(12/15/16) Board Meeting- Item 7
TUCP
Deadline: 12/14/15 by 9:00 am

The Bay Institute
NRDC
Defenders of Wildlife

RECEIVED
12-14-15
SWRCB Clerk

December 14, 2015

Felicia Marcus, Chair
State Water Resources Control Board
P.O. Box 100
Sacramento, CA 95812-0100

RE: DECEMBER 7 DRAFT ORDER DENYING IN PART AND GRANTING IN PART PETITIONS FOR RECONSIDERATION OF AND ADDRESSING OBJECTIONS TO 2015 ORDERS APPROVING TEMPORARY URGENCY CHANGES FOR THE STATE WATER PROJECT AND CENTRAL VALLEY PROJECT

Dear Chairwoman Marcus,

This letter is submitted as the comments of the Bay Institute (TBI), the Natural Resources Defense Council (NRDC) and Defenders of Wildlife regarding the December 7, 2015 draft State Water Resources Control Board (SWRCB) order granting in part and denying in part the petitions for reconsideration of the Executive Director's February 3, 2015 order that approved Temporary Urgency Changes in license and permit terms and conditions for the State Water Project and Central Valley Project and subsequent modifications to that order.

While we appreciate the draft order's acknowledgement that implementation of its orders in 2015 has caused severe and unacceptable impacts to Delta habitat and fisheries, we strongly disagree with the proposed denial of TBI's petitions for reconsideration on the basis that "at the time the changes were approved, the tradeoff appeared to be reasonable based on the information available at the time, including" concurrence from state and federal agencies (Draft Order at p. 3). TBI's February 13, 2015 protest of the February 3, 2015 order provided detailed information regarding the severity of the likely impacts to fish and wildlife beneficial uses (including potential extinction of one or more species) as a result of relaxing Delta inflow and outflow objectives and export criteria in the Bay-Delta Water Quality Control Plan (WQCP), warned the SWRCB against repeating the utter failure of upstream operations in 2014 to protect salmonid spawning and migration, and accurately predicted what would ensue if the order was implemented. TBI, NRDC, Defenders of Wildlife, and others reiterated these concerns throughout the spring and summer of 2015 in appearances before the SWRCB, additional protests, and petitions for reconsideration, and emphasized that the SWRCB is required to protect a broad range of public trust fish and wildlife values above and beyond the narrow focus of the agency concurrences. The National Marine Fisheries Service also warned the SWRCB in February 2015 that Reclamation's temperature model was highly inaccurate, predicting temperatures that proved to be as much as 4ºF cooler than actual measured temperatures in 2014.[1] It was the SWRCB's failure to take this information seriously when it authorized relaxations of WQCP objectives and approved the original Sacramento River Temperature Management Plan that resulted in the devastation of fish and wildlife beneficial uses, including continuing record and near-record low population indices for numerous estuarine species and the devastation of the 2015 winter-run spawning class and other anadromous fish spawning in the Sacramento River. Indeed, the SWRCB has repeatedly justified its decisions on the basis of providing increased deliveries to senior water rights holders in the Central Valley, even at the risk of causing adverse impacts to fish and wildlife beneficial uses at their lowest ebb.

The draft Order is certainly correct in finding that "the status quo of the past two years is not sustainable for fish and wildlife and that changes to the drought planning and response process are needed to ensure that fish and wildlife are not unreasonably impacted in the future and to ensure that various species do not go extinct" (p. 39). Given that finding and the dismal record of performance in 2014 and 2015, we strongly agree that it is "appropriate to grant reconsideration of the TUCP Order in part to ensure protection of the public interest, fish and wildlife, and minimal water supplies for various uses going forward into 2016" (Draft Order at p. 5).

The December 7 draft Order calls for a number of measures "to prevent further catastrophic species declines and to ensure that minimal water supplies are conserved in storage for other critical needs if drought conditions continue" (Draft Order at p. 5). While the intention is good, the measures identified are not sufficient to prevent a recurrence of the same failures to protect fish and wildlife beneficial uses that were experienced in 2014 and 2015. Moreover, given the drastic impacts to which these species have been subjected over the last two years under approved drought operations, it is no longer enough to aim for minimal levels of protection if extinction is going to be avoided. Below we identify several critical measures that should be included in the final Order, including stricter constraints on relaxing WQCP objectives, improved minimum carryover storage requirements for Central Valley reservoirs, operating the system with greater sensitivity to changing hydrology which can vary greatly from month to month even during drought conditions, and considering new strategies for managing coldwater storage in upstream facilities.

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[1] *See* http://www.waterboards.ca.gov/waterrights/water_issues/programs/drought/docs/tucp/2015/nmfs_stelle012915.pdf at 4 ("throughout much of the summer of 2014, actual water temperatures, as monitored through the California Data Exchange Center, were upwards of 4°F higher than Sacramento River temperature modeling results").

1. The SWRCB should only consider relaxing water quality objectives under the draft Order or any other future orders during those months when extraordinarily low antecedent runoff and/or other conditions that are specifically identified in the Bay-Delta WQCP as triggers occur, and should take other actions to improve downstream water quality and habitat conditions and prevent catastrophic impacts to species at high risk of extinction if the drought persists.

The draft Order focuses only on the need to increase water stored upstream, presumably for the benefit of spawning, incubating, and rearing juvenile salmon. But this approach fails to address the need to protect estuarine resident species, like Delta smelt and longfin, which are also facing imminent extinction under recent operations. The draft Order correctly acknowledges that the strategy of trading protection of estuarine environmental conditions for presumed improvements in water quality conditions upstream has failed to protect both anadromous and estuarine fish populations. In 2016 the SWRCB must do a better job of maintaining adequate Bay-Delta water quality conditions both for those species that occur only or largely in the estuary – many of whom are experiencing record or near-record low population levels – and to protect critical life stages of salmonids and other migratory species as they pass through the estuary en route to the ocean or spawning grounds, and to prevent low flow conditions that encourage the occurrence of new species invasions, *Microcystis* blooms, and other toxic water quality problems.

In order to prevent continuing devastating impacts to estuarine species and to the estuarine life stages of anadromous species, the draft Order should:

- Condition the consideration of any future relaxations on the occurrence of specific antecedent condition triggers identified in the WQCP for variations, and limit those relaxations strictly to those months when such variations are authorized if triggered by antecedent conditions (rather than continue relaxations even when hydrological conditions change and the WQCP triggers no longer apply for subsequent months). The WQCP objectives were explicitly designed with such extreme drought variations in mind. Relaxing the objectives outside of the parameters adopted in the WQCP ignores that fact and constitutes a substantive change to objectives approved by the US Environmental Protection Agency under the federal Clean Water Act.

- Ensure that Delta flow conditions described in the NMFS and USFWS Biological Opinions for salmonids and Delta smelt will also be achieved, in order to reduce the potential for extinction of these and other species at high risk.

- Prohibit increases in export pumping that are intended to capture ecologically important storm pulses, in order to allow for the recovery of estuarine and anadromous species that are dependent on these pulses to maintain adequate habitat conditions and to avoid disproportionately high pumping–induced losses of these species when their populations are at extremely depleted levels.

Among other things, these protections are designed to avoid a repeat of the SWRCB's 2015 failure to end or suspend relaxations when hydrologic conditions improved. Specifically, relaxation of the February Delta outflow objective was triggered by extremely low antecedent runoff, but runoff in February exceeded the level that would have justified continuing the outflow relaxation in March, yet the relaxation was not lifted, and fish and wildlife beneficial uses were deprived of one of the few pulse flows that could have improved estuarine habitat conditions during the drought.

2. The SWRCB should modify the draft Order to require more timely and targeted increases in reservoir storage and include other provisions that are likely to provide real benefits to anadromous fish spawning, incubating, and rearing upstream.

While the draft Order appear well-intentioned in proposing end-of-October carryover storage behind Shasta and Folsom dams (1.6 MAF and 200,000AF, respectively), we are concerned that the proposal is inadequate and incomplete, and could easily lead to very poor outcomes for fish, wildlife, and Delta water quality in the coming year. End-of-season reservoir storage is only one of the water allocation constraints that must be described in order to evaluate the potential effects of any drought contingency plan intended to prevent further unnecessary damage to fish, wildlife, and other beneficial uses. The SWRCB must also specify the temperature and flow conditions that Reclamation and DWR are to maintain during water year 2016. In addition to storage and temperature conditions upstream, the SWRCB must describe how water will be allocated to protection of estuarine resources and water quality conditions in 2016 (see recommendation #1 above). Furthermore, water allocation to storage, temperature management, and protection of estuarine flow conditions must reflect the available runoff in the Central Valley such that conditions improve dramatically as hydrological conditions improve – the individual end-of-season storage targets identified in the draft order will not be protective of fish and wildlife upstream of the Delta (e.g. salmon spawning, incubation, and early rearing) under most hydrological conditions that could occur in WY 2016.

End-of-October Shasta storage was approximately 200 TAF higher at the end of 2015 than it was a year earlier; however, the increase in storage was inadequate, leading to persistently high water temperatures and winter-run Chinook salmon mortality rates that were at least as high as those observed during a disastrous 2014 spawning season. As we warned in early 2015 (and, regarding a similar proposal, in 2014), the decision to store additional water upstream, at the expense of required outflow conditions downstream, did not benefit winter-run Chinook salmon because Reclamation did not manage water reserves in a manner that maintained required temperatures throughout that population's incubation and early rearing period. The SWRCB's proposal for 2016 calls for adding additional end-of-October Shasta storage in 2016; however, there is no indication that this amount of water will be dedicated to or prove adequate to maintain required temperatures for winter-run, spring-run, and fall-run Chinook salmon spawning and incubation in 2016 (indeed, the storage end of season storage specified for Shasta Dam is well below the minimum target of the NMFS Biological Opinion, *see below*). As the past two years of operations have demonstrated, simply increasing storage, without attaining well-documented temperature and flow requirements for Chinook salmon throughout their spawning, incubation, and early juvenile phases does not improve outcomes for fish, wildlife, and water quality upstream and downstream.

What is needed in the draft Order are both temperature requirements that will allow for successful Chinook salmon spawning upstream in an adequate range of habitat (while maintaining required flow and salinity conditions downstream) and storage targets that can achieve those temperature levels. As we described in testimony earlier this year (and in communication with NMFS and CDFW), the 56°F daily average temperature standard is inadequate to protect incubating Chinook salmon. As the SWRCB is now aware, Reclamation is unable to consistently meet the temperature projections of its own temperature model on a daily average basis; thus, continuing to allow Reclamation to operate towards a temperature standard that is already, clearly sub-optimal is asking for a repeat of the extraordinarily high egg mortality rates witnessed in 2014 and 2015. Winter-run, spring run, and fall-run Chinook salmon spawning in the Sacramento River cannot withstand another year of these unreasonable impacts.

US EPA (2003) identified 55°F, measured as an average of maximum temperatures over 7 days (7 day average of daily maxima; 7DADM), as the upper threshold of optimal temperatures for Chinook salmon incubation. The EPA standard is based on a comprehensive and in-depth analysis, including the studies that have been used to justify the inadequate 56°F daily average standard. By requiring Reclamation to meet the US EPA temperature standard downstream of the most distant winter-run redd detected in the Sacramento in 2016, the Board would align temperature management for Chinook salmon egg incubation in the Central Valley with EPA's findings based on comprehensive research and would provide the "margin of safety" that the Board has indicated it desires to provide in 2016.

The final Order must also ensure that Shasta operations (including deliveries) are reasonably certain to lead to adequate end of season storage, Delta outflow and salinity conditions, and coldwater pool management. One component of this, as suggested in the draft Order, is setting end-of-season storage requirements for both Shasta and Folsom reservoirs. Storage in early fall will affect both (a) temperature and flow conditions that fall-run Chinook salmon experience at the end of 2016 and (b) Reclamation's ability to provide cold water in the following year (Nickel et al. 2004). Another component is setting a spring Shasta storage target to ensure that sufficient storage and cold-water pool will be maintained as we approach the winter-run Chinook salmon spawning season (i.e., end of April or May storage). NMFS has provided guidance on both end-of-April and end-of-September storage requirements to maintain temperatures that support winter-run Chinook salmon incubation (NMFS letter from M. Rea to SWRCB, P. Crader, April 2010 *attached*) and Reclamation has provided an analysis with similar findings (http://www.cwemf.org/AMPresentations/2015/FitzHugh_popup.pdf). We caution that both sets of numbers rely on (a) Reclamation's faulty temperature modeling and (b) the inadequate 56°F daily average temperature standard; furthermore, it is not clear that the modeling underlying these end-of-April storage recommendations incorporates the negative effect of aggressive use of cold water reserves in one year on the size of the cold water pool in the next year (Nickel et al. 2004). Thus, the end-of-April storages identified (~3.3 MAF to maintain the Clear Creek temperature compliance point) likely underestimate the storage required to meet even minimum temperature protections in 2016. On the other hand, the available end-of-April storage estimates may assume higher levels of water delivery (e.g., to senior water rights holders in the Sacramento and San Joaquin Valley) than can be sustained given the imminent threat facing numerous anadromous and estuarine fish populations. The Board should require detailed analyses of the operations that Reclamation and DWR will employ to attain required Delta outflows, coldwater pool management, and end-of-season storage. The Board should then require Reclamation and DWR to actually implement operations that will fully protect public trust resources, including a margin-of-safety; we note again that in water year 2015, Reclamation deviated from the schedule of releases it identified early in the year and exceeded releases recommended by both NMFS and the Board, with catastrophic results.

3. *Required 2016 end-of-season storages, coldwater pool management, Delta outflow and salinity conditions, and the operations necessary to attain these must be responsive to changing hydrology.*

The current draft proposal identifies only one storage target for Shasta Reservoir and one for Folsom Reservoir, but these targets fail to allow for improved protection as hydrologic conditions improve. At a minimum, the SWRCB must specify the levels of Sacramento Valley runoff for which these storages apply and set higher levels of storage if runoff exceeds the minimum thresholds. For example, between 2009 and 2010, carryover storage at Shasta increased by 1.6 MAF – as currently written, the Board's draft requirement would allow release to consumptive users of most of that volume instead of dedicating it, as needed, to stave off extinction for struggling salmonids, and possibly leaving Shasta at an extremely low level going into 2017.

The current draft proposal would require end-of-October storage to increase by 200 TAF in Shasta Reservoir, regardless of Sacramento Valley runoff in WY 2016. End-of-October Shasta storage increased by a similar amount in both WY 1992 and 2015 (antecedent storage in 1992 was similar to that going into 2015; see Figure 1). The Board should require the 200 TAF increase in Shasta storage for any Sacramento 4-River Index <8.5 MAF. Although this would represent an improvement, relative to hydrology, over last year's failed efforts to protect winter-run Chinook salmon, the resulting level of storage would still be well below the lowest target storage level identified by the NMFS biological opinion -- end-of-September carryover of 1.9 MAF. NMFS expected that this target would be exceeded in ~90% of years. The target is described in the Biological Opinion, as follows:

> "Before the [Shasta Temperature Control Device] was built, NMFS required that a 1.9 MAF end-of-September (EOS) minimum storage level be maintained to protect the cold water pool in Shasta Reservoir, in case the following year was critically dry (drought year insurance). This was because a relationship exists between EOS storage and the cold water pool. The greater the EOS storage level, typically the greater the cold water pool. The requirement for 1.9 MAF EOS was a reasonable and prudent alternative (RPA) in NMFS' winter-run opinion (NMFS 1992). Since 1997, Reclamation has been able to control water temperatures in the upper Sacramento River through use of the TCD. Therefore, NMFS changed the RPA to a target, and not a requirement …"

at 250.

Given that Shasta end-of-September storage has dropped below this "target" level in 4 of the seven years (57% of years) since the Biological Opinion was published and the Temperature Control Device has not enabled Reclamation to maintain temperatures required for successful incubation of Chinook salmon for the past two years, as anticipated, the Board should require that if runoff in 2016 is projected to equal or exceed 8.5 MAF, then required Shasta storage must increase above the level identified in the draft Order in a manner proportionate to hydrological conditions. To determine an appropriate rate of increase in Shasta Reservoir storage, we calculated the historic relationship between Sacramento Basin runoff and the change from one year to the next in Shasta storage at the end of October for years where the initial storage was < 1.7 MAF (Figure 1); when storage is low initially, reservoir recharge is always a priority for water managers. We found that when Shasta Reservoir storage is low entering a water year, storage tends to increase by ~154 TAF per 1 MAF increase in the Sacramento 4-River index. Because the Board recognizes the need to increase Shasta storage more aggressively in 2016, we applied a higher intercept to the historic relationship between Sacramento Valley runoff and change in Shasta Reservoir storage (i.e., starting with a 200 TAF increase in storage at a Sacramento 4-River index of 8.5 MAF). Under our proposal, this would result in end-of-October Shasta Reservoir storage of 1.8 MAF (~1.9 MAF end-of September storage) if the Sacramento 4-River Index reached 9.8 MAF. Storage would continue to increase if Sacramento runoff exceeded 9.8 MAF.

A similar approach should be applied to determining required storage levels behind Folsom Dam such that the minimum storage increase identified in the draft Order applies to very dry conditions and storage increases incrementally in response to improving hydrological conditions.

Again, we emphasize that reservoir recharge (throughout the Central Valley) must be coupled with maintenance of WQCP objectives as well as requirements of the USFWS and NMFS Biological Opinions. Estuarine fishes (including juvenile anadromous fishes attempting to migrate through the Delta) have suffered at least as much damage (perhaps irreversible damage) from the decisions made in 2014 and 2015 as the salmonid year classes did; as the last two years clearly demonstrate, cutting estuarine environmental safeguards in order to promote increased reservoir storage is a failed strategy based on a false choice between priorities.

4. The SWRCB should require Reclamation to study and report on reservoir management strategies (e.g., those described in Nickel et al. 2004) for maximizing available cold-water pool at any given storage level.

Active reservoir management may allow Reclamation to optimize the cold water pool available for any given level of reservoir end-of-April storage. For example Nickel et al. (2004) recommend strategies to maximize reservoir cooling during the winter and to maximize reservoir stratification as conditions warm during the winter and spring. The draft Order should be modified to include a requirement that Reclamation evaluate and report on these strategies and implement those that offer the opportunity to maximize reservoir cold water pool going into the 2016 winter-run Chinook salmon spawning season.

The draft Order represents an important moment by acknowledging the mistakes of the past two years. In order to avoid repeating them, we urge the Board to modify the order to include the additional and more specific requirements that we have identified. Please contact Dr. Jonathan Rosenfield of the Bay Institute at rosenfield@bay.org or 510-684-4757 if you have questions regarding the technical basis for our recommendations. Thank you for considering our comments in this matter.

Sincerely,

Gary Bobker The Bay Institute bobker@bay.org 415-272-6616	Kate Poole Natural Resources Defense Council kpoole@nrdc.org 415-875-6168	Rachel Zwillinger Defenders of Wildlife rzwillinger@defenders.org 415-686-2233

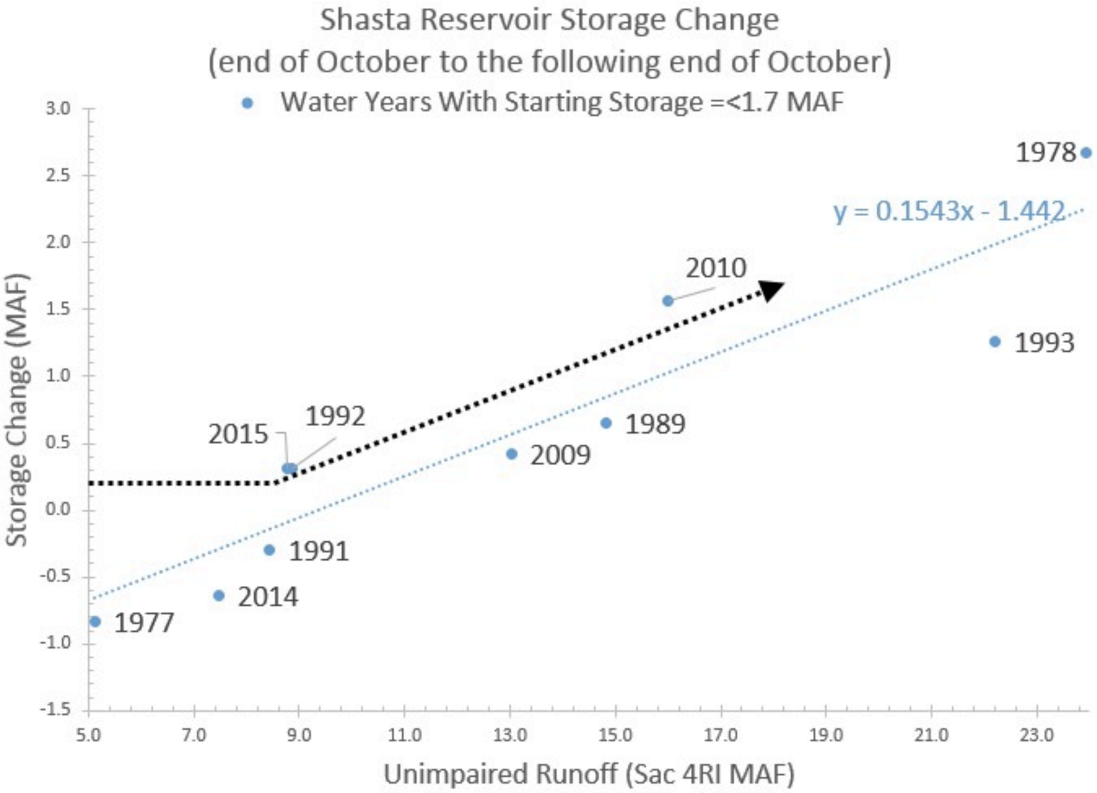

Figure 1: Recommended 2016 Shasta storage requirements relative to Sacramento Valley Unimpaired Runoff (Sac 4RI) relative to historic patterns. The historic rate of improvement in storage with increasing Sacramento Valley runoff is represented by the blue dotted line. Recommended storage improvement in 2016 is indicated by the black dotted line and arrow. Storage at Shasta should increase by 0.2MAF for Sac 4-River indices ≤ 8.5MAF; for wetter conditions, storage should increase by an additional 0.154 MAF for every additional 1 MAF of runoff in the Sac 4RI.

ATTACHMENTS:

1. U.S. Environmental Protection Agency Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards, 2003

2. April 14, 2010 letter from Maria Rea, National Marine Fisheries Service, to Philip Crader, SWRCB

3. Nickel, D.K., M.T. Brett, and A.D. Jassby. 2004. Factors regulating Shasta Lake (California) cold water accumulation, a resource for endangered salmon conservation. Water Resources Research, Vol. 40, W05204, doi:10.1029/2003WR002669, 2004

United States
Environmental Protection Agency

Region 10
Office of Water

EPA 910-B-03-002
April 2003

EPA Region 10 Guidance For Pacific Northwest State and Tribal Temperature Water Quality Standards

Acknowledgments

The *EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards* is a product of a three year interagency effort involving the Idaho Department of Environmental Quality, Oregon Department of Environmental Quality, Washington Department of Ecology, National Marine Fisheries Service, U.S. Fish and Wildlife Service, Nez Perce Tribe, Columbia River Inter-Tribal Fish Commission (representing its four governing tribes: the Nez Perce Tribe, Confederated Tribes of the Umatilla Indian Reservation, Confederated Tribes and Bands of the Yakima Nation, and the Confederated Tribes of the Warm Springs Reservation of Oregon), and EPA Region 10.

John Palmer of EPA Region 10's Office of Water chaired an interagency policy workgroup and was the principal author of the guidance with assistance from the following workgroup members: Randy Smith and Dru Keenan of EPA Region 10's Office of Water; Dave Mabe and Don Essig of the Idaho Department of Environmental Quality; Mark Charles and Debra Sturdevant of the Oregon Department of Environmental Quality; Dave Peeler and Mark Hicks of the Washington Department of Ecology; Russ Strach, Jeff Lockwood, and Robert Anderson of the National Marine Fisheries Service; Stephen Zylstra, Elizabeth Materna, and Shelley Spalding of the U.S. Fish and Wildlife Service; Barbara Inyan of the Nez Perce Tribe, and Patti Howard and Dale McCullough of the Columbia River Inter-Tribal Fish Commission.

The scientific and technical foundation for the guidance, as reflected in six scientific papers, was developed by an interagency technical workgroup led by Dru Keenan and Geoff Poole of the EPA Region 10. Other members of the technical workgroup were: Chris Mebane and Don Essig of the Idaho Department of Environmental Quality; Debra Sturdevant of the Oregon Department of Environmental Quality; Mark Hicks of the Washington Department of Ecology; Jeff Lockwood of the National Marine Fisheries Service; Elizabeth Materna and Shelley Spalding of the U.S. Fish and Wildlife Services; Dale McCullough of the Columbia River Inter-Tribal Fish Commission; John McMillan of the Hoh Tribe; Jason Dunham of the U.S. Forest Service, and John Risley and Sally Sauter of the U. S. Geological Service. Marianne Deppman of EPA Region 10 provided organizational and facilitation support for the technical workgroup.

Two independent scientific peer review panels were convened to provide comment on various aspects of the guidance and the scientific issue papers. The peer review scientists are identified in the peer review reports, which are referenced in Section X of the guidance.

EPA issued two public review drafts, the first in October, 2001 and the second in October, 2002, and received valuable comments from the public that helped shape the guidance.

An EPA review team consisting of the following individuals also provided valuable input into the development of the guidance: Carol Ann Siciliano of EPA's Office of General Counsel; Cara Lalley, Lars Wilcut, and Jim Keating of EPA's Office of Water; Adrianne Allen, Keith Cohon, and Rich McAllister of EPA Region 10's Office of Regional Counsel; Paula Vanhaagen, Marcia Lagerloef, Kerianne Gardner, Robert Robichaud, Kristine Koch, Kathy Collins, Patty McGrath, Mike Lidgard, Christine Psyk, Jannine Jennings, Rick Parkin, and Jayne Carlin of EPA Region 10's Office of Water; Ben Cope and Peter Leinenbach of EPA Region 10's Office of Environmental Assessment; and Derek Poon and Steve Ralph of EPA Region 10's Office of Ecosystems and Communities.

EPA gratefully acknowledges the above individuals, members of the peer review panels, and the public for their participation and valuable input into the development of the guidance. Although members of the organizations listed above contributed to the development of the guidance, this guidance ultimately reflects the views of EPA.

This report should be cited as:

U.S. Environmental Protection Agency. 2003. *EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards.* EPA 910-B-03-002. Region 10 Office of Water, Seattle, WA.

To obtain a copy of this guidance free of charge, contact:

EPA Region 10's Public Environmental Resource Center
Phone: 1-800-424-4372

This guidance, along with other supporting material, is available on the internet at:

www.epa.gov/r10earth/temperature.htm

Forward

The goal of the Clean Water Act (CWA) is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters and, where attainable, to achieve water quality that provides for the protection and propagation of fish, shellfish, and wildlife and recreation in and on the water. As a means of meeting this goal, section 303(c) of the CWA requires States and authorized Tribes to adopt water quality standards (WQS) and requires the U.S. Environmental Protection Agency (EPA) to approve or disapprove those standards.

At this time, many Pacific Northwest salmonid species are listed as threatened or endangered under the Endangered Species Act (ESA). As a result, the ESA requires that EPA must insure that its approval of a State or Tribal WQS is not likely to jeopardize the continued existence of any endangered or threatened species or result in the destruction or adverse modification of their critical habitat.

Water temperature is a critical aspect of the freshwater habitat of Pacific Northwest salmonids. Those salmonids listed as threatened or endangered under the ESA and other coldwater salmonids need cold water to survive. Human-caused increases in river water temperatures have been identified as a factor in the decline of ESA-listed salmonids in the Pacific Northwest. State and Tribal temperature WQS can play an important role in helping to maintain and restore water temperatures to protect Pacific Northwest salmonids and aid in their recovery. For these reasons, EPA in collaboration with others, developed this guidance to better describe appropriate water temperatures to protect Pacific Northwest salmonids.

The *EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards* is intended to assist States and Tribes to adopt temperature WQS that EPA can approve consistent with its obligations under the Clean Water Act (CWA) and the Endangered Species Act (ESA). This guidance document, however, does not substitute for applicable legal requirements; nor is it a regulation itself. Thus, it does not impose legally binding requirements on any party, including EPA, other federal agencies, the states, or the regulated community. Comments and suggestions from readers are encouraged and will be used to help improve the available guidance as EPA continues to build experience and understanding of water temperature and salmonids.

L. John Iani, Regional Administrator
U.S. EPA Region 10
Seattle, WA 98101

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EPA Region 10 Guidance
for
Pacific Northwest State and Tribal Temperature Water Quality Standards

I. Introduction

This guidance describes an approach that EPA Region 10 encourages States and authorized Tribes (Tribes) in the Pacific Northwest to use when adopting temperature water quality standards (WQS) to protect coldwater salmonids. The recommendations in this guidance are intended to assist States and Tribes to adopt temperature WQS that EPA can approve consistent with its obligations under the Clean Water Act (CWA) and the Endangered Species Act (ESA). This guidance specifically addresses the following coldwater salmonid species in the Pacific Northwest: chinook, coho, sockeye, chum, and pink salmon; steelhead and coastal cutthroat trout; and bull trout. The information provided in this guidance may also be useful for States and Tribes to protect other coldwater salmonid species that have similar temperature tolerances but are not explicitly addressed in this guidance.

This guidance provides recommendations to States and Tribes on how they can designate uses and establish temperature numeric criteria for waterbodies that help meet the goal of "protection and propagation of fish, shellfish, and wildlife" in section 101(a)(2) of the CWA. States or Tribes that choose to adopt new or revised temperature WQS must submit those standards to EPA for review and approval or disapproval. CWA section 303(c)(2)(A). EPA expects to be able to expedite its review of revised temperature standards that follow the recommendations in this guidance. States and Tribes that choose to follow the recommendations in this guidance, particularly those described in Section V, may wish to reference this guidance when submitting new or revised salmonid use designations and supporting criteria to EPA for approval.

EPA action on State and Tribal WQS that are consistent with this guidance is expected to be significantly expedited because the scientific rationale in support of the State and Tribal WQS would in large part already be described and supported by EPA, and by the National Marine Fisheries Service and the U.S. Fish and Wildlife Service (the Services). However, because this is a guidance document and not a regulation, EPA cannot bind itself to approve a WQS submission that follows the recommendation of this guidance. Furthermore, the Services cannot bind themselves to future consultation determinations (i.e., a "no jeopardy" determination) under the ESA. So even though EPA expects the review process to be significantly expedited if this guidance is followed, EPA and the Services must still examine every WQS submission on a case-by-case basis, taking into consideration any public comments received or other new information.

It is also important to note that this guidance does not preclude States or Tribes from adopting temperature WQS different from those described here. EPA would approve any temperature

WQS that it determines are consistent with the applicable requirements of the CWA and its obligations under the ESA. Because this guidance reflects EPA's current analysis of temperature considerations for Pacific Northwest salmonid species, EPA intends to consider it when reviewing Pacific Northwest State and Tribal temperature WQS or promulgating federal temperature WQS in Idaho, Oregon, or Washington.

Temperature WQS are viewed by EPA and the Services as an important tool for the protection and recovery of threatened and endangered salmonid species in the Pacific Northwest. Attaining criteria and protecting existing cold temperatures for waters used by these salmonids will help maintain and improve their habitat and aid in their recovery. Meeting temperature WQS, however, should be viewed as part of the larger fish recovery efforts to restore habitat. Wherever practicable, implementation actions to restore water temperatures should be integrated with implementation actions to improve habitat in general, and should be targeted first toward those reaches within a basin that will provide the biggest benefit to the fish. It should also be noted that the actions needed to improve water temperatures are, in many cases, the same as those needed to improve other fish habitat features. For example, restoring a stream's riparian vegetation can reduce water temperature as well as reduce sediment erosion, provide over bank micro-habitat, and add fallen wood to the river that over time creates pools and a more diverse stream habitat preferred by salmonids.

This guidance was developed with the assistance of representatives of the Pacific Northwest States, the Services, and the Columbia River Inter-Tribal Fish Commission (CRITFC) Tribes. As part of developing this guidance, EPA, with the assistance of technical experts from Federal, State, and Tribal organizations, developed five technical issue papers and a technical synthesis report summarizing technical issues related to water temperature and salmonids. These reports represent the technical foundation of this guidance and summarize the latest literature related to temperature and salmonids. See Section X, References, at the end of this guidance for a list of these technical papers.

II. Regulatory Background

The goal of the CWA is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters and, where attainable, to achieve water quality that provides for the protection and propagation of fish, shellfish, and wildlife and recreation in and on the water. See CWA section 101(a)(2). As a means of meeting this goal, section 303(c) of the CWA requires States and Tribes to adopt WQS that include designated uses and water quality criteria to protect those designated uses. In addition, Federal WQS regulations require States and Tribes to adopt a statewide antidegradation policy and identify methods to implement such policy. See 40 C.F.R. § 131.12. States and Tribes may also adopt into their standards policies generally affecting the application and implementation of WQS, such as mixing zones and variances. See 40 C.F.R. § 131.13.

EPA is required to approve or disapprove new or revised State and Tribal WQS under section 303(c) of the CWA to ensure they are consistent with the requirements of the CWA and EPA's implementing regulations. See CWA section 303(c)(3). New or revised State and Tribal WQS are not in effect for CWA purposes until they are approved by EPA. If EPA disapproves a new or revised WQS submitted by a State or Tribe, or if the EPA Administrator determines that a new or revised WQS is necessary to meet the requirements of the CWA, EPA must propose and promulgate appropriate WQS itself, unless appropriate changes are made by the State or Tribe. See CWA section 303(c)(4).

Where EPA determines that its approval of State or Tribal WQS may affect threatened or endangered species or their critical habitat, the approval action is subject to the procedural and substantive requirements of section 7(a)(2) of the ESA. Section 7(a)(2) of the ESA requires EPA to ensure, in consultation with the Service(s), that any action it takes is not likely to jeopardize the continued existence of any endangered or threatened species or result in the destruction or adverse modification of critical habitat. Under the ESA regulations, such consultations can be concluded informally where EPA determines that its action is not likely to adversely affect listed species or critical habitat, and where the Service(s) concur with that finding in writing. See 50 C.F.R. § 402.13. Where EPA does not make such a determination, or where the Service(s) do not concur in writing, the ESA regulations require EPA to engage in formal consultation, which results in the issuance of a biological opinion by the Service(s). See 50 C.F.R. § 402.14. If the Service(s) anticipate that "take" will occur as a result of the action, the opinion in most cases will include required reasonable and prudent measures and associated terms and conditions to minimize such take, along with an incidental take statement providing EPA legal protection from ESA section 9 take liability for its approval action. See 50 C.F.R. § 402.14(i). Section 7(a)(1) of the ESA requires EPA to use its authorities to carry out programs for the conservation of endangered and threatened species. The ESA, however, does not expand EPA's authorities under the CWA. EPA approval or disapproval decisions regarding State and Tribal WQS must be authorized by the CWA and EPA's implementing regulations.

In addition, EPA has a federal trust relationship with federally recognized Pacific Northwest tribes. In the Pacific Northwest, federal courts have affirmed that certain tribes reserved through treaty the right to fish at all usual and accustomed fishing places and to take a fair share of the fish destined to pass through such areas. *See* Puyallup Tribe v. Department of Game, 391 U.S. 392 (1968); Washington v. Passenger Fishing Vessel, 443 U.S. 658 (1979); United States v. Winans, 198 U.S. 371 (1905). EPA's approval of a State or Tribal WQS, or promulgation of its own WQS, may impact the habitat that supports the treaty fish. EPA has a responsibility to ensure that its WQS actions do not violate treaty fishing rights.

Water Quality Standards set the water quality goals for specific waterbodies and serve as a regulatory basis for other programs, such as National Pollutant Discharge Elimination System (NPDES) permits, listings of impaired water bodies under CWA section 303(d), and total maximum daily loads (TMDLs). In general, NPDES permits contain effluent limitations to meet WQS; section 303(d) lists identify those water bodies where the WQS are not being met; and TMDLs are mathematical calculations indicating the pollutant reductions needed to meet WQS.

III. Relationship of Guidance to EPA's 304(a) Criteria for Water Temperature

Under CWA section 304(a), EPA issues national criteria recommendations to guide States and Tribes in developing their WQS. When EPA reviews a State or Tribal WQS submission for approval under section 303(c) of the CWA, it must determine whether the adopted designated uses and criteria are consistent with the CWA and EPA's regulations. See CWA section 303(c)(3). Specifically, 40 C.F.R § 131.11 requires States and Tribes to adopt water quality criteria that are based on sound scientific rationale and contain sufficient parameters or constituents to protect the designated uses. For waters with multiple use designations, the criteria must support the most sensitive use. See 40 C.F.R. § 131.11(a). When establishing criteria, States should: (1) establish numerical values based on 304(a) guidance, or 304(a) guidance modified to reflect site-specific conditions, or other scientifically defensible methods; or (2) establish narrative criteria or criteria based upon biomonitoring methods where numerical criteria cannot be established or to supplement numerical criteria. See 40 C.F.R. § 131.11(b).

EPA develops its section 304(a) criteria recommendations based on a uniform methodology that takes into account a range of species' sensitivities to pollutant loadings using certain general assumptions; therefore, the national recommendations are generally protective of aquatic life. However, these criteria recommendations may not be protective of all aquatic life designated uses in all situations. It may be appropriate for States and Tribes to develop different water quality criteria using current data concerning the species present, and taking into account site-specific or regional conditions. EPA approval or disapproval would not depend on whether a criterion adopted by a State or Tribe is consistent with a particular guidance document, such as this guidance or the national 304(a) criteria recommendations, but rather on whether the State or Tribe demonstrates that the criterion protects the most sensitive designated use, as required by section 303(c) of the CWA and EPA's WQS regulations.

EPA's current 304(a) criteria recommendations for temperature can be found in *Quality Criteria for Water 1986*, commonly known as the "gold book." The freshwater aquatic life criteria described in this 1986 document were first established in 1977, and were not changed in the 1986 document. In general, EPA's national temperature recommendations for salmonids and other fish consist of formulas to calculate the protective temperatures for short-term exposure and a maximum weekly average exposure. Protective short term temperature exposure is based on subtracting 2°C from the upper incipient lethal temperature (the temperature at which fifty percent of the sample dies). Protective weekly average temperature exposure is based on the optimal growth temperature plus 1/3 the difference between the optimal growth temperature and the upper incipient lethal temperature. Using these formulas and EPA data for coho and sockeye salmon, the 1986 document calculates suggested temperature criteria for short-term exposure as 22°C (sockeye) and 24°C (coho) and a maximum weekly average exposure of 18°C for both species.

Based on extensive review of the most recent scientific studies, EPA Region 10 and the Services believe that there are a variety of chronic and sub-lethal effects that are likely to occur to Pacific Northwest salmonid species exposed to the maximum weekly average temperatures calculated using the current 304(a) recommended formulas. These chronic and sub-lethal effects include reduced juvenile growth, increased incidence of disease, reduced viability of gametes in adults prior to spawning, increased susceptibility to predation and competition, and suppressed or reversed smoltification. It may be possible for healthy fish populations to endure some of these chronic impacts with little appreciable loss in population size. However, for vulnerable fish populations, such as the endangered or threatened salmonids of the Pacific Northwest, EPA and the Services are concerned that these chronic and sub-lethal effects can reduce the overall health and size of the population.

For these reasons, the national assumptions made when developing the section 304(a) criteria recommendations for temperature may not necessarily protect the vulnerable coldwater salmonids in the Pacific Northwest. EPA Region 10, therefore, has developed this guidance to assist Pacific Northwest States and Tribes in developing temperature criteria that protect the coldwater salmonids in the Pacific Northwest identified above.

IV. Water Temperature and Salmonids

IV.1. Importance of Temperature for Salmonids

Water temperatures significantly affect the distribution, health, and survival of native salmonids in the Pacific Northwest. Since salmonids are ectothermic (cold-blooded), their survival is dependent on external water temperatures and they will experience adverse health effects when exposed to temperatures outside their optimal range. Salmonids have evolved and thrived under the water temperature patterns that historically existed (i.e., prior to significant anthropogenic impacts that altered temperature patterns) in Pacific Northwest streams and rivers. Although evidence suggests that historical water temperatures exceeded optimal conditions for salmonids at times during the summer months on some rivers, the temperature diversity in these unaltered rivers provided enough cold water during the summer to allow salmonid populations as a whole to thrive.

Pacific salmon populations have historically fluctuated dramatically due to climatic conditions, ocean conditions, and other disturbances. High water temperatures during drought conditions likely affected the historical abundance of salmon. In general, the increased exposure to stressful water temperatures and the reduction of suitable habitat caused by drought conditions reduce the abundance of salmon. Human-caused elevated water temperatures significantly increase the magnitude, duration, and extent of thermal conditions unsuitable for salmonids.

The freshwater life histories of salmonids are closely tied to water temperatures. Cooling rivers in the autumn serve as a signal for upstream migrations. Fall spawning is initiated when water temperatures decrease to suitable temperatures. Eggs generally incubate over the winter or early spring when temperatures are coolest. Rising springtime water temperatures may serve as a cue for downstream migration.

Because of the overall importance of water temperature for salmonids in the Pacific Northwest, human-caused changes to natural temperature patterns have the potential to significantly reduce the size of salmonid populations. Of particular concern are human activities that have led to the excess warming of rivers and the loss of temperature diversity.

IV.2. Human Activities That Can Contribute to Excess Warming of Rivers and Streams

Rivers and streams in the Pacific Northwest naturally warm in the summer due to increased solar radiation and warm air temperature. Human changes to the landscape have magnified the degree of river warming, which adversely affects salmonids and reduces the number of river segments that are thermally suitable for salmonids. Human activities can increase water temperatures by increasing the heat load into the river, by reducing the river's capacity to absorb heat, and by eliminating or reducing the amount of groundwater flow which moderates temperatures and provides cold water refugia. Specific ways in which human development has caused excess warming of rivers are presented in Issue Paper 3 and are summarized below:

1) Removal of streamside vegetation reduces the amount of shade that blocks solar radiation and increases solar heating of streams. Examples of human activities that reduce shade include forest harvesting, agricultural land clearing, livestock grazing, and urban development.

2) Removal of streamside vegetation also reduces bank stability, thereby causing bank erosion and increased sediment loading into the stream. Bank erosion and increased sedimentation results in wider and shallower streams, which increases the stream's heat load by increasing the surface area subject to solar radiation and heat exchange with the air.

3) Water withdrawals from rivers for purposes such as agricultural irrigation and urban/municipal and industrial use result in less river volume and generally remove cold water. The temperatures of rivers with smaller volumes equilibrates faster to surrounding air temperature, which leads to higher maximum water temperatures in the summer.

4) Water discharges from industrial facilities, wastewater treatment facilities and irrigation return flows can add heat to rivers.

5) Channeling, straightening, or diking rivers for flood control and urban and agricultural land development reduces or eliminates cool groundwater flow into a river that moderates summertime river temperatures. These human actions can reduce two forms of groundwater flow. One form is groundwater that is created during over-bank flooding and is slowly returned to the main river channel to cool the water in the summer. A

second form is water that is exchanged between the river and the riverbed (i.e. hyporheic flow). Hyporheic flow is plentiful in fully functioning alluvial rivers systems.

6) Removal of upland vegetation and the creation of impervious surfaces associated with urban development increases storm runoff and reduces the amount of groundwater that is stored in the watershed and slowly filters back to the stream in the summer to cool water temperatures.

7) Dams and their reservoirs can affect thermal patterns in a number of ways. They can increase maximum temperatures by holding waters in reservoirs to warm, especially in shallow areas near shore. Reservoirs, due to their increased volume of water, are more resistant to temperature change which results in reduced diurnal temperature variation and prolonged periods of warm water. For example, dams can delay the natural cooling that takes place in the late summer-early fall, thereby harming late summer-fall migration runs. Reservoirs also inundate alluvial river segments, thereby diminishing the groundwater exchange between the river and the riverbed (i.e., hyporheic flow) that cools the river and provides cold water refugia during the summer. Further, dams can significantly reduce the river flow rate, thereby causing juvenile migrants to be exposed to high temperatures for a much longer time than they would under a natural flow regime.

It should also be noted that some human development can create water temperatures colder than an unaltered river. The most significant example of this occurs when cold water is released from the bottom of a thermally stratified reservoir behind a dam.

IV.3. Human-Caused Elevated Water Temperature as a Factor in Salmonid Decline

Many reports issued in the past decade have described the degradation of freshwater salmonid habitat, including human-caused elevated temperatures, as a major factor in salmonid decline. The following provides a brief summary of some of these reports:

National Marine Fisheries Service's Listing and Status Reviews for Pacific Northwest Salmonids

The National Marine Fisheries Service (NMFS) identified habitat concerns (including alteration of ambient stream water temperatures) as one of the factors for decline of listed west coast steelhead (NMFS 1996), west coast chinook (NMFS 1998), and Snake River spring/summer chinook salmon (Mathews and Waples 1991). Specific effects attributed to increased temperatures by NMFS include increased juvenile mortality, increased susceptibility and exposure to diseases, impaired ability to avoid predators, altered migration timing, and changes in fish community structure that favor competitors of salmonids. NMFS included high water temperatures among risk factors related to the listings under the ESA of the following evolutionarily significant units (ESUs) of chinook salmon: Puget Sound, Lower Columbia River, Snake River spring/summer, and Upper Willamette (Myers et al. 1998). NMFS also noted high water temperatures in its analyses of risk factors related to the ESA listings of Upper Willamette River steelhead and Ozette Lake sockeye.

U.S. Fish and Wildife Service Listing and Status Reviews for Bull Trout

When listing bull trout in the Columbia River and Coastal-Puget Sound population segments, USFWS identified activities such as forestry, agriculture, and hydropower that have degraded bull trout habitat and specifically have resulted in increased stream temperatures. Bull trout are found primarily in colder streams, although individual fish are found in larger river systems. Water temperature above 15°C is believed to limit bull trout distribution and this may partially explain their patchy distribution within a watershed. The strict cold water temperature needs of bull trout make them particularly vulnerable to human activities identified by USFWS that warm spawning and rearing waters.

Return to the River Reports by the Independent Science Group

The Independent Scientific Group is a group of scientists chartered by the Northwest Power Planning Council to provide independent scientific advice to the Columbia River Basin Fish and Wildlife Program. In their 1996 Return the River report (updated in 2000), they include a section discussing the effects of elevated temperature on salmonids as part of their overall discussion of freshwater habitats. The report states:

> "Temperature is a critical habitat variable that is very much influenced by regulation of flow and impoundments. The mainstem reservoirs are relatively shallow and heat up in late summer causing concern for salmon survival. The lower reaches of some key tributaries also are very warm in late summer because they are dewatered by irrigation withdrawals. Due to the extreme importance of temperature regimes to the ecology of salmonids in the basin, temperature information merits special attention as a key habitat descriptor (Coutant 1999)."
>
> "Water temperatures in the Columbia River basin have been altered by development and are, at times, suboptimal or clearly detrimental for salmonids. High temperatures alone can be directly lethal to both juvenile and adult salmonids in the Snake River in summer under recent conditions based on generally accepted thermal criteria and measured temperatures."

Oregon Coastal Salmon Restoration Initiative

The Oregon Coastal Salmon Restoration Initiative (1997) included water temperature as a factor for decline in populations of Oregon coastal coho salmon, noting that:

> "Water temperatures are too warm for salmonids in many coastal streams. Altered water temperatures can adversely affect spawning, fry emergence, smoltification, maturation

> period, migratory behavior, competition with other aquatic species, growth and disease resistance."

Summer Chum Salmon Conservation Initiative

The Summer Chum Salmon Conservation Initiative (2000) for the Hood Canal and Strait of Juan de Fuca region listed elevated water temperature in its limiting factor analysis, noting that:

> "Elevated temperatures impede adult passage, cause direct mortality, and accelerate development during incubation leading to diminished survival in subsequent life stages."

Interior Columbia Basin Ecosystem Management Project

The aquatic habitat assessment for the Interior Columbia Basin Ecosystem Management Project (Lee et al. 1997) indicates that:

1. Changes in riparian canopy and shading, or other factors influencing stream temperatures, are likely to affect some, if not most, bull trout populations.
2. In desert climates, the loss of riparian canopy has been associated with elevated water temperature and reduced redband trout abundance.
3. Loss of vegetation has resulted in stream temperatures that have far exceeded those considered optimal for Lahontan Cutthroat Trout.
4. Water temperatures in reaches of the John Day, upper Grande Ronde, and other basins in eastern Oregon commonly exceed the preferred ranges and often exceed lethal temperatures for chinook salmon.

Northwest Indian Fisheries Commission - Critical Habitat Issues by Basin for Natural Chinook Stocks in the Coastal and Puget Sound Areas of Washington State

In this report, the Northwest Indian Fisheries Commission reviewed the habitat issues for the basins in the coastal and Puget Sound areas of Washington State, and identified elevated temperature as a critical habitat issue in 12 out of 15 basins reviewed.

Other Basin and Watershed Studies

Numerous scientific studies of habitat and elevated water temperature impacts on salmon, steelhead and resident native fish have been completed in the Pacific Northwest over the past two decades. The Northwest Power Planning Council is in the process of developing habitat assessments and restoration strategies for all the sub-basins of the Columbia River Basin. In many of these sub-basin summaries (e.g., Okanogan, Methow, Wenatchee, Yakima, Tucannon, Grande Ronde, Umatilla, and John Day draft summaries - see www.cbfwa.org) elevated temperatures are cited as a major factor contributing to salmonid decline. These and other studies elsewhere in the Pacific Northwest provide a consistent view of the importance of restoring temperatures suitable for coldwater salmonds to aid in their recovery.

One specific study worth noting is by Theurer et al. (1985) in the Tucannon River in southeastern Washington. This study shows how human-caused changes in riparian shade and channel morphology contributed to increased water temperatures, reduced available spawning and rearing space, and diminished production of steelhead and chinook salmon. Using a physically-based water temperature model, the authors concluded that approximately 24 miles of spawning and rearing habitat had been made unusable in the lower river due to temperature changes. If the temperatures were restored, they estimated chinook adult returns would increase from 884 that currently exist to 2240 (near historic levels) and that chinook rearing capacity would increase from 170,000 to 430,000. The authors state that the change in temperature regime caused by the loss of riparian vegetation alone is sufficient to explain the reduction in salmonid population in the Tucannon River, while noting that increased sediment input also has played a subsidiary role.

Another similar analysis was done by Oregon Department of Environmental Quality (ODEQ, 2000) for the upper Grande Ronde River as part of their TMDL for this river. ODEQ modeling showed that restoration of riparian shade, channel width and depth, and water flow would drastically reduce maximum temperatures. As shown in Figure 1 (Figures 11 and 12 in ODEQ 2000), over 90% of the river currently exceeds 68°F (20°C), but with full restoration that percentage drops to less than 5%. Similarly, the percentage of the river that exceeds 64°F (18°C) is reduced from over 90% to less than 50% with full restoration. This represents nearly 50 additional miles that are colder than 18°C, which is a very large increase in available rearing habitat. Although actual estimates of increased fish production were not calculated in this study, one might expect similar results as those calculated for the Tucannon River.

Although temperature is highlighted here as a factor in the decline of native salmonid populations, it by no means is the only factor in their decline. Certainly, degradation of habitat unrelated to temperature (e.g., impassable barriers to spawning and rearing areas and physical destruction or inundation of spawning grounds), fishing harvest, and hatchery operations have all played a role in their decline. However, as described above, elevated temperatures are an important factor in the decline of salmonids and restoring suitable temperature regimes for salmonids is a critical element in protecting salmonid populations.

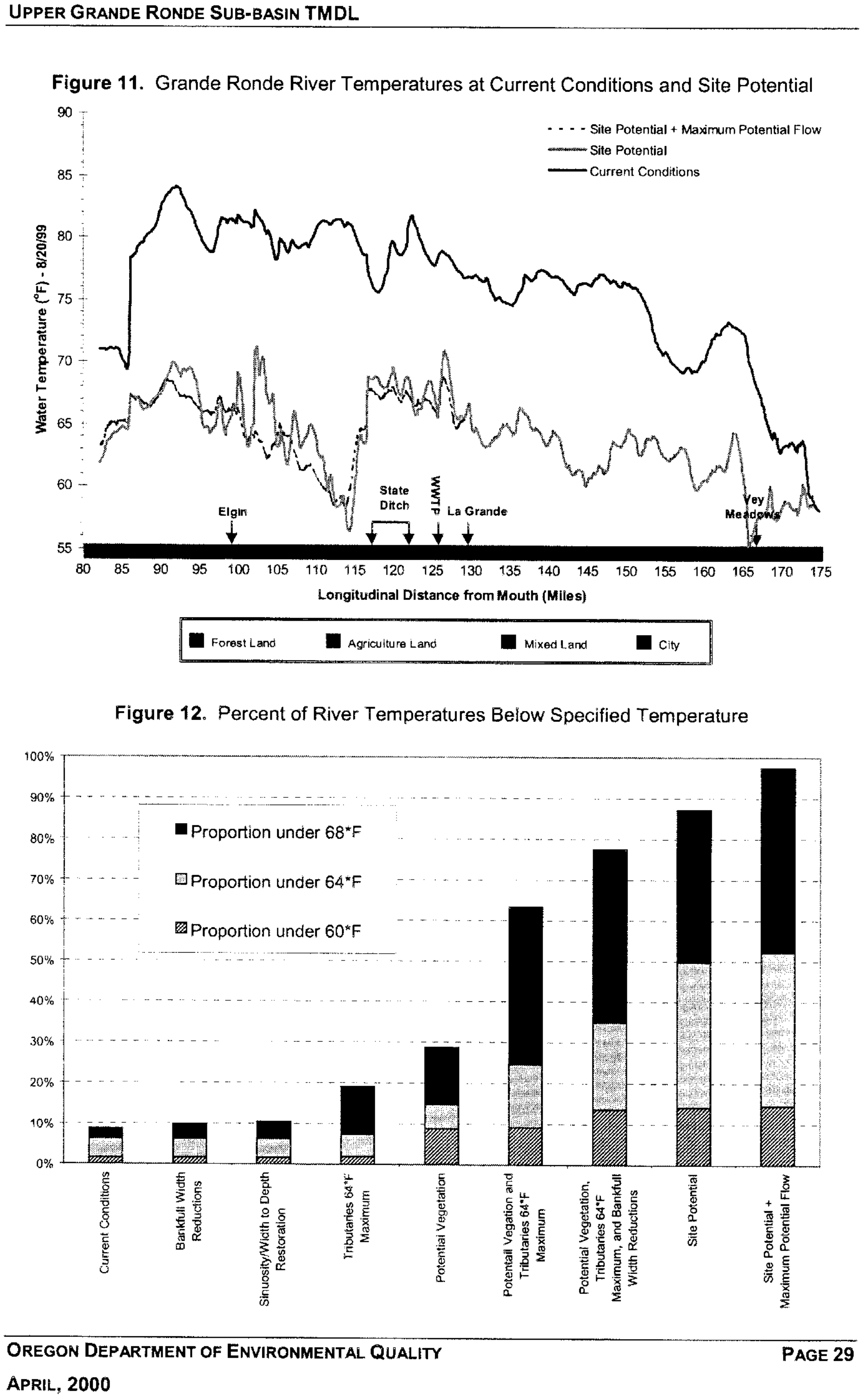
UPPER GRANDE RONDE SUB-BASIN TMDL

Figure 11. Grande Ronde River Temperatures at Current Conditions and Site Potential

Figure 12. Percent of River Temperatures Below Specified Temperature

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Figure 1. Grande Ronde River temperature modeling using ODEQ's Heat Source Model, showing site potential.

IV.4. General Life Histories of Salmonids and When Human-Caused Elevated Water Temperatures May Be a Problem

Different salmonid species have evolved to take advantage of the Pacific Northwest's cold water environment in different ways. Each species has a unique pattern of when and where they use the rivers, and even for a specific species this pattern of use may change from year to year. This diversity in freshwater life history is a critical evolutionary trait that has allowed salmonids to persist in a freshwater environment that naturally fluctuates and has natural disturbances.

Below is a general summary of the freshwater life history strategies for some of the coldwater salmonids. This summary is intended to provide a "big picture" understanding of how each of these fish use Pacific Northwest rivers and to highlight when and where human elevated water temperatures have impacted these fish. As noted above, because of their life history diversity, the discussion below may be an over-generalization for some situations. Further, because this general discussion on fish distribution is simplified for purposes of understanding, it is not intended to be used as a basis for salmonid use designations.

Chinook Salmon

Adult spring chinook salmon generally leave the ocean and enter Pacific Northwest rivers in the spring (April - June) and swim upstream to hold and spawn in the mid-to-upper reaches of river basins. Spawning generally occurs in late summer and fall (August - October). Egg and alevin incubation extends over the winter and fry generally emerge in the early spring (March - May). Juveniles rear in their natal streams and lower in the basin for a year, then migrate out to the ocean the following spring. Human-caused elevated temperatures can adversely affect spring chinook when adults hold and begin to spawn in the late-summer/early fall and throughout the summer when juveniles rear. Human-caused elevated temperatures in these mid-to-upper reaches can "shrink" the available habitat for adult holding/spawning and juvenile rearing limiting spring chinook to habitat higher in the watershed.

Adult fall chinook salmon generally enter Pacific Northwest rivers in the summer (July - August) and swim upstream to hold and spawn in the lower reaches of mainstem rivers and large tributaries. Spawning generally occurs in the fall (October - December). For example, Snake River fall chinook migrate past Bonneville dam from August-October and spawn in the Snake River below Hells Canyon Dam and the lower reaches of the Clearwater, Grand Ronde, Imnaha, and Tucannon rivers. Fry emerge from March through April and begin their downstream migration several weeks after emergence. Downstream migration occurs mainly in the spring under existing conditions, but may extend throughout the summer in some areas (e.g., Columbia River). Historically, juvenile fall chinook out-migrated throughout the summer months, but today human-caused elevated temperatures have made this impossible in some rivers (e.g., Yakima river). Human-caused elevated temperatures can adversely affect fall chinook in lower river reaches during the summer months when the adults are migrating upstream and holding to spawn and when juveniles are migrating downstream. Human-caused elevated temperatures in the early fall may also delay spawning.

Coho Salmon

Adult coho salmon generally enter Pacific Northwest rivers in the fall (late September through October) and spawn in low gradient 4th and 5th order streams in fall-winter. Fry emerge in the spring. Juvenile coho rear for 1 to 2 years prior to migrating to sea during the spring. Juvenile coho salmon may migrate considerable distances upstream to rear in lakes or other river reaches suitable for rearing. Coho salmon are most predominant in the rivers of the coastal mountains of Washington and Oregon and the west-slopes of the Washington Cascades. Wild coho populations were extirpated years ago in the Umatilla (OR), Yakima (WA), and Clearwater (ID) rivers but they are now being re-introduced in these rivers. Human-caused elevated temperatures can adversely affect coho salmon in the summer months when juveniles are rearing and in early fall when adults start migrating. Human-caused elevated temperatures may render waters unsuitable for rearing, thereby "shrinking" the amount of available habitat.

Sockeye Salmon

Adult sockeye salmon generally enter freshwater from mid summer through early fall and migrate up to lakes and nearby tributaries to spawn in the fall. Juveniles generally rear in lakes from 1 to 3 years, then migrate to the ocean in the spring. Pacific Northwest lakes that support sockeye include Redfish (Idaho), Okanogan, Wenatchee, Baker, Washington, Sammamish, Quinault, and Osoyoos. Historically, there were many other lakes in the Pacific Northwest used by sockeye. Human-caused elevated temperatures can adversely affect sockeye adult salmon as they migrate upstream in the mid-to-late summer.

Chum Salmon

Adult chum salmon generally enter freshwater in late-summer and the fall and spawn (October - December) in the low reaches and side channels of major rivers just upstream from tidewater areas. Upon emergence, juveniles begin their short migration to saltwater which generally occurs between March and June. Juveniles will rear in estuaries for a while prior to entering the ocean. Human-caused elevated temperatures can adversely affect adult chum salmon as they migrate upstream in the late summer.

Pink Salmon

Adult pink salmon generally enter freshwater in late summer and spawn in the lower reaches of large rivers in late summer and early fall. Like chum, juveniles will migrate to saltwater soon after emerging in the late winter. Human-caused elevated temperatures can adversely affect adult pink salmon as they migrate upstream in the late summer.

Steelhead Trout

Adult steelhead enter Pacific Northwest rivers throughout the year, but can generally be divided into a summer run (May - October) and a winter run (November-June). Both runs typically spawn in the spring. Summer steelhead enter freshwater sexually immature and generally travel greater distances to spawn than winter steelhead, which enter freshwater sexually mature (i.e. with well-developed gonads). All steelhead runs upstream of the Dalles Dam are summer steelhead. Fry generally emerge from May through July and juvenile steelhead will rear in the mid-upper reaches of river basins for 1-2 years (sometimes 3 or 4 years) before migrating to the ocean in the spring. Human-caused elevated temperatures can adversely affect steelhead in the summer months when the juveniles are rearing in the mid-upper reaches. Human-caused elevated temperatures may render waters unsuitable for rearing, thereby “shrinking” the amount of available habitat. Human-caused elevated temperatures also can adversely affect summer run adults as they migrate upstream during the summer as well as eggs and fry that incubate into July in some watersheds.

Bull Trout

Bull trout generally are freshwater fish (although the adults of a few populations enter saltwater estuaries). Adult bull trout generally migrate upstream in the spring and summer from their feeding grounds (lower reaches in a basin for migrating fluvial forms or a lake for adfluvial forms) to their spawning grounds higher in the basin. Bull trout generally spawn in September-October, but in some watersheds spawning can occur as early as July. Bull trout have a long incubation time with fry emergence generally from March through May. Juveniles will rear in their natal streams for 2-4 years, then the migratory forms will migrate downstream to more productive feeding grounds (i.e., lower river reaches or lakes) in the spring, but some fall downstream migration has also been noted. Human-caused elevated temperatures can adversely affect summer juvenile rearing in the upper reaches where elevated temperatures have rendered water unsuitable for rearing, thereby “shrinking” the amount of available habitat. Adults migrating upstream to spawn in the summer can also experience adverse effects from human-elevated temperatures. Additionally, migratory adults can be adversely affected by the loss of cold water refugia due to human activities.

V. EPA Region 10 Recommendations for Pacific Northwest State and Tribal Temperature WQS

EPA Region 10 offers the following recommendations to assist States and Tribes in adopting temperature WQS that fully support coldwater salmonids in the Pacific Northwest. The recommendations are intended to assist States and Tribes to adopt temperature WQS that EPA can approve consistent with its obligations under the CWA and the ESA. As noted in Section I, Pacific Northwest States and Tribes that adopt temperature WQS consistent with these recommendations can expect an expedited review by EPA and the Services, subject to new data and information that might be available to during that review.

EPA Region 10 recommends that States and Tribes adopt new or revised temperature WQS that incorporate each of the following elements for the protection of salmonid designated uses. Each of these elements is discussed in more detail below:

1) Coldwater Salmonid Uses and Numeric Criteria to Protect Those Uses;

2) Provisions to Protect Water Temperatures That Are Currently Colder Than the Numeric Criteria; and

3) Provisions to Protect Salmonids from Thermal Plume Impacts.

If a State or Tribe decides to adopt new or revised temperature WQS, it is free, of course, to adopt WQS that are different than these recommendations. EPA would evaluate these submissions on a case-by-case basis to determine if it can approve the WQS consistent with its obligations under the CWA and the ESA.

V.1. Coldwater Salmonid Uses and Numeric Criteria to Protect Those Uses

Tables 1 and 2 provide a summary of the important water temperature considerations for each life stage for salmon and trout, and bull trout: spawning, egg incubation, and fry emergence; juvenile rearing; and adult migration. Each temperature consideration and associated temperature values noted in Tables 1 and 2 includes a reference to the relevant technical issue papers prepared in support of this guidance (or other studies) that provide a more detailed discussion of the supporting scientific literature. The temperatures noted in Tables 1 and 2 form the scientific basis for EPA's recommended numeric criteria to protect coldwater salmonids in the Pacific Northwest, which are presented in Tables 3 and 4.

V.1.A. Overall Context for Recommended Uses and Criteria

In addition to Tables 1 and 2, there are a number of other general factors that EPA considered in recommending coldwater salmonid uses and numeric criteria to protect those uses. These factors

Table 1 - Summary of Temperature Considerations For Salmon and Trout Life Stages

Life Stage	Temperature Consideration	Temperature & Unit	Reference
Spawning and Egg Incubation	*Temp. Range at which Spawning is Most Frequently Observed in the Field	4 - 14°C (daily avg)	Issue Paper 1; pp 17-18 Issue Paper 5; p 81
	* Egg Incubation Studies		
	- Results in Good Survival	4 - 12°C (constant)	Issue Paper 5; p 16
	-Optimal Range	6 - 10°C (constant)	
	*Reduced Viability of Gametes in Holding Adults	> 13°C (constant)	Issue Paper 5; pp 16 and 75
Juvenile Rearing	*Lethal Temp. (1 Week Exposure)	23 - 26°C (constant)	Issue Paper 5; pp 12, 14 (Table 4), 17, and 83-84
	*Optimal Growth		
	- unlimited food	13 - 20°C (constant)	Issue Paper 5; pp 3-6 (Table 1), and 38-56
	- limited food	10 - 16°C (constant)	
	*Rearing Preference Temp. in Lab and Field Studies	10 - 17°C (constant) < 18°C (7DADM)	Issue Paper 1; p 4 (Table 2). Welsh et al. 2001.
	*Impairment to Smoltification	12 - 15°C (constant)	Issue Paper 5; pp 7 and 57-65 Issue Paper 5; pp 7 and 57-65
	*Impairment to Steelhead Smoltification	> 12°C (constant)	
	*Disease Risk (lab studies)		Issue Paper 4, pp 12 - 23
	-High	> 18 - 20°C (constant)	
	- Elevated	14 - 17°C (constant)	
	- Minimized	12 - 13°C (constant)	
Adult Migration	*Lethal Temp. (1 Week Exposure)	21- 22°C (constant)	Issue Paper 5; pp 17, 83 - 87
	*Migration Blockage and Migration Delay	21 - 22°C (average)	Issue Paper 5; pp 9, 10, 72-74. Issue Paper 1; pp 15 - 16
	*Disease Risk (lab studies)		
	- High	> 18 - 20°C (constant)	Issue Paper 4; pp 12 - 23
	- Elevated	14 - 17°C (constant)	
	- Minimized	12- 13°C (constant)	
	*Adult Swimming Performance		
	- Reduced	> 20°C (constant)	Issue Paper 5; pp 8, 9, 13, 65 - 71
	- Optimal	15 - 19°C (constant)	
	* Overall Reduction in Migration Fitness due to Cumulative Stresses	> 17-18°C (prolonged exposures)	Issue Paper 5; p 74

Table 2 - Summary of Temperature Considerations For Bull Trout Life Stages

Life Stage	Temperature Consideration	Temperature & Unit	Reference
Spawning and Egg Incubation	*Spawning Initiation	< 9°C (constant)	Issue Paper 5; pp 88 - 91
	*Temp. at which Peak Spawning Occurs	< 7°C (constant)	Issue Paper 5; pp 88 - 91
	*Optimal Temp. for Egg Incubation	2 - 6°C (constant)	Issue Paper 5; pp 18, 88 - 91
	*Substantially Reduced Egg Survival and Size	6 - 8°C (constant)	Issue Paper 5; pp 18, 88 - 91
Juvenile Rearing	*Lethal Temp. (1 week exposure)	22 - 23°C (constant)	Issue Paper 5; p 18
	*Optimal Growth - unlimited food - limited food	12 - 16 °C (constant) 8 - 12°C (constant)	Issue Paper 5; p 90. Selong et al 2001. Bull trout peer review, 2002.
	*Highest Probability to occur in the field	12 - 13 °C (daily maximum)	Issue Paper 5; p 90. Issue Paper 1; p 4 (Table 2). Dunham et al., 2001. Bull trout peer review, 2002.
	*Competition Disadvantage	>12°C (constant)	Issue Paper 1; pp 21- 23. Bull trout peer review, 2002.

and EPA's recommended approach for considering these factors (described below) provide the overall context for EPA's salmonid use and criteria recommendations.

Coldwater Salmonid Uses

Coldwater salmonids are considered a sensitive aquatic life species with regard to water temperatures and are a general indicator species of good aquatic health. EPA, therefore, believes it is appropriate for States and Tribes in the Pacific Northwest to focus on coldwater salmonids when establishing temperature criteria to support aquatic life.

Under EPA's WQS regulations, States and Tribes must adopt appropriate uses and set criteria to protect those uses. See 40 C.F.R § 131.10(a). Because Pacific Northwest salmonids have multiple freshwater life stages with differing temperature tolerances, it is generally appropriate to designate uses based on life stages. In addition, EPA's WQS regulations allow States and Tribes to adopt seasonal uses where a particular use applies for only a portion of the year. See 40 C.F.R § 131.10(f). EPA's recommended approach is for States and Tribes to utilize both of these use designation options in order to more precisely describe where and when the different coldwater salmonid uses occur.

In this guidance, EPA recommends seven coldwater salmonid uses (see Tables 3 and 4). Four uses apply to the summer maximum temperature condition and three apply to specific locations and times for other times of the year (except for some instances when these uses may apply during the period of summer maximum temperatures).

Focus on Summer Maximum Conditions

In general, increased summertime temperatures due to human activities are the greatest water temperature concern for salmonids in the Pacific Northwest, although temperatures in the late spring and early fall are also a concern in some areas. EPA therefore believes it is appropriate that temperature criteria focus on the summer maximum conditions to protect the coldwater salmonid uses that occur then. Generally, improving river conditions to reduce summer maximum temperatures will also reduce temperatures throughout the summer and in the late spring and early fall (i.e., shift the seasonal temperature profile downward). Thus, the data indicate that, because of the natural annual temperature regime, providing protective temperatures during the summer maximum period will in many areas provide protective temperatures for more temperature sensitive uses that occur other times of the year.

In some areas, however, more temperature-sensitive salmonid uses (e.g., spawning, egg incubation, and steelhead smoltification) that occur in the spring-early summer or late summer-fall may not be protected by meeting the summer maximum criterion. Thus, in addition to summer maximum criteria, EPA also recommends criteria be adopted to protect these more temperature-sensitive uses when and where they occur. Doing so provides an added degree of protection for those situations where control of summer maximum temperatures is inadequate to protect these more temperature-sensitive uses. An additional reason for having these seasonal uses is to provide protection for rivers that are flow-regulated, which can alter the natural annual temperature pattern.

In recommending protective summer maximum criteria, EPA took into consideration that meeting a criterion during the warmest period of the summer (e.g., warmest week) will result in cooler temperatures during other times in the summer. The duration of exposure to near summer maximum conditions, however, can vary from one to two weeks in some areas to over a month in other areas.

Optimal, Harmful, and Lethal Temperatures for Salmonids

Each salmonid life stage has an optimal temperature range. Physiological optimum temperatures are those where physiological functions (e.g., growth, swimming, heart performance) are optimized. These temperatures are generally determined in laboratory experiments. Ecological optimum temperatures are those where fish do best in the natural environment considering food availability, competition, predation, and fluctuating temperatures. Both are important considerations when establishing numeric criteria. Exposure to temperatures above the optimal range results in increased severity of harmful effects, often referred to as sub-lethal or chronic effects (e.g., decreased juvenile growth which results in smaller, more vulnerable fish; increased susceptibility to disease which can lead to mortality; and decreased ability to compete and avoid predation), as temperatures rise until at some point they become lethal (See Table 1 and 2). Water temperatures below the optimal range also cause sub-lethal effects (e.g., decreased growth); however, this is generally a natural condition (with the exception of cold water releases from a storage dam) and is not the focus of this guidance.

When determining the optimal range for bull trout and salmon/trout juvenile rearing, EPA looked at both laboratory and field data and considered both physiological and ecological aspects. Optimal growth under limited food rations in laboratory experiments, preference temperatures in laboratory experiments where fish select between a gradient of temperatures, and field studies on where rearing predominately occurs are three independent lines of evidence indicating the optimal temperature range for rearing in the natural environment. As highlighted in Tables 1 and 2 (and shown in detail in the technical issue papers) these three lines of evidence show very consistent results, with the optimal range between 8 - 12°C for bull trout juvenile rearing and between 10 - 16°C for salmon and trout juvenile rearing.

Use of the 7 Day Average of the Daily Maximum (7DADM) Unit of Measurement

The recommended metric for all of the following criteria is the maximum 7 day average of the daily maxima (7DADM). This metric is recommended because it describes the maximum temperatures in a stream, but is not overly influenced by the maximum temperature of a single day. Thus, it reflects an average of maximum temperatures that fish are exposed to over a week-long period. Since this metric is oriented to daily maximum temperatures, it can be used to protect against acute effects, such as lethality and migration blockage conditions.

This metric can also be used to protect against sub-lethal or chronic effects (e.g., temperature effects on growth, disease, smoltification, and competition), but the resultant cumulative thermal exposure fish experience over the course of a week or more needs to be considered when selecting a 7DADM value to protect against these effects. EPA's general conclusion from studies on fluctuating temperature regimes (which is what fish generally experience in rivers) is that fluctuating temperatures increase juvenile growth rates when mean temperatures are colder than the optimal growth temperature derived from constant temperature studies, but will reduce growth when the mean temperature exceeds the optimal growth temperature (see Issue Paper 5, pages 51-56). When the mean temperature is above the optimal growth temperature, the "mid-point" temperature between the mean and the maximum is the "equivalent" constant temperature. This "equivalent" constant temperature then can be directly compared to laboratory studies done at constant temperatures. For example, a river with a 7DADM value of 18°C and a 15°C weekly mean temperature (i.e., diurnal variation of ± 3°C) will be roughly equivalent to a constant laboratory study temperature of 16.5°C (mid-point between 15°C and 18°C). Thus, both maximum and mean temperatures are important when determining a 7DADM value that is protective against sub-lethal/chronic temperature effects.

For many rivers and streams in the Pacific Northwest, the 7DADM temperature is about 3°C higher than the weekly mean (Dunham, et al. 2001; Chapman, 2002). Thus, when considering what 7DADM temperature value protects against chronic effects, EPA started with the constant temperatures that scientific studies indicate would be protective against chronic effects and added 1-2°C degrees (see Table 1 for summary of studies done under constant temperatures). For bull trout waters, EPA started with the constant temperatures that scientific studies indicate would be protective for chronic effects and added about 0.5°C because bull trout waters typically have less diurnal variation. Following this general procedure takes into account the maximum and mean temperature (i.e., reflects a "mid-point") when protecting for growth and other sub-lethal effects.

It is important to note that there are also studies that analyzed sub-lethal effects based on maximum or 7DADM temperature values which need not be translated for purposes of determining protective 7DADM temperatures. For example, there are field studies that assess probability of occurrence or density of a specific species based on maximum temperatures (Issue Paper 1, Haas (2001), Welsh et al. (2001)). These field studies represent an independent line of evidence for defining upper optimal temperature thresholds, which complements laboratory studies.

It is also important to note that there are confounding variables that are difficult to account for but are important to recognize. For instance, the amount of diurnal variation in rivers and streams in the Pacific Northwest varies considerably; therefore, the difference between the 7DADM and the weekly mean will vary. The difference between the 7DADM temperature and the weekly mean may be less than 1°C for rivers with little diurnal variation and as high as 9°C for streams with high diurnal variation (Dunham et al., 2001). Another variable is food availability. The temperature for which there is optimal juvenile growth depends on the food supply. Optimal growth temperatures under limited food supply are lower than those under unlimited/satiated food supply. Generally, EPA believes that laboratory studies under limited food availability are most reflective of environmental conditions fish typically experience. However, there are likely situations where food is abundant, with the result that optimal growth temperatures would be higher. Thus, a particular 7DADM numeric criteria will be more protective in situations where there is high diurnal variation and/or abundant food and will be less protective in situations where there is low diurnal variation and limited food.

Unusually Warm Conditions

In order to have criteria that protect designated uses under the CWA, EPA expects that the criteria would need to apply nearly all the time. However, EPA believes it is reasonable for a State or Tribe to decide not to apply the numeric temperature criteria during unusually warm conditions for purposes of determining if a waterbody is attaining criteria. One possible way for a State or Tribe to do this would be to explain in its WQS that it will determine attainment with the numeric temperature criterion based on the 90th percentile of the yearly maximum 7DADM values calculated from a yearly set of values of 10 years or more. Thus, generally speaking, the numeric criteria would apply 9 out 10 years, or all but the hottest year. Another way may be to exclude water temperature data when the air temperature during the warmest week of the year exceeds the 90th percentile for the warmest week of the year based on a historical record (10 years or more) at the nearest weather reporting station.

A State or Tribe wishing to consider adopting a provision to account for unusually warm conditions might be able to justify that decision by pointing out that extreme annual peaks in water temperature typically caused by drought conditions are a natural component of the environment and then concluding, as a matter of policy, that these infrequent conditions should not drive attainment determinations. Salmonids may experience some adverse effects during these periods, but by definition, they would be infrequent. It is important to note that not taking into account unusually warm conditions should only be for CWA 303(d) listing purposes when determining if a waterbody is in attainment with temperature WQS. NPDES permitted facilities should not be exempt from applicable temperature effluent limits during these periods.

Even assuming that a State or Tribe decides to account for unusually warm conditions in its temperature WQS, attainment determinations should be based on all climatic conditions except for the extreme condition in order to protect the salmonid designated uses. Thus, given that river temperatures exhibit year-to-year variation in their maximum 7DADM values, the average maximum 7DADM value from a yearly series, as a statistical matter, would need to be lower than the numeric criteria in order to meet the criteria 9 out of 10 years. Therefore, in most years, the maximum 7DADM temperature would also probably need to be lower than the numeric criteria in order to meet the criteria in the warm years. EPA took this into consideration when it formulated its numeric criteria recommendations.

A De Minimis Temperature Increase Allowance

A State or Tribe may, if it has not already done so, wish to consider adopting a provision in its WQS that allows for a de minimis temperature increase above the numeric criteria or the natural background temperature. A State or Tribe might choose to include a de minimis increase allowance as a way of accounting for monitoring measurement error and tolerating negligible human impacts. The data and information currently available to EPA appear to indicate that an increase on the order of 0.25°C for all sources cumulatively (at the point of maximum impact) above fully protective numeric criteria or natural background temperatures would not impair the designated uses, and therefore might be regarded as de minimis.

Numeric Criteria Should Apply Upstream of the Furthest Downstream Extent of Use

Water quality criteria must protect the relevant designated uses. See 40 C.F.R. § 131.11(a). Therefore, a criterion should apply to all the river miles for which a particular use is designated, including the lowest point downstream at which the use is designated. Because streams generally warm progressively in the downstream direction, waters upstream of that point will generally need to be cooler in order to ensure that the criterion is met downstream. Thus, a waterbody that meets a criterion at the furthest downstream extent of use will in many cases provide water cooler than the criterion at the upstream extent of the use. EPA took this into consideration when it formulated its numeric criteria recommendations.

EPA also believes that the numeric criteria should apply upstream of the areas of actual use because temperatures in upstream waters significantly affect the water temperatures where the actual use occurs and upstream waters are usually colder. Of course, if a more sensitive use is designated upstream, the more protective criterion would apply upstream. See 40 C.F.R. § 131.11(a).

Selection of Protective Criteria for the Recommended Salmon Uses

As described above, numeric criteria that apply to uses that occur during the summer maximum period are intended to apply to the warmest times of the summer, the warmest years (except for extreme conditions), and the lowest downstream extent of use. Because of the conservative nature of this application, EPA believes that it is appropriate to recommend numeric criteria near the warmer end of the optimal range for uses intended to protect high quality bull trout and salmon/trout rearing (see Section V.1.C for use descriptions). EPA expects that adopting a numeric criterion near the warmer end of the optimal range that is applied to the above conditions is likely to result in temperatures near the middle of the optimal range for most of the spring through fall period in the segments where most of the rearing use occurs. EPA has identified two reasons for this. First, if the criterion is met at the summer maximum, then temperatures will be lower than the criterion during most of the year. Second, because the criterion would apply at the furthest point downstream where the use is designated, temperatures will generally be colder across the full range of the designated use.

EPA also recognizes that salmonids will use waters that are warmer than their optimal thermal range and further recognizes that some portions of rivers and streams in the Pacific Northwest naturally (i.e., absent human impacts) were warmer than the salmonid optimal range during the period of summer maximum temperatures. To account for these realities, EPA is also recommending two salmonid uses (see Section V.1.C) during the period of summer maximum temperatures where the recommended numeric criteria exceed the optimal range, but provide protection from lethal conditions and sub-lethal effects that would significantly adversely affect these uses.

If applied collectively, EPA believes its recommended salmonid uses and associated numeric criteria, if attained, will support healthy sustainable salmonid populations. However, EPA notes that it must still consider any new or revised temperature WQS submitted by a State or Tribe on a case-by-case basis and must take into account any new information made available to EPA at that time.

Determining the Spatial Extent of the Recommended Salmonid Uses

It is well recognized that the current distribution of salmonids in the Pacific Northwest has significantly shrunk and is more fragmented than their historical distribution due to human development. It is also unlikely that the current distribution of salmonids will provide for sustainable salmonid populations. EPA believes that, in order to meet the national goal of providing for the protection and propagation of fish wherever attainable, salmonid use designations should be of sufficient geographic and temporal scope to support sustainable levels of use. This is because, unless the designated use specifically provides otherwise, a salmonid use reasonably implies a healthy and sustainable population. Because of the importance of restoring healthy salmonid populations in the Pacific Northwest, EPA Region 10 advises States and Tribes not to limit salmonid use designations to where and when salmonid uses occur today when assigning uses in areas with thermally degraded habitat.

For areas with degraded habitat, EPA recommends that coldwater salmonid uses be designated in waters where the defined use currently occurs or is suspected to currently occur, and where there is reasonable potential for that use to occur (e.g., if temperatures or other habitat features, including fish passage improvements, were to be restored in areas of degraded habitat). In most areas of degraded habitat, temperatures have risen, thereby forcing salmonids upstream to find suitable water temperatures for rearing and spawning. As a result, the downstream extent of current use is likely farther upstream than it was prior to habitat degradation. For areas with minimal habitat degradation, where human impacts have not likely altered fish distribution, EPA recommends use designations based on where the use currently occurs or is suspected to currently occur.

EPA's recommendations for designating the spatial extent of the various salmonid uses are described below in Sections V.1.C and V.1.D. The goal of these recommendations is to include the potential use areas for each salmonid use where the habitat has been degraded due to human impacts. For example, for the bull trout rearing use and the salmon/trout core rearing use, which are intended to protect waters of moderate to high density rearing use, EPA recommends that for areas of degraded habitat, these uses cover the downstream extent of low density rearing that currently occurs during the period of maximum summer temperatures (typically July and August). The concept here is that waters where rearing currently occurs in low density during the summer is a reasonable approximation of waters that could support moderate to high density use if the temperature were reduced.

EPA fully recognizes the difficulties in spatially designating the recommended salmonid uses. First, information on fish distribution, particularly juvenile rearing distribution, is sparse in many locations. For example, in some situations there may be fairly good information on spawning areas, but minimal information on juvenile rearing distribution. In those situations, a State or

Tribe could consider using the spawning distribution along with inferences drawn from what information exists on juvenile rearing as the primary basis for designating the bull trout and the core salmon and trout rearing uses. Second, there is a fair degree of both inter-annual and seasonal variability in fish distribution. Third, there is no bright line that defines degraded habitat; rather there is a spectrum from non-degraded to highly degraded.

States and Tribes, therefore, should use the best available scientific information (e.g., the types of information described in Sections V.1.C and V.1.D) and make well-reasoned judgments when designating the various salmonid uses. In some cases, that may mean extrapolating from limited information and making generalizations based on stream order, size, and elevation. Thus, EPA recognizes there is an inherent element of subjectivity to designating the recommended salmonid uses. However, because the recommended salmonid uses are fairly broad scale (applying to large areas of a river basin), EPA believes that the recommended use designations are reasonable given the current level of information. If a State or Tribe decides to revise its salmonid use designations and submit them to EPA for approval, it should include a description of the information and judgments it made to determine the spatial extent of its salmonid uses.

Lastly, EPA also believes that better information on fish distribution is valuable for both CWA and ESA purposes and that adopting the recommended salmonid use designations (or others justified by the best available scientific information) will provide impetus to acquire more and better information in the future.

V.1.B. EPA Region 10's Recommended Salmonid Uses and Numeric Criteria

EPA Region 10's recommended coldwater salmonid uses and criteria to protect those uses are presented in Tables 3 and 4. Table 3 describes uses that occur during the summer maximum temperature conditions. Designating the uses in Table 3 would result in apportioning a river basin to up to 4 salmonid use categories with associated criteria (e.g., 12°C, 16°C, 18°C, and 20°C). The colder criteria would apply in the headwaters and the warmer criteria would apply in the lower river reaches, which is consistent with the typical thermal and salmonid use patterns of rivers in the Pacific Northwest during the summer. It should be noted, however, that there may be situations where a warmer use and criteria would apply upstream of a colder use and criteria (e.g., where a relatively large cold tributary enters a warmer river, which significantly cools the river).

Table 4 describes coldwater salmonid uses that generally occur at times other than during the summer maximum period, except for some circumstances. EPA recommends that these criteria apply when and where these uses occur and may potentially occur.

Table 3. Recommended Uses & Criteria That Apply To Summer Maximum Temperatures

Notes: 1) "7DADM" refers to the Maximum 7 Day Average of the Daily Maximums; 2) "Salmon" refers to Chinook, Coho, Sockeye, Pink, and Chum salmon; 3) "Trout" refers to Steelhead and coastal cutthroat trout

Salmonid Uses During the Summer Maximum Conditions	**Criteria**
Bull Trout Juvenile Rearing	12°C (55°F) 7DADM
Salmon/Trout "Core" Juvenile Rearing *(Salmon adult holding prior to spawning, and adult and sub-adult bull trout foraging and migration may also be included in this use category)*	16°C (61°F) 7DADM
Salmon/Trout Migration plus Non-Core Juvenile Rearing	18°C (64°F) 7DADM
Salmon/Trout Migration .	20°C (68°C) 7DADM, plus a provision to protect and, where feasible, restore the natural thermal regime

Table 4. Other Recommended Uses & Criteria

Notes: 1) "7DADM" refers to the Maximum 7 Day Average of the Daily Maximums; 2) "Salmon" refers to Chinook, Coho, Sockeye, Pink, and Chum salmon; 3) "Trout" refers to Steelhead and coastal cutthroat trout;

Salmonid Uses	**Criteria**
Bull Trout Spawning	9°C (48°F) 7DADM
Salmon/Trout Spawning, Egg Incubation, and Fry Emergence	13°C (55°F) 7DADM
Steelhead Smoltification	14°C (57°F) 7DADM

V.1.C. Discussion of Uses and Criteria Presented in Table 3

Bull Trout Juvenile Rearing - 12°C 7DADM

EPA recommends this use for the protection of moderate to high density summertime bull trout juvenile rearing near their natal streams in their first years of life prior to making downstream migrations. This use is generally found in a river basin's upper reaches.

EPA recommends a 12°C maximum 7DADM criterion for this use to: (1) safely protect juvenile bull trout from lethal temperatures; (2) provide upper optimal conditions under limited food for juvenile growth during the period of summer maximum temperature and optimal temperature for other times of the growth season; (3) provide temperatures where juvenile bull trout are not at a competitive disadvantage with other salmonids; and (4) provide temperatures that are consistent with field studies showing where juvenile bull trout have the highest probability to occur (see Table 2).

EPA recommends that the spatial extent of this use include: (1) waters with degraded habitat where high and low density juvenile bull trout rearing currently occurs or is suspected to currently occur during the period of maximum summer temperatures, except for isolated patches of a few fish that are spatially disconnected from more continuous upstream low density use; (2) waters with minimally-degraded habitat where moderate to high density bull trout rearing currently occurs or is suspected to currently occur during the period of maximum summer temperatures; (3) waters where bull trout spawning currently occurs; (4) waters where juvenile rearing may occur and the current 7DADM temperature is 12°C or lower; and (5) waters where other information indicates the potential for moderate to high density bull trout rearing use during the period of maximum summer temperatures (e.g., recovery plans, bull trout spawning and rearing critical habitat designations, historical distributions, current distribution in reference streams, studies showing suitable rearing habitat that is currently blocked by barriers that can reasonably be modified to allow passage, or temperature modeling).

Salmon and Trout "Core" Juvenile Rearing - 16°C 7DADM

EPA recommends this use for the protection of moderate to high density summertime salmon and trout juvenile rearing. This use is generally found in a river basin's mid-to-upper reaches, downstream from juvenile bull trout rearing areas. However, in colder climates, such as the Olympic mountains and the west slopes of the Cascades, it may be appropriate to designate this use all the way to the saltwater estuary.

Protection of these waters for salmon and trout juvenile rearing also provides protection for adult spring chinook salmon that hold throughout the summer prior to spawning and for migrating and foraging adult and sub-adult bull trout, which also frequently use these waters.

EPA recommends a 16°C maximum 7DADM criterion for this use to: (1) safely protect juvenile salmon and trout from lethal temperatures; (2) provide upper optimal conditions for juvenile growth under limited food during the period of summer maximum temperatures and optimal temperatures for other times of the growth season; (3) avoid temperatures where juvenile salmon and trout are at a competitive disadvantage with other fish; (4) protect against temperature-induced elevated disease rates; and (5) provide temperatures that studies show juvenile salmon and trout prefer and are found in high densities (see Table 1).

EPA recommends that the spatial extent of this use include: (1) waters with degraded habitat where high and low density salmon and trout juvenile rearing currently occurs or is suspected to currently occur during the period of maximum summer temperatures, except for isolated patches of a few fish that are spatially disconnected from more continuous upstream low density use; (2) waters with minimally-degraded habitat where moderate to high density salmon and trout juvenile rearing currently occurs or is suspected to currently occur during the period of maximum summer temperatures; (3) waters where trout egg incubation and fry emergence and salmon spawning currently occurs during the summer months (mid-June through mid-September); (4) waters where juvenile rearing may occur and the current 7DADM temperature is 16°C or lower; (5) waters where adult and sub-adult bull trout foraging and migration occurs during the period of summer maximum temperatures; and (6) waters where other information indicates the potential for moderate to high density salmon and trout rearing use during the period of maximum summer temperatures (e.g., recovery plans, critical habitat designations, historical distributions, current distribution in reference streams, studies showing suitable rearing habitat that is currently blocked by barriers that can reasonably be modified to allow passage, or temperature modeling).

Please note that at this time EPA is recommending that adult and sub-adult bull trout foraging and migration be included in this use category as opposed to establishing a separate use and associated criterion. Our current knowledge of bull trout migration timing and their *main channel* temperature preference is limited, but we do know that they prefer water temperatures less than 15°C, that they take advantage of cold water refugia during the period of summer maximum temperatures, and that spawning adults move toward spawning grounds during the period of summer maximum temperatures. EPA, therefore, believes its recommended approach would protect migrating and foraging bull trout because average river temperatures will likely be below 15°C, a fair amount of cold water refugia is expected in rivers that attain a maximum 7DADM of 16°C, and maximum temperatures below 16°C are likely to occur upstream of the downstream point of this use designation where most bull trout migration and foraging is likely to occur during the period of summer maximum temperatures. As more is learned about adult and sub-adult bull trout foraging and migration, EPA, in consultation with the U.S. Fish and Wildlife Service, may reconsider this recommendation.

Salmon and Trout Migration Plus Non-Core Juvenile Rearing - 18°C 7DADM

EPA recommends this use for the protection of migrating adult and juvenile salmonids and moderate to low density salmon and trout juvenile rearing during the period of summer maximum temperatures. This use designation recognizes the fact that salmon and trout juveniles will use waters that have a higher temperature than their optimal thermal range. For water bodies that are currently degraded, there is likely to be very limited current juvenile rearing during the period of maximum summer temperatures in these waters. However, there is likely to be more extensive current juvenile rearing use in these waters during other times of the year. Thus, for degraded waters, this use designation could indicate a potential rearing use during the period of summer maximum temperatures if maximum temperatures are reduced.

This use is generally found in the mid and lower part of a basin, downstream of the Salmon and Trout Core Juvenile Rearing use. In many river basins in the Pacific Northwest, it may be appropriate to designate this use all the way to a river basin’s terminus (i.e., confluence with the Columbia River or saltwater).

EPA recommends an 18°C maximum 7DADM criterion for this use to: (1) safely protect against lethal conditions for both juveniles and adults; (2) prevent migration blockage conditions for migrating adults; (3) provide optimal or near optimal juvenile growth conditions (under limited food conditions) for much of the summer, except during the summer maximum conditions, which would be warmer than optimal; and (4) prevent adults and juveniles from high disease risk and minimize the exposure time to temperatures that can lead to elevated disease rates (See Table 1).

The upstream extent of this use designation is largely driven by where the salmon and trout core juvenile rearing use (16°C) is defined. It may be appropriate to designate this use downstream to the basin’s terminus, unless a salmon and trout migration use (20°C) is designated there. Generally, for degraded water bodies, this use should include waters where juvenile rearing currently occurs during the late spring-early summer and late summer-early fall, because those current uses could indicate potential use during the period of summer maximum temperatures if temperatures were to be reduced.

Salmon and Trout Migration - 20°C 7DADM plus a provision to protect and, where feasible, restore the natural thermal regime

EPA recommends this use for waterbodies that are used almost exclusively for migrating salmon and trout during the period of summer maximum temperatures. Some isolated salmon and trout juvenile rearing may occur in these waters during the period of summer maximum temperatures, but when it does, such rearing is usually found only in the confluence of colder tributaries or other areas of colder waters. Further, in these waters, juvenile rearing was likely to have been mainly in cold water refugia areas during the period of maximum temperatures prior to human alteration of the landscape. It should also be noted that most fish migrating in these waters do so in the spring-early summer or in the fall when temperatures are cooler than the summer maximum temperatures, but some species (e.g., late migrating juvenile fall chinook; adult summer chinook, fall chinook, summer steelhead, and sockeye) may migrate in these waters during the period of summer maximum temperatures.

This use is probably best suited to the lower part of major rivers in the Pacific Northwest, where based on best available scientific information, it appears that the natural background maximum temperatures likely reached 20°C. When designating the spatial extent of this use, EPA expects the State or Tribe to provide information that suggests that natural background maximum temperatures reached 20°C. However, EPA does not expect the State or Tribe to have conducted a process-based temperature model (see Section VI.3 below for a discussion on methods to demonstrate natural background temperatures). If a State or Tribe determines that the natural background temperature is higher than 20°C for a particular location and wants to establish a numeric criterion higher than 20°C, it should follow the procedures described in Section VI.1.B for the establishment of site-specific numeric criteria based on natural background conditions.

To protect this use, EPA recommends a 20°C maximum 7DADM numeric criterion *plus* a narrative provision that would require the protection, and where feasible, the restoration of the natural thermal regime. EPA believes that a 20°C criterion would protect migrating juveniles and adults from lethal temperatures and would prevent migration blockage conditions. However, EPA is concerned that rivers with significant hydrologic alterations (e.g., rivers with dams and reservoirs, water withdrawals, and/or significant river channelization) may experience a loss of temperature diversity in the river, such that maximum temperatures occur for an extended period of time and there is little cold water refugia available for fish to escape maximum temperatures. In this case, even if the river meets a 20°C criterion for maximum temperatures, the duration of exposure to 20°C temperatures may cause adverse effects in the form of increased disease and decreased swimming performance in adults, and increased disease, impaired smoltification, reduced growth, and increased predation for late emigrating juveniles (e.g., fall chinook in the Columbia and Snake Rivers). Therefore, in order to protect this use with a 20°C criterion, it may be necessary for a State or Tribe to supplement the numeric criterion with a narrative provision to protect and, where feasible, restore the natural thermal regime for rivers with significant hydrologic alterations.

Critical aspects of the natural thermal regime that should be protected and restored include: the spatial extent of cold water refugia (generally defined as waters that are 2°C colder than the surrounding water), the diurnal temperature variation, the seasonal temperature variation (i.e., number of days at or near the maximum temperature), and shifts in the annual temperature pattern. The narrative provision should call for the protection, and where feasible, the restoration of these aspects of the natural temperature regime. EPA notes that the *protection* of existing cold water refugia should already be provided by the State's or Tribe's antidegradation provisions or by the cold water protection provisions discussed in Section V.2 below. Thus, the new concept introduced by the narrative provision EPA recommends here is the *restoration* of the natural thermal regime, where feasible.

Although some altered rivers, such as the Columbia and Snake, experience similar summer maximum temperatures today as they did historically, there is a big difference between the temperatures that fish experience today versus what they likely experienced historically. Unaltered rivers generally had a high degree of spatial and temporal temperature diversity, with portions of the river or time periods that were colder than the maximum river temperatures. These cold portions or time periods in an otherwise warm river provided salmonids cold water refugia to tolerate such situations. The loss of this temperature diversity may be as significant to salmon and trout in the Columbia and Snake Rivers and their major tributaries as maximum temperatures. Therefore, protection and restoration of temperature diversity is likely critical in order for salmonids to migrate through these waters with minimal thermal stress.

The areas where relatively cold tributaries join the mainstem river and where groundwater exchanges with the river flow (hyporheic flow) are two critical areas that provide cold water refugia for salmonids to escape maximum temperatures. As described in Issue Paper 3 and the *Return to the River* report (2000), alluvial floodplains with a high level of groundwater exchange historically provided high quality habitat that served as cold water refugia during the summer for large rivers in the Columbia River basin (and other rivers of the Pacific Northwest). These alluvial reaches are interspersed between bedrock canyons and are like beads on a string along the river continuum. Today, most of the alluvial floodplains are either flooded by dams, altered through diking and channelization, or lack sufficient water to function as refugia. Efforts to restore these alluvial river functions and maintain or cool down tributary flows will probably be critical to protect this use.

As noted above, EPA recommends that States and Tribes include a natural thermal regime narrative provision to accompany the 20°C numeric criterion. If a State or Tribe chooses to do so, TMDL allocations would reflect the protection, and where feasible, the restoration of the cold water refugia and other aspects of the natural thermal regime described above. If it is impracticable to quantify allocations to restore the natural thermal regime in the TMDL load allocations, then the TMDL assessment document should qualitatively address the human impacts that alter the thermal regime. Plans to implement the TMDL (e.g., watershed restoration plans) should include measures to restore the potential areas of cold water refugia and the natural daily and seasonal temperature patterns. See Section VI.2.B below for a similar discussion regarding TMDLs designed to meet temperature targets exceeding 18°C.

V.1.D. Discussion of Uses and Criteria Presented in Table 4

As discussed in Section V.1.B above, EPA recommends additional uses and criteria that would generally apply during times other than the period of summer maximum temperatures. These additional uses and criteria are intended to provide an added degree of protection for those situations where control of the summer maximum temperature is inadequate to protect these sensitive uses. EPA's recommendations assume that when these uses do occur during the time of summer maximum temperatures, these more sensitive uses and associated numeric criteria would apply.

In many situations, if the summer maximum criteria are attained (e.g., 12°C, 16°C, 18°C, 20°C), EPA expects that temperatures will be low enough due to typical spring warming and fall cooling patterns to support the uses described below. However, in developing this guidance, EPA did not assess data in sufficient detail to determine the extent to which these uses are protected vis-a-vis the summer maximum criterion. With respect to spawning and egg incubation, EPA is most concerned about protecting spawning and egg incubation that occurs during, or soon before or after, the period of summer maximum temperatures (e.g., spring chinook, summer chum, and bull trout spawning that occurs in the mid-to-late summer, and steelhead trout egg incubation that extends into the summer months).

In waters where there is a reasonable basis in concluding that control of the summer maximum criterion sufficiently protects some or all of the uses described below, it may be reasonable not to designate some of all of these specific salmonid uses (i.e., the use will be protected by the summer maximum criterion).

Bull Trout Spawning - 9°C 7DADM

EPA recommends this use for the protection waterbodies used or potentially used by bull trout for spawning, which generally occurs in the late summer-fall in the upper basins (the same waters that bull trout juveniles use for summer rearing). EPA recommends a 9°C maximum 7DADM criterion for this use and recommends that the use apply from the average date that spawning begins to the average date incubation ends (the first 7DADM is calculated 1 week after the average date that spawning begins). Meeting this criterion at the onset of spawning will likely provide protective temperatures for egg incubation (2 - 6°C) that occurs over the winter assuming the typical annual thermal pattern.

Salmon and Trout Spawning, Egg Incubation, and Fry Emergence - 13°C 7DADM

EPA recommends this use for the protection of waterbodies used or potentially used for salmon and trout spawning, egg incubation, and fry emergence. Generally, this use occurs: (a) in spring-early summer for trout (mid-upper reaches); (b) in late summer-fall for spring chinook (mid-upper reaches) and summer chum (lower reaches); and (c) in the fall for coho (mid-reaches), pink, chum, and fall chinook (the latter three in lower reaches). EPA recommends a 13°C maximum 7DADM criterion to protect these life stage uses for salmon and trout and recommends that this use apply from the average date that spawning begins to the average date incubation ends (the first 7DADM is calculated 1 week after the average date that spawning begins). Meeting this criterion at the onset of spawning for salmon and at the end of incubation for steelhead trout will likely provide protective temperatures for egg incubation (6 - 10°C) that occurs over the winter (salmon) and spring (trout), assuming the typical annual thermal pattern.

Steelhead Trout Smoltification - 14°C 7DADM

EPA recommends this use for the protection of waters where and when the early stages of steelhead trout smoltification occurs or may occur. Generally, this use occurs in April and May as steelhead trout make their migration to the ocean. EPA recommends a 14°C maximum 7DADM steelhead smoltification criterion to protect this sensitive use. As described in Table 1, steelhead smoltification can be impaired from exposure to greater than 12°C constant temperatures. The greatest risk to steelhead is during the early stages of smoltification that occurs in the spring (April and May). For the Columbia River tributaries, 90% of the steelhead smolts are typically past Bonneville dam by the end of May (Issue Paper 5, pg 59), indicating that applying this criterion at the mouths of major tributaries to the Columbia River in April and

May will likely protect this use. Applying this criterion to the Columbia River itself is probably unnecessary because the more temperature-sensitive early stages of smoltification occur in the tributaries. If steelhead in the early smoltification process are exposed to higher temperatures than the recommended criterion, they may cease migration or they may migrate to the ocean undeveloped, thereby reducing their estuary and ocean survival.

V.2. Provisions to Protect Water Temperatures That Are Currently Colder Than The Numeric Criteria

One of the important principles in protecting populations at risk for any species is to first protect the existing high quality habitat and then to restore the degraded habitat that is adjacent to the high quality habitat. Further, EPA's WQS regulations recognize the importance of protecting waters that are of higher quality than the criteria (in this case, waters that are colder than numeric temperature criteria). See 40 C.F.R. § 131.12. EPA, therefore, believes it is important to have strong regulatory measures to protect waters with ESA-listed salmonids that are currently colder than EPA's recommended criteria. These waters likely represent the last remaining strongholds for these fish.

Because the temperatures of many waters in the Pacific Northwest are currently higher than the summer maximum criteria recommended in this guidance, the high quality, thermally optimal waters that do exist are likely vital for the survival of ESA-listed salmonids. Additional warming of these waters will likely cause harm by further limiting the availability of thermally optimal waters. Further, protection of these cold water segments in the upper part of a river basin likely plays a critical role in maintaining temperatures downstream. Thus, in situations where downstream temperatures currently exceed numeric criteria, upstream temperature increases to waters currently colder than the criteria may further contribute to the non-attainment downstream, especially where there are insufficient fully functioning river miles to allow the river to return to equilibrium temperatures (Issue Paper 3). Lastly, natural summertime temperatures in Pacific Northwest waters were spatially diverse, with areas of cold-optimal, warm-optimal, and warmer than optimal water. The 18°C and 20°C criterion described in Table 3 and the natural background provisions and use attainability pathways described in Section VI are included in this guidance as suggested ways to address those waters that are warmer than optimal for salmonids. EPA believes it is important, however, for States and Tribes to balance the effects of the warmer waters by adopting provisions to protect waters that are at the colder end of their optimal thermal range.

EPA, therefore, recommends that States and Tribes adopt strong regulatory provisions to protect waterbodies with ESA-listed salmonids that currently have summer maximum temperatures colder than the State's or Tribe's numeric criteria. EPA believes there are several ways a State or Tribe may do this. One approach could be to adopt a narrative temperature criterion (or alternatively include language in its antidegradation rules) that explicitly prohibits more than a de minimis increase to summer maximum temperatures in waters with ESA-listed salmonids that are currently colder than the summer maximum numeric criteria. Another approach could be to identify and designate waterbodies as ecologically significant for temperature and either establish site-specific numeric criteria equal to the current temperatures or prohibit temperature increases above a de minimis level in these waters. States and Tribes following this latter approach should conduct a broad survey to identify and designate such waters within the state (or tribal lands). For non-summer periods it may be appropriate to set a maximum allowable increase (e.g., 25% of the difference between the current temperature and the criterion) for waters with ESA-listed salmonids where temperatures are currently lower than the criteria.

Provisions to protect waters currently colder than numeric criteria can also be important to ensure numeric criteria protect salmonid uses. As discussed in Section V.1.A, the recommended criteria in this guidance are based in part on the assumption that meeting the criteria at the lowest downstream point at which the use is designated will likely result in cooler waters upstream. Cold water protection provisions as described here provide more certainty that this will be true. Further, if a State chooses to protect some or all of the sensitive uses in Table 4 (e.g., spawning) by using only the summer maximum criteria, it may also be necessary to protect waters currently colder than the summer maximum numeric criteria in order to assure that these sensitive uses are protected. Further, as described in Section V.1.B, protecting existing cold water is likely important in river reaches where a 20°C numeric criterion applies to protect salmon and trout migration use.

V.3. Provisions to Protect Salmonids from Thermal Plume Impacts

EPA recommends that States and Tribes add specific provisions to either their temperature or mixing zone sections in their WQS to protect salmonids from thermal plume impacts. Specifically, language should be included that ensures that thermal plumes do not cause instantaneous lethal temperatures; thermal shock; migration blockage; adverse impact on spawning, egg incubation, and fry emergence areas; or the loss of localized cold water refugia. The following are examples from the scientific literature of potential adverse impacts that may result from thermal plumes, and EPA's recommendations to avoid or minimize those impacts.

- Exposures of less than10 seconds can cause instantaneous lethality at 32°C (WDOE, 2002). Therefore, EPA suggest that the maximum temperature within the plume after 2 seconds of plume travel from the point of discharge does not exceed 32°C.

- Thermal shock leading to increased predation can occur when salmon and trout exposed to near optimal temperatures (e.g., 15°C) experience a sudden temperature increase to 26 - 30°C for a short period of time (Coutant, 1973). Therefore, EPA suggests that thermal plumes be conditioned to limit the cross-sectional area of a river that exceeds 25°C to a small percent of the river (e.g., 5 percent or less).

- Adult migration blockage conditions can occur at 21°C (Table 1). Therefore, EPA suggests that the cross-sectional area of a river at or above 21°C be limited to less than 25% or, if upstream temperature exceeds 21°C, the thermal plume be limited such that 75% of the cross-sectional area of the river has less than a de minimis (e.g., 0.25°C) temperature increase.

- Adverse impacts on salmon and trout spawning, egg incubation, and fry emergence can occur when the temperatures exceed 13°C (Table 1). Therefore, EPA suggests that the thermal plume be limited so that temperatures exceeding 13°C do not occur in the vicinity of active spawning and egg incubation areas, or that the plume does not cause more than a de minimis (e.g., 0.25°C) increase in the river temperature in these areas.

VI. Approaches to Address Situations Where the Numeric Criteria are Unachievable or Inappropriate

There are likely to be some streams and rivers in the Pacific Northwest where the criteria recommended in this guidance cannot be attained or where the criteria recommendations would otherwise be inappropriate. The following approaches are available under EPA's regulations to address these circumstances. See 40 C.F.R. Part 131. EPA describes these approaches below and recommends when it believes each approach may be appropriate.

It is important to note that most of these approaches are subject to EPA review and approval on a case-by-case basis (either in the form of a WQS, TMDL, or a 303(d) list approval), and where appropriate, are subject to consultation with the Services and affected Tribes.

VI.1. Alternative Criteria

The following are three possible ways to establish alternative numeric criteria that would apply to a specific location.

VI.1.A. Site-Specific Numeric Criteria that Supports the Use

Under this approach, the State or Tribe would demonstrate that conditions at a particular location justify an alternative numeric criterion to support the designated salmonid use. See 40 C.F.R. § 131.11(b)(1)(ii). One example may be the adoption of a 13°C 7DADM criterion (instead of EPA's recommended 12°C criterion) to protect bull trout rearing use in areas where competition with other fish is minimal and food sources are abundant. Another example may be where there is exceptionally high natural diurnal temperature variation and where the maximum weekly mean temperature is within the optimal temperature range but, because of the high diurnal variation, summer maximum temperatures exceed the State or Tribe's numeric criteria. In this situation, a State or Tribe may choose to develop a site-specific numeric criterion based on a metric other that the 7DADM (e.g., a maximum weekly mean criterion plus a daily maximum criterion). There may be other situations as well when an alternative site-specific criterion would be appropriate. The State or Tribe would need to provide a clear description of the technical basis and methodology for deriving the alternative criterion and describe how it fully supports the designated use when it submits the criterion to EPA for approval. See 40 C.F.R. § 131.11(a).

VI.1.B. Numeric Criteria Based on Estimates of Natural Background Temperatures

Under this approach a State or Tribe could establish numeric criteria based on an estimate of the natural background temperature conditions. This would be another form of site-specific criteria under 40 C.F.R. § 131.11(b)(1)(ii). Natural background temperatures are those that would exist in the absence of human-activities that alter stream temperatures. States or Tribes following this approach may elect to adopt a single numeric criterion for a particular stream segment, such as a lower mainstem river, or adopt a numeric profile (i.e., a range of numbers typically colder in the headwaters and warmer downstream) for a whole watershed or sub-basin.

EPA views numeric criteria that reflect natural background conditions to be protective of salmonid designated uses because river temperatures prior to human impacts clearly supported healthy salmonid populations. Thus, when establishing site-specific numeric criteria in this manner, EPA believes it is unnecessary to modify the use designations. For example, if a State has designated a waterbody as salmon/trout core juvenile rearing use with an associated numeric criterion of 16°C 7DADM and later estimates the natural background temperature is 18°C 7DADM, the 18°C 7DADM could be adopted as a site-specific criterion that fully supports the salmon and trout core juvenile rearing use. A State or Tribe may also want to modify the spatial extent of its various salmonid use designations within the basin if the estimates of natural background provide new information that warrants such revisions. Additionally, at the time the State revises a salmonid use for a waterbody (e.g., designating a salmon/trout migration use), it could choose to establish a numeric criterion based on natural background conditions for that particular waterbody (e.g., 22°C 7DADM), which may be different from the generally applicable numeric criterion to support that use in the State's WQS (e.g., 20°C 7DADM).

States and Tribes following this approach will need to submit any such new or revised numeric criteria to EPA for approval and must include the methodology for determining the natural background condition. See 40 C.F.R. §§ 131.6 & 131.11(a). An alternative to establishing numeric criteria based on natural background conditions as described here is to adopt a narrative natural background provision, which would then be used in CWA section 303(d) listings, TMDLs, and NPDES permits as described in Section VI.2.

VI.1.C. Numeric Criteria In Conjunction with a Use Attainability Analysis

In situations where it appears that the numeric criterion or natural background provision (see Section VI.2) cannot be attained and the appropriateness of the designated use is in question, a State or Tribe could conduct a use attainability analysis (UAA) pursuant to 40 C.F.R. §§ 131.3(g) & 131.10. If it can be demonstrated that the current designated use is not attainable due to one of the factors at 40 C.F.R § 131.10(g), the State or Tribe must then adopt a different use appropriate to that water. See 40 C.F.R. § 131.10(a). In most cases, EPA expects that the appropriate use would be the most protective salmonid use that is attainable. The State or Tribe must then adopt a temperature criterion sufficient to protect that new use. See 40 C.F.R. § 131.11. EPA notes that, in all cases, uses attained since 1975, referred to as "existing uses," must be protected. See 40 C.F.R Part 131.10(h)(1). The new use could be described as a "compromised" or "degraded" salmonid use. It should be noted that a "compromised" or "degraded" level of use may be appropriate during part of the year (e.g., summer), but that an unqualified, healthy salmonid use may be attainable other times of the year and therefore may be the appropriate use then.

Examples of factors at 40 C.F.R. § 131.10(g) that could preclude attainment of the use include: human caused conditions or sources of pollution that cannot be remedied or would cause more environmental damage to correct than to leave in place; dams, diversions or other types of hydrologic modifications that cannot be operated in such a way as to result in the attainment of the use; and controls more stringent than those required by sections 301(b) and 306 of the CWA that would result in substantial and widespread economic and social impact.

Whenever a State or Tribe adopts new or revised designated uses, such as those described here, it is changing its WQS. Therefore, the State or Tribe must make the proposed change available for public notice and comment and must submit the new use and associated criteria, together with the supporting UAA, to EPA for review and approval. See CWA section 303(c)(1) & (c)(2)(A); 40 C.F.R. §§ 131.5 & 131.6. EPA recommends that a UAA seeking to demonstrate human impacts (including dams, diversions, or other hydrologic modifications) that prevent attainment of the current use, should include a full assessment of all possible mitigation measures and their associated costs when demonstrating which mitigation measures are not feasible. EPA's decision to approve or disapprove a use and criteria change associated with a UAA will need to be made on a case-by-case basis, taking into account the information available at the time, and where appropriate, after consultation with the Services and affected Tribes.

VI.2. Use of a State's or Tribe's "Natural Background" Provisions

If it has not already done so, a State and Tribe may wish to consider adopting *narrative* natural background provisions in its WQS that would automatically take precedence over the otherwise applicable numeric criteria when natural background temperatures are higher than the numeric criteria. See 40 C.F.R. § 131.11(b)(2). If adopted by a State or Tribe and approved by EPA, narrative natural background provisions would be the applicable water quality criteria for CWA purposes when natural background temperatures are higher than the numeric criteria and would be utilized in 303(d) listings of impaired waterbodies, TMDLs, and NPDES permits in such situations. As discussed in Section V.1.B above, a State could also consider adopting a specific numeric criterion that reflects natural background temperatures (rather than leave natural background temperatures to case-by-case interpretation). The discussion here, however, assumes that a State or Tribe has not done so and instead has adopted a *narrative* natural background provision and would interpret it when necessary for CWA purposes.

VI.2.A. 303(d) Listings

If it can be demonstrated that a particular waterbody exceeds a temperature numeric criterion due to natural conditions (or natural conditions plus a de mimimis human impact, if a State or Tribe has this allowance in its WQS - see Section V.1.A), then the waterbody need not be listed on a State's or Tribe's 303(d) list. Such waterbodies would not be considered impaired because they would be meeting the narrative natural background provisions of the WQS. These waterbodies should be identified as an attachment to a State's or Tribe's section 303(d) list submission to EPA along with the demonstration that these waters do not exceed the natural background provision.

For situations where waterbodies exceed the applicable numeric criteria due to a combination of apparent natural background conditions and known or suspected human impacts (above a de minimis impact level, if applicable), it would be appropriate to list those waters on the 303(d) list because the waters would be exceeding the narrative natural background provision because of the human impacts. The TMDL process, described below, will provide the opportunity to distinguish the natural sources from the human caused sources.

VI.2.B. TMDLs

A State's or Tribe's narrative natural background provisions can be utilized in TMDLs to set water quality targets and allocate loads when natural background conditions are higher than the otherwise applicable numeric criteria. When doing so, estimated temperatures associated with natural background conditions would serve as the water quality target for the TMDL and would be used to set TMDL allocations. Thus, the TMDL would be written to meet the WQS natural background provision, and the load reductions contemplated by the TMDL would be equivalent to the removal of the human impacts (or all but de minimis human impacts, if applicable). It should be noted that if a State or Tribe has a de minimis temperature increase allowance above natural background temperatures (see Section V.1.A), the TMDL allocations should be based on attaining the natural background temperature plus the de minimis temperature allowance (e.g., natural background temperature plus 0.25°C).

When estimating natural background conditions, States and Tribes should use the best available scientific information and the techniques described in Section VI.3 below. For TMDLs, this usually includes temperature models. Those human impacts that cannot be captured in a model (e.g., loss of cooling due to loss of hyporheic flow, which is water that moves between the stream and the underlying streambed gravels) should be identified in the TMDL assessment document (i.e., supporting material to the TMDL itself) along with rough or qualitative estimates of their contribution to elevated water temperatures. Estimates of natural conditions should also be revisited periodically as our understanding of the natural system and temperature modeling techniques advance.

When using natural background maximum temperatures as TMDL targets and to set TMDL allocations, the TMDL assessment document should assess other aspects of the natural thermal regime including the spatial extent of cold water refugia (which, generally are defined as waters that are ≥2°C colder than the surrounding water), the diurnal temperature variation, seasonal temperature variation (i.e., number of days at or near the maximum temperature), and shifts in the annual temperature pattern. Findings from this assessment should be integrated into the TMDL and its allocations to the extent possible. For example, if possible, TMDL allocations should incorporate restoration of the diurnal and seasonal temperature regime and cold water refugia that reflect the natural condition. If it is impracticable to address these impacts quantitatively through allocations, then the TMDL assessment document should qualitatively discuss the human activities that modify these aspects of the natural thermal regime. Plans to implement the TMDL should include measures to restore and protect these unique aspects of the natural condition.

EPA believes it is particularly important for the TMDL itself or the TMDL assessment document to address the above aspects of the natural thermal regime for waterbodies where the natural background maximum 7DADM temperature exceeds 18°C and where the river has significant hydrologic alterations (e.g., dams and reservoirs, water withdrawals, and/or significant river channelization) that have resulted in the loss of temperature diversity in the river or shifted the natural temperature pattern. For example, there may be situations where the natural background maximum temperatures exceed 18°C, but historically the exposure time to maximum temperatures was limited due to the comparatively few number of hours in a day that the water reached these temperatures, the comparatively few number of days that reached these temperatures, and plentiful cold water refugia from cold tributary flows and hyporheic flow in alluvial floodplains where salmonids could avoid the maximum water temperatures.

If human impacts as identified at 40 C.F.R. 131.10(g) are determined to prevent attainment of the natural background conditions, the State or Tribe should follow the UAA process described in Section VI.1.C above and revise the use and adopt numeric criteria that would support a revised use. This new numeric criteria, if approved by EPA, would then be the temperature target in the TMDL and used to set load allocations.

Before determining that some of the human impacts preclude use attainment and pursuing a UAA, EPA Region 10 encourages States to develop and begin implementing TMDLs that reflect the applicable numeric criteria or natural background provisions and allow some time for implementation to proceed. EPA Region 10 encourages this approach because it is often the case that at the time a TMDL is developed there is little information on all the possible implementation measures and their associated costs, which may be important to justify a UAA. Further, after feasible implementation measures are completed, there will be better information as to what is the actual attainable use and associated water temperatures. If information is available at the time, however, it is possible for a State to conduct a UAA concurrently with the TMDL development process and, if appropriate, to revise the designated use and adopt new applicable numeric criteria for use when establishing the TMDL.

VI.2.C. NPDES Permits

When a permitting authority is establishing a temperature water quality-based effluent limit for an NPDES source, it must base the limit on the applicable water quality standards, which could be the numeric criteria or, if applicable, the narrative natural background provision. See 40 C.F.R. § 122.44(d)(1). EPA expects that, in most cases, the natural background temperature will be interpreted and expressed for the first time in a TMDL, but it is possible for the natural background temperature to be determined outside the context of a TMDL, although this would be unusual given the complexities involved in estimating natural background temperatures.

VI.3. Overview of Methods to Estimate Natural Background Temperatures

There are a number of different ways of estimating natural background temperature conditions for the purposes of either adopting a site-specific criterion (see Section VI.1.B) or interpreting a narrative natural background provision (see Section VI.2). These include: (1) demonstrating that current temperatures reflect natural background conditions, (2) using a non-degraded reference stream for comparison, (3) using historical temperature data, (4) using statistical or computer simulation models, and (5) assessing the historical distribution of salmonids. There may be other ways as well. Each approach has its strengths and weaknesses and therefore may or may not be most appropriate for a given situation. Moreover, all of these approaches have uncertainty, which should be quantitatively described where possible. EPA encourages the use of a combination of approaches to estimate natural background temperatures, where feasible. Below is an overview of the five approaches listed above.

Demonstrating That Current Temperatures Reflect Natural Background Conditions

Under this approach, the past and present human activities that could impact the river temperatures are documented and a technical demonstration is made that the human activities do not currently impact temperatures. This approach is most applicable to non-degraded watersheds (e.g., state and national parks, wilderness areas, and protected state and national lands). These watersheds can be used as "reference" streams for estimating the natural background temperatures of degraded streams (see below). If there is a small human impact on temperatures, it may also be possible to estimate the human impact and subtract it from current temperatures to calculate the natural background temperatures.

Comparisons to a Reference Stream

It is often reasonable to assume that the natural background temperatures of a thermally degraded stream are similar to that of a non-degraded stream, so long as the location, landscape context, and physical structure of the stream are sufficiently similar. The challenge to this approach is finding a reference stream that is of similar location, landscape context, and physical structure. Because large rivers are unique and most in the Pacific Northwest have been significantly impacted by human activities, this approach is most applicable to smaller streams where a reference stream with current temperatures at natural background conditions exist.

Historical Data

For some rivers, historical temperature data are available that reflect temperatures prior to human influences on the river's temperature regime, and can be used as an estimate of natural background temperatures. Factors that lend uncertainty to historic temperature data are the uncertain nature of the quality of the data and whether or not humans affected temperature prior to data collection. Further, historical temperature data often do not adequately capture the spatial and/or temporal variability in stream temperature due to limited spatial or temporal sampling. Historical data may be useful, however, for verifying estimates of modeled natural background temperatures.

Temperature Models

Two major methods have been commonly used for water quality modeling in the United States over the last 20 years: 1) statistical models, which are based on observed relationships between variables and are often used in conjunction with measurements from a reference location, and 2) process-based models, which attempt to quantify the natural processes acting on the waterbody. Process-based models are often employed when no suitable reference locations can be identified.

Statistical models, also referred to as empirical models, estimate the thermal conditions of streams by using statistics to find correlations between stream temperature and those landscape characteristics that control temperature (e.g., elevation, latitude, aspect, riparian cover, etc.). The equations in statistical models describe the observed relationships in the variables as they were measured in a specific location. If the specific location is a non-degraded reference stream, then the model can be used to estimate natural background conditions in degraded streams. Statistical models have the advantage of being relatively simple, as they rely on general data and statistics to develop correlations.

The comparability between the reference waterbody where the statistical correlations are generated and the assessment waterbody strongly affects the applicability of statistical models. Uncertainties in statistical model results increase with increasing dissimilarity between the landscape characteristics of the reference and assessment water bodies. Uncertainties also increase when models do not include landscape characteristics that control important processes affecting the water temperature. For these reasons, statistical models are best suited for small headwater streams or for generalized predictions across a large landscape.

Process models, also referred to as simulation models, are based on mathematical characterizations of the current scientific understanding of the critical processes that affect water temperature in rivers. The equations are constructed to represent the observed or expected relationships and are generally based on physical or chemical principles that govern the fate and transport of heat in a river (e.g., net heat flux from long-wave radiation, direct short wave radiation, convection, conduction, evaporation, streamside shading, streambed friction, and water's back radiation) (Bartholow, 2000).

Estimating water temperature with a process model is generally a two-step process. As a first step, the current river temperatures are estimated with the input parameters (e.g., amount of shade provide by the canopy and river depth, width, and flow) reflecting current conditions and the model error is calculated by comparisons of the model estimate to actual temperature measurements. The second step involves changing the model input parameters to represent natural conditions, which results in a model output that predicts the natural background conditions. In recent years, increases in computer processing power have led to the development of distributed process models, which incorporate a high degree of spatial resolution. These models use Geographical Information Systems (GIS), remotely-sensed data, and site-specific data to vary the model's input parameters at different locations in the waterbody or the landscape.

Unlike statistical models, process models do not rely upon data from reference locations, so they can be used for rivers that have no suitable natural reference comparisons available. Thus, process models are well suited for estimating natural conditions for larger streams and rivers. Although powerful, process models are by no means infallible. Errors can arise when there are locally important factors that the model does not address, or when there is a great deal of uncertainty in input parameters that strongly influence the model results.

In addition to estimating natural background conditions, process-based models are useful for understanding the basic mechanisms influencing water temperature in a watershed, understanding the relative contributions from different sources at different locations, understanding cumulative downstream impacts from various thermal loads, performing "what if" scenarios for different mitigation options, and setting TMDL allocations.

Historical Fish Distributions

Maps of historic salmonid distributions and their time of use can provide rough estimates of natural background temperatures. Where and when salmonids existed historically likely provided temperatures suitable for salmonids and, as described in this guidance, we have a fairly good understanding of suitable temperatures for various life stages of salmonids.

VII. Using EPA's Guidance to Change Salmonid Use Designations

The States of Idaho, Oregon, Washington and Pacific Northwest Tribes with WQS currently have salmonid use designations that are less spatially and temporally specific than those recommended in Section V.1 of this guidance. For instance, several States and Tribes employ broad salmonid use designations (e.g., migration, rearing, spawning) that apply generally to an entire basin or watershed. EPA's recommendations in Section V.1 are intended to assist States and Tribes with broad use designations to more precisely define when and where the different salmonid uses currently occur or may potentially occur within a basin.

For example, at the present time, a State may have a spawning use designated for an entire basin (or large waterbody), but not specify the waterbody segments or times of year to which that use designation should apply. After considering information that indicates where and when spawning currently occurs or may potentially occur, that State might decide that only certain locations and times in the basin should be designated for spawning. This same situation may also occur in the context of rearing and migration uses.

The intent of EPA's recommendations is to encourage States and Tribes, through these types of use refinements, to adopt a suite of interdependent salmonid uses. This suite of uses, in essence, would function as a single aquatic life use designation for the protection, at all life stages, of a sustainable salmonid population. Consequently, EPA believes that, as a general matter, use designations within a basin that reflect, at the appropriate times and places, the complete suite of uses to protect healthy salmonid populations at all life stages would fully protect the CWA section 101(a)(2) aquatic life uses. EPA, therefore, would not expect a UAA to accompany such use refinements as long as the overall sustainable salmonid population use is still being protected. See 40 C.F.R. § 131.10(k). It should be noted, however, that these types of use refinements are changes to a State's of Tribe's WQS and therefore require public notice and review and EPA approval.

VIII. Temperature Limits for NPDES Sources

Section 301(b)(1)(C) of the CWA requires the achievement of NPDES effluent limitations as necessary to meet applicable WQS. EPA Region 10's general practice is to require that numeric criteria be met at end-of-pipe in impaired waterbodies (i.e., those that exceed water quality criteria). However, EPA Region 10 believes that in some situations numeric criteria end-of-pipe effluent limits for temperature may not be necessary to meet applicable WQS and protect salmonids in impaired waters. This is because the temperature effects from point source discharges generally diminish downstream quickly as heat is added and removed from a waterbody through natural equilibrium processes. The effects of temperature are unlike the effects of chemical pollutants, which may remain unaltered in the water column and/or accumulate in sediments and aquatic organisms. Further, temperature impairments in Pacific Northwest waters are largely caused by non-point sources. However, there may be situations where numeric criteria (or near numeric criteria) end-of-pipe effluent limits would be warranted, such as where a point source heat discharge is significant relative to the size of the river.

If a facility discharging heat into an impaired waterbody is seeking an effluent limit that is different than end-of-pipe numeric criteria, it should undertake a comprehensive temperature study. EPA recommends that regulatory authorities develop guidance on the content of these studies and on how alternative effluent limits may be developed that protect salmonids. EPA recommends that a temperature study, at a minimum, should consist of the following:

- A detailed engineering evaluation of sources of heat and possible measures to eliminate/reduce the heat sources and/or mitigate the effect of the heat sources. This could, for example, take the form of an engineering analysis of manufacturing processes or an investigation of sources of heat into publically-owned treatment plants. The engineering evaluation should include cost estimates for the possible temperature reduction measures.

- A modeling evaluation to determine a preliminary temperature effluent limit that meets the numeric criterion for the waterbody (or natural background temperature if applicable - see Section VI.2.C). For instance, it may be appropriate to use a simple energy balance equation (U.S. EPA, 1996) to calculate an effluent temperature that would ensure any downstream temperature increase above the numeric criterion (or natural background temperature) is de minimis (e.g., less than 0.25°C) after complete mixing. This approach assumes the State's or Tribe's WQS includes a de minimis temperature allowance as described in Section V.1.A. When using this approach, EPA recommends that the upstream water temperatures be assumed to be at the numeric criterion (or natural background temperature) and that a river flow be used that minimizes the percentage of the flow utilized for mixing purposes (e.g., 25% of 7Q10). The preliminary temperature effluent limit using this method should not exceed the current effluent temperature. In some situations it may be appropriate to utilize more complex modeling than described here (e.g., waters with multiple point source impacts).

- An evaluation of localized impacts of the thermal plume on salmonids based on plume modeling. The physical characteristics of the thermal plume (e.g., a 3-dimensional profile of temperatures) can be estimated using a near-field dilution model and adequate input data to run the model (e.g., river and effluent temperatures and flows). The preliminary effluent temperature derived from above (i.e., the effluent temperature derived from the energy balance equation or the current effluent temperature, whichever is lower) should be used in the model along with the current river temperature and flow for the seasons of concern. The preliminary effluent limit should be lowered, if necessary, to ensure that the localized adverse impacts on salmonids described in Section V.3 are avoided or minimized.

The results of these evaluations should be used to assist in the development of the final permit effluent limit in waters where a temperature TMDL has yet to be completed. Modeling evaluations, such as those described above, should be used in temperature TMDLs to help set wasteload allocations that can be used as temperature limits in NPDES permits. It may not be practicable, however, to complete near-field plume modeling for some or all point sources in large-scale temperature TMDLs. In these situations, the TMDL should indicate that the thermal plume modeling be done during permit development, which may result in an effluent limit lower than the TMDL wasteload allocation.

EPA Region 10 also believes that water quality trading may hold some promise to meet temperature WQS in a cost-effective manner that is beneficial for salmonids. In particular, a point source may be able to seek trades with non-point sources as a mechanism to meet its NPDES obligations. For example, a point source may help secure non-point controls beyond minimum state requirements, such as re-vegetation of a river's riparian zone, and use those temperature reductions to help meet its temperature reduction obligations. EPA encourages the use of this potentially valuable approach to help attain temperature WQS.

IX. The Role of Temperature WQS in Protecting and Recovering ESA-Listed Salmonids and Examples of Actions to Restore Suitable Water Temperatures

EPA Region 10 and the Services believe that State and Tribal temperature WQS can be a valuable tool to protect and aid in the recovery of threatened and endangered salmonid species in the Pacific Northwest. The following are three important ways that temperature WQS, and measures to meet WQS, can protect salmonid populations and thereby aid in the recovery of these species. The first is to protect existing high quality waters (i.e., waters that currently are colder than the numeric criteria) and prevent any further thermal degradation in these areas. The second is to reduce maximum temperatures in thermally degraded stream and river reaches immediately downstream of the existing high quality habitat (e.g., downstream of wilderness areas and unimpaired forest lands), thereby expanding the habitat that is suitable for coldwater salmonid rearing and spawning. The third is to lower maximum temperatures and protect and restore the natural thermal regime in lower river reaches in order to improve thermal conditions for migration.

The following are examples of specific on-the-ground actions that could be done to meet temperature WQS, protect salmonid populations and also aid in the recovery of threatened and endangered salmonid species. Logically, these example actions are oriented toward reversing the human activities that can contribute to excess warming of river temperatures described in Section IV.2. See Issue Paper 3, Coutant (1999), and Return to the River (2000) for more detailed discussion. EPA encourages and hopes to help facilitate these types of actions and recognizes that collaborative efforts with multiple stakeholders holds the most promise to implement many of these measures.

- Replant native riparian vegetation
- Install fencing to keep livestock away from streams
- Establish protective buffer zones to protect and restore riparian vegetation
- Reconnect portions of the river channel with its floodplain

- Re-contour streams to follow their natural meandering pattern
- Increase flow in the river derived from more efficient use of water withdrawals
- Discharge cold water from stratified reservoirs behind dams
- Lower reservoirs to reduce the amount of shallow water in “overbank” zones
- Restore more natural flow regimes to allow alluvial river reaches to function
- Restore more natural flow regimes so that river temperatures exhibit a more natural diurnal and seasonal temperature regime

EPA and the Services acknowledge that efforts are underway on the part of some landowners, companies, non-profit organizations, tribes, local and state governments, and federal agencies in the Pacific Northwest to take actions to protect and restore suitable temperatures for salmonids and improve salmonid habitat generally. A few examples of broad-scale actions to improve temperatures for salmonids are: the Aquatic Conservation Strategy of the Northwest Forest Plan (federal lands); the State of Washington’s forest protection regulations; and timber company Habitat Conservation Plans (HCPs), particularly the Simpson HCP, which was done concurrent with a temperature TMDL. Additionally, there are small-scale projects, which are too numerous to list here (e.g., tree plantings, fencing, and re-establishing the natural meandering channel of small streams), that have already contributed or will contribute to improved thermal conditions for salmonids. These efforts represent a good direction and start in the process of restoring stream temperatures in the Pacific Northwest.

EPA and the Services believe it is important to highlight these examples of on-the-ground actions to recognize their contribution to improving water temperatures, to demonstrate their feasibility, and to provide a model for others to take similar actions.

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APR 14 2010

Mr. Phillip Crader
Senior Environmental Scientist
Division of Water Rights
State Water Resources Control Board
P.O. Box 2000
Sacramento, California 95812-2000

Dear Mr. Crader:

We thank the State Water Resources Control Board (SWRCB) members and staff for the opportunity to participate in the Delta Flow Criteria Informational Proceeding on March 22-24, 2010. With jurisdiction over marine resources, including anadromous salmon, steelhead, and sturgeon that migrate through and rear in the Sacramento-San Joaquin Delta (Delta), NOAA's National Marine Fisheries Service (NMFS) is providing these closing comments in our role of offering technical assistance. We are ready to assist the SWRCB in its efforts to develop criteria for flow, temperature, and other conditions necessary for a Delta ecosystem that can support viable fish populations.

Adequate flows are an essential component of habitat for all life stages of listed and non-listed anadromous fish, both upstream in rivers and spawning habitats, and in the Delta. Flows affect cues for both upstream and downstream migration; affect access to and quality and quantity of rearing habitat; affect temperatures necessary for maintaining spawning, egg incubation and juvenile rearing; and are positively correlated with juvenile salmon survival. Delta flow criteria (as well as upstream flow needs) necessary to protect public trust resources in the Delta are summarized below and referenced to relevant exhibits in the materials submitted by NMFS on February 16, 2010.

FLOW RECOMMENDATIONS FROM THE NMFS OPINION[1]

The *Biological and Conference Opinion on the Long-Term Operations of the Central Valley Project (CVP) and State Water Project* (SWP) (Opinion) issued by NMFS in June of 2009

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[1] The Opinion was submitted to the SWRCB as NMFS Exhibit 3 on 2/16/2010.

provides many flow-related actions within its Reasonable and Prudent Alternative (RPA) to protect species listed under the Federal ESA for which NMFS has jurisdiction.[2,3]

- In the Sacramento River Basin, the Opinion includes actions to manage the cold water pool in Shasta Reservoir in order to provide suitable habitat for winter-run Chinook salmon and spring-run Chinook salmon in most years, without sacrificing the potential for cold water management in a subsequent year (Action Suite I.2, p.590-603).

- The Opinion includes a flow schedule for the American River to provide minimum flows for all steelhead life stages (Action II.1, p. 612)

- In the San Joaquin River Basin, the Opinion provides a minimum in-stream flow schedule throughout the year for the Stanislaus River, to protect Central Valley steelhead (Action III.1.3, p. 622-625; Appendix 2-E).

- The Opinion provides an interim minimum flow schedule for the San Joaquin River at Vernalis during April and May (Action IV.2.1, p. 641-645), effective through 2011. These flows are based on maintaining a minimum status quo for San Joaquin River basin salmonids populations. Long term flow schedules for the San Joaquin River are expected to result from the SWRCB proceedings on San Joaquin flows.

- Additionally, in order to improve the outmigration success of San Joaquin River steelhead (as well as Sacramento River salmonids diverted into the interior Delta), Action IV.2.1 of the NMFS Opinion protects a fraction of San Joaquin River flow by means of an inflow (at Vernalis):export (combined CVP and SWP) ratio during April and May. This inflow to export ratio is responsive to water year type and has additional flexibility in the case of multiple dry years or health and safety concerns.

FLOW RECOMMENDATIONS FROM THE NMFS DRAFT RECOVERY PLAN[4]

In October of 2009, NMFS released a *Public Draft Recovery Plan for the Evolutionarily Significant Units of Sacramento River Winter-Run Chinook Salmon and Central Valley Spring-Run Chinook Salmon and the Distinct Population Segment of Central Valley Steelhead* (NMFS

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[2] It is important to note that the flow protections described in the project description and RPA are the minimum flows necessary to avoid jeopardy. The Delta flow criteria necessary to "protect public trust resources" may not be the same as those called for in the NMFS Opinion, and will likely be greater than those described in the opinion. In addition, NMFS considered provision of water to senior water rights holders to be non-discretionary for purposes of the federal ESA as it applies to Section 7 consultation with the Bureau of Reclamation. This constrained development of RPA actions related to Shasta storage actions and flow schedules on the Sacramento River and Stanislaus River. This constraint may not apply to the SWRCB flow criteria process. Vernalis flows in the Opinion were constrained by the Opinion's scope extending only to CVP New Melones operations. Operations on other San Joaquin tributaries were not within the scope of the consultation.

[3] Many of the actions described in the Opinion and NMFS Draft Recovery Plan to improve conditions for ESA-listed species will also improve conditions for fall-run Chinook salmon.

[4] The NMFS Draft Recovery Plan was submitted to the SWRCB as NMFS Exhibit 5 on 2/16/2010.

Draft Recovery Plan). There are numerous actions in the plan that call for improvements to flows for specific life stages and locations. For example, one of the priority actions of the NMFS Draft Recovery Plan is to implement a Sacramento River flow management plan that balances carryover storage need with instream flow and water temperature needs for winter-run Chinook salmon, spring-run Chinook salmon, and steelhead[3] based on runoff and storage conditions, including flow fluctuation and ramping criteria (Action 1.6.6 on p. 159, see also p. 194). Also, the plan calls for development of ecological flows to inundate floodplains and create rearing habitat.

FLOW RECOMMENDATIONS FROM THE NMFS EFH CONSULTATION[5]

In addition to its authority under the Federal ESA, NMFS has authorities under the Magnuson-Stevens Fishery Conservation and Management Act to identify and describe Essential Fish Habitat (EFH) in fishery management plans, and to provide conservation recommendations to any agency taking an action that may adversely affect EFH. NMFS concluded that the proposed long-term operations of the CVP and SWP would adversely affect EFH for Pacific salmon, and offered conservation recommendations (p. 21-29) which include actions upstream of the Delta as well as in the Delta (p. 26-29). Many of the conservation recommendations include flow provisions to protect the habitat of all life history stages of Pacific salmon.

OTHER FLOW RECOMMENDATIONS

As was noted by other participants in the proceeding, many species that live in or migrate through the Delta are affected not just by the amount of flow, but also by the timing, location, and frequency of flows. For example, pulse flows on the Sacramento River drive juvenile abundance and migration patterns of winter-run Chinook salmon in the Delta[6] and flows are also important in improving the production and migration of green sturgeon and white sturgeon[7]. In setting Delta flow criteria, NMFS urges the board to consider the importance of spatial and temporal connectivity of appropriate habitat conditions such that the criteria establish effective rearing and migratory corridors in and through the Delta.

NEEDS UPSTREAM OF THE DELTA MUST BE CONSIDERED WHEN SETTING DELTA FLOW CRITERIA[8]

In order to protect all life history stages of Central Valley salmon, steelhead, and sturgeon, Delta flow criteria must not preclude the ability to meet upstream requirements for flow and temperature maintenance. For example, in the Bay Delta Conservation Plan process, NMFS has recommended the following end of April (and September) Shasta storage numbers deemed necessary to support adequate water temperatures for winter-run Chinook salmon, spring-run Chinook salmon, and fall-run Chinook salmon below Shasta Dam:

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[5] The EFH Conservation Recommendations were submitted to the SWRCB as NMFS Exhibit 6 on 2/16/2010.

[6] Submitted to the SWRCB as NMFS Exhibit 7 on 2/16/2010.

[7] Submitted to the SWRCB as NMFS Exhibit 9 on 2/16/2010.

[8] This discussion of upstream needs is excerpted from the NMFS Written Summary, submitted to the SWRCB on 2/16/2010.

<u>End of April storage in Shasta Reservoir:</u>
Minimum end of April storage for all water year types other than those specified below: 3.8 million acre-feet (MAF; objective to meet Balls Ferry temperature compliance point (TCP) through management of cold water pool releases).

Minimum end of April storage for wet years: 4.2 MAF (objective to meet Jelly's Ferry TCP through adaptive management of cold water pool releases).

Minimum end of April storage for third (or more) year in a series of dry and/or critically dry of years (*i.e.*, a prolonged drought): 3.3 MAF (objective to meet Clear Creek TCP through management of cold water pool releases).

<u>End of September storage in Shasta Reservoir:</u>
Minimum end of September storage: 2.2 MAF (objective to meet 3.8 MAF in end of April in the following year).

Minimum end of September storage for second (or more) year in a series of dry and or critically dry years: 1.9 MAF (objective to meet 3.3 MAF in end of April in the following year).

Similar storage recommendations are included in the Opinion (Action I.2, p 590-603), with consultation among fishery agencies and Bureau of Reclamation built in to develop release schedules that optimize use of the cold water pool and help to maintain sufficient carryover storage.

We look forward to continued collaboration with the SWRCB, the California Department of Fish and Game, the U.S. Fish and Wildlife Service and other interested parties to develop flow criteria and other resource management options that can used throughout the Delta watershed to provide effective protection of resources held in the public trust.

Please contact Barbara Byrne, of my staff, at (916) 930-5612, or via e-mail at barbara.byrne@noaa.gov if you need additional information.

Sincerely,

Maria Rea
Sacramento Area Office Supervisor

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Factors regulating Shasta Lake (California) cold water accumulation, a resource for endangered salmon conservation

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[1] Shasta Lake, in northern California, has recently experienced reduced cold water storage, making it difficult to meet downstream temperature objectives for endangered winter-run chinook salmon spawning habitat. This study used a novel form of time series analysis to examine the causes, timing, and predictability of cold water storage in Shasta Lake. This analysis detected two independent modes of variability in Shasta Lake cold water storage. The first mode, representing variability during February–July and describing 64% of the overall variability in cold water storage, was negatively correlated with both the preceding year's late summer hypolimnetic discharges and that spring's air temperatures. A second mode, representing December–January and describing an additional 24% of variability, was negatively correlated with Shasta Lake fall water temperatures and winter air temperatures and positively correlated with winter inflows. These results suggest hypolimnetic discharges, air and water temperatures, and inflows act in concert to determine cold water storage in Shasta Lake. These results also suggest water column mixing should be promoted during the cold midwinter period and thermal stratification should be promoted the remainder of the year to minimize surface warming of the entire water column. *INDEX TERMS:* 1845 Hydrology: Limnology; 1857 Hydrology: Reservoirs (surface); 1884 Hydrology: Water supply; *KEYWORDS:* climate, cold water, hypolimnion, limnology, reservoir, Shasta Lake

Citation: Nickel, D. K., M. T. Brett, and A. D. Jassby (2004), Factors regulating Shasta Lake (California) cold water accumulation, a resource for endangered salmon conservation, *Water Resour. Res.*, *40*, W05204, doi:10.1029/2003WR002669.

1. Introduction

[2] Shasta Lake is the largest and most important water supply reservoir for the agriculturally rich Central Valley of California. One of the greatest challenges to federal and state dam operators is managing the oftentimes competing interests of various users such as agriculture, urban areas, hydropower, flood protection, and, more recently, habitat protection for endangered and economically important fish. In some cases the difficulties inherent in balancing these interests have resulted in intense disputes between the various user groups and the federal agencies responsible for managing water resources and endangered species [*National Research Council*, 2002; *Levy*, 2003]. Since 1987, the Bureau of Reclamation (BOR) has been under a federal court order to provide suitable spawning habitat for endangered winter-run chinook salmon (*Oncorhynchus tshawytscha*) in the Sacramento River below Shasta and Keswick Dams [*National Marine Fisheries Service* (*NMFS*), 1987]. This court order, and the classification of winter-run chinook as first threatened and then endangered, was motivated by the fact that winter-run spawning returns declined from an average of ~90,000 fish annually during the late 1960s to ~2000 fish annually during the late 1980s and early 1990s. In response to the court order, the Central Valley Regional Water Quality Control Board adopted a late summer/fall discharge temperature objective of 13.3°C (56°F) for the 100 km river reach between Keswick Dam and Red Bluff, California [*Deas et al.*, 1997]. To compensate for intense solar and atmospheric heating during the summer, operators at Shasta Dam were forced by the court order to release cold water through a low-level dam outlet. The target release temperature from Shasta Lake is 8.3°C (47°F) from May through August [*Hanna et al.*, 1999]. The BOR must also release more cold water during especially warm summer periods because river heating is inversely proportional to river flow. Between 1987 and 1997, cold water was discharged through the lower outlet works, bypassing the power generating turbines, resulting in an approximate $63 million loss in hydropower generation during this period [*Vermeyen*, 2000]. To recapture this lost hydropower, the BOR installed an $80 million temperature control device (TCD) in 1997, which now directs all

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outflow through the penstock intake. Shutter gates on the TCD move vertically to selectively withdraw water from varying depths allowing for control of outflow temperature while still passing water through the power generating turbines.

[3] During most of the 1990s, large volumes of hypolimnetic water were discharged to maintain downstream temperatures. During this period, Shasta Lake also had some of the lowest recorded volumes of cold water storage preceding the periods when this cold water was needed for downstream temperature control [*Brett et al.*, 1998]. This reduced cold water accumulation often made it difficult for dam operators to meet the outflow temperature objectives in the late summer/fall and led authorities with the National Marine Fisheries Service (NMFS) to reduce the protected spawning reach to less than the desired 100 km. Some of this observed poor accumulation of cold water could have been due to droughts during the early 1990s. However, poor cold water accumulation during this time also raised concerns that the hypolimnetic bypass operations may have directly or indirectly impacted the ability of Shasta Lake to trap incoming cold water.

[4] The objectives of this study are twofold; first, to determine whether the observed poor cold water accumulation during the 1990s was due in some way to the concurrent hypolimnetic discharges. This is important because the court ordered hypolimnetic bypasses are in many respects similar to expected TCD impacts on the hydrology of Shasta Lake. The second, and more critical, objective is to develop a predictive model which elucidates the primary mechanisms driving cold water accumulation in Shasta Lake. It is imperative that Shasta Dam operators know which factors determine cold water accumulation in order to optimize TCD operation to maximize cold water storage. This study assesses the factors which drive cold water accumulation in Shasta Lake by examining time series data of inflow and outflow volumes, reservoir temperature profiles, river inflow temperatures, and regional meteorological data.

2. Methods

2.1. Data Compilation

[5] The development and analysis of long-term time series records for Shasta Dam included the compilation of a 52-year daily data record (1948–1999) for the following parameters: air temperature, tributary inflow, tributary temperature, regional meteorology, Shasta Dam operations, and intermittent reservoir temperature profiles. Regional air temperatures, obtained from the National Oceanographic and Atmospheric Administration National Climatic Data Center's Web site (http://www.ncdc.noaa.gov/), were collected for four stations: Burney, McCloud, Redding, and Shasta Dam. These stations were chosen based on their widespread positions within the watershed, proximity to Shasta Lake, and the completeness of the available data. These data provided an index of overall climatic trends in the region and important regional descriptors for modeling tributary temperatures. Average monthly solar radiation values for the Shasta Lake region were obtained from Smithsonian Meteorological Tables [*Beard and Willey*, 1972] and fit to a fourth-order polynomial equation. Monthly values for the Pacific Decadal Oscillation (PDO) index were obtained from the Joint Institute for the Study of the Atmosphere and Oceans, University of Washington (http://tao.atmos.washington.edu/data_sets/). The El Niño-Southern Oscillation (ENSO) was characterized by monthly values for the Multivariate ENSO Index (MEI), provided by the Climate Diagnostics Center, National Oceanic and Atmospheric Administration Web site (http://www.cdc.noaa.gov/~kew/MEI/).

[6] Tributary inflows are recorded at U.S. Geological Survey gauging stations located near each of the three main reservoir inflows (the upper Sacramento River, the McCloud River, and the Pit River). Temperature models were developed to simulate inflow temperatures for the three main tributaries to Shasta Lake using the 10 years (1989–1999) of available daily river temperature data for these sites. While a variety of parameters were utilized during model development, air temperature, solar radiation, and time of year provided the best fits for these data. These temperature models used piecewise multiple regression techniques [*Salas et al.*, 1980; *Neter et al.*, 1996] to remove a strongly cyclical residual error by developing separate regression models for approximately monthly increments. That is, a separate multiple regression model was developed for each month in each tributary. We applied these inflow temperature models to all years assessed in our study so that any estimation error/bias from this model was distributed evenly between prebypass and bypass years.

2.2. Cold Water Volume Estimates

[7] The BOR's Central Valley Operations Office maintains records of Shasta Dam's daily operations and local meteorology. Daily reservoir operation data include surface elevation, reservoir volume, and total outflow volume. Outflow volume, subdivided based on discharge elevation, was categorized as power generation, spillway release, and upper, middle, and lower outlet releases. BOR personnel have taken biweekly temperature profiles of Shasta Lake on a semiregular basis since 1944, including several long periods of intensive sampling resulting in a nearly complete data set of the reservoir's thermal characteristics for the years 1960–1974 and 1989–1999. Reservoir thermal profiles were consistently taken at 7.6-m intervals (the original sampling interval was 25 feet) from 191 m (above mean sea level) to the surface, at a location within 122 m of the outlet structure. Temperature profiles were linearly interpolated between the 7.6-m intervals, at a 0.76-m interval scale. The volume of cold water in Shasta Lake on a given sampling day was derived using thermal profiles, a hypsographic curve, and averaging the volumes of water below and above 8.3°C to calculate a mass of water with an average temperature of 8.3°C. For example, if Shasta Lake had a bottom layer of cold water with an average temperature and volume of 8.0°C and 1 km^3, respectively, overlain by another layer with an average temperature of 8.9 and a volume of 0.5 km^3, the combined "mixed" temperature and volume of these two layers would be 8.3°C and 1.5 km^3.

2.3. Principal Components Analysis (PCA) Time Series Analysis

[8] The use of PCA for analyzing interannual variability in time series was first proposed by *Craddock* [1965] and is described in detail by *Jassby* [1999]. Here we apply it to the

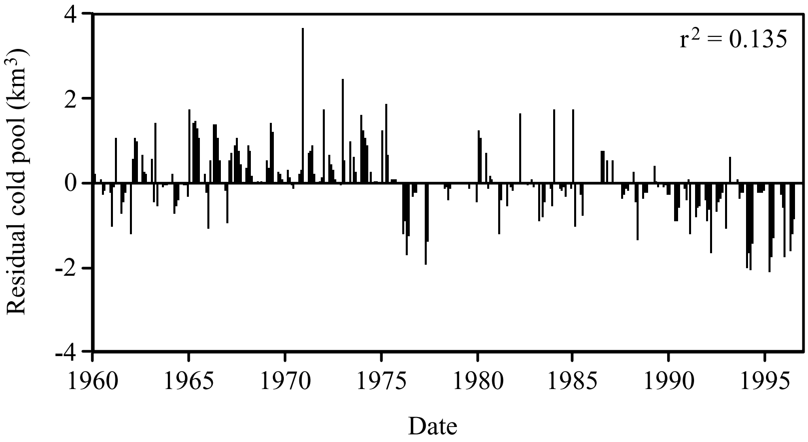

Figure 1. Time series plot of residual cold water volume in Shasta Lake. The residual cold water volume was calculated by subtracting the long-term average cold water volume for a specific time of the year from the actual cold water volume for a specific date. Cold water volume was determined by averaging the volume of water below and above 8.3°C to calculate the total mass of water with an average temperature of 8.3°C. The long-term trend in cold water residuals is highly significant (*F* test = 57.33, $P < 0.0001$).

cold water time series. This unique application of PCA decomposes time series with a higher than annual frequency into seasonal "modes" of variability, each of which is characterized by its own time series. By isolating the modes contributing to interannual variability, the underlying mechanisms become easier to identify and less likely to obscure each other as in more traditional approaches. The method reveals the number of independent modes of variability, the time of year in which they are most important (represented by the component coefficients), and their relative strength from one year to the next (represented by the amplitude time series, or ATS). These features often provide strong constraints on and clues for the identity of the underlying mechanisms. When analyzing a monthly time series, such as the cold water storage series, an n by p data matrix is first formed in which each of the $p = 12$ columns represents a specific month for the n years of record. Principal components (PCs) were estimated by singular value decomposition of the covariance matrix of the data matrix. The number of significant PCs must be chosen because if at least two significant PCs are found, the subset of significant PCs must be rotated [*Richman*, 1986]. We used the scree test, in which all PCs up to and including the first major inflection point in the cumulative variance plot are considered significant [*Cattell*, 1966]. We retained the significant PCs and rotated them using the varimax algorithm [*Richman*, 1986], calculating the new component coefficients and ATS. The ATS can then be explored for their relations to other explanatory variables in an effort to explain the seasonal variation in the original time series.

2.4. Linear Modeling

[9] We examined the relationship between cold water accumulation and possible predictor variables using linear models. The relatively small number of years and the multiplicity of potential predictor variables preclude use of more complicated models. In constructing multivariate models for ATS 1 and ATS 2, we considered the following general predictor variables: reservoir volume, inflows and outflows, and Shasta dam air temperatures for the corresponding modes of variability, as well as August–September hypolimnetic bypass volume. We also considered fall reservoir water temperatures and winter cold water supplies, respectively, when developing multivariate regression models for ATS 1 and ATS 2. We selected the best subset of possible predictors on the basis of Mallows C_p statistic [*Mallows*, 1973], one of several approaches for choosing predictor variables that minimize prediction error [*Jassby*, 1999]. We chose the model with the lowest C_p, with the additional constraint that all predictor values had to be statistically significant ($P < 0.05$).

3. Results

[10] In order to analyze interannual variability for cold water volume, we first eliminated the average annual cycle, calculated by taking monthly averages for 1960–1974 and 1989–1999. The residuals exhibit a striking pattern (Figure 1): Prior to 1989 the residuals about the average annual cycle were mostly positive, while after 1989, when hypolimnetic bypass operations were in effect, residuals were mostly negative.

[11] The PCA time series decomposition allowed identification of distinct processes affecting year-to-year variability in the monthly time series of cold water volume. Figure 2 shows the different modes detected and their corresponding variance, along with the cumulative variance for all modes. In the scree test, all modes up to and including the first major inflection point in the cumulative variance plot were considered significant [*Cattell*, 1966]. In Figure 2 the first two modes described 88% of the year-to-year variability. The first mode (Figure 3a) explained 64% of the variability alone and was strongest from February through July. The second mode (Figure 3b) explained an additional 24% of the variance and was strongest during December and January. The resulting ATS, showing how the modes varied over the length of the time series, are given in Figures 3c and 3d. The first mode was generally positive from 1960 to 1974 and negative from 1989 to 1996 (Figure 3c). The second mode was positive throughout most of the 1960s, negative

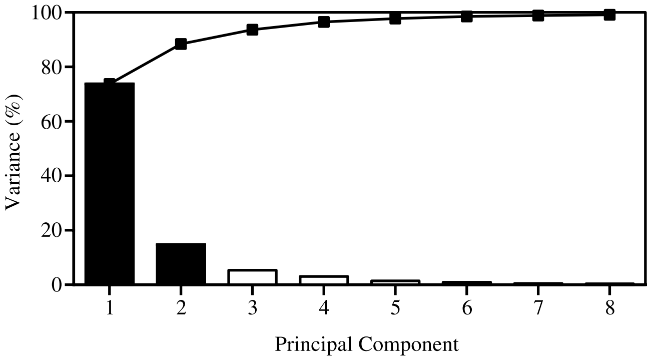

Figure 2. A scree plot of variances obtained from the rotated PCA. Only principal components (modes) 1 and 2 were statistically significant at the P = 0.05 level as determined by Monte Carlo simulations. Solid line indicates cumulative variance.

from 1968 to 1974, and mostly positive from 1989 to 1996 (Figure 3d).

[12] The last step in this time series decomposition was to assess the variation in the ATS with explanatory variables during this same time period. In order to make this analysis more intuitive, the actual data values of cold water volume were used in place of the ATS. This is possible because the two modes overlap very little and the two series are therefore highly correlated with the average dynamics of the most important months in the respective modes. As we are primarily interested in the factors that influence cold water accumulation in Shasta Lake, and cold water inputs usually end by early April, we examined average cold water volumes during the months of February to April. The variables considered for these multivariate models and their individual correlations with February–April and December–January cold water volumes are given in Table 1.

[13] The late summer/fall hypolimnetic discharges (i.e., low-level bypass) and spring air temperatures accounted for 76% of the variability in ATS 1, while winter air temperatures at Shasta Dam, winter inflows to Shasta Lake, and fall reservoir temperatures accounted for 68% of the variability in ATS 2 (Table 2). The multivariate model developed for ATS 1 was well behaved. Two predictor variables were statistically significant at the 0.01 or better level (Table 2), and the partial residual plots also support this model (Figure 4). However, it should be noted that 1993 had the highest residual error in both Figures 4a and 4b.

[14] To place these statistical results in perspective, we can convert each of the coefficients obtained to actual predicted changes in cold water accumulation during the bypass period by multiplying the appropriate coefficient by the respective mean difference for a given parameter between the prebypass and bypass years. For example, the average fall residual reservoir temperature during the prebypass period was −0.63°C and the average fall residual temperature during the bypass period was 0.98°C, for a mean difference of 1.61°C. As the fall temperature coefficient was −0.253, the multivariate model for ATS 2 predicts that Shasta Lake accumulated 0.41 km^3 (1 km^3 = 0.81 × 10^6 acre feet) less cold water (i.e., 1.61°C × −0.253 km^3/°C = −0.41 km^3) during the winter following bypass years due to warmer fall water temperatures.

[15] We can use the average differences between nonbypass and bypass years as well as the coefficients reported in Table 2 (as was done for the example above) to calculate how differences in reservoir operation and climate lead to reduced cold water accumulation during the bypass years. If we start sequentially, we find that during the years 1991–1996 BOR dam operators bypassed on average 1.28 km^3 cold water during the late summer/fall period. (Shasta Lake has a total volume of 5.6 km^3). The volume of hypolimnetic water discharged in late summer/fall was strongly correlated

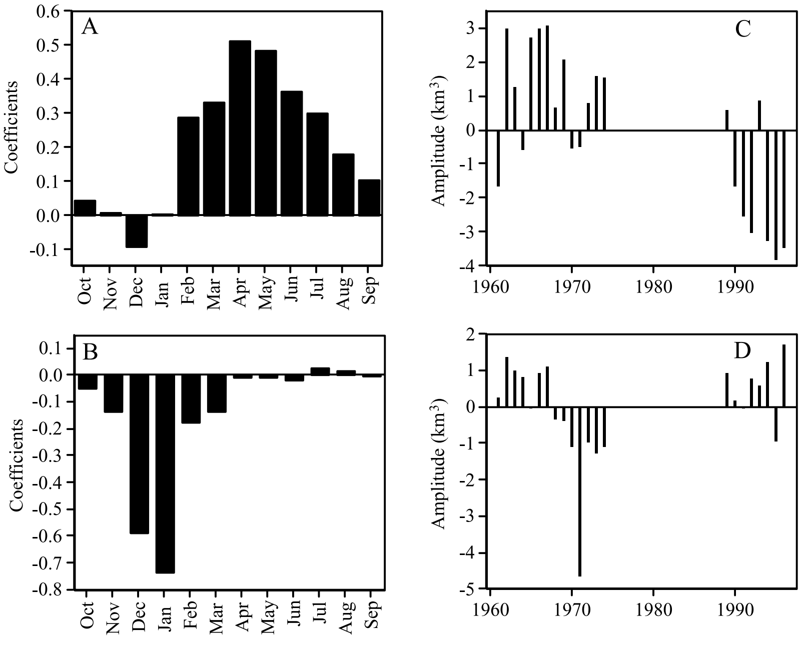

Figure 3. Annual modes of variability for (a) mode 1 and (b) mode 2 with (c and d) their respective amplitude time series.

Table 1. A Matrix of Simple Regression Coefficients (r^2) Between Measures of Seasonal Cold Water Storage and Various Predictor Variables for Shasta Lake

Variable	Dec.–Jan. Cold Pool	Feb.–April Cold Pool	Time Lag, days
ATS1	0.06	0.84	
ATS2	0.92	0.10	
Bypass	0.18	0.66	
Volume	0.11	0.23	0, 0
Inflow	0.36	0.04	8, 0
Outflow	0.43	0.00	3, 0
Air temperature	0.33	0.53	13, 30
Pacific Decadal Oscillation	0.16	0.40	0, 0
El Niño-Southern Oscillation	0.04	0.15	0, 0
Oct./Nov. reservoir temperatures	0.25	...	
Dec.–Jan. cold pool	...	0.26	

with fall reservoir water temperatures (r^2 = 0.66) because these hypolimnetic discharges removed almost all of the coldest water from Shasta Lake, which effectively warmed the entire reservoir. During the winter following bypass years, Shasta Lake accumulated 0.41 km^3 less cold water due to warmer fall reservoir temperatures. Furthermore, Shasta Lake winter air temperatures were on average 0.68°C warmer during the bypass years, which should have according to our multivariate model for ATS 2 resulted in approximately 0.18 km^3 less cold water accumulating. The recent bypass period 1989–1996 had on average 0.66 km^3 less total winter inflows, which according to our multivariate model should have resulted in approximately 0.21 km^3 less cold water accumulating during the bypass years. Because hypolimnetic bypasses warm the reservoir and because Shasta Lake is experiencing a trend of warmer winter air temperatures, BOR dam operators can expect Shasta Lake to accumulate approximately 0.67 km^3 less cold water in the future (relative to long-term averages) during the winter period.

[16] The PCA time series decomposition suggests winter (December–January) and early spring (February–April) cold water accumulation are in large part independent (r^2 = 0.26). Early spring cold water accumulation will therefore have a much greater impact than winter accumulation on cold water availability during the critical late summer/fall period. Early spring cold water accumulation was most strongly related to the previous fall's bypass volumes (Figure 4a), which on average resulted in 0.89 km^3 less cold water accumulation during the following spring compared to prebypass years. Cold water accumulation was also related to spring air temperatures (Figure 4b). As recent bypass years were on average 1.0°C warmer during the spring than the prebypass years, this amounted to 0.37 km^3 less cold water. These results are consistent with the general result that the bypass years had on average 1.56 km^3 less cold water during the months of February–April.

[17] To further explore the strong correlations between fall hypolimnetic bypasses and spring cold water accumulation, we correlated the magnitude of the fall bypasses against Shasta Lake cold water volumes in each successive month (Figure 5). This plot shows fall hypolimnetic bypasses correlated moderately strongly with fall cold water storage, weakly with winter cold water storage, and moderately strongly with the succeeding spring's cold water storage. While this pattern is perplexing, the management implications of this association are clear. According to the coefficient presented in Table 2, approximately 0.89 km^3 less cold water will accumulate in Shasta Lake during springs following late summer/fall hypolimnetic discharges averaging 1.04 km^3. This quantity is 25% of the mean annual cold water storage (3.53 km^3) in Shasta Lake prior to these hypolimnetic bypasses.

[18] Calculations comparing the volume of hydrologic inputs and their temperatures to cold water accumulation in Shasta Lake showed net cold water inflows on average accounted for only 38% of total cold water accumulation in

Table 2. The Statistical Results of the Multivariate Models for ATS 1 and ATS 2, As Well As Mean Comparisons for the Prebypass and Bypass Years[a]

Variable	Coefficient	*t*-Test	Probability	Multivariate Model Fit (r^2)	Prebypass Mean, ±1 SD	Bypass Mean, ±1 SD	Difference	*t*-Test	Probability	Coefficient × Difference, km^3
				February-April (ATS 1)						
				0.79	3.47 ± 0.37	1.97 ± 0.88	−1.56	3.77	0.0012	
Intercept	3.324									
Fall bypass	−0.855	4.01	0.0008		0 ± 0	1.04 ± 0.57	1.04	3.72	0.0014	−0.89
Spring air temperatures	−0.372	2.74	0.0135		−0.33 ± 0.87	0.66 ± 0.77	0.99	2.71	0.0135	−0.37
Spring volume	0.264	1.72	0.1029		0.22 ± 0.23	−0.64 ± 0.96	−0.86	2.23	0.0377	−0.23
Sum										−1.48
Error (RMS)										±0.48
				December–January (ATS 2)						
				0.68	1.37 ± 0.80	0.69 ± 0.43	−0.68	2.60	0.0171	
Intercept	0.887									
Winter air temperatures	−0.264	3.43	0.0030		−0.62 ± 1.24	0.06 ± 1.49	0.68	1.07	0.2961	−0.18
Winter inflows	0.322	2.81	0.0117		0.65 ± 1.04	−0.01 ± 0.64	−0.66	1.83	0.0820	−0.21
Oct./Nov. reservoir temperatures	−0.253	2.23	0.0387		−0.63 ± 0.40	0.98 ± 0.73	1.61	4.51	0.0002	−0.41
Sum										−0.80
Error (RMS)										±0.48

[a] The units of the ATS cold water volumes, fall bypass, spring volume, and winter inflows are cubic kilometers for the relevant time period. The units for all temperature results are degrees Celsius. The ATS 1, ATS 2, and bypass volumes are actual values; all other results are residuals from long-term mean annual trends.

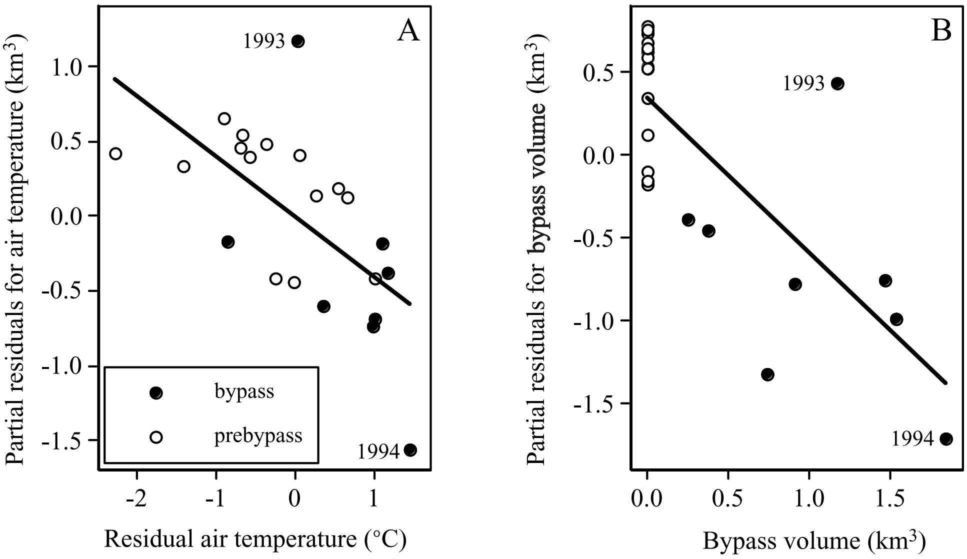

Figure 4. Residual plots for the air temperature and bypass volume terms of the multivariate model for ATS 1 using data from the prebypass and bypass periods.

Shasta Lake during January [*Nickel*, 2000]. This result suggests air-water heat exchange (or reservoir cooling) accounted for on average 62% of cold water accumulation during January. During January the Shasta Lake region typically experiences its coldest air temperatures and the water column mixes down to an average depth of 50 m. It is likely that the timing between cool air temperature and deep mixing has a very important impact on how the reservoir accumulates cold water during the winter. Figure 6 shows that maximum deep winter mixing during bypass years occurs approximately 3 weeks earlier (mid to late December) than in prebypass years. During prebypass years the maximum deep winter mixing occurred near mid-January, when air temperatures are typically at their lowest.

[19] We also considered what we thought would be the simplest model of cold water accumulation to Shasta Lake, i.e., cold water accumulation as a simple function of the inflow rate and temperature, without finding any clear trends. An index of inflow and temperature impacts on Shasta Lake cold water accumulation was calculated by taking the predicted river temperature and subtracting 8.3°C (to derive warming or cooling inflows) and multiplying this residual temperature by the river inflows at any given time. Other reference temperatures besides 8.3°C were also tried. Despite the simplicity of this input approach, it gave a much weaker fit to actual cold water dynamics than did models based on processes occurring in the reservoir itself.

[20] January air temperatures have increased significantly over the length of this time series (Figure 7). Thus, if the cold water accumulation during this same time period is being driven by air temperature, which is suggested by our multivariate analysis of PCA ATS 2, this increase could be one of the main factors driving the reduction in winter cold water storage during the bypass period. This trend also suggests winter warming may continue into the future. The Shasta Dam air temperature annual cycle is shown in Figure 8, with horizontal lines depicting the 8°–9°C temperature range. The air temperature cycle falls below this bar during the months of December and January, further suggesting that air temperature drives additional cold water accumulation. However, as Figure 7 shows, the present January air temperature may not follow the annual cycle depicted in Figure 8. According to Figure 7, January air temperatures may currently be almost 1°C higher than depicted in Figure 8.

4. Discussion

[21] Understanding the mechanisms driving interannual variation in cold water accumulation in Shasta Lake will make it easier to optimize reservoir operations to maximize cold water storage. A refinement of reservoir management could lead to increased spawning habitat for endangered chinook salmon during late summer and early fall. This is important for several reasons. First, our time series analysis suggests less cold water may be available for salmon conservation in the future due to direct and indirect impacts of late summer/fall hypolimnetic discharges on cold water accumulation in Shasta Lake. Second, regional climatic trends suggest Shasta Lake might experience less winter cooling and greater spring warming in the future. Third, the BOR is proposing to reduce water diversions from Trinity

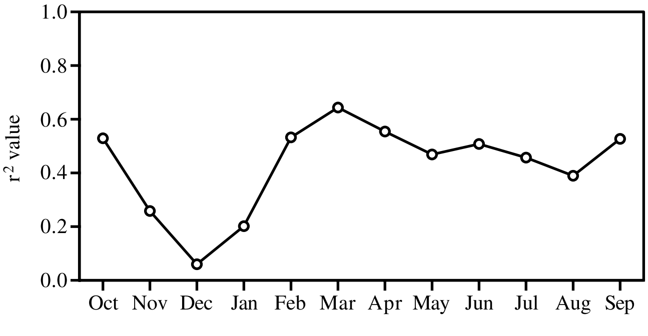

Figure 5. The cross correlation between fall hypolimnetic bypass volumes and Shasta Lake cold water storage in successive months.

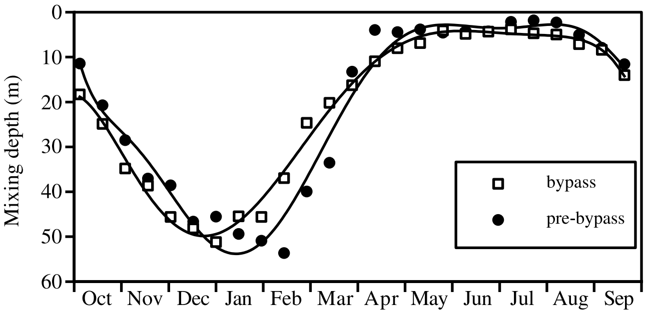

Figure 6. Changes in the mixing regime during prebypass and postbypass years. Mixing depth was calculated as the depth at which the water temperature differs by 1°C from the near-surface temperature (i.e., 0.5 m depth).

Reservoir (Claire Engle Lake) to the Sacramento River in order to maintain minimum flow requirements in the Trinity River for endangered steelhead trout (*Oncorhynchus mykiss*). For the years 1995–2000, an average of 0.62 ± 0.15 (±1 standard deviation) km^3 was diverted from the Trinity system (via Whiskeytown Reservoir) during the hot summer period of July to mid-October. If less water is diverted from the Trinity system, this shortfall will have to be met from Shasta Lake, which will further tax Shasta Lake's ability to meet cold water delivery objectives in the critical late summer/fall period.

[22] The PCA showed that there were two major components to the cold water cycle that acted independently. Together, these modes (February–April and December–January) described 88% of the variation in the overall time series. If these two periods act independently, as the PCA indicates, it would be difficult to achieve a good fit using one statistical model for the entire year. In fact, we initially attempted this approach and achieved a poor overall fit (r^2 = 0.29). One factor related to reservoir operation (hypolimnetic bypasses) and one related to climate (spring air temperatures) explained the majority of the first mode (ATS 1), which characterized variability in February–April cold water volumes. A multiple regression model for the second mode (ATS 2) suggests that fall reservoir water temperatures, winter inflows, and winter air temperatures drive most of the cold water accumulation during December–January. However, since the two PCA modes are orthogonal and cold water storage in the months of December–January and February–April are only weakly correlated, these results also suggest that factors influencing cold water accumulation during the months of February–April will overall have a much greater impact on cold water accumulation in Shasta Lake. One could plausibly argue these statistical results justify ignoring the factors regulating cold water accumulation during the midwinter. In fact, adding a term describing the December–January cold water volumes to the multivariate model for ATS 1 did not improve its overall fit.

[23] *Hanna* [1999] and *Hanna et al.* [1999] used the hydrodynamic water quality model CE-QUAL-W2 to conclude downstream temperature objectives were more likely to be met if the reservoir elevation was maximized for as long as possible during the winter and spring. Although not included in the final multivariate model obtained for ATS 1 (because it failed to meet our $P < 0.05$ criteria), our statistical analysis provided some evidence that reservoir volume could impact cold water accumulation (*t* test = 1.72, $P = 0.10$). Because Shasta Lake volume is controlled during the spring in accordance with flood protection rule curves, overall variability in February–April reservoir volume was only ±12% (±1 standard deviation) of overall reservoir volume. This modest variability in February–April volume may have made it difficult to detect a strong association with cold water accumulation using a regression approach. The coefficient for spring volume versus cold water accumulation regression suggests that on average 26% of any additional volume maintained in Shasta Lake would be manifest as additional cold water. However, it should be noted that in some years, maximizing Shasta Lake volume is not possible due to high water demands and/or the need for flood protection during "wet" years.

[24] Another alternative, as discussed by *Hanna* [1999], would be to relax the downstream temperature objective during early summer in an effort to preserve more cold water for the late summer and early fall (the primary spawning time for winter-run chinook salmon). This alternative may make it easier to maintain the optimal 100-km spawning reach throughout the summer and fall. Ideally, an optimization scheme should be developed to allocate Shasta Lake cold water supplies to the times of the year when they will have the greatest benefit for endangered and economically important salmonids.

[25] Our multiple regression model results for ATS 2 suggest cold water storage can be optimized at the beginning of the year (January) by raising the reservoir level to the maximum allowable elevation. This strategy would take advantage of lake mixing when local meteorological conditions are optimal for cooling. Lakes which are subjected to intense wind mixing during cool winter temperatures will have lower overall temperatures [*Farmer and Carmack*, 1982]. As soon as average air temperatures rise above 9°C (the upper target release temperature), attempts should be made to promote thermal stratification in Shasta Lake. This would help minimize the surface warming evident in our multiple regression model of ATS 1. This type of scenario (deep winter mixing followed by a rapid change to thermal stratification) was prevalent in the prebypass years (Figure 6), when cold water accumulation was greatest. The change in

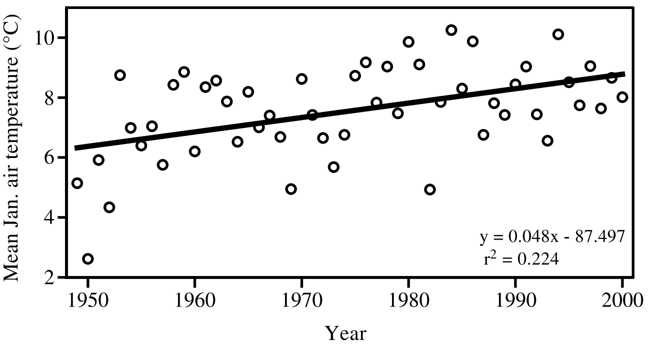

Figure 7. Average January air temperatures at Shasta Dam (1949–2000). The long-term trend in Shasta Lake January air temperatures is statistically significant (*F* test = 14.41, $P < 0.0004$).

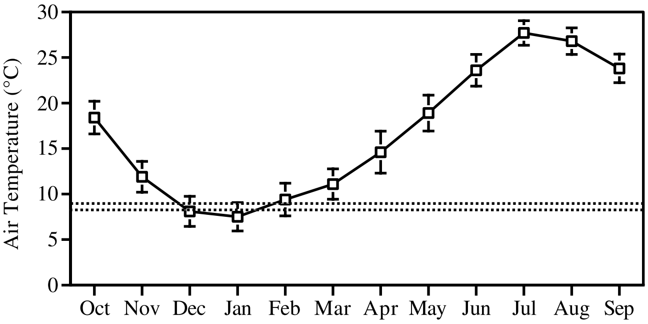

Figure 8. Average annual air temperature cycle at Shasta Dam. Horizontal lines identify the 8°–9°C range. The confidence intervals represent ±1 standard deviation.

outflow strategies has apparently altered the mixing dynamics of Shasta Lake, shifting the period of maximum deep winter mixing 3 weeks earlier, which is offset from the coldest January air temperatures.

[26] To optimize cold water accumulation, deep mixing should be promoted via releases as close to the surface as practical from mid-December to late January. This time period coincides with declining air temperatures and, most important, cooler average air temperatures than reservoir surface temperatures. As air temperatures begin to seasonally increase at Shasta Lake, we recommend switching to an operating scenario designed to facilitate thermal stratification in order to provide an insulating surface water layer to protect any previously accumulated cold water from surface warming. According to our data, 5 February is the average date when the annual cycle of Shasta Dam air temperature surpasses 9°C (Figure 8). Studies performed on Wellington Reservoir in Australia suggest metalimnetic withdrawals promote thermal stratification [*Fischer et al.*, 1979; *Imberger and Patterson*, 1990]. Withdrawing water at the thermocline depth intensifies the density difference between the epilimnion and hypolimnion, promoting stronger thermal stratification. During the late winter/early spring period in Shasta Lake, when strong thermal stratification has still not set up, we recommend releasing water from the metalimnetic thermocline, i.e., ~10–15 m below the reservoir surface. However, additional investigation needs to be performed on strategies for promoting thermal stratification because Wellington Reservoir is not only located in a different climatic region, but it is also much smaller (maximum depth = 30 m) than Shasta Lake and thus may exhibit quite different thermal characteristics. Flood releases should be made from the epilimnion during the midwinter and from the metalimnion during late winter and early spring. These flood releases should never be made from the hypolimnion (low-level releases) because this will deplete Shasta Lake of its coldest water. However, low-level flood releases are already avoided in order to control turbidity downstream of the reservoir.

[27] In contrast to the relation between bypass volume and fall reservoir water temperatures, the correlation between spring cold water accumulation and the previous late summer/fall's hypolimnetic discharges is perplexing. This is especially the case since this is the strongest correlation observed in this study and it is strong for the following fall and spring, but weak during the winter (Figure 5). Hypolimnetic releases appear to cause Shasta Lake to accumulate approximately 0.9 km^3 less cold water in the following spring. Regardless of the mechanism behind this correlation, Shasta Lake typically accumulates less cold water during winter and springs following late summer/falls with large hypolimnetic discharges. The multiple regression model presented in Table 2 suggests this is due not simply to the bypass years being unusually warm and dry, although this was a contributing factor. Our result which shows that years with large hypolimnetic discharges are characterized by poor cold water accumulation during the following winter/spring is in contrast to *Hanna et al.*'s [1999] finding using the CE-QUAL-W2 model that hypolimnetic discharges do not influence reservoir temperatures in successive years.

[28] Similar to the results of several studies of large lakes [*McCormick and Fahnenstiel*, 1999; *George et al.*, 2000; *Livingstone and Dokulil*, 2001; *Livingstone*, 2003], our study of Shasta Lake showed air temperature anomalies had a strong impact on interannual water temperature fluctuations. In a detailed analysis of long-term temperature fluctuations in Lake Washington (United States), *Arhonditsis et al.* [2004] found Lake Washington water temperatures were strongly correlated with air temperature anomalies and that due to recent warming in the Seattle, Washington, region, Lake Washington water temperatures have exhibited a strong warming trend during the last 40 years. *Arhonditsis et al.* [2004] also found epilimnetic warming in Lake Washington was much more intense than hypolimnetic warming (i.e., 0.45° and 0.19°C per decade, respectively) and that warming was especially intense in the surface layer during the summer stratified period (0.63°C per decade). Both our study of Shasta Lake and Arhonditsis et al.'s study of Lake Washington found the El Niño-Southern Oscillation (ENSO) was only weakly correlated with the reservoir/lake temperature fluctuations. *Arhonditsis et al.* [2004] found both spring/summer and fall/winter temperature fluctuations in Lake Washington were moderately strongly correlated with the Pacific Decadal Oscillation (PDO) [*Mantua and Hare*, 2002], whereas we found only the Shasta Lake February–April cold water volume was moderately strongly correlated with the PDO. In further contrast to the results of Arhonditsis et al., our multiple regression models did not include the PDO as a significant term, whereas the PDO was a significant component of both the spring/summer and fall/winter lake temperature models for Lake Washington [*Arhonditsis et al.*, 2004]. It is notable, however, that both the Shasta Lake and Lake Washington analyses indicated the PDO has much stronger associations with lake/reservoir water temperature fluctuations than does the ENSO.

[29] The strong relation between cold water accumulation and winter and spring air temperatures is worrisome because there already appears to be a significant warming trend in winter air temperatures at Shasta Lake (Figure 7) and because it is well established that the world's climate is warming [*Huang et al.*, 2000]. According to the results of our multiple regression model, Shasta Lake will accumulate 0.64 km^3 less cold water in the future for each 1°C increase in mean winter/spring air temperatures.

[30] A warmer climate could also result in reduced snowpack accumulation, causing cold water inputs to Shasta Lake to occur during a shorter period of time

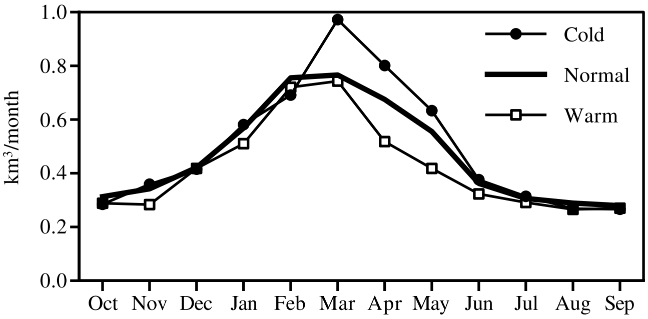

Figure 9. Median monthly hydrologic inputs to Shasta Lake during warm, normal, and cold years. Warm conditions were represented by the 12 warmest years in the 50-year record (approximately the upper quartile), normal conditions were represented by the intermediate 26 years (approximately the second and third quartiles), and cold conditions were represented by the 12 coldest years (approximately the lower quartile). The warmest years were on average 1.3°C warmer than the coldest years. Typical monthly inputs were represented by the median monthly hydrologic inflow rate for the three groupings. The differences in warm and cold year inflows to Shasta Lake were statistically significant as determined by a two tailed *t*-test during the months of March and April ($P < 0.05$) and marginally significant during May ($P < 0.10$) but are not significantly different any other months.

[*Hamlet and Lettenmaier*, 1999], which could also make it more difficult to store this cold water for the late summer period since Shasta Lake has a relatively short effective retention time of 0.69 ± 0.16 years (i.e., mean annual inputs/mean annual volume). To examine how long-term climate change might impact hydrologic inputs to Shasta Lake, we used the 50-year database assembled for this study to compare monthly hydrologic input rates during warm and cold annual quartiles for this database. Figure 9 shows that during warm years Shasta Lake had smaller hydrologic inflows during the months of March, April, and May. Since inputs to Shasta Lake are usually below 8.3°C during March, these results suggest Shasta Lake is likely to receive less water and less cold water if climatic warming trends continue as projected. The combination of increased warming of the reservoir itself, as well as reduced and warmer inflows, suggests climatic warming could pose a serious threat to the long-term prospects for winter-run chinook salmon survival downstream of Shasta Lake.

[31] We found that all cold water accumulates in Shasta Lake by mid-April, which provides 4 months for the responsible agencies (i.e., BOR, California Department of Fish and Game (CDFG), NMFS, U.S. Fish and Wildlife Service (USFWS), etc.) to plan for the critical late summer/fall period. Thus, by midspring, Shasta Dam operators can determine exactly how much cold water will be available the remainder of the year. Given this information it should be possible to develop a series of scenarios given a representative range of future conditions. The main factor influencing change in cold water availability by late summer/fall will be summer temperatures in the Central Valley and their impact on the ability of the BOR to meet downstream temperature and agricultural and urban water demands. BOR dam operators can use past water demands during cold, average, and warm summer conditions in the Central Valley to predict cold water supply at the end of summer for a range of conditions given known initial conditions (i.e., the beginning of May cold water supply). The scenarios developed should be designed to maximize the river area with suitable spawning habitat without exposing any of this habitat to excessively warm water before critical temperature sensitive salmon life history stages (i.e., eggs in redds, and fry in the river) have fully developed. One of the most risky operating strategies is to have an overly optimistic projection for late summer cold water supplies and to ultimately run out of cold water before the temperature-sensitive life history stages have been completed. Because Shasta Lake is thermally stratified during the late summer, running out of cold water can result in a sudden increase in downstream temperatures. This is important because a big mistake for a short time period in meeting downstream temperature objectives will have a greater impact on fish mortality than a smaller mistake for a longer period of time [*Kilgour et al.*, 1985]. Our results clearly show cold water delivery schemes based on prebypass conditions will be overly optimistic. During the last decade with bypass scenarios, far less cold water has accumulated in Shasta Lake than typically occurred prior to 1990.

[32] Because of the population growth, recent droughts, climatic warming, and increasing demands to maintain habitat for threatened or endangered fish, conflicts between demands for water and how water resources are managed are becoming increasingly prevalent in the western United States [*Adams and Cho*, 1998; *Schmidt et al.*, 1998]. There are several important parallels between our study of Shasta Lake and the ongoing Upper Klamath Lake controversy [*Cooperman and Markle*, 2003; *Levy*, 2003; *Lewis*, 2003]. These include the fact that the BOR manages both systems, climate change may be warming the water of both systems, threatened and endangered fish are involved, and the demands on water supplies in both the Shasta Lake and Klamath Lake systems are likely to increase in the future. However, these systems are also very different. The BOR has much greater control over water retention in Shasta Lake because it has an 8 times larger volume, it is much deeper, and its relative storage can be varied much more than is the case for Klamath Lake. Because Klamath Lake is very shallow (mean depth 2.6 m), it only has an epilimnion and is therefore not capable of storing large volumes of cold hypolimnetic water like Shasta Lake does.

5. Conclusions

[33] Our analyses suggest Shasta Lake has two modes (December–January and February–April) of variability in cold water accumulation, the latter of which is the most important. February–April cold water accumulation is strongly correlated with a combination of the preceding late summer/fall hypolimnetic discharges and spring air temperatures. The bypass years of 1989–1996 had poor cold water accumulation due to direct impacts of the hypolimnetic bypasses, reduced winter inflows, and warmer air temperatures during the winter and spring. Late summer/fall hypolimnetic releases led to Shasta Lake accumulating approximately 0.9 km^3 less cold water in the following

spring. On the basis of the weak correlation ($P = 0.10$) between spring cold water accumulation and reservoir volume, increasing the volume of Shasta Lake by the currently proposed 6.5% will only slightly alleviate cold water shortages in the future. However, having a greater reservoir volume should improve operational flexibility for Shasta Lake, which might improve this system's capacity to deliver cold water in the future. Since almost all cold water inflow and accumulation in Shasta Lake occurs before May, resource managers will have several months to plan cold water utilization and salmon spawning habitat management during critical periods of the year. Because our statistical analyses suggest atmospheric heat exchange has a strong impact on Shasta Lake cold water accumulation, we recommend that Shasta Lake be managed to promote water column mixing during midwinter and thermal stratification during late winter and spring.

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