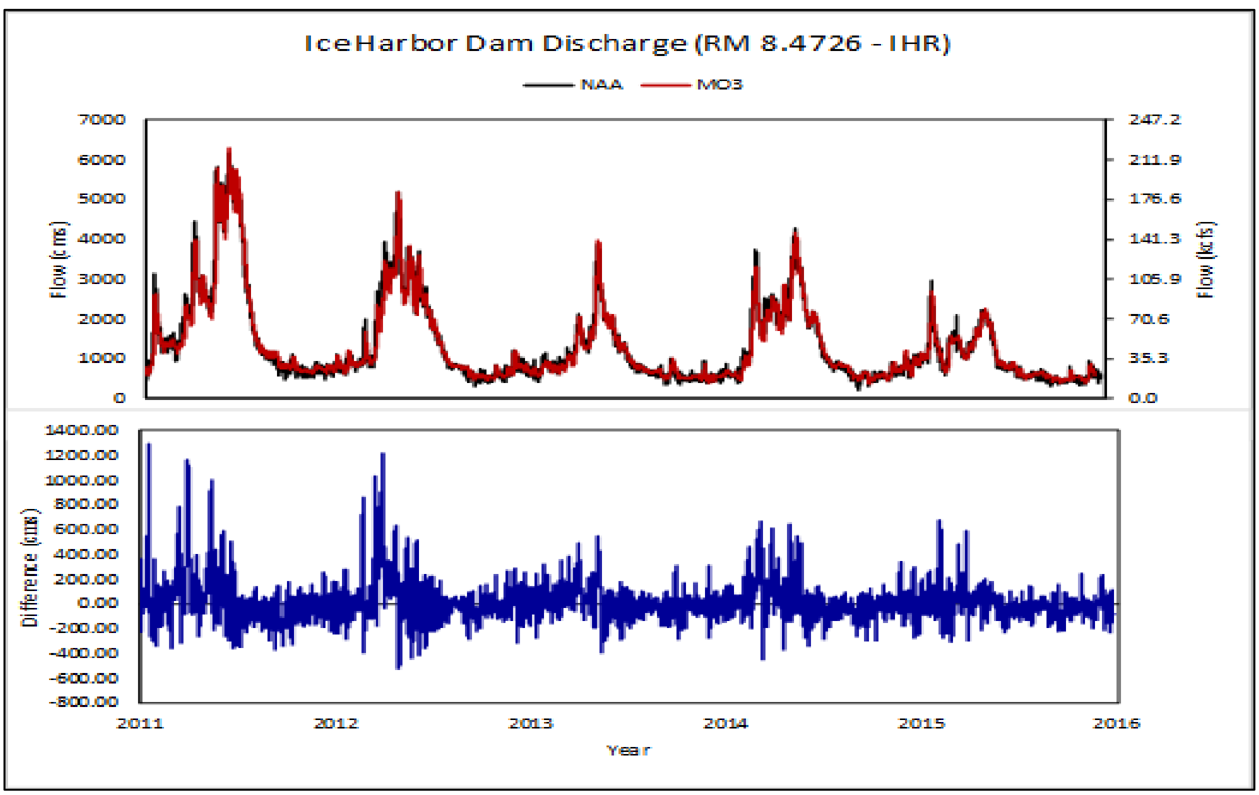

Figure 1-31. Discharge Comparison at Ice Harbor Dam

1.3.10.2 Temperature Comparison to No Action Alternative

The upstream boundary temperatures appear to be slightly different as can be seen in Figure 1-32 through Figure 1-34. This phenomenon is likely due to changes in the hydraulic calculation between the No Action Alternative and MO3 in the lower Snake River, which can cause slight changes in the hydraulic calculation upstream (e.g., timestep, dispersion, and cell size). The results shown are at the end of the most upstream reach. The effects seen at Peck and Spalding, Idaho, (Figure 1-35 and Figure 1-36) are uncertain as well. The predictions are different due to both flow differences (Figure 1-23 through Figure 1-31) and possibly the dam breaching. Figure 1-37 through Figure 1-40 show the largest differences due to the dam breaching. MO3 temperatures are cooler by approximately 0.2°C at the lower Snake River dam sites. Table 1-14 gives an overview of the model comparison between the No Action Alternative and MO3 (No Action Alternative-MO3).

Table 1-14. 5-Year No Action Alternative versus Multiple Objective Alternative 3 Statistical Comparisons for Temperature (°C)

	Average Temperature		Min Temperature		Max Temperature		(NAA - MO3) Statistics		
	NAA	**MO3**	**NAA**	**MO3**	**NAA**	**MO3**	**ME**	**MAE**	**RMSE**
DWR	6.33	6.33	2.56	2.48	10.80	10.82	-0.01	0.03	0.07
ORFI	9.50	9.50	-0.35	-0.35	27.91	27.91	0.00	0.00	0.00
PEK	7.21	7.19	0.61	0.62	17.77	17.56	-0.01	0.04	0.06
SPD	7.58	7.58	0.08	0.07	19.63	19.63	-0.01	0.02	0.05
ANA	11.89	11.89	0.57	0.57	24.92	24.92	0.00	0.00	0.00
LWG	11.10	10.57	0.36	0.38	21.95	22.17	-0.22	0.78	0.95
LGS	11.10	10.62	0.36	0.00	21.95	23.71	-0.16	0.92	1.14
LMN	11.30	10.67	0.49	0.00	22.48	24.11	-0.20	0.98	1.21
IHR	11.50	10.77	0.94	0.00	23.17	24.52	-0.25	1.03	1.31

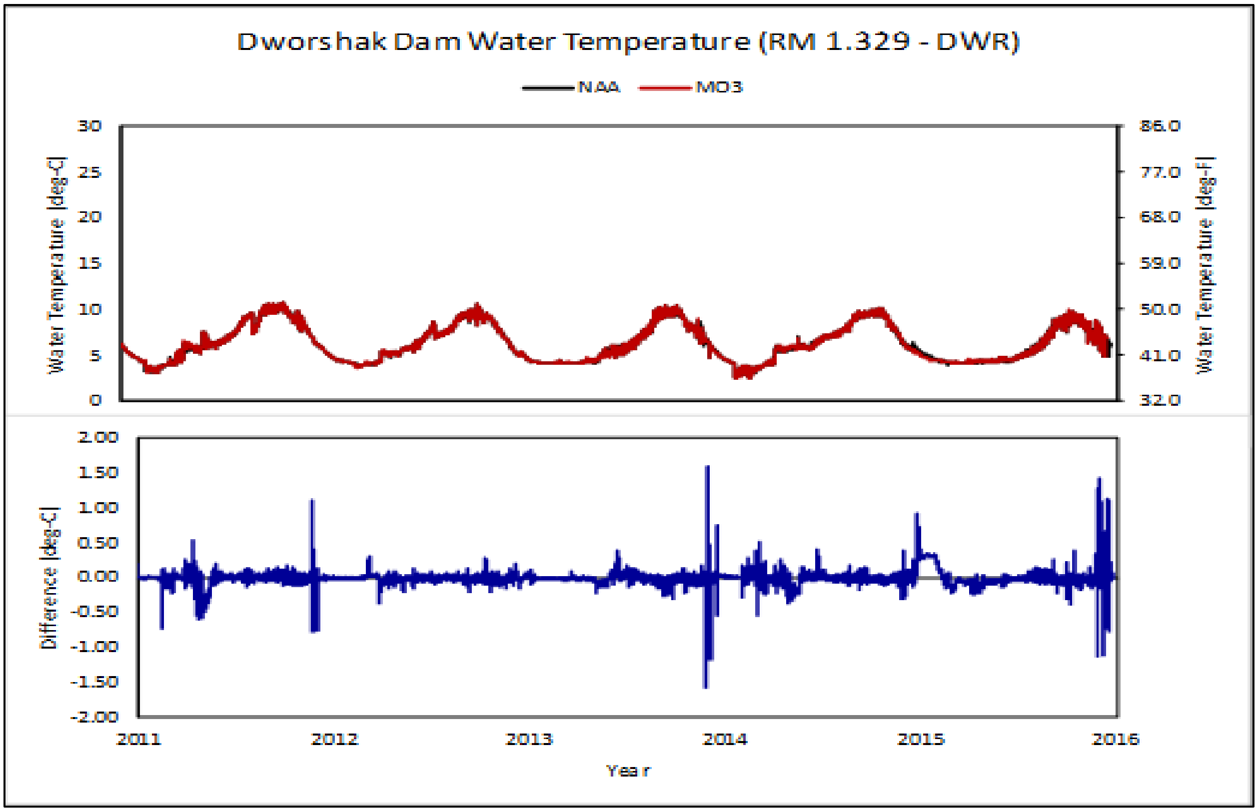

Figure 1-32. Temperature Comparison at Dworshak Dam

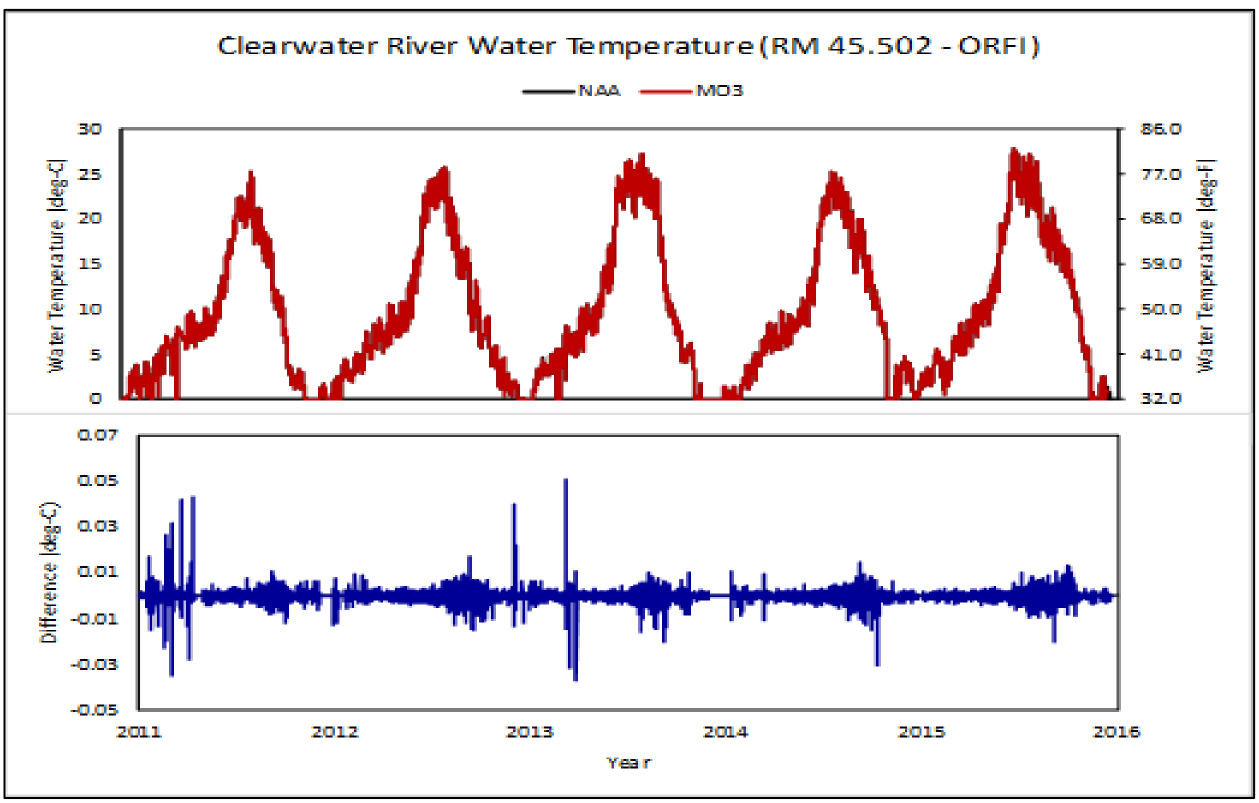

Figure 1-33. Temperature Comparison at the Clearwater River at Orofino, Idaho

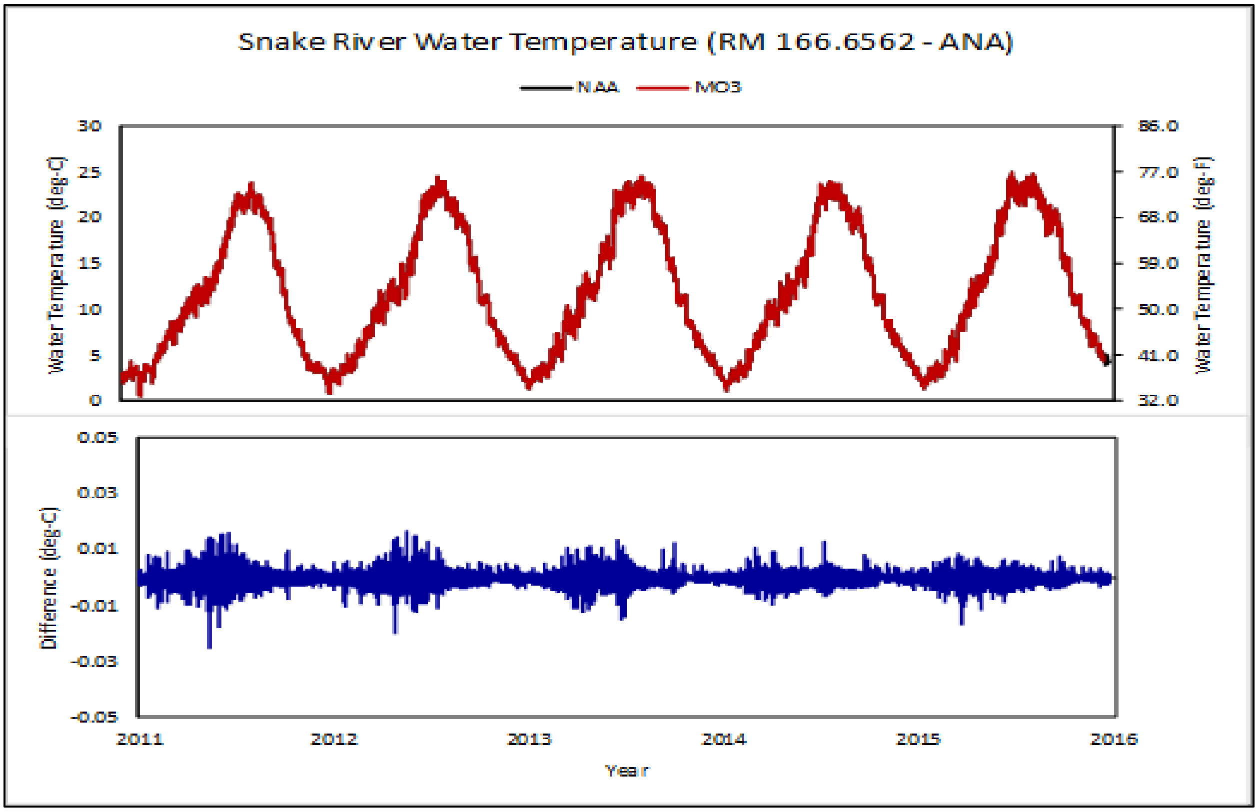

Figure 1-34. Temperature Comparison at the Snake River near Anatone, Idaho

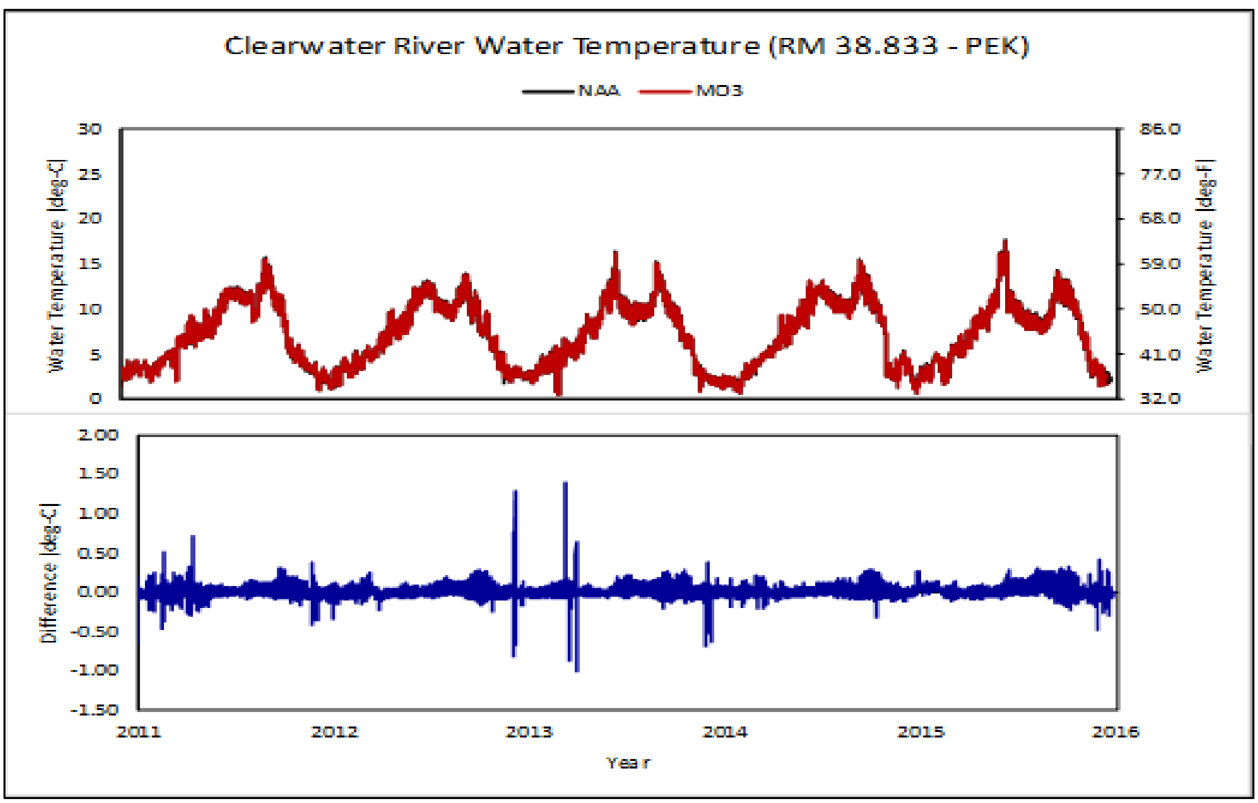

Figure 1-35. Temperature Comparison at the Clearwater River near Peck, Idaho

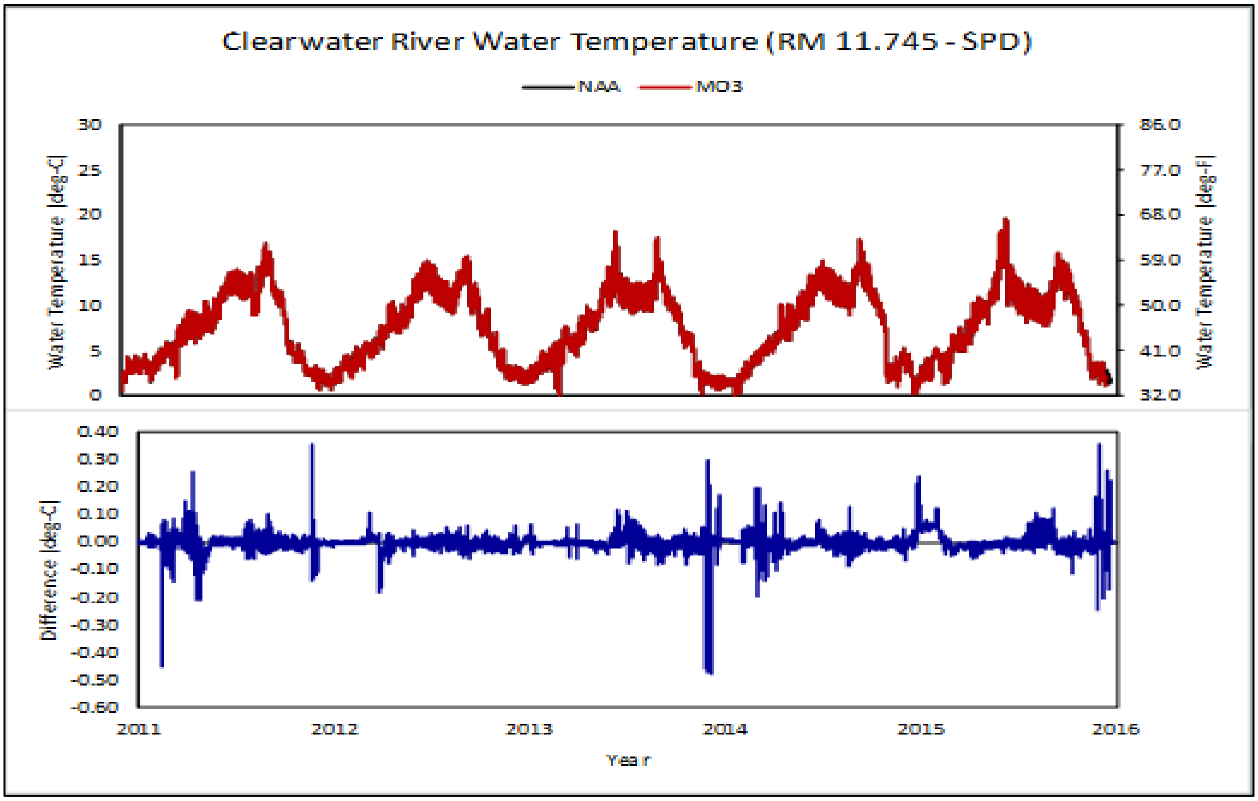

Figure 1-36. Temperature Comparison at the Clearwater River near Spalding, Idaho

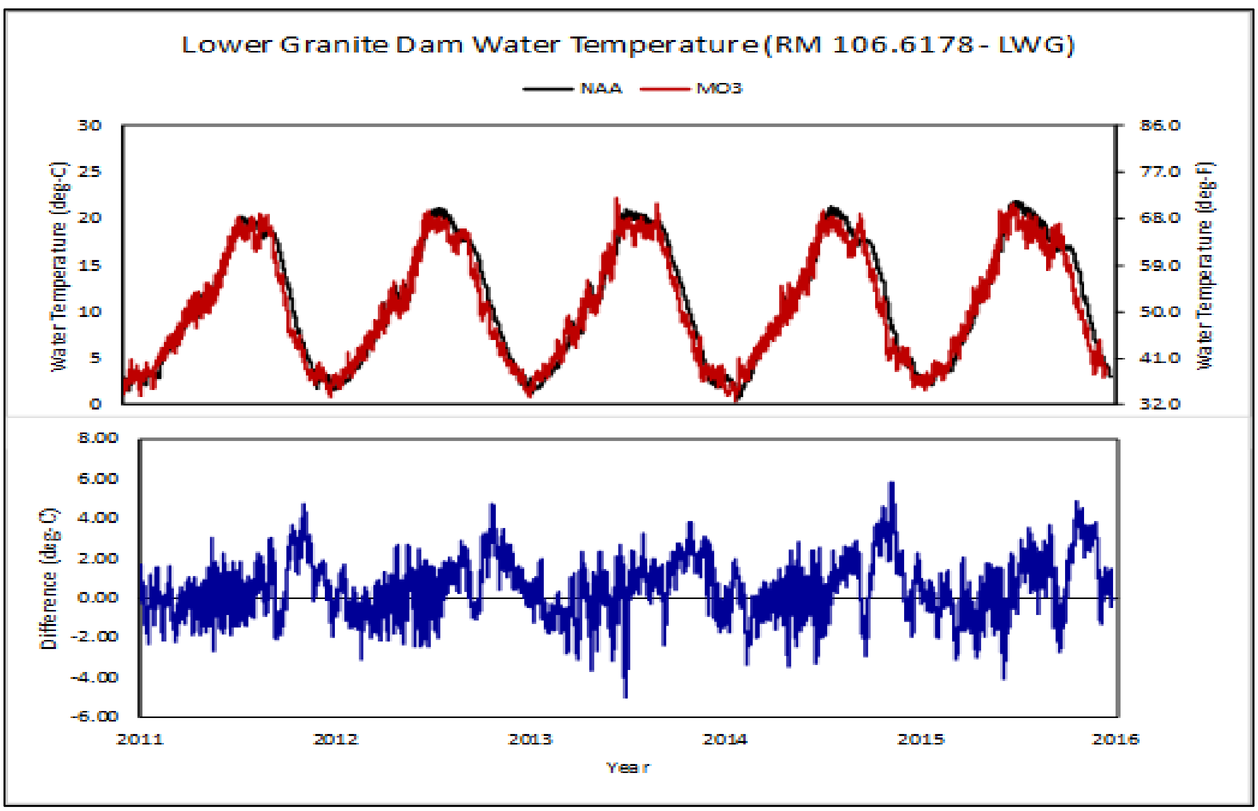

Figure 1-37. Temperature Comparison at Lower Granite Dam

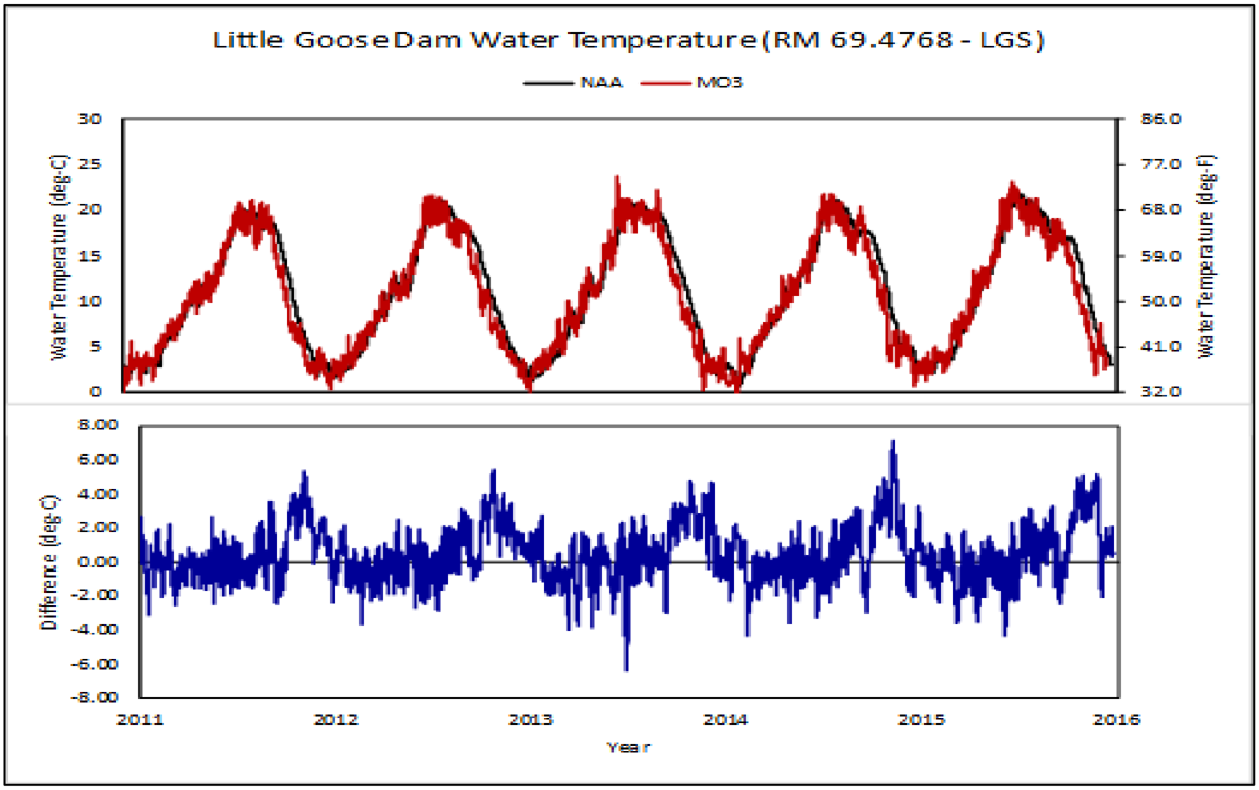

Figure 1-38. Temperature Comparison at Little Goose Dam

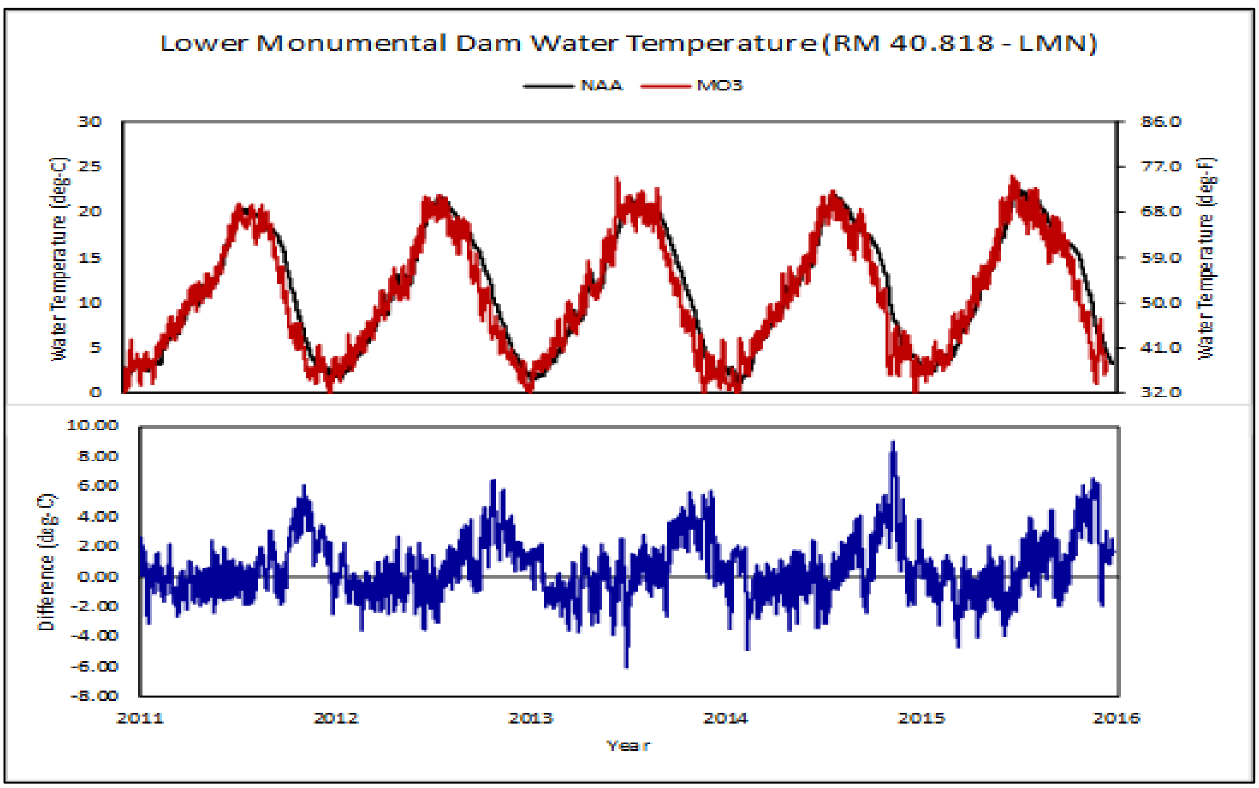

Figure 1-39. Temperature Comparison at Lower Monumental Dam

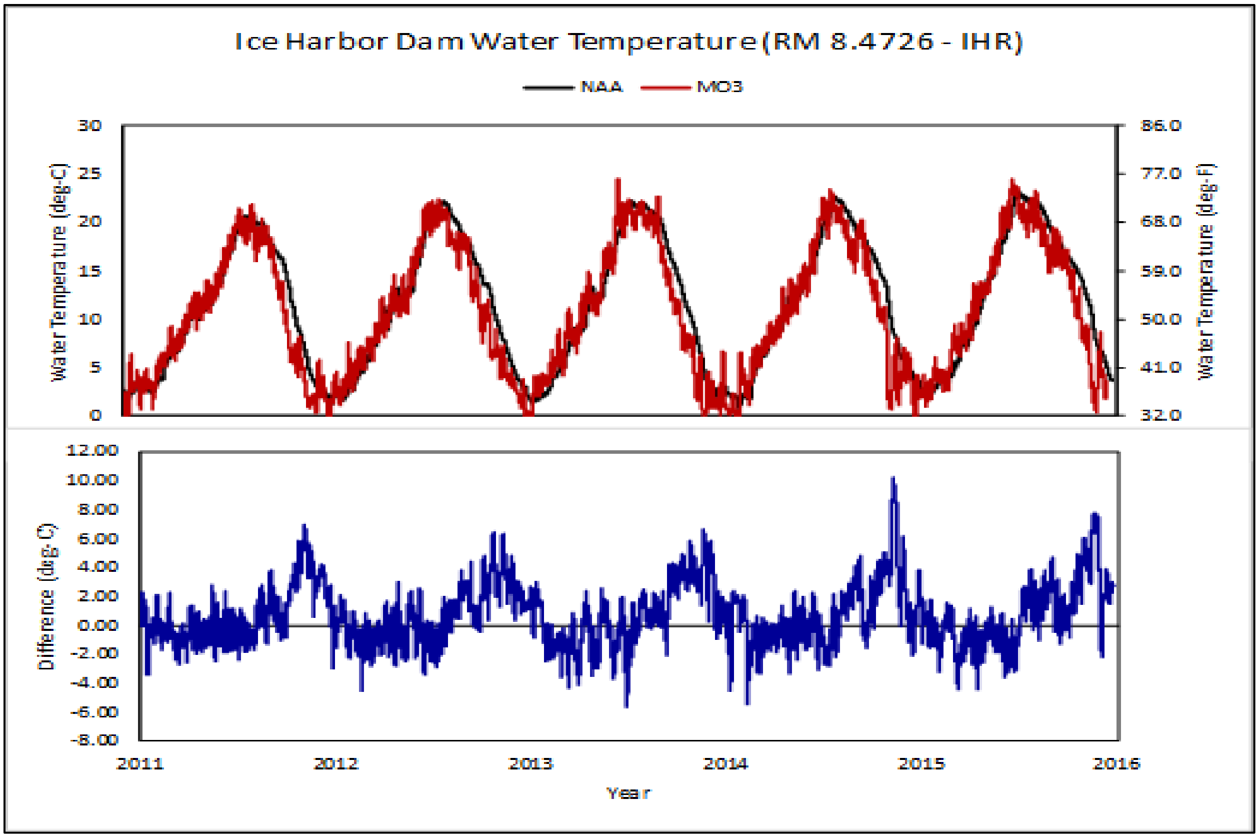

Figure 1-40. Temperature Comparison at Ice Harbor Dam

CHAPTER 2 - MODEL CONCLUSIONS

The LSR-MO3 model was developed to model the water quality effects (water temperature) from breaching of the lower Snake River dams. Unless explicitly stated above, all coefficients, parameters, and computation equations, 2011 initial conditions, and modeling methodology were identical to the calibrated W2 system model and the No Action Alternative.

2.1 MODEL ASSUMPTIONS AND UNCERTAINTY

MO3 temperature predictions have the greatest uncertainty in the EIS water quality modeling analysis because of the major change in the hydraulics of the system. Uncertainty analysis of mechanistic model predictions is an emerging field and a quantified assessment was beyond the constraints of the EIS due to model run times and needed development of an approach. Uncertainty was reduced and evaluated to the extent practicable.

Several assumptions were made for the LSR-MO3 model development. All flow boundaries and downstream stage at McNary Reservoir were set based on MO3 flow conditions from the CRSO reservoir operations team. Any flow deviations from the No Action Alternative will have an impact on the model results. All upstream temperature boundary conditions were set identical to those used in the No Action Alternative (v2).

Types of model uncertainty can be separated into four broad categories (after EPA 2009):

- Framework uncertainty, resulting from incomplete knowledge about factors that control the behavior of the system being modeled; limitations in spatial or temporal resolution; and simplifications of the system
- Input uncertainty, resulting from data measurement errors and inconsistencies between measured values and those used by the model (e.g., in their level of aggregation/averaging)
- Parameter uncertainty, resulting from a non-unique calibration and simplified physical processes
- Niche uncertainty, resulting from the use of a model outside the system for which it was originally developed and/or developing a larger model from several existing models with different spatial or temporal scales.

2.1.1 Framework Uncertainty

Mathematical models offer a simplified representation of physical processes. The model framework for the CRSO is composed of W2 and HEC-RAS, both of which are well known and widely used models with a relatively long history. The models are appropriate choices to evaluate the impacts of operations on water temperature. The model framework operates at high spatial and temporal resolutions which capture the appropriate processes. The model framework's longitudinal resolutions vary from 1.5 to 4,185 m and the temporal resolution is less than 1 hour. W2, a two-dimensional, laterally averaged model is used to represent the reservoirs, so stratification and longitudinal differences can be calculated. For the rivers, HEC-RAS assumes that the lateral and depth variations are much less important than the longitudinal variations. The simplifications of the heat budget and inputs to the model are widely tested and generally accepted. The WQ team believes very little uncertainty is introduced into the EIS analysis through the development of the basic model framework.

2.1.2 Input Uncertainty

Boundary conditions are used in the model framework to represent external sources and forces (i.e., tributaries and meteorology, respectively). Typically, boundary conditions are altered to test different water quality scenarios, so uncertainty is introduced not only in the current representation of boundary conditions but also in the scenarios. The uncertainty due to flow and temperature boundary conditions by using measurements at an hourly resolution for the calibration of the model at gage locations at the geographic boundaries of the model. For scenarios, daily flow inputs were derived from a rule-based operations model: ResSim. The WQ team confirmed that measured flow inputs and model-derived routing produced similar temperature results as using daily ResSim flows for each project and reach. Hourly solar radiation inputs were derived using W2 formulas rather than measured inputs. It was the professional judgment of the WQ team that this approach reduces uncertainty associated with a sparse and less reliable solar radiation monitoring network. Weather inputs were based on readily available and reliable data streams from stations within the basin (e.g., USBR AgriMet and airports). The WQ team believes very little uncertainty is introduced into the EIS analysis through the development of model inputs that represent current conditions or changes to operations of the current dams. However, the bathymetry and resulting hydraulics of the dam breach scenario are important factors in the temperature prediction. The WQ team did not evaluate the uncertainty of the dam breach bathymetry and the impact on uncertainty of the temperature prediction.

2.1.3 Parameter Uncertainty

Model parameters are semi-empirical in that they are determined not through site-specific field or laboratory measurements but through literature review and goodness-of-fit between model output and field measurements. For example, the wind sheltering coefficient in W2 is a parameter that adjusts the wind speed, which was measured at a given location (not the reservoir itself) (e.g.., an airport). Parameters are adjusted, but constrained to the range of typical literature values, to minimize the error between the measured water temperature and the model estimates of the current system. The inherent assumption in most modeling similar to this effort is that parameter uncertainty has been minimized when an acceptable calibration has been achieved. Parameter uncertainty can be quantified; however, the WQ team does not know of any cases where the impact of parameter uncertainty on allocations has been quantified for a model of this complexity. The iterative process of adjusting parameters to calibrate the model inherently considers the sensitivity of the model to the parameters. The typical parameter estimation process of minimizing error was not possible on the lower Snake River, one-dimensional model, HEC-RAS. To minimize the uncertainty due to the derivation of M03 parameters of the lower Snake River, the WQ team conducted the following analysis:

review of literature values, sensitivity analysis, comparison to similar modeling efforts, and corroboration with measurements. The WQ team believes that further decrease in model parameter uncertainty for MO3 results could result in an increase to model niche uncertainty.

2.1.4 Niche Uncertainty

The appropriateness of the model the setting of the CRSO was discussed in Section 2.1.1, above. An important part of niche uncertainty is whether the parameters used to represent the current condition are also representative of a different condition. A dam breach would result in an extreme change in hydraulics. The heat exchange occurs at the water surface, so changes to the channel width will impact every aspect of the heat balance. The depth of the water also impacts how heat fluxes result in temperature changes. Lastly, the travel time of a parcel of water changes, so the overall exposure to heat fluxes changes. Therefore, application of parameters from an existing condition to altered hydraulics are an important source of model niche uncertainty. The decision not to incorporate seasonally variable wind coefficients was intended to reduce model niche uncertainty. Since W2 was able to represent current conditions with constant wind coefficients, the WQ team believes that seasonally variable could take on surrogate roles in the heat balance to account for the one-dimensional simplification. In other words, a more complex parameterization may result in an “overcalibrated” model that leads to greater model niche uncertainty.

The pattern and magnitude of the mean daily MO3 results with estimated uncertainty bounds are compared to the No Action Alternative with uncertainty bounds. The RMSE between the system model and hourly observed measurements was calculated for the following results:

- W2 system model results at the Ice Harbor Dam tailwater (used in the No Action Alternative)
- HEC-RAS system model results at the Clearwater River at Spalding, Idaho (used in the No Action Alternative), used to estimate the uncertainty of HEC-RAS representation of a riverine site.
- HEC-RAS existing condition (one-dimensional representation of the system model) at the Ice Harbor tailwater (described above, Figure 1-17).

These three RMSE values were used as estimates of the MO3 uncertainty and were applied to model results. No Action Alternative temperature predictions are more certain than MO3 because there are fewer changes to the model from the calibrated conditions. Therefore, No Action Alternative uncertainty was estimated using W2 at Ice Harbor.

RMSE is a close approximation of the standard deviation, which is a typical measure used to quantify the amount of variation or dispersion of a set of values. A true uncertainty analysis is beyond the scope of this analysis. Using RMSE is a conservative estimate of uncertainty which, at best, accounts for model framework uncertainty and model input uncertainty. The actual uncertainty is greater than reported here because this estimate does not include model parameter or model niche uncertainty. This analysis does not include variability in weather or hydrology beyond the 2011–2015 period (Table 2-1 and Figure 2-1).

Table 2-1. Root Mean Square Error (°C) by Month

Month	W2 Calibration IHR	HEC-RAS Calibration SPD	HEC-RAS "Existing" IHR
January	0.88	1.15	1.68
February	0.88	0.99	1.11
March	0.84	1.32	0.62
April	0.95	0.87	0.68
May	0.79	0.61	0.44
June	0.59	0.76	0.31
July	0.70	1.02	0.71
August	0.45	0.83	0.66
September	0.35	0.81	0.66
October	0.52	0.57	1.66
November	0.42	0.85	2.14
December	0.62	1.00	2.30

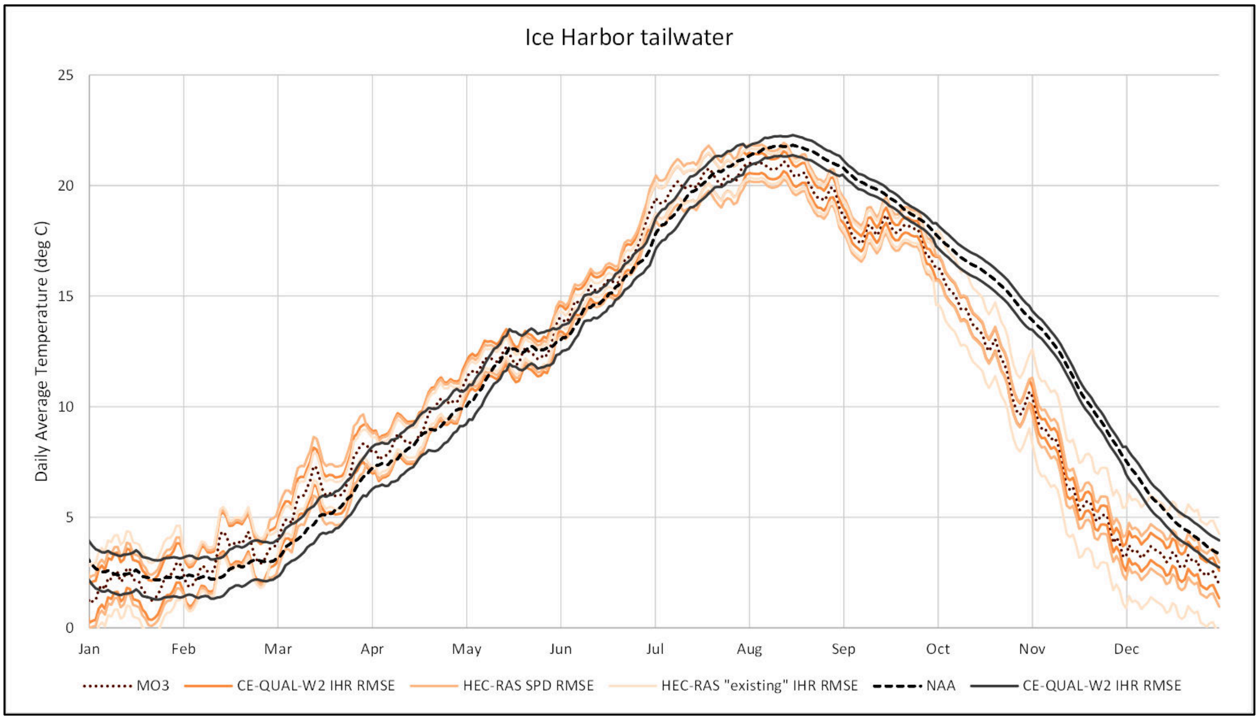

Figure 2-1. Estimated Uncertainty of MO3 Predictions Compared to the No Action Alternative.

When the estimates of the 5-year daily means plus/minus the RMSE overlap, there is a low confidence that MO3 will result in different temperatures than the No Action Alternative. Based on overlapping uncertainty bounds, we observe the following:

- At no time is the predicted MO3 temperature warmer than the No Action Alternative and the bounds of uncertainty, except for five scattered days between February and June.

- MO3 is predicted to be cooler than the No Action Alternative (outside the bounds of uncertainty) for the following periods: August 16 to September 19 and October 9 to December 7 (except scattered two-day periods).
- The predictions of MO3 and the No Action Alternative, including uncertainty, overlap for most of the year: December 8 to August 16. There is still a possible temperature impact of dam breach during that period but it is not predicted to be greater than the uncertainty of the analysis.

2.2 MODEL ACCEPTABILITY

Based on results presented in this report and the calibration reports, the CRSO WQ modeling team concluded that this model is sufficient to use for water temperature predictions under MO3. This model predicts the expected water temperature response expected from dam breaching based on well-documented thermal effects of reservoirs.

CHAPTER 3 - REFERENCES

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Columbia River System Operations
Final Environmental Impact Statement

Annex B
Water Quality Methods for Fish Survival Modeling

EXECUTIVE SUMMARY

PURPOSE OF TECHNICAL APPENDIX

This technical appendix documents the analysis and post-processing of Columbia River System water quality modeling results (Appendix X) for the Columbia River System Operations (CRSO) Multiple Objective Alternatives (MO) (including the No Action Alternative). Methods described include: (1) development of a water temperature mapping tool that allows 5 years of water quality modeling results to be re-sequenced to the 80-year period of record (POR) and (2) estimation of daily average total dissolved gas (TDG) at each CRSO dam during the POR. Both efforts were compiled under each MO with POR operational data from the Hydrology and Hydraulics (H & H) Technical Team and delivered as data products to the Fish Technical Team. This appendix has been prepared as documentation for multiple ongoing efforts by the co-lead agencies including, but not limited to, the CRSO Environmental Impact Statement.

ORGANIZATION OF THIS APPENDIX

This appendix consists of two parts:

1) Development and implementation of the water temperature mapping tool.
2) Methods used to estimate TDG under each alternative in the CRSO study.

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Acronyms and Abbreviations

Bonneville	Bonneville Power Administration
cfs	cubic feet per second
Corps	U.S. Army Corps of Engineers
CRSO	Columbia River System Operations
EIS	environmental impact statement
EXT	extended timeframe for water quality modeling (2011–2015)
H & H	hydrology and hydraulics
HEC	Hydrologic Engineering Center
HEC-RAS	Hydrologic Engineering Center River Analysis System
kcfs	thousand cubic feet per second
MO	Multiple Objective Alternative
NOAA	National Oceanic and Atmospheric Administration
POR	period of record (for this study, 1928–2007)
RBM10	one-dimensional water temperature model of Columbia/Snake R
ResSim	Reservoir Simulator (U.S. Army Corps of Engineers software)
TDG	total dissolved gas
USGS	U.S. Geological Survey
WSE	water surface elevation

CHAPTER 1 - INTRODUCTION

Water quality modeling is a time- and data-intensive procedure. Recent data (2011–2015) have been used to calibrate water quality models (temperature and total dissolved gas [TDG]) of the Columbia River. As part of the Columbia River System Operations (CRSO) study, historical flows were simulated during a historical 80-year (1928–2008) period of record (POR). In order to run fish models under multiple alternatives that rely on this 80-year period, a method of generating longer-term data sets for water temperature and TDG was needed. The lack of observed meteorological and water quality data available in the 80-year POR made developing water quality models (CE-QUAL-W2, Hydrologic Engineering Center River Analysis System [HEC-RAS], RBM10) complicated and time intensive for the CRSO project due dates (Table 1-1). The 2011–2015 period (referred to as EXT) captured a wide range of flow, weather, and water quality conditions for assessing potential operational/structural changes within each MO. This allowed a wider array of water quality data to be mapped back to the 80-year POR.

Table 1-1. Strengths and Weaknesses of Different Approaches to Analyzing the Multiple Objective Alternatives in the 1928–2008 Period of Record

	CE-QUAL-W2 + HEC-RAS	Statistical “Mapping” Approach	RBM10
Temporal Resolution	Sub-daily	Daily	Daily
Spatial Resolution	2D: vertical (depth) and longitudinal (downstream)	2D: vertical (depth) and longitudinal (downstream)	1D: Longitudinal (downstream)
Calibration Data Timeframe	2011–2015; limited quality data availability prior to 2008	Data available 1972–2018	Data available 1970-2016
TDG estimates	Physically/empirically based equations	Physically/empirically based equations	None
Development Effort/Time	High	Low	High
Run-Time	Days	Hours	Days

This technical appendix has been prepared as documentation for multiple ongoing efforts by the co-lead agencies including, but not limited to, the CRSO Environmental Impact Statement (EIS). Effects of the MOs on river mechanics (e.g., sediment transport), groundwater, power, and fish passage, etc., all of which may generally fall under the H & H umbrella, are covered in separate appendices. Projects may occasionally be referred to using an acronym instead of the full name (e.g., LWG instead of Lower Granite) in tables, or as a group (e.g., lower Snake projects instead of Lower Granite, Little Goose, Lower Monumental, and Ice Harbor) in tables or the text. Table 1-2 may be used as a guide to these acronyms and groupings.

Table 1-2. Project Acronyms and Groupings

Acronym	Common Name	Project Group
BON	Bonneville	Lower Columbia
TDA	The Dalles	
JDA	John Day	
MCN	McNary	
IHR	Ice Harbor	Lower Snake
LMN	Lower Monumental	
LGS	Little Goose	
LWG	Lower Granite	
DWR	Dworshak	Dworshak
PRD	Priest Rapids	Middle Columbia
WAN	Wanapum	
RIS	Rock Island	
RRH	Rocky Reach	
WEL	Wells	
CHJ	Chief Joseph	
GCL	Grand Coulee	
HGH	Hungry Horse	Hungry Horse
LIB	Libby	Libby

CHAPTER 2 - WATER TEMPERATURE MAPPING

2.1 OVERVIEW

The goal of this effort is to represent water temperature in the forebay (multiple depths) and tailwater at each project in the CRSO domain in the POR. Generally, this was done as follows:

- Step 1. Develop monthly water temperature regression models at Bonneville Dam in the 1972–2018 period.
- Step 2. Use regression models to estimate monthly Bonneville Dam water temperature in POR and EXT periods.
- Step 3. Calculate percentiles for model development period (1972–2018; including EXT) and POR period.
- Step 4. Find closest percentile for each month in EXT that matches to POR percentiles and assign System Model temperature results in the forebay (surface, mid, bottom depths) and tailwater for each month in POR.

The regression models allow a comparison of historical monthly water temperatures based on monthly flow and regional air temperature. This methodology assumes that the average residence time in this portion of the Columbia system is about one month.

2.1.1 Development of Water Temperature Regression Models

A series of regression models estimating monthly Columbia River water temperature at Bonneville Dam as a function of monthly air temperature and streamflow were developed to predict water temperature in a historical period (1928–2008 POR) in which minimal water temperature data at Bonneville Dam is available.

The best regression fits as determined by the statistical program R (R Core Team 2018) depended on the following data from U.S. Army Corps of Engineers (Corps) Dataquery 2.0 (Corps 2018a) (some sourced from U.S. Geological Survey [USGS 2018]):

- BON-ScrollCase.Temp-Water.Inst.~1Day.0.CBT-RAW, (Daily water temperature at Bonneville Dam)
- IHR.Flow-Out.Ave.~1Day.1Day.CBT-REV [*IHR*], (Ice Harbor outflow, in cubic feet per second [cfs])
- PRD.Flow-Out.Ave.~1Day.1Day.CBT-REV [*PDT*], (Priest Rapids outflow, in cfs)
- BON.Flow-Out.Ave.~1Day.1Day.CBT-REV [*BON_Flow.Out*], (Bonneville outflow, in cfs)

Additionally, monthly mean northwest region air temperature data (°F) [named *nwt*] was retrieved from the National Oceanic and Atmospheric Administration (NOAA) National Center for Environmental Information data portal (NOAA 2017). Regression models were developed with BON-scrollcase data 1975–2017. Years with more than 3 months of missing data were removed from the dataset. This led to removal of years 1981–1985 and 1992.

Data was transformed as follows:

- BON_Flow data was inverted: e.g., BON_Flow.Out.Inv=1/BON_Flow.Out
- The ratio of IHR/PDT was used to represent the ratio of Snake River to Columbia River flows upstream of McNary Dam (named IHR_PDT_Ratio): IHR_PDT_Ratio=IHR/PDT
- Inverse flow, flow ratio, and air temperature data (nwt) were lagged by 1 and 2 months yielding the following variables (BON_Flow.Out.Inv.L1, BON_Flow.Out.Inv.L2, IHR_PDT_Ratio.L1, IHR_PDT_Ratio.L2, nwt.L1, and nwt.L2)

Regression models were developed for each month using the lm() and stepAIC() methods in the statistical software R version 3.3.2 (R Core Team 2018). Table 2-1 shows the model coefficients for each monthly model (empty cells indicate that the term was determined not significant in predicting water temperature in that month). The form of each monthly model equation is as follows:

$$BON_{WT} = \text{(Intercept)} +$$

c1*BON_Flow.Out.Inv + c2*BON_Flow.Out.Inv.L1 + c3*BON_Flow.Out.Inv.L2 +

c4*IHR_PDT_Ratio + c5*IHR_PDT_Ratio.L1 + c6*IHR_PDT_Ratio.L2 +

c7*nwt + c8*nwt.L1 + c9*nwt.L2

Most monthly regression models depended on the air temperature from the previous 2 months (NWT.L1, NWT.L2). Only January and February equations resulted in a (negative) dependence on air temperature with the current month. These months also had some of the highest error associated with the fit statistics.

While regression equations for most months depended on flow variables, winter (Dec-Feb) and late summer (Jul-Sep) had fewer dependencies, and instead, depended primarily on air temperature. Qualitatively, higher magnitude of flow (BON_Flow.Out.Inv variables) model coefficients (c1, c2, c3) can be associated with a greater dependence to Bonneville flow. In other words, larger positive or negative values in c1, c2, and c3 indicate a greater dependence on Bonneville flow in those months' equations. For example, August water temperature increases as August flow increases (c1 ~ 6.4E5), and as July flow decreases (c2 ~ -4.2E5). However, the lowest magnitude of these August BON_Flow.Out.Inv coefficients is associated with August (c1), so water temperature in August is more dependent on August flow increases, than July flow decreases. Another example, September, has a relatively minor dependence on flow increases in August (relatively small magnitude c2), but significant coefficient values related to air temperature (c7, c8, and c9). Coefficients of Snake to Columbia River flow variables (c4, c5, c6) were important in most months except for March, Jul, Aug, Sep, and Dec. Negative values associated with these coefficients indicate that water temperatures increase as Snake River flow decreases in comparison to the Columbia River. Future developments of these regression equations could work toward standardizing coefficients across data type, so that relative dependencies between flow and air temperature could be assessed better across months and data types.

Table 2-1. Multiple Linear Regression Coefficients Predicting Monthly Water Temperature at Bonneville Dam

Month	(Intercept)	c1 BON_Flow.Out.Inv	c2 BON_Flow.Out.Inv.L1	c3 BON_Flow.Out.Inv.L2	c4 IHR_PDT_Ratio	c5 IHR_PDT_Ratio.L1	c6 IHR_PDT_Ratio.L2	c7 nwt	c8 nwt.L1	c9 nwt.L2
Jan	1.24E+01			7.74E+05		-1.11E+01	2.60E+01	2.88E-01	3.41E-01	
Feb	2.69E+01				-4.97E+00			1.53E-01	3.22E-01	
Mar	3.50E+01	8.14E+05	-1.11E+06	6.21E+05					1.97E-01	
Apr	3.22E+01		6.97E+05	-9.05E+05		2.96E+00	-5.64E+00	2.71E-01	1.81E-01	
May	2.80E+01		5.14E+05	-3.59E+05		2.94E+00	-3.44E+00	2.21E-01	2.40E-01	1.36E-01
Jun	3.60E+01	1.11E+06		-3.66E+05	2.65E+00			1.80E-01	2.04E-01	
Jul	3.94E+01		4.91E+05					2.05E-01	2.12E-01	
Aug	4.08E+01	6.40E+05	-4.22E+05					4.24E-01		
Sep	4.24E+01		1.74E+05					2.44E-01	2.73E-01	-1.13E-01
Oct	2.16E+01	-5.50E+05	3.49E+05		6.83E+00			4.13E-01	3.60E-01	
Nov	2.21E+01	8.62E+05	-4.77E+05		-9.96E+00	1.51E+01		2.66E-01	3.72E-01	
Dec	2.62E+01							3.08E-01	2.73E-01	

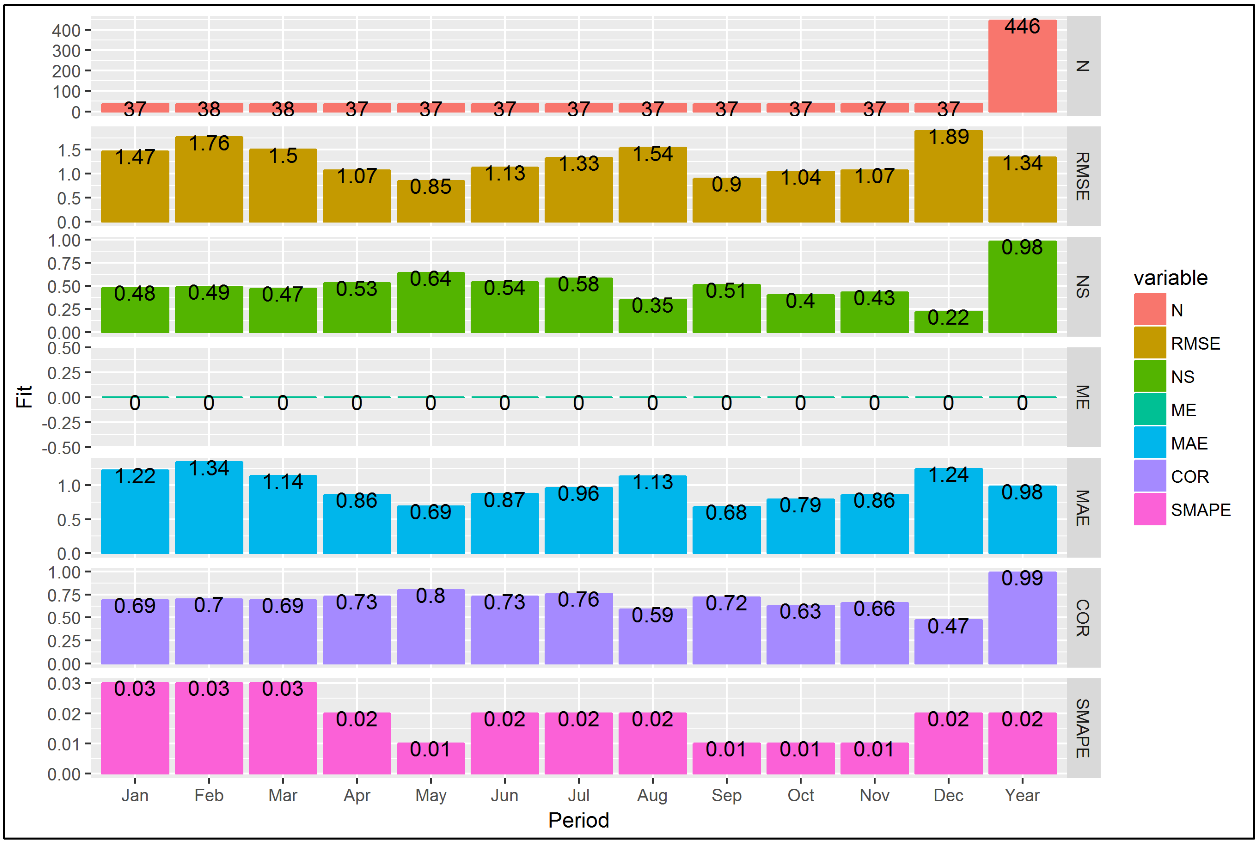

Figure 2-1. Monthly Water Temperature Regression Model Fit Statistics

Note: N = number of observations, RMSE = root mean squared error, NS = Nash-Sutcliffe error, ME = mean error (°F), MAE = mean absolute error (°F), COR = Pearson correlation coefficient, SMAPE = standard mean absolute percent error.

Monthly model fits were calculated and tabulated in Figure 2-1. Monthly fits are generally less than 1.34°F (0.74°C) MAE. Monthly model results were then re-assembled to the model development date range (1975–2017), where an overall MAE value was 0.98 shown in Figure 2-1 in the "Year" column.

A time-series comparison of the model and measured data is shown in Figure 2-2. While the extremes in the summer and winter months are not as close of a model fit as spring and fall, the overall trend is a fairly close fit. Scatter plots of each monthly model are shown in Figure 2-3.

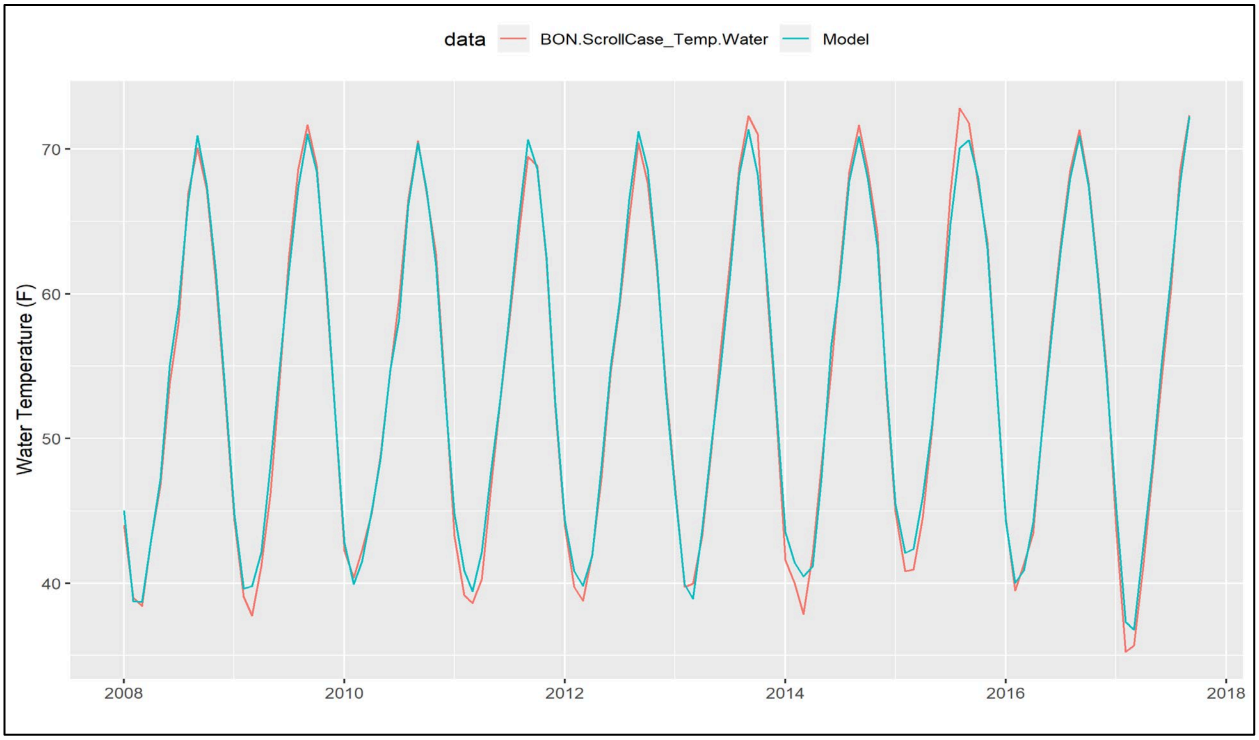

Figure 2-2. Time-series Representation of Measured and Modeled Water Temperature of the Columbia River at Bonneville Dam

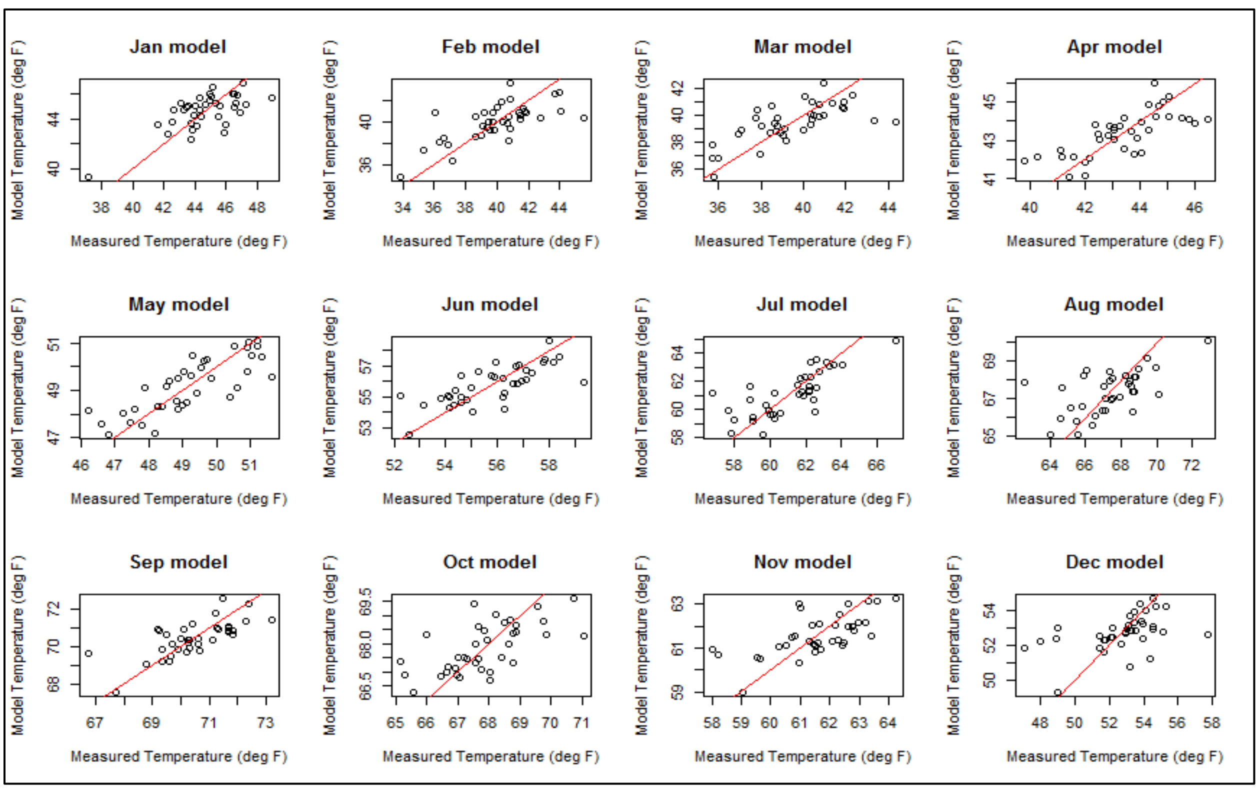

Figure 2-3. Scatter-plot Representation of Measured and Modeled Water Temperature of the Columbia River at Bonneville Dam for each Month

2.1.2 Estimation of Monthly Bonneville Dam Water Temperature

Prior to applying the regression models to the EXT and POR timeframe for the temperature mapping, the monthly temperature distribution was examined in the model development period (1975–2017) and the two periods in which the percentile mapping occurs (from EXT to POR) (Figure 2-4). The 2011–2015 EXT period is generally within the distribution of the 1928–2008 POR, but shows a smaller variation among years compared to the POR, which could be explained by the fewer number of years in the EXT period. Caution is advised in applying this model over long periods to infer climatic signals, as it is empirically based on the 1975–2017 timeframe, which assumes the environmental conditions in that period are stationary and do not change over time. This is likely an inaccurate assumption when applied to multi-decadal timeframes. However, for the purposes of the CRSO EIS, these regression equations provide a snapshot in time and a reference condition with which to compare the alternatives.

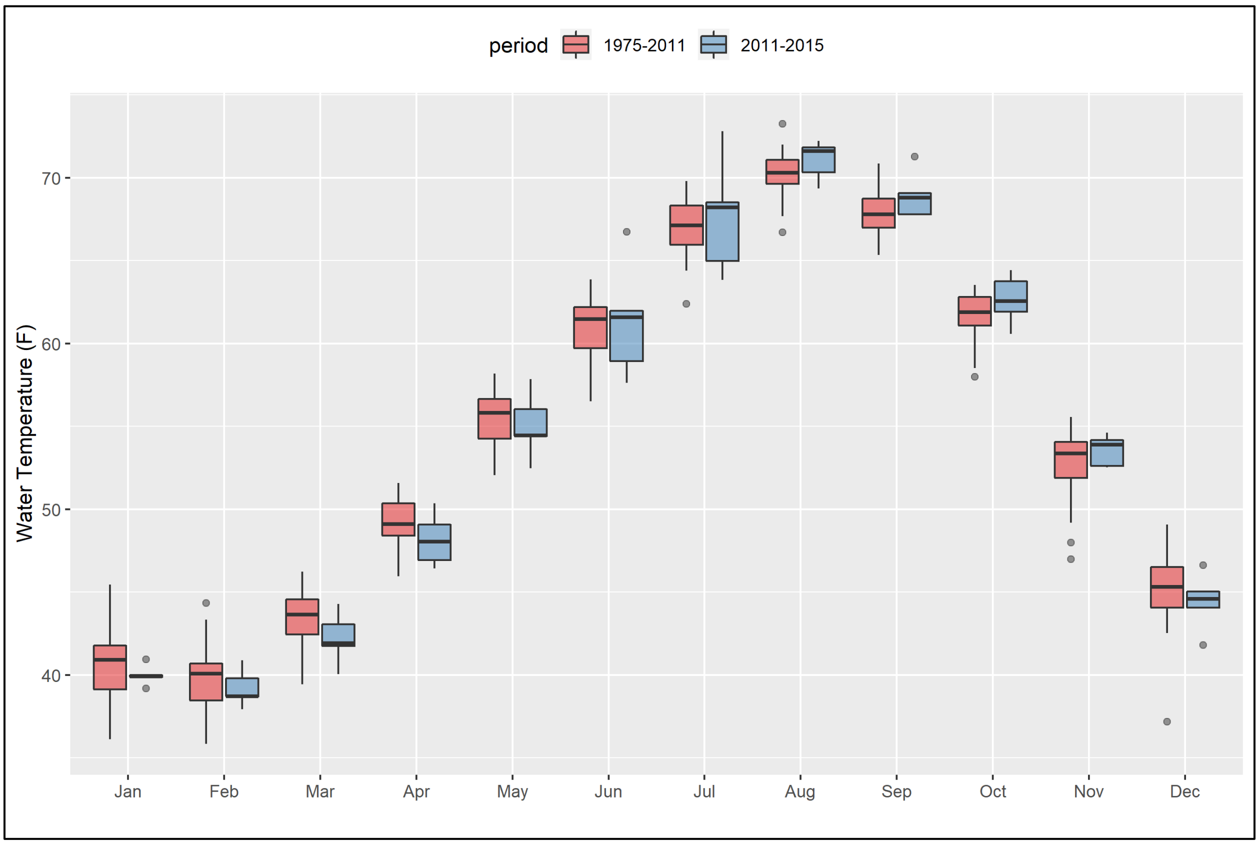

Figure 2-4. Monthly Box Plots of Estimated Columbia River Water Temperature at Bonneville Dam for Two Timeframes: the Model Development Period (1975–2017) and the EXT Period (2011–2015)

Note: Boxes indicate the inner quartile range (25th and 75th percentiles).

2.1.3 Synthesizing a Historical Period Water Temperature Dataset

Following the development of the monthly water temperature regression models, the percentiles for each month in the present regression model development period (1975–2017) and POR (1928–2008) periods were calculated (Figure 2-5 and Figure 2-6). Percentiles for the EXT water quality modeling period (2011–2015) were extracted from the regression period in Figure 2-5. Next, the percentile in each month of the historical period was used to find the closest-fitting percentile in the water quality modeling period. For example, the percentile for June 1928 (0.56) was matched to the closest absolute difference in percentile from all of the June percentiles in the water quality modeling period (0.55 in June 2013). This process was repeated for each month in the historical period.

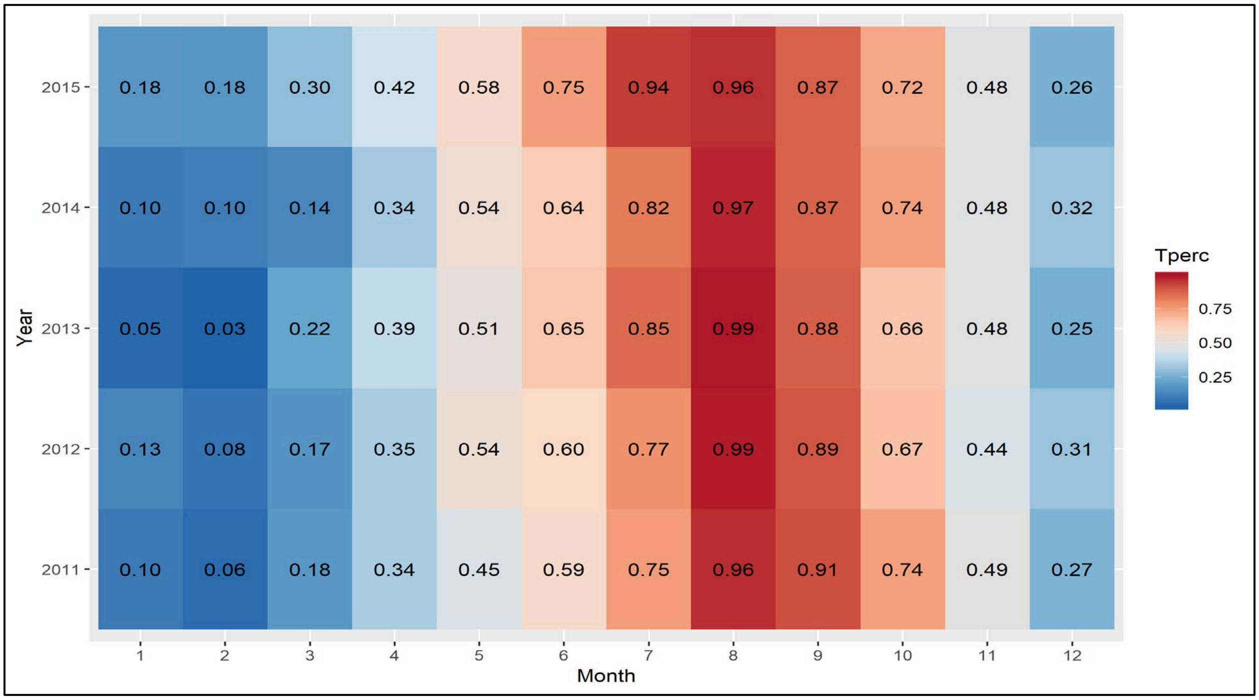

Figure 2-5. Colorized Table of Percentiles for the Water Quality Modeling EXT Period (2011-2015), Where Percentiles were Calculated Based on the Regression Period of 1975–2017

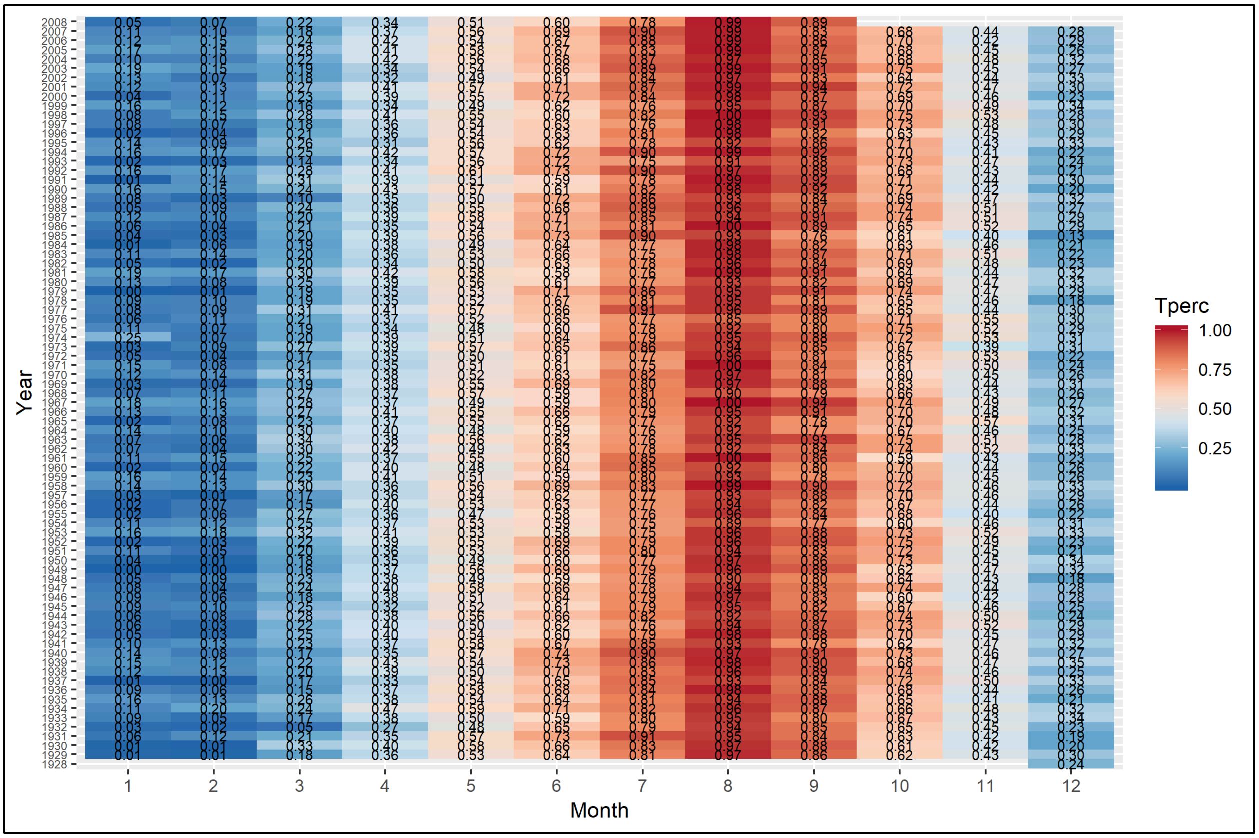

Figure 2-6. Colorized Table of Water Temperature Percentiles for the Columbia River System Operations Period of Record (1928–2008)

2.1.3.1 Mapped Water Temperature Validation

The mapped data was compared to observations and is shown for Ice Harbor Dam on the Snake River and The Dalles Dam on the Columbia River in Figure 2-7 and Figure 2-8, respectively. Mapped data fits with observations were best on the Snake River and decreased in goodness-of-fit moving downstream in the lower Columbia. Fit statistics were tabulated for each project over the entire year and the spring months (April–June) in Figure 2-9. The mean error (bias) is generally less than 1°F over the entire year, and less than 2°F during the spring. A count of the number of times in which a year was picked for a given month is shown in Figure 2-8.

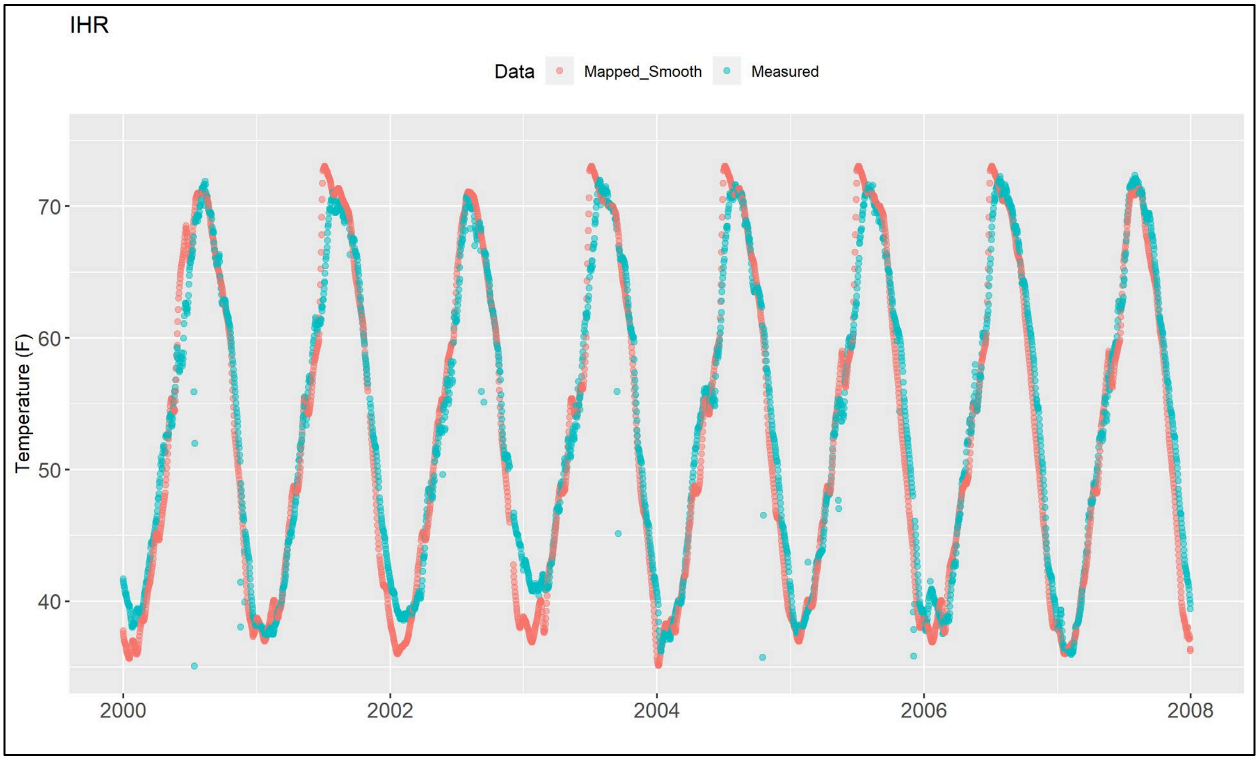

Figure 2-7. Mapped Water temperature Data Comparison to Measurements Downstream of Ice Harbor Dam on the Snake River

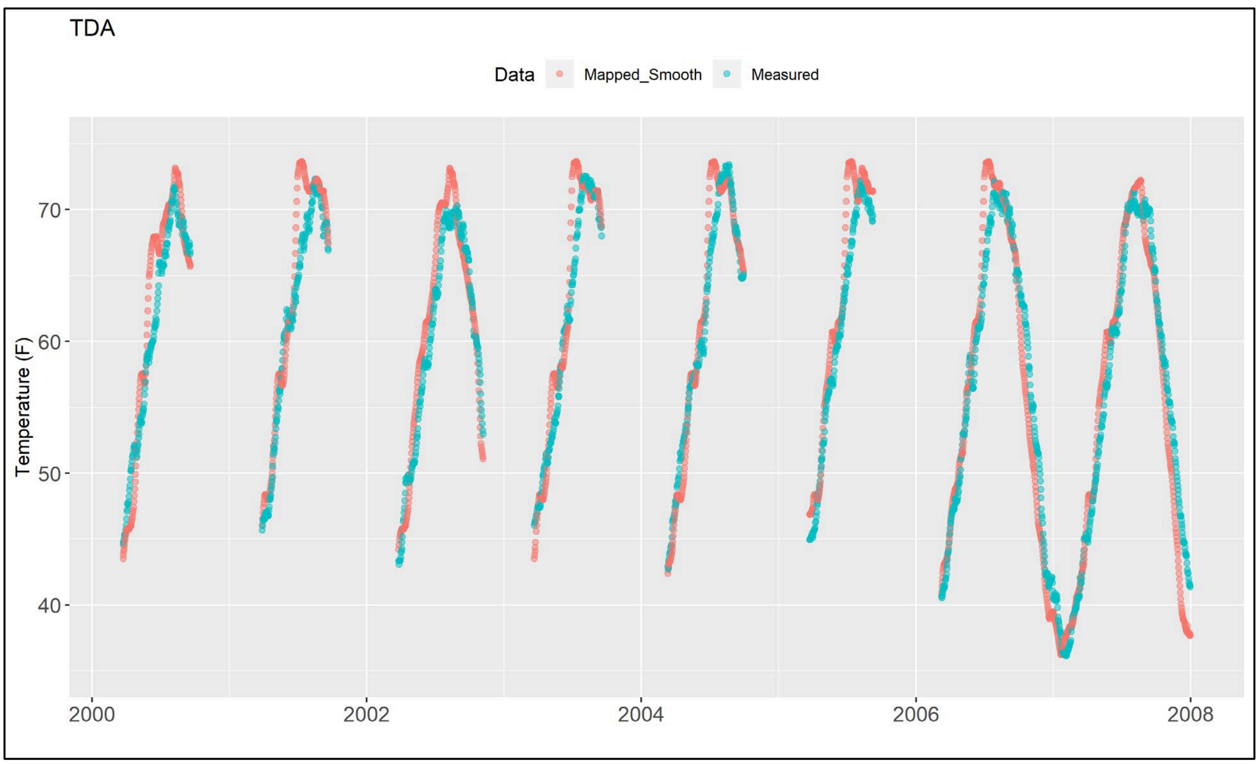

Figure 2-8. Mapped Water Temperature Data Comparison to Measurements Downstream of The Dalles Dam on the Columbia River

Figure 2-9. Fit Statistics of Mapped Data Compared to Observations (2008–2017) for the Entire Year and Spring for Each Project in the CRSO Model Domain

Note: ME = mean error, MAE = mean absolute error, AllYear = entire year, Spring = April to June.

CHAPTER 3 - TOTAL DISSOLVED GAS ESTIMATIONS

3.1 METHODS

TDG was estimated under each MO at Grand Coulee, Chief Joseph, Dworshak, Lower Granite, Lower Monumental, Little Goose, Ice Harbor, McNary, John Day, The Dalles, and Bonneville Dams for the 1928–2008 period using the equations and parameters within the CE-QUAL-W2 models and those calibrated for SYSTDG-Lite (Corps 2018b). These equations calculate downstream tailwater and forebay TDG below each dam based on the variables shown in Table 3-1.

Table 3-1. Data Variables Used to Compute Tailwater and Downstream Forebay Total Dissolved Gas at Selected Dams within the CRSO Water Quality Model Domain

Predictor Variables	Source	Averaging Timestep	Used for Tailwater TDG	Used for Downstream Forebay TDG
Spill Flow, Power Flow	H & H operation modeling	Daily	X	
Tailwater Elevation	H & H operation modeling	Daily	X	
Total Flow	H & H operation modeling	Daily		X
Forebay Elevation	H & H operation modeling	Daily		X
Barometric Pressure	Long-term observations	Monthly	X	X
Wind Speed, Degassing Rate	Long-term observations	Monthly		X
Spill Pattern	Long-term observations	Monthly	X	
Tailwater Temperature, Downstream Forebay Temperature	Water quality simulation and mapped to POR	Daily		X
Upstream TDG	SYS-TDG-Lite estimates	Daily	X	X

Tailwater TDG was based on the upstream forebay TDG (estimated from long-term monthly average observations at Dworshak and Grand Coulee), total spill, total flow, forebay elevation, tailwater elevation, and long-term monthly average barometric pressure. Downstream forebay TDG was primarily based on a monthly average degassing rate for each reservoir and is used to calculate the downstream forebay TDG, which is then used to calculate tailwater TDG at the next dam downstream (Corps 2019). The upstream TDG in Grand Coulee, Dworshak, and Lower Granite forebays was assumed to be the long-term historical monthly average forebay TDG. TDG through the middle Columbia dams between Chief Joseph and McNary was not altered, but simply passed downstream from Chief Joseph to McNary. For degassing within the McNary Reservoir, the upstream TDG was assumed as follows:

$$TDG_{MCN\_usMix} = \frac{TDG_{HNF} * Q_{HNF} + TDG_{IHR} * Q_{IHR}}{Q_{HNF} + Q_{IHR}}$$

where Q_{IHR} = total flow from Ice Harbor (from H & H modeling), Q_{PRD} = total flow from Priest Rapids Dam (from H & H modeling), TDG_{HNF} = long-term monthly average TDG at the Hanford Reach, TDG_{IHR} = Ice Harbor Dam tailwater TDG (from SYSTDG methods), TDG_{MCN_usMix} =

mixed total dissolved gas upstream of the McNary Reservoir. Only total flow, water temperature, and TDG from the Hanford Reach was used in the McNary Reservoir. Following some comparisons of forebay TDG to historical observations in 2011–2018 (Figure 3-1–Figure 3-8), wind speed was multiplied by 2.5 in the McNary and John Day Reservoirs and by 3 in The Dalles Reservoir to better estimate the degassing occurring in each of those reservoirs.

The following figures were used to check the TDG estimates against measurements at each project in the lower Snake and lower Columbia Rivers for the No Action Alternative.

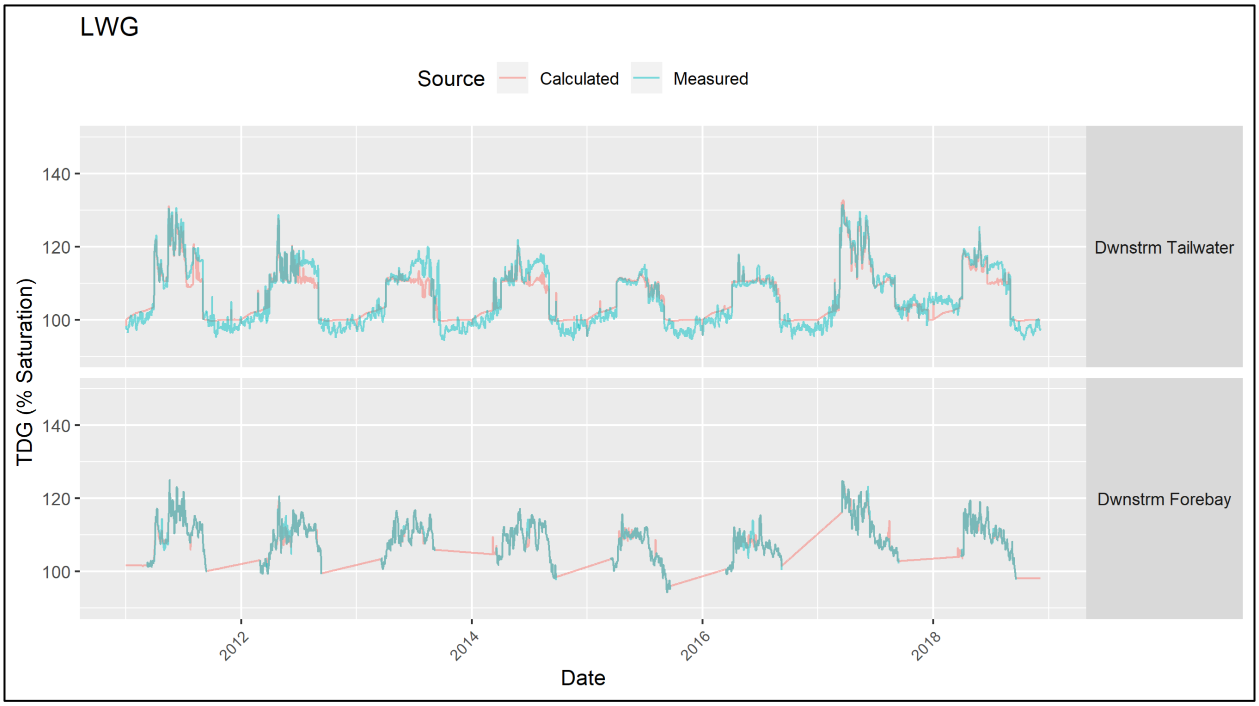

Figure 3-1. Observed and Calculated Tailwater (Dwnstrm Tailwater) Total Dissolved Gas below Lower Granite Dam and Downstream Forebay (Dwnstrm Forebay) Total Dissolved Gas in Little Goose Dam

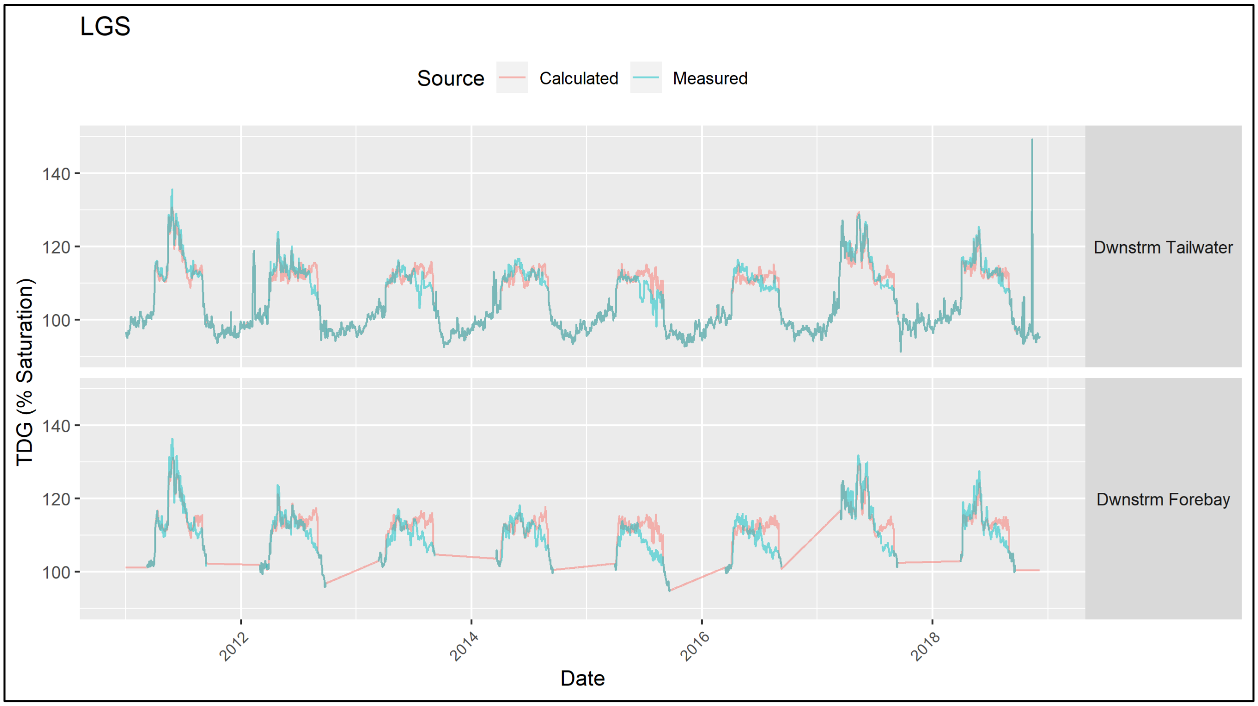

Figure 3-2. Observed and Calculated Tailwater (Dwnstrm Tailwater) Total Dissolved Gas below Little Goose Dam and Downstream Forebay (Dwnstrm Forebay) Total Dissolved Gas in Lower Monumental Dam

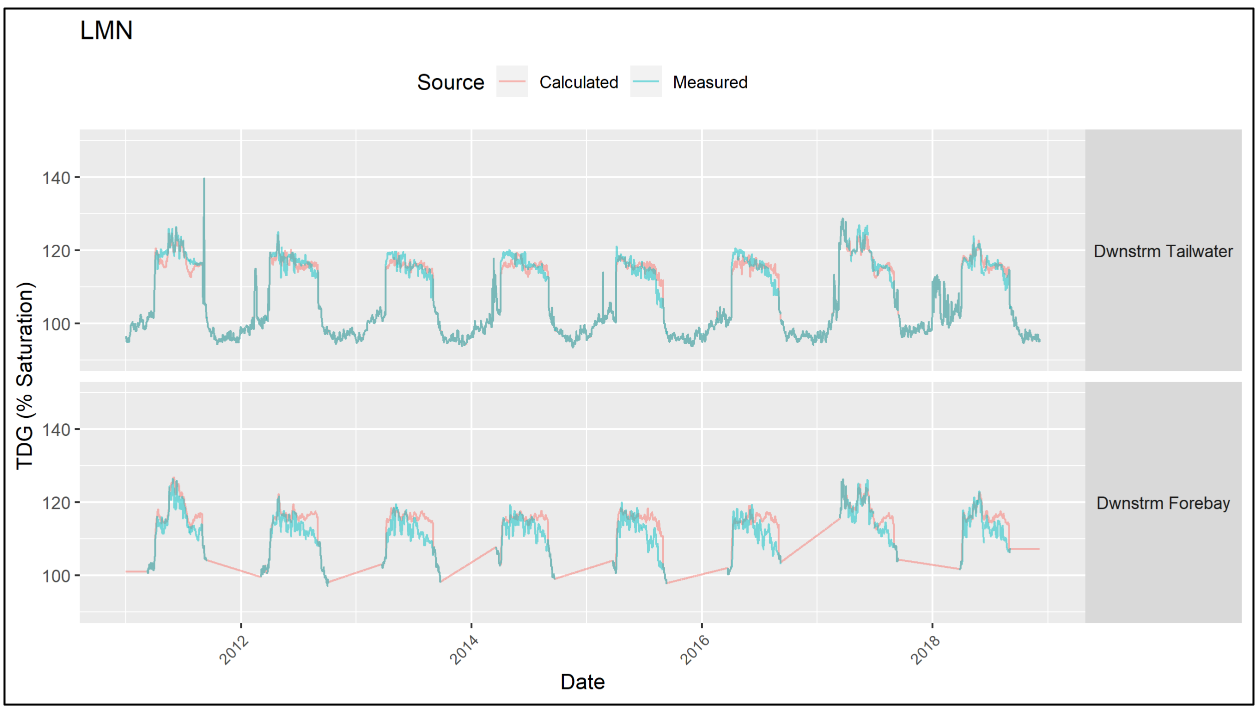

Figure 3-3. Observed and Calculated Tailwater (Dwnstrm Tailwater) Total Dissolved Gas below Lower Monumental Dam and Downstream Forebay (Dwnstrm Forebay) Total Dissolved Gas in Ice Harbor Dam

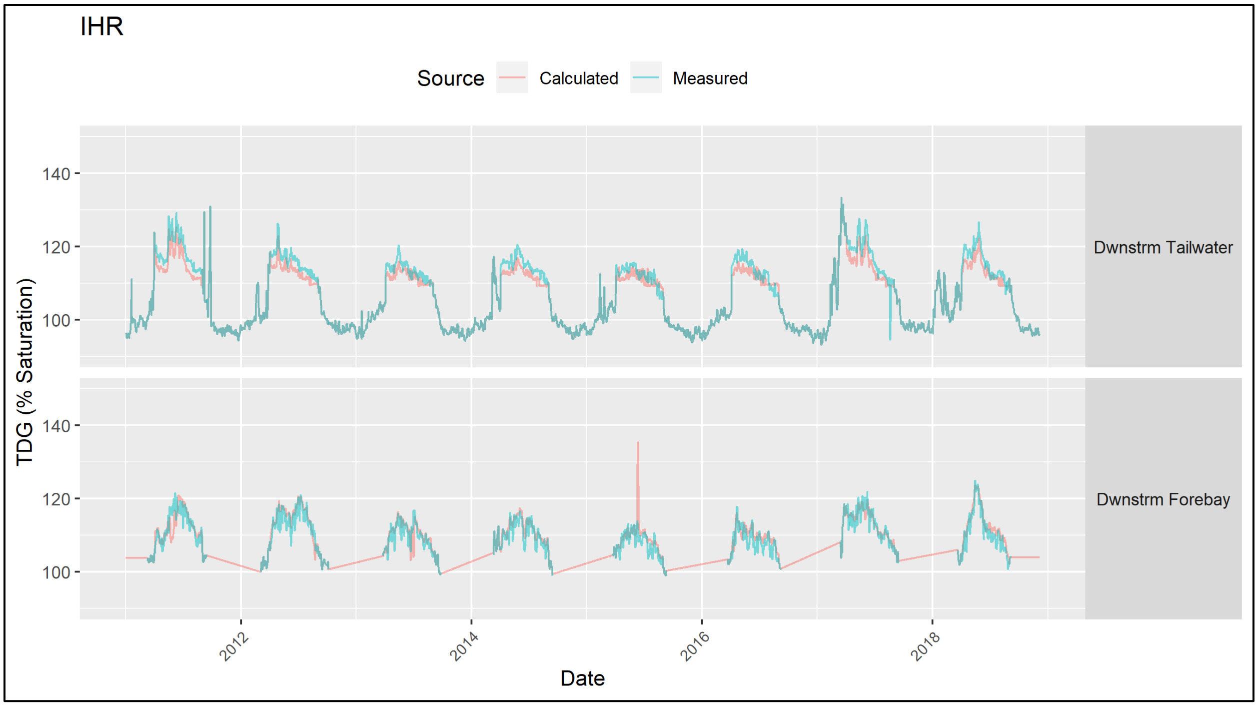

Figure 3-4. Observed and Calculated Tailwater (Dwnstrm Tailwater) Total Dissolved Gas below Ice Harbor Dam and Downstream Forebay (Dwnstrm Forebay) Total Dissolved Gas in McNary Dam

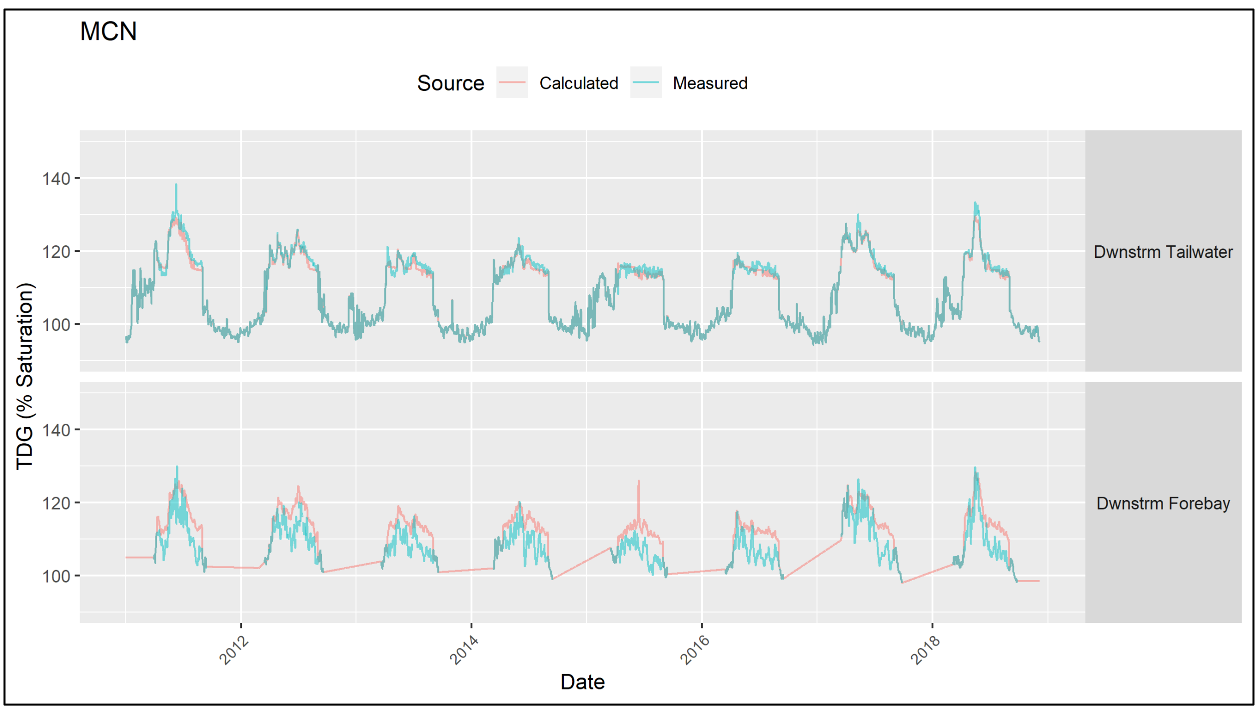

Figure 3-5. Observed and Calculated Tailwater (Dwnstrm Tailwater) Total Dissolved Gas below McNary Dam and Downstream Forebay (Dwnstrm Forebay) Total Dissolved Gas in John Day Dam

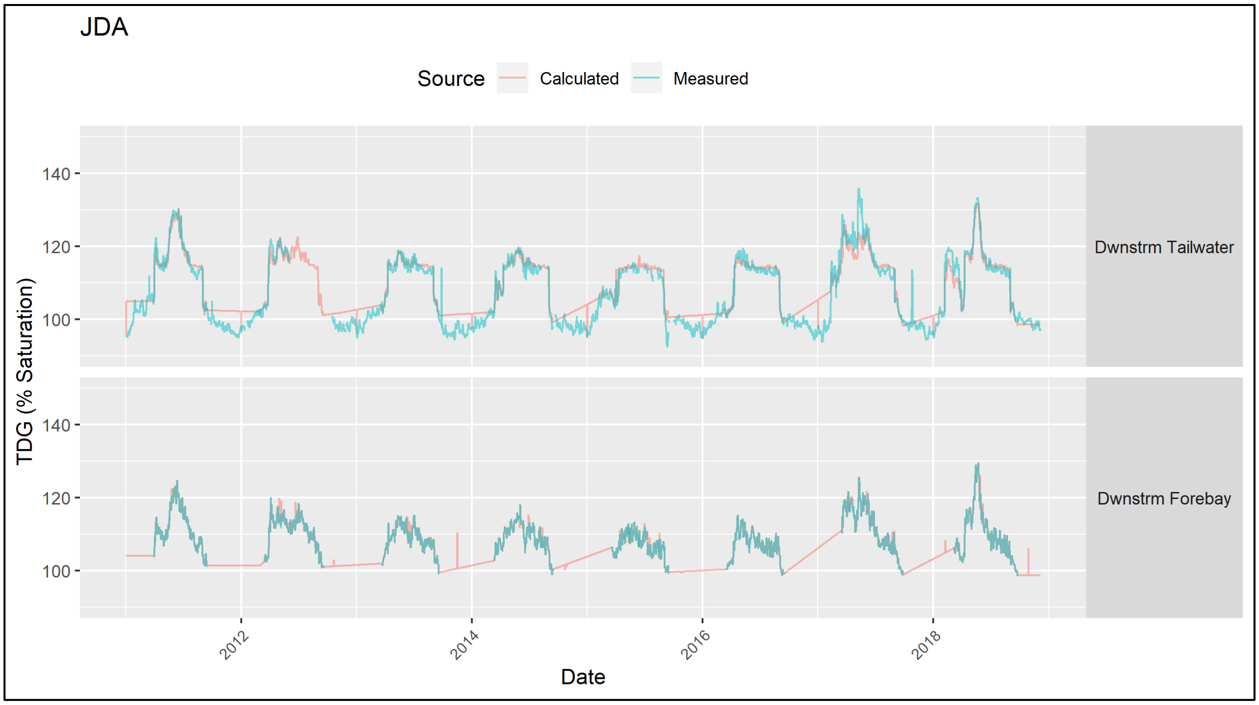

Figure 3-6. Observed and Calculated Tailwater (Dwnstrm Tailwater) Total Dissolved Gas below John Day Dam and Downstream Forebay (Dwnstrm Forebay) Total Dissolved Gas in The Dalles Dam

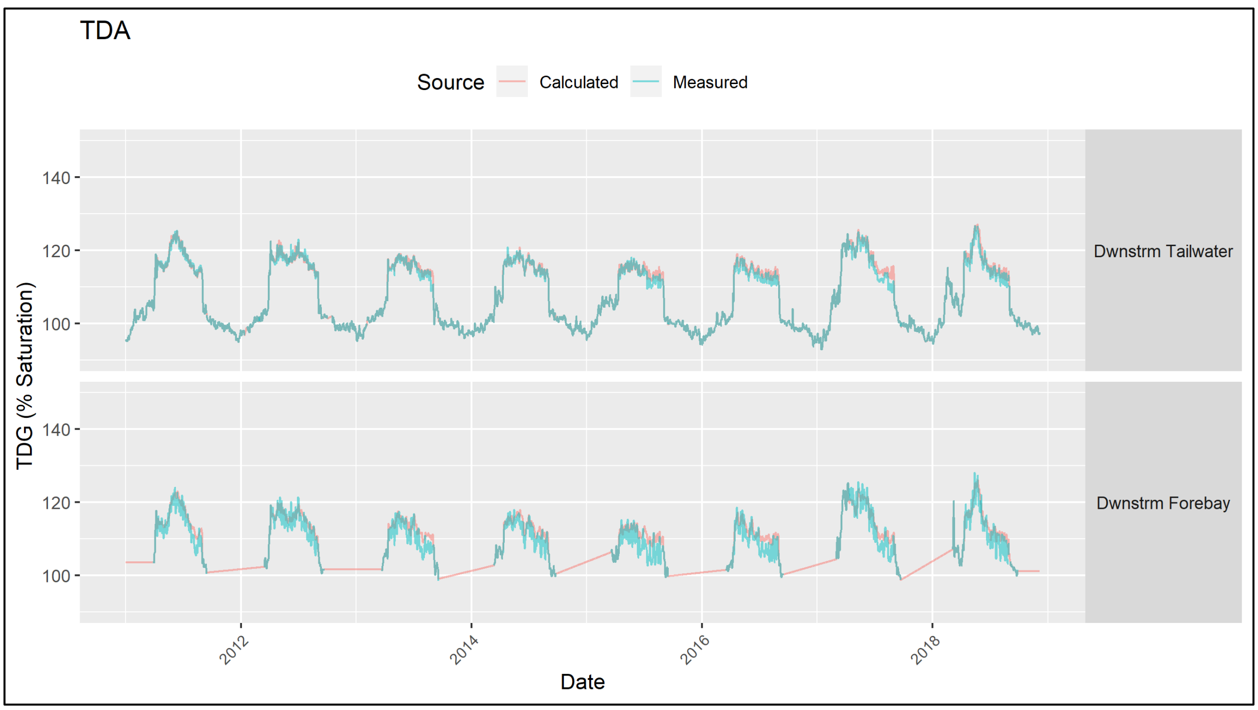

Figure 3-7. Observed and Calculated Tailwater (Dwnstrm Tailwater) Total Dissolved Gas below The Dalles Dam and Downstream Forebay (Dwnstrm Forebay) Total Dissolved Gas in Bonneville Dam

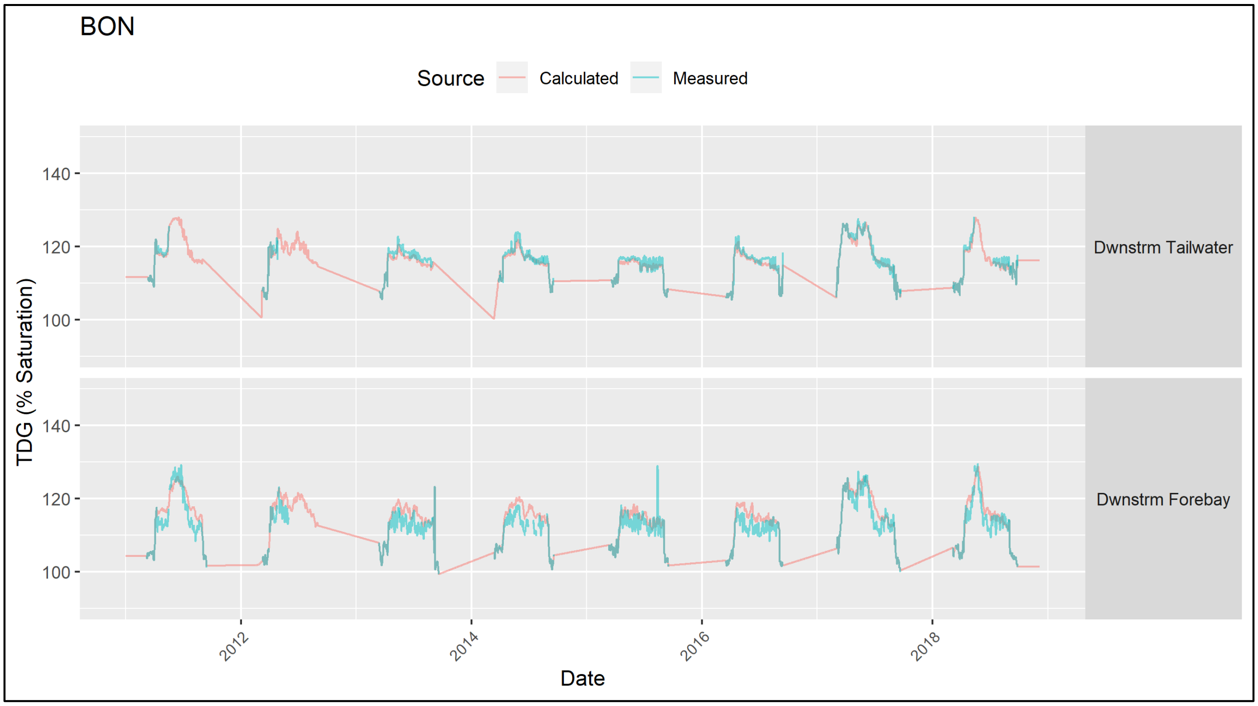

Figure 3-8. Observed and Calculated Tailwater (Dwnstrm Tailwater) Total Dissolved Gas below Bonneville Dam and Total Dissolved Gas at Warrendale (Dwnstrm Forebay)

3.1.1 Spill Patterns

Spill patterns were used to estimate the distribution of flow among the various spillbays throughout the year with varying amounts of total spill flow. Spill pattern changes can lead to changes in TDG as measured at the gage below the dam. SYSTDG-Lite is a model developed for real-time management of the Columbia-Snake River dissolved gas concentrations (Corps 2018b). The equations from SYSTDG-Lite were used in the CRSO project to estimate TDG downstream of each project. The following logic was used to assign spill patterns to each project when calculating tailwater TDG in the specific month of interest.

Lower Granite Dam:

- If the number of the month is [1,2,3,9,10,11,12], use “No RSW” patterns
- If the number of the month is [4,5,6], use “Spring Spill Patterns with RSW”
- If the number of the month is [7,8]:
  - At total flow ≥ 30 thousand cubic feet per second (kcfs), use “Summer Spill Patterns with RSW”
  - At total flow < 30 kcfs, use “Spill Patterns with No RSW”

Little Goose Dam:

- If the number of the month is [1,2,3,9,10,11,12], use "Spill Patterns with No ASW"
- If the number of the month is [4, 5, 6]:
    - At total flow ≤ 85 kcfs, use "Spill Patterns with ASW-Hi"
    - At total flow > 85 kcfs, use "Spill Patterns with ASW-Lo"
- If the number of the month is [7, 8]:
    - At total flow ≥ 35 kcfs, use "30% Spill Patterns with ASW in High Crest"
    - At total flow < 35 kcfs, use "30% Spill Patterns with No ASW"

Lower Monumental Dam_uniform:

- If the number of the month is [1,2,3,9,10,11,12], use "Spill Patterns with No RSW"
- If the number of the month is [4, 5, 6, 7, 8]: use "Uniform Spill Patterns with RSW"

Lower Monmental Dam_bulk:

- If the number of the month is [1,2,3,9,10,11,12], use "Spill Patterns with No RSW"
- If the number of the month is [4, 5, 6, 7, 8]: use "Bulk Spill Patterns with RSW"

Ice Harbor Dam:

- If the number of the month is [1,2,3,9,10,11,12], use "Spill Patterns with No RSW"
- If the number of the month is [4, 5, 6], use "Spill Patterns with RSW"
- If the number of the month is [7, 8]:
    - At total flow ≥ 30 kcfs, use "Spill Patterns with RSW"
    - At total flow < 30 kcfs, use "Spill Patterns with No RSW"

McNary Dam:

- If the number of the month is [0,1,2,3,6,7,8,9,10,11,12], use "No TSWs" patterns
- If the number of the month is [4,5], use "With TSWs" patterns

John Day Dam:

- If the number of the month is [0,1,2,3,9,10,11,12], use "No TSWs" patterns
- If the number of the month is [4,5,6,7,8], use "With TSWs" patterns

The Dalles Dam:

- Always use "Juvenile Fish Passage at 40% of Total Project Outflow"

Bonneville Dam:

- Always use the one published spill pattern

Chief Joseph Dam:

- Always use "Center First" spill pattern.

Grand Coulee Dam:

- Drum gate and outlet tube, always use a uniform pattern

3.1.2 Alternative-Specific Details

Some exceptions to the general rules described for the No Action Alternative are as follows:

- **Multiple Objective Alternative 1:** Two year types were used: Test and Base (see further description in the Spill Analysis [Appendix X], Section 3.3.2, Multiple Objective Alternative 1 Spill Operations and Plots). The two year types only affected Lower Monumental Dam, where the spill pattern changed depending on Table 3-2 and Table 3-3.

Table 3-2. Rules Specifying Spill Patterns Used for Lower Monumental Dam in Odd-numbered Years for Multiple Objective Alternative 1

Date	Filename	Flowmin (kcfs)	Flowmax (kcfs)
January 1	LMN_spill_pattern_noSWeirOp.csv	0	9999
April 3	LMN_spill_pattern_bulk.csv	0	65
April 3	LMN_spill_pattern_bulk.csv	65	9999
May 12	LMN_spill_pattern_bulk.csv	0	65
May 12	LMN_spill_pattern_uniform.csv	65	9999
June 21	LMN_spill_pattern_bulk.csv	0	30
June 21	LMN_spill_pattern_uniform.csv	30	9999
September 1	LMN_spill_pattern_noSWeirOp.csv	0	9999

Table 3-3. Rules Specifying Spill Patterns used for Lower Monumental Dam in Even-numbered Years for Multiple Objective Alternative 1

Date	Filename	Flowmin	Flowmax
April 3	LMN_spill_pattern_bulk.csv	0	65
April 3	LMN_spill_pattern_uniform.csv	65	9999
May 12	LMN_spill_pattern_bulk.csv	0	65
May 12	LMN_spill_pattern_bulk.csv	65	9999

Date	Filename	Flowmin	Flowmax
June 21	LMN_spill_pattern_bulk.csv	0	30
June 21	LMN_spill_pattern_uniform.csv	30	9999
September 1	LMN_spill_pattern_noSWeirOp.csv	0	9999

- **Multiple Objective Alternative 2:** This measure specifies unprecedented low spill flow values, in which very limited observations exist to calibrate the SYSTDG-Lite equation parameters. TDG was estimated to be 110 percent when spill flow was at or below the threshold of 50 kcfs at McNary and John Day.
- **Multiple Objective Alternative 3:** TDG at the lower Snake River projects was assumed to be 100 percent due to dam breaches at Lower Granite, Little Goose, Lower Monumental, and Ice Harbor.
- **Multiple Objective Alternative 4:** Spill patterns that began in April were extended to also include March.

CHAPTER 4 - REFERENCES

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Columbia River System Operations
Final Environmental Impact Statement

Annex C
Lower Snake River Multiple Objective Alternative 3
Dissolved Oxygen Analysis Report

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Acronyms and Abbreviations

Corps	U.S. Army Corps of Engineers
W2	CE-QUAL-W2
CIN	concentration input
CRSO	Columbia River System Operations
DO	dissolved oxygen
FTU	Formazin Turbidity Units
g/cm^3	grams per cubic centimeter
$g/m^2/d$	grams per square meter per day
H & H	hydrology and hydraulics
HABTATC	Habitat analysis card in W2
HEC	Hydrologic Engineering Center
HEC-RAS	Hydrologic Engineering Center River Analysis System
mg/L	milligrams per liter
MO	Multiple Objective Alternative
N_2	nitrogen
RM	River Mile
SOD	sediment oxygen demand
SSC	suspended solid concentration
TURB	turbidity

CHAPTER 1 - LOWER SNAKE RIVER MULTIPLE OBJECTIVE ALTERNATIVE 3 DISSOLVED OXYGEN ANALYSIS

1.1 INTRODUCTION

Multiple Objective Alternative 3 (MO3) calls for the drawdown and breaching of the four lower Snake River dams in a 2-year period. In the first year, Lower Granite and Little Goose Dams would be breached, while in the second year Lower Monumental and Ice Harbor Dams would be breached. This analysis focuses on the first year of dam breaching, when it is anticipated that dissolved oxygen (DO) concentrations could be most compromised since few tributaries exist connected to the Lower Monumental Reservoir to counteract the oxygen demand that would be created from the high amounts of suspended sediment released from upstream. Under the second year of breaching, when Lower Monumental and Ice Harbor Dams are breached, significant sediment would be deposited in McNary Reservoir; however, the Columbia River should help to dilute anoxic water flowing downstream from the lower Snake River, lessening the effects in McNary Reservoir.

1.2 ANALYSIS

To estimate the short-term effects of reservoir drawdown and breaching on DO concentrations, a simplistic modeling approach that focused on Lower Monumental Reservoir was pursued using two methods. The first method was developed using correlations of measured data from Fall Creek Lake, Oregon (USGS, 2019). The second method was based on the mobilization of anoxic pore water and the biochemical oxidation of organic matter associated with deposited and re-mobilized/re-suspended sediments during reservoir drawdown and dam breach. This method assumed sediment oxygen demand (SOD) rates of 0.1, 0.5, 1.0, and 2.0 grams per square meter per day ($g/m^2/d$). These analysis methods are described in further detail below.

1.2.1 Method 1

Using the Lower Monumental CE-QUAL-W2 (W2) model, a method was developed to create an “informed” time series concentration input file (CIN). The W2 model, as constructed, does not model the intricate aspects of DO in the reservoir/system. Instead, the CRSO modeling focus included water temperature and total dissolved gas (nitrogen [N_2] and DO) related to flow/spill rates, reaeration, and meteorological conditions. The CIN file includes DO concentration. A “baseline” CIN representing 100 percent DO saturation was developed using water temperature, and stage from the MO3 S-CW_RAS output at River Mile (RM) 68.8467 (Little Goose Dam), and Little Goose Dam dew point temperature from the lower Snake meteorological input. Initial DO concentrations (100 percent saturation) were then adjusted based on estimated sediment concentrations during the simultaneous drawdown and breaching of Lower Granite and Little Goose Dams.

Estimation of movement of stored sediments upstream of Lower Monumental Dam during the drawdown and breach was performed by the H & H River Mechanics team. Estimated suspended sediment concentration (SSC) time series data at the Little Goose site (immediately upstream of Lower Monumental) during drawdown and breach, for a "moderate hydrology" scenario, was obtained and attributed to 2011 No Action Alternative flows. Estimated elevated SSC concentrations occur in two distinct pulses related to mobilized sediments during the drawdown period and during the breaching of dam embankments in the evaluated construction plan where drawdown occurs August 1 to September 20 and breach occurs October 2 to 9. Estimated peak SSC concentrations are as high as 24,300 milligrams per liter (mg/L) with concentrations greater than 5,000 mg/L for 26 days. Assuming a bulk density of 1.5 grams per cubic meter (g/cm^3), the estimated SSC concentrations, and 2011 flows in the lower Snake River, approximately 22 million cubic yards of sediment would enter the Lower Monumental Reservoir in the first 3 months following Lower Granite and Little Goose Dam breachings, representing approximately 20 percent of all sediments stored upstream from 1934 through 2010 (Figure 1-1).

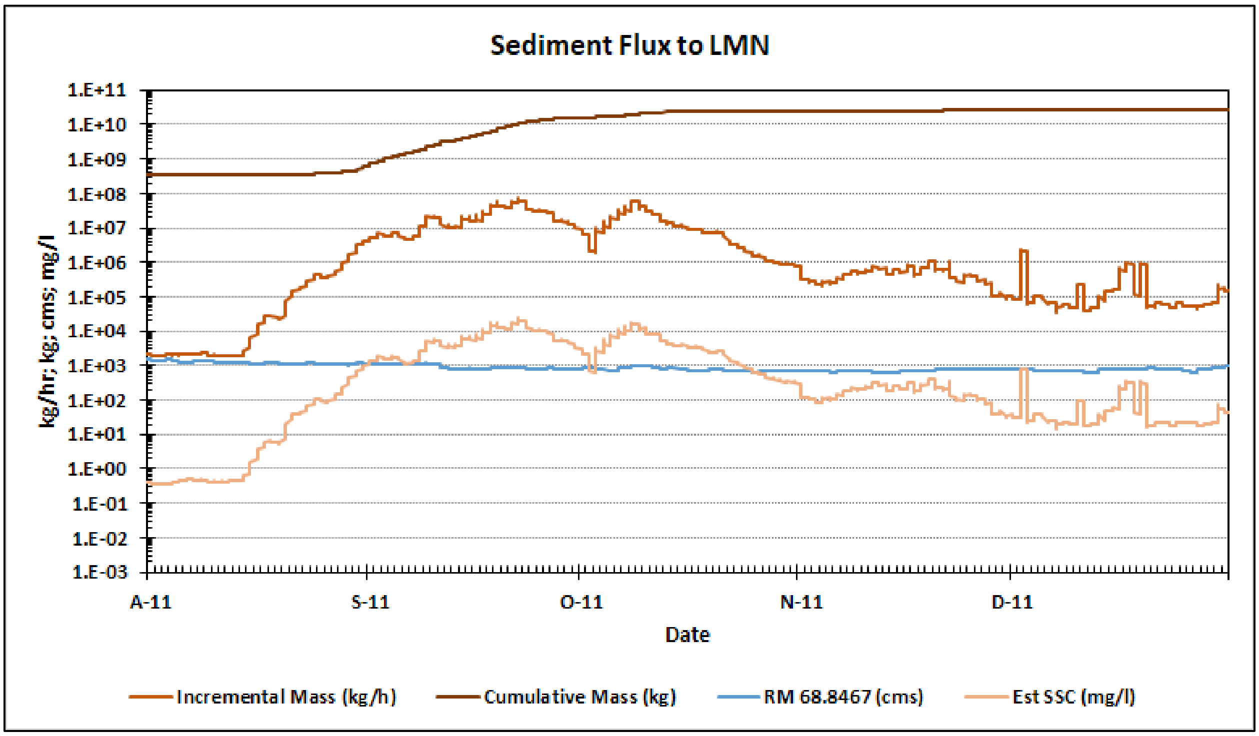

Figure 1-1. Time Series Plot of Sediment Flux into Lower Monumental Dam Based on Estimated Suspended Sediment Concentrations 2011 Flows

Note: Data is from Little Goose dam site (Hydrologic Engineering Center River Analysis System [HEC-RAS]), and assumes bulk density of 1.5 g/cm^3 during drawdown and breach of Lower Granite and Little Goose Dams.

Measured data (SSC, DO) downstream of a dam breach is not abundantly available, but data collected during drawdowns of Fall Creek Lake, OR (2012-13) and ensuing years included SSC, turbidity, and DO. That raw data was obtained from the USGS gauge, Fall Creek Lake, Oregon (USGS Gage 14151000, Fall Creek Blw Winberry Creek, Near Fall Creek, OR [USGS, 2019]). Measured data was then used to develop statistical relationships. A limited dataset of coincident turbidity (TURB) and SSC data (2017) yielded a linear relationship of TURB = 0.4964SSC (R^2=0.78). Coincident DO and TURB data (2012 - 2018) suggested decreasing DO with increasing TURB, although the linear relationship was weak (DO = -0.0025TURB + 12.03, R^2= 0.05) (DO range: 0.7 to 13.9 mg/l; Turbidity range: 0.1 to 3000 [3000 FTU was maximum possible recorded by the equipment]). An altered LMN CIN file was developed by estimating a time series of TURB from SSC data, then adjusting (reducing) 100% saturation CIN DO time series based on the DO/TURB relationship.

The W2 model of LMN was then run with the altered CIN. An additional W2 feature (HABTATC) was employed to aid in quantification of LMN volume meeting selected DO criteria. Model results indicated 80% or greater of whole reservoir volume with DO concentration less than or equal to 2.5 mg/l for about 4 days during the initial SSC pulse, and about 3 days during the secondary SSC pulse. 100% of whole reservoir volume with DO less than 2.5 mg/l occurred for less than 1 day. Using the 5 mg/l DO criterion, during the initial SSC pulse, 80% or greater of the whole reservoir volume had DO concentrations of 5 mg/l or less for about 11days with about 3 days of 100% reservoir volume less than 5 mg/l. During the secondary SSC pulse, 80% or greater of the whole reservoir volume had DO concentrations of 5 mg/l or less for about 6 days, with 4 days of 100% reservoir volume less than 5 mg/l. From a spatial perspective, the headwater segment in the LMN model maintained DO concentrations of 2.5 mg/l or less for about 18 days during the initial SCC pulse, and 7 days during the secondary SSC pulse. The segment of the LMN model including the forebay maintained DO concentrations of 2.5 mg/l or less for about 10 days during the initial SCC pulse, and about 7 days during the secondary SSC pulse.

1.2.2 Method 2

A second methodology was developed also based on the assumptions of the mobilization of anoxic pore water and the biochemical oxidation of organic matter associated with deposited (and remobilized/resuspended) sediments during water level drawdown and dam breach. Based on river mechanics modeling and the anticipated release of high concentrations of suspended sediment during drawdown and dam breaching, and estimating sediment is mostly composed of silt/clay [83%], the organic material bound to this sediment is assumed to be high. Based on these factors, combined with observations from other systems, the following assumptions were made:

1) Assume an SOD of the stored sediments (0.5 $g/m^2/d$),
2) Assume a wet bulk density of the stored sediment (1.5 g/cm^3),
3) Assume if SSC > 10 mg/l, 83% of SSC is silt/clay,
4) Assume 5% of silt/clay fraction is volatile solids/anoxic pore water immediately affecting DO.

These conservative parameter estimates were informed using the literature and are cited below.

Using this methodology, informing a CIN where DO at 100% saturation is reduced based on the above assumptions, resulted in DO concentration effects in LMN during the drawdown and breach very similar to the first method. Model results indicated 80% or greater of whole reservoir volume with DO concentration less than or equal to 2.5 mg/l for about 4 days during the initial SSC pulse, and 3 days during the secondary SSC pulse. 100% of whole reservoir volume with DO less than 2.5 mg/l occurred for about 1 day. Using the 5 mg/l DO criterion, during the initial SSC pulse, 80% or greater of the whole reservoir volume had DO concentrations of 5 mg/l or less for about 11 days with about 3 days of 100% reservoir volume less than 5 mg/l. During the secondary SSC pulse, 80% or greater of the whole reservoir volume had DO concentrations of 5 mg/l or less for about 7 days, with 5 days of 100% reservoir volume less than 5 mg/l. From a spatial perspective, the headwater segment in the LMN model maintained DO concentrations of 2.5 mg/l or less for about 19 days during the initial SCC pulse, and about 7 days during the secondary SSC pulse. The segment of the LMN model including the forebay maintained DO concentrations of 2.5 mg/L or less for about 10 days during the initial SCC pulse, and about 7 days during the secondary SSC pulse (Figure 1-2).

A comparison of volume-weighted results from these two approaches is summarized for two model segments/locations, at the head of reservoir and forebay in Lower Monumental Reservoir (Figure 1-3).

SOD determinations were completed for several sediment cores collected from the Lower Snake River system in 1997 (Normandeau Associates 1999) and are shown in Table 1-1. Observations made in 1997 correspond reasonably well with sediment composition assumptions made by the H & H river mechanics team (83 percent silt/clay) and the assumed 5 percent organic matter component of sediments. Measured 1997 SOD levels were all higher (0.8 to 2.2 $g/m^2/d$) than the estimated 0.5 $g/m^2/d$.

To encompass a more complete range of potential DO effects within Lower Monumental Reservoir following upstream dam drawdown and breach, the second method was used to generate CIN files for Lower Monumental at SOD levels of 0.1, 0.5, 1.0, and 2.0 $g/m^2/d$. Although a range of DO concentrations are provided based on a range of SOD levels, SOD, as measured in the lower Snake River in 1997 showed levels in the 1.0 to 2.0 $g/m^2/d$ range. That said, the DO effects associated with the 0.5 g/m2/d estimates are likely optimistic, at best, given that 1997 SOD levels were all higher (0.8 to 2.2 $g/m^2/d$). Figure 1-4 indicates significantly diminished volumes of habitable reservoir space of greater duration with increased SOD levels. Similarly, Figure 1-5 shows that with increasing SOD levels, volume weighted DO concentrations in the headwater and forebay segments of Lower Monumental diminish more rapidly, and low concentrations are maintained longer, during and after the drawdown and breach.

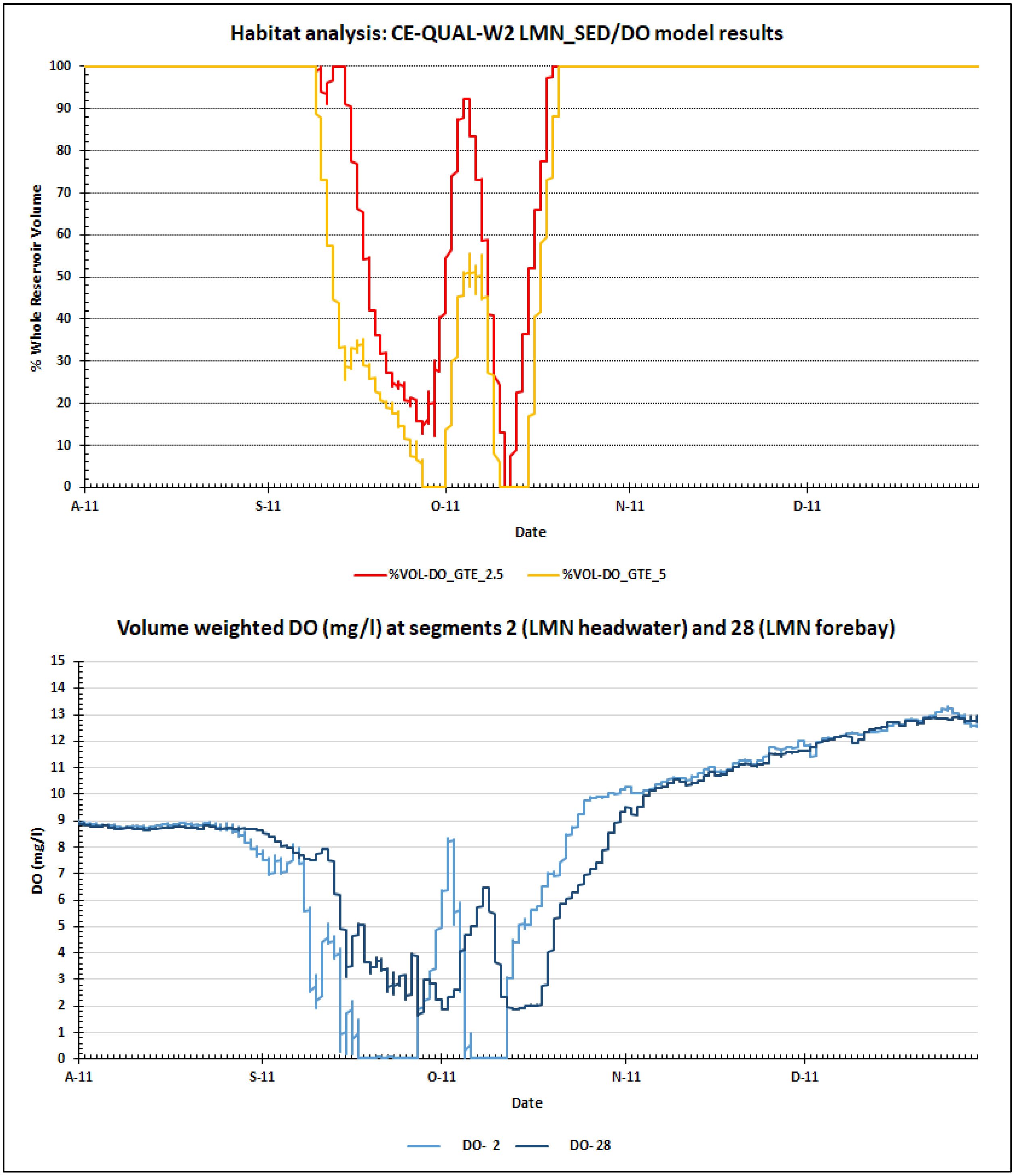

Figure 1-2. Habitat (DO concentration) Analysis of the Lower Monumental Reservoir

Note: Figures show data during/after drawdown and breach of Lower Granite and Little Goose assuming SOD of 0.5 $g/m^2/d$ of the mobilized sediment. Top figure shows percentage of whole reservoir volume greater than or equal to the two selected DO criteria (2.5 [red] and 5 [yellow] mg/L in the period following drawdown and breach. The bottom figure shows volume weighted DO concentrations at the Lower Monumental headwater segment (DO-2 [light blue]) and the Lower Monumental forebay segment (DO-28 [dark blue]) following drawdown and breach.

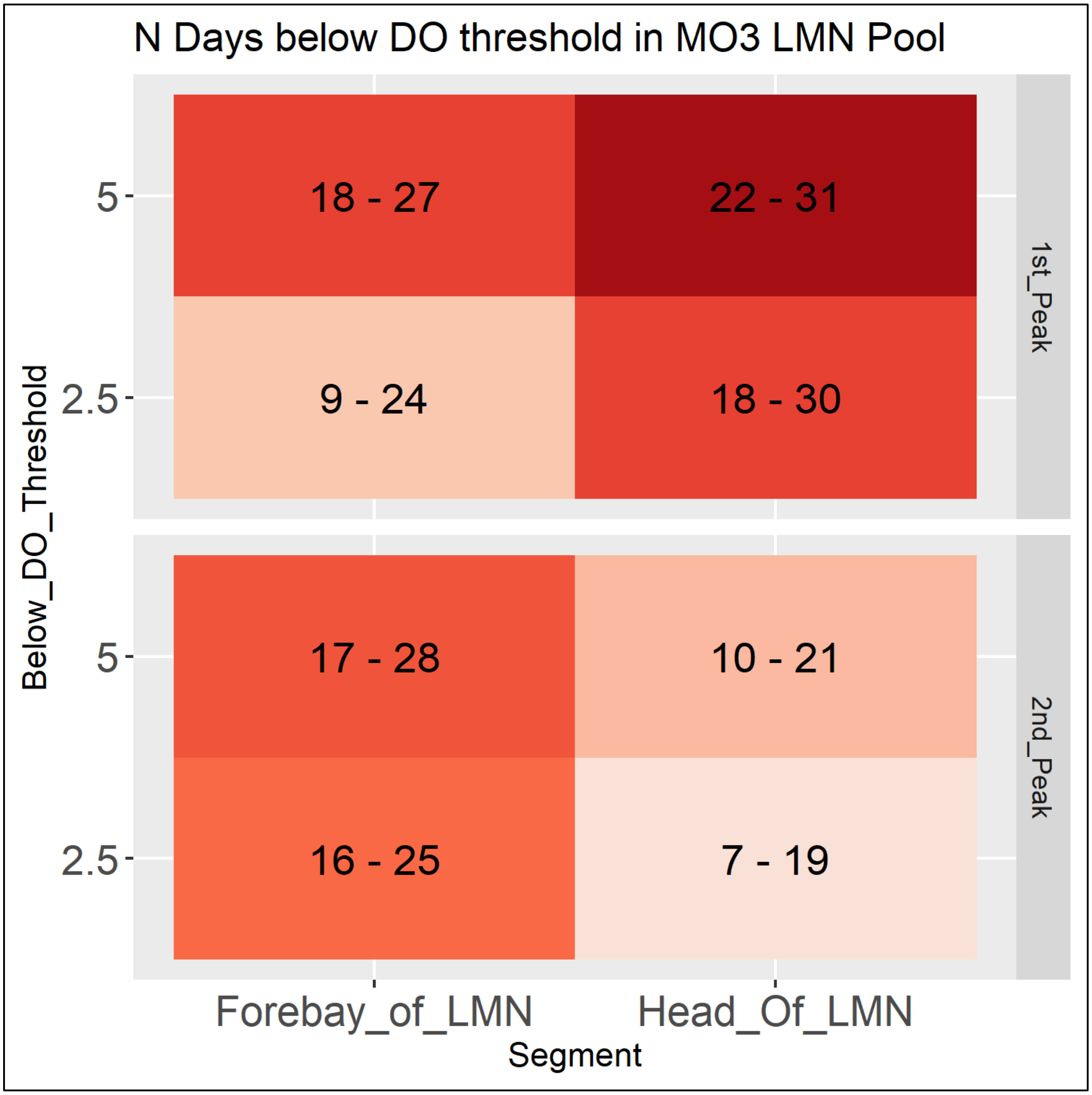

Figure 1-3. Range in the Number of Days in which the Volume-weighted Average Dissolved Oxygen Concentration was Below a Given Threshold (Below_DO_Threshold)

Note: Data is from during the two peaks in suspended sediment derived from a hypothetical dam breach at two model segments/locations: at the head of reservoir (Head_Of_LMN) and forebay (Forebay_of_LMN) in Lower Monumental Reservoir

Table 1-1. Lower Snake River Sediment Data

Sample Date	Location	SOD $g/m^2/d$	Organic Matter (%)	Particle Size [mm]: Percent Composition							
				No. 6 >3.33	No. 10 3.33-2.00	No. 20 0.84-2.00	No. 35 0.42-0.84	No. 60 0.25-0.42	No. 140 0.11-0.25	No. 200 0.08-0.11	Bottom Pan < 0.08
08/06/97	SNR-50	0.9	6.8	0.0	0.0	0.0	0.1	0.4	1.8	1.8	95.7
	SNR-123	0.8	4.8	0.0	0.0	0.1	0.2	0.3	15.2	14.1	70.1
	SNR-132	0.9	2.2	0.0	0.0	0.0	0.1	0.1	33.1	33.1	34.0
10/03/97	SNR-50	2.2	5.3	0.0	0.0	0.1	0.1	0.4	5.6	6.3	87.3
	SNR-123	2.1	7.3	0.0	0.0	0.1	0.3	0.4	2.3	3.4	93.6
	SNR-132	1.9	7.0	0.0	0.0	0.3	0.4	1.0	36.6	14.5	46.9

Source: Normandeau Associates 1999

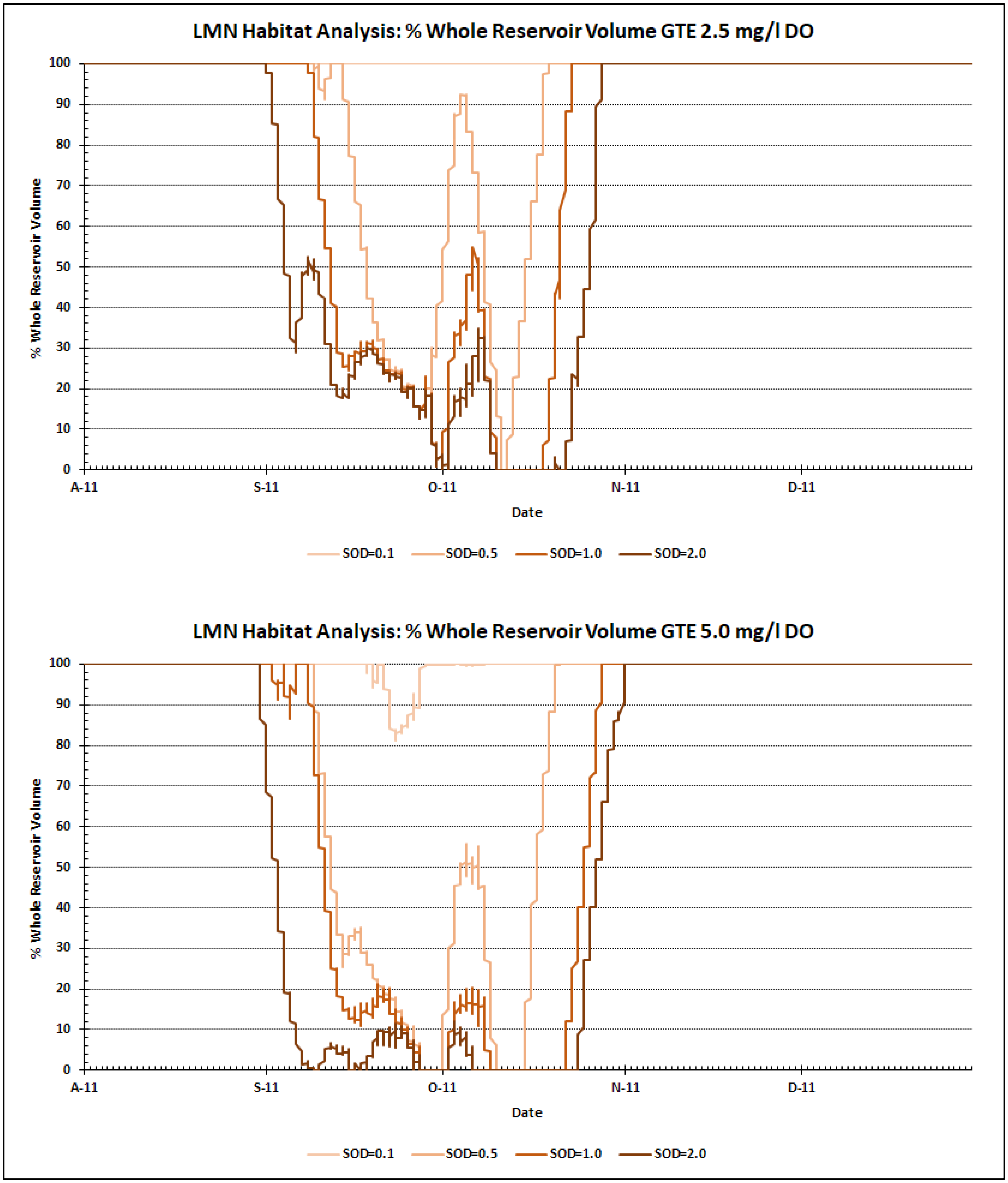

Figure 1-4. Lower Monumental Reservoir Habitat (DO) Analysis at Differing Sediment Oxygen Demand Levels (0.1, 0.5, 1.0, and 2.0 g/m²/d).

Note: The top figure shows percentage of whole reservoir volume greater than or equal to 2.5 mg/L DO at each SOD level, and the bottom shows percentage of whole reservoir volume greater than or equal to 5.0 mg/L DO at each SOD level.

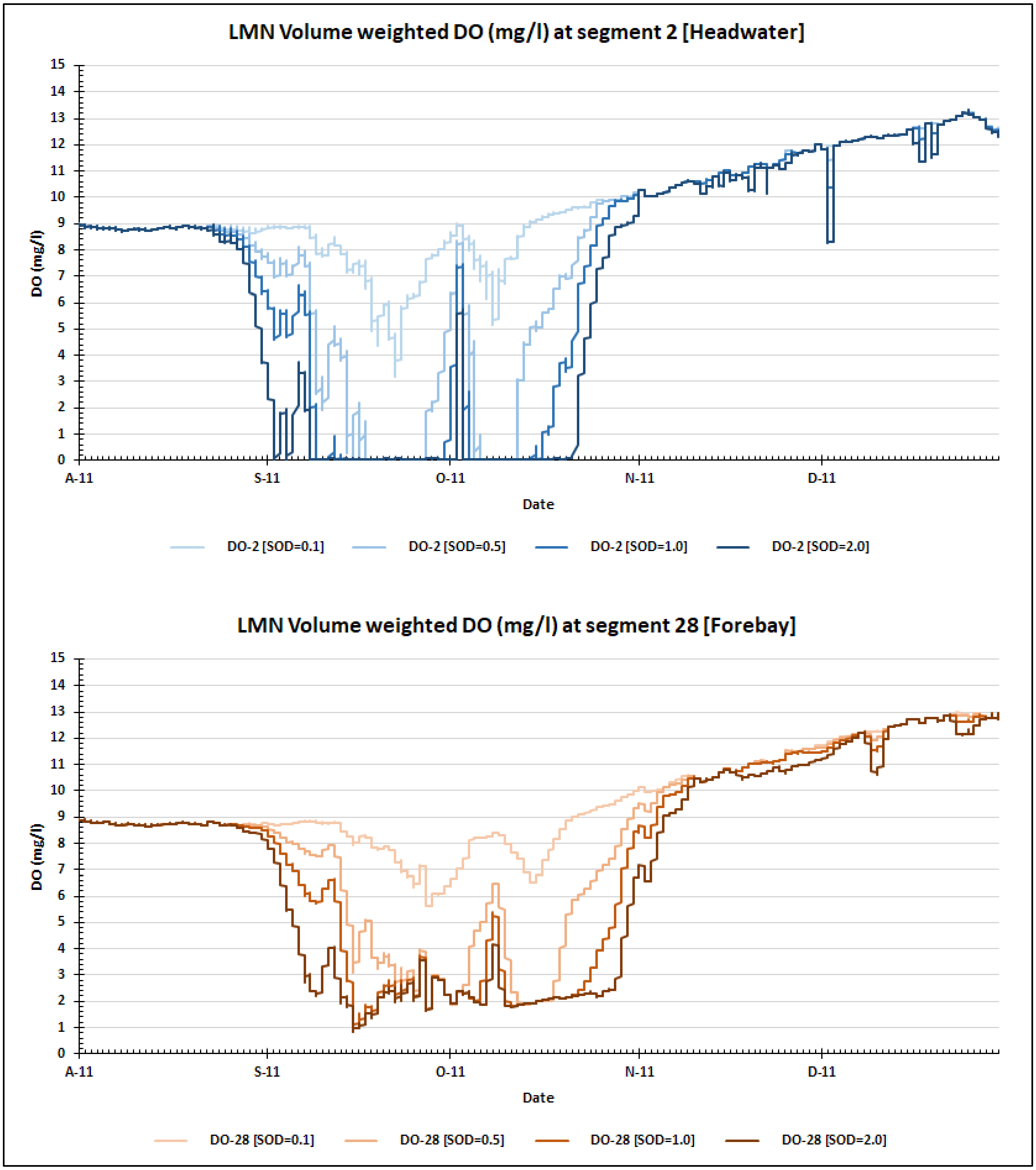

Figure 1-5. Estimates of Volume Weighted DO Concentrations at the Lower Monumental Dam Headwater Segment (DO-2 [top]) and Forebay Segment (DO-28 [bottom])

Note: Figures shows data at differing sediment SOD levels (0.1, 0.5, 1.0, and 2.0 g/m2/d) following drawdown and breach.

1.3 CONCLUSION

A comparison of volume-weighted DO concentration results from both methods are summarized for two model segments/locations (at the head of Lower Monumental Reservoir and in the forebay) for each pulse of high total suspended solids following drawdown and breach (Table 1-2).

Extended periods of anoxia would be greater in the headwater segment of the Lower Monumental Reservoir as compared to the forebay, or area of reservoir just upstream of Lower Monumental Reservoir. In addition, the first peak of sediment (during reservoir drawdown) would likely create worse DO conditions as compared to the second peak (dam breach) based on estimated total suspended sediment concentrations predicted by the sediment transport model, HEC-RAS Version 5.0.7.

Table 1-2. Number of Days when the Volume-Weighted Average Dissolved Oxygen Concentration in Lower Monumental Reservoir is Estimated to be Below Selected Criteria

TSS Pulses	DO Criteria (mg/L)	Headwater (Segment 2)					Forebay (Segment 28)				
		Method 1 Data Correlation	Method 2 SOD 0.1	Method 2 SOD 0.5	Method 2 SOD 1.0	Method 2 SOD 2.0	Method 1 Data Correlation	Method 2 SOD 0.1	Method 2 SOD 0.5	Method 2 SOD 1.0	Method 2 SOD 2.0
First Peak (August–September)	<5	21	5	23	32	37	17	1	20	27	29
	<2.5	15	1	19	27	33	4	0	7	14	22
	<0.5	11	0	17	23	32	0	0	0	0	0
Second Peak (October–December)	<5	10	2	14	19	22	14	1	18	26	28
	<2.5	7	0	10	18	20	8	0	9	19	23
	<0.5	6	0	7	15	19	0	0	0	0	0

Note: TSS = total suspended solids. Data is from during the two peaks in suspended sediment derived from a hypothetical dam breach.

Very low DO concentrations of below 0.5 mg/L are anticipated in some portions of Lower Monumental Reservoir under the first year of dam breaching. If actual anoxia is reached, impacts could be severe and include mortality to other aquatic life typically thought of as relatively tolerant to low DO, such as lamprey, aquatic invertebrates, and warm water fish. Mobilization of contaminants could also be enhanced. If this alternative is moved forward for potential implementation, mitigation will be necessary to at least prevent total anoxia.

Looking long term, DO concentrations that would occur during subsequent spring freshet events were not modeled. However, concentrations are anticipated to be greater than the 8 mg/L Washington State standard after the free-flowing river state becomes established.

CHAPTER 2 - REFERENCES

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