PEER REVIEW DRAFT

STAFF REPORT FOR THE REVISION OF DISSOLVED OXYGEN WATER QUALITY OBJECTIVES

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CHAPTER I. INTRODUCTION

The North Coast Regional Water Quality Control Board (Regional Water Board) directed staff in its triennial review of the Water Quality Control Plan for the North Coast Region (Basin Plan) in 2007 to develop a proposal for the revision of the dissolved oxygen (DO) objectives contained in the Basin Plan. This report includes staff's proposal and the scientific documentation necessary to support the proposal both for the purposes of the Regional Water Board's decision making process and the public's environmental review under the California Environmental Quality Act (CEQA).

Staff distributed a CEQA Scoping Document for public review in September 2008 and held two CEQA Scoping Meetings in October 2008. This staff report and proposed Basin Plan Amendment are drafted with consideration of the public comments received during the CEQA scoping process. The Regional Water Board will hold a hearing to provide opportunity to interested parties to comment on the proposed Basin Plan Amendment and supporting documentation prior to the Board's decision regarding adoption of the amendment. Following this, the State Water Resources Control Board (State Water Board) will hold a hearing in preparation for their decision regarding adoption of the amendment. Finally, the Office of Administrative Law (OAL) will provide a legal review of the amendment before forwarding it to the U.S. Environmental Protection Agency (USEPA) for final approval.

I.1 Description of Region

As described in the Basin Plan, the North Coast Region encompasses a total area of approximately 19,390 square miles, including 340 miles of scenic coastline and remote wilderness areas, as well as urbanized and agricultural areas. The region is characterized by distinct temperature zones. Along the coast, the climate is moderate and foggy and the temperature variation is not great. Inland, however, seasonal temperatures in excess of 100 °F have been recorded. Precipitation over the North Coast Region (greater than for any other part of California) in combination with the mild climate found over most of the region has provided a wealth of fish, wildlife, and scenic resources. The mountainous nature of the region, with its dense coniferous forests interspersed with grassy or chaparral covered slopes, provides shelter and food for numerous terrestrial animal species. The numerous streams and rivers contain anadromous fish and the reservoirs, although few in number, support both coldwater and warm water fish. Tidelands and marshes too are extremely important to many species of waterfowl and shore birds, as are cultivated lands (NCRWQCB 2007).

I.2 Background Information on Existing DO Objectives

The Regional Water Board adopted and the State Water Board approved the first comprehensive management plan in 1975 which was revised and became known in 1988 as the Basin Plan. Objectives for DO were included in the 1975 plan and have remained unchanged since that time. The DO objectives are contained in two places within the Basin Plan: 1) page 3-4.00 under the heading "Dissolved Oxygen" and 2) Table 3-1 on pages 3-6.00 through 3-8.00. (See Appendix A for a copy of these pages).

The DO objectives on page 3-4.00 (referred to here as the *life cycle DO objectives*) are based on the life cycle requirements of sensitive aquatic species and are applicable in waterbodies throughout the region based on the designated beneficial use(s) of individual waterbodies. There are four separate life cycle DO objectives, each designed to protect specific beneficial uses: 1) WARM[1], MAR[2], or SAL[3]; 2) COLD[4]; 3) SPWN[5]; and 4) SPWN during critical spawning and egg incubation periods.

The objectives in Table 3-1 of the Basin Plan are based on background conditions (referred to here as *background DO objectives*) as measured by extensive regional sampling in the 1950s and 1960s and are applicable in individually named waterbodies. The background DO objectives take precedence over the life cycle DO objectives for those waterbodies named in Table 3-1 of the Basin Plan.

I.3 Revision of Existing DO Objectives

Staff's assessment indicates as appropriate three fundamental changes to the existing DO objectives. First, the framework of the DO objectives should be reversed so that the life cycle DO objectives take precedence over the background DO objectives. Staff recommends this change because of the threatened and endangered status of several aquatic species in the region and the need to ensure water quality conditions are fully supportive of all beneficial uses. Further, staff recommends this change because the data associated with the DO requirements of sensitive aquatic organisms is robust and guidance on the development of ambient aquatic life criteria straightforward, while the data used to determine background DO conditions are outdated as compared to current monitoring capabilities.

Second, the life cycle DO objectives should be updated to include weekly average limits so as to better prevent the occurrence of multiple days of marginal, stressful conditions. When the daily minimum limits are reached periodically, no harm is predicted. However, when they are reached for several days or weeks at a time, chronic effects are possible, including reduction in reproductive success, reduction in growth, and greater susceptibility to disease. To protect against this, staff propose the adoption of weekly average limits to accompany daily minimum limits.

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[1] WARM stands for Warm Freshwater Habitat and refers to uses of water that support warm water ecosystems including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish, or wildlife, including invertebrates.

[2] MAR stands for Marine Habitat and refers to uses of water that support marine ecosystems, including, but not limited to, preservation or enhancement of marine habitats, vegetation such as kelp, fish, shellfish, or wildlife (e.g., marine mammals, shorebirds).

[3] SAL stands for Inland Saline Water Habitat and refers to uses of water that support inland saline water ecosystems including, but not limited to, preservation or enhancement of aquatic saline habitats, vegetation, fish, or wildlife, including invertebrates.

[4] COLD stands for Cold Freshwater Habitat and refers to uses of water that support cold water ecosystems including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish, or wildlife, including invertebrates.

[5] SPWN stands for Spawning, Reproduction, and/or Early Development and refers to uses of water that support high quality aquatic habitats suitable for reproduction and early development of fish.

Third, in those waterbodies where natural conditions prevent the attainment of life cycle objectives, the background DO objectives must be updated. The Table 3-1 objectives are based on background conditions as represented by grab sample data collected in the 1950s and 1960s. These data reflect the influence of the land management activities present at the time, including: mining, logging, agriculture, dams, and more. Further, the data do not capture the minimum DO conditions over a 24-hour period because they were collected primarily during daylight hours when the effects of photosynthesis generally cause a rise in DO concentrations. Finally, there is insufficient data on a region-wide scale to allow for the recalculation of the Table 3-1 objectives. As such, staff recommends that the existing background DO objectives be replaced with a method for individually calculating background DO conditions based on DO saturation. Specifically, staff recommends that background DO concentrations be calculated based on an estimate of natural temperatures, existing salinity, and existing barometric pressure.

I.4 Staff Report Outline

The Staff Report includes the following information:

1. An introduction;
2. A review of the existing DO objectives;
3. A general discussion of DO and its interaction and function in the environment;
4. A discussion of the native fish species of the North Coast Region and their water quality requirements;
5. An assessment of the existing DO objectives and staff recommendations;
6. Discussion of Project Alternatives and identification of staff's Preferred Alternative;
7. A monitoring plan; and
8. An implementation plan.

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CHAPTER II.

EXISTING WATER QUALITY OBJECTIVE FOR DISSOLVED OXYGEN

The Regional Water Board adopted and the State Board approved the first comprehensive management plan in 1975 which was revised and became known in 1988 as the Basin Plan. Objectives for DO were adopted in 1975 and have remained unchanged since that time. The DO objectives are contained in two places within the Basin Plan: 1) page 3-4.00 under the heading *Dissolved Oxygen* and 2) Table 3-1 on pages 3-6.00 through 3-8.00. (See Appendix A for a copy of these pages).

II.1 Life Cycle DO Objectives

The DO objectives on page 3-4.00 of the Basin Plan, the life cycle DO objectives, are based on the life cycle requirements of sensitive aquatic species (salmonids) and are applicable in waterbodies throughout the region based on the designated beneficial use(s) of individual waterbodies. The Porter-Cologne Water Quality Control Act, (Cal. Water Code, Division 7), Section 13050(f), defines beneficial uses as follows:

> "Beneficial uses" of the waters of the state that may be protected against quality degradation include, but are not limited to, domestic, municipal, agricultural and industrial supply; power generation; recreation; aesthetic enjoyment; navigation; and preservation and enhancement of fish, wildlife, and other aquatic resources or preserves.

Life cycle DO objectives are developed for the protection of five beneficial uses related to the preservation and enhancement of fish: marine habitat (MAR), inland saline water habitat (SAL), warm freshwater habitat (WARM), cold freshwater habitat (COLD), and spawning, reproduction, and/or early development (SPWN).

Table 2-1 of the Basin Plan (see Appendix B for a copy of these pages) lists all of the waterbodies in the North Coast region and their beneficial uses. There are 132 separate waterbodies listed in Table 2-1. Of these, 13% (17) are designated as existing or potentially existing marine habitat, 2% (2) as existing or potentially existing inland saline water habitat, 49% (64) as existing or potentially existing warm freshwater habitat, 98% (129) as existing or potentially existing cold freshwater habitat, and 95% (125) as existing or potentially existing spawning, reproduction, and/or early development. Of the beneficial uses related to the preservation and enhancement of fish, then, COLD and SPWN are the most widely represented.

The Basin Plan establishes ambient water quality objectives for DO, as follows.

- ✓ 5.0 mg/L DO as a daily minimum for the protection of MAR, SAL, and WARM.
- ✓ 6.0 mg/L DO as a daily minimum for the protection of COLD.
- ✓ 9.0 mg/L DO as a daily minimum for the protection of SPWN during critical spawning and egg incubation periods and 7.0 mg/L DO as a daily minimum for the protection of SPWN during the rest of the year.

II.2 Background DO Objectives

The second set of DO objectives included in the Basin Plan is found in Table 3-1 of the Basin Plan (see Appendix A). They are based on background conditions as measured by extensive regional sampling in the 1950s and 1960s and are applicable in individually named waterbodies. The data used to establish background conditions were collected by a range of partners including federal, state and local agencies. The Department of Water Resources published the data in annual bulletins beginning with data from 1951. Generally, the data are monthly grab samples that were collected during day light hours and analyzed in the field using the Winkler titration method.

The objectives in Table 3-1 of the Basin Plan are referred to as background DO objectives and take precedence over the life cycle DO objectives in those waters listed in Table 3-1. For waterbodies from the Stemple Creek north up to but not including the Klamath River, the background DO objective is 7.0 mg/L as a daily minimum, except in Humboldt and Bodega bays which are assigned a background DO objective of 6.0 mg/L as a daily minimum. A 90% lower limit of 7.5 mg/L and a 50% lower limit of 10.0 mg/L, based on the monthly means for a calendar year, also apply in these waterbodies.

For waterbodies from the Klamath River up to the Oregon border, the background DO objectives range from 5.0 mg/L to 9.0 mg/L as a daily minimum, depending on the waterbody. A 50% lower limit ranging from 8.0 to 10.0 mg/L, based on the monthly means for a calendar year, also applies. There are no 90% lower limits for these waterbodies.

II.3 Relationship Between Life Cycle and Background DO Objectives

As the Basin Plan is currently structured, the background DO objectives take precedence over the life cycle DO objectives for those waterbodies listed in Table 3-1. This structure is based on the principle that beneficial uses are protected by maintaining the background conditions in which they have historically existed. Only for those waterbodies not listed in Table 3-1 do the life cycle DO objectives apply.

It is important to note that for those waterbodies draining to the Pacific Ocean from the Klamath River to the Oregon border, the DO objectives listed in Table 3-1 apply to all the streams within a named hydrologic area, including tributaries. This is indicated in the Table 3-1 language with the terms "streams," "other streams," or "all streams." For those waterbodies draining to the Pacific Ocean south of the Klamath River, however, the DO objectives listed in Table 3-1 apply only to those streams specifically named. This is indicated by the absence of terms such as "streams," "other streams," or "all streams." The difference in approach between waterbodies south of the Klamath River and those north of and including the Klamath River is an artifact of the original Basin Plan having been developed by two separate consultants as two separate documents.

CHAPTER III. GENERAL DISCUSSION OF DISSOLVED OXYGEN

Dissolved Oxygen (DO) provides an excellent measure of general aquatic health. It is one of the primary water quality factors that define the habitability of a given aquatic system. Yet, it varies considerably both temporally and spatially in the natural environment. Thus, to interpret DO data, one must know something about the factors influencing its concentration and the expected pattern and range of its variation to be able to discern any deviation from background conditions and/or any critical impact. A general discussion of these issues follows.

III.1 What is Dissolved Oxygen?

Dissolved oxygen, most often measured in mg/L, is the amount of oxygen gas present in a volume of water. Water has a limited capacity to hold oxygen gas in solution. This capacity is defined by a mathematical relationship among the temperature, atmospheric pressure, and salinity at a given site. When water has reached its capacity to hold oxygen gas in solution it is said to be *saturated*. When it exceeds its capacity, it is said to be *supersaturated*. And, when it does not reach its capacity, it is said to be *subsaturated*.

III.2 Why is dissolved oxygen important?

Oxygen is necessary for the respiration of aerobic organisms. Because water has a limited capacity to hold oxygen gas in solution, aquatic organisms have evolved specialized structures or methods of extracting from water the limited amount of oxygen gas that is present in it. These structures or methods generally rely on the partial pressure differential between oxygen in the water column and oxygen in the blood (or the equivalent oxygen receptor). Gills, as an example, are designed to allow the passive diffusion of oxygen from water across the gill membrane to the arterial system.

A healthy riverine system is generally one in which the DO concentration is at or approaches full saturation and maintained by diffusion (Allan1995). Under these conditions, aerobic organisms can extract from the water column the oxygen necessary to ensure basic metabolic success (e.g., growth, general health, and reproduction) leading to a greater likelihood of population success. Further, a riverine system approaching DO saturation is better able to support a wide and diverse array of life forms than one which does not.

As the concentration of DO in water is reduced to levels significantly less than saturation, the oxygen partial pressure gradient between the water column and blood (or equivalent oxygen receptor) is reduced and the ability of the gill structure (or equivalent oxygen receptor) to acquire the necessary oxygen for respiration is impaired. This can lead to chronic effects, such as reduced growth, increased susceptibility to disease, reduced reproductive success, or loss of habitat through avoidance. It can also lead to acute effects, such as asphyxiation and death. The term *hypoxia* (meaning "low oxygen") refers to the water quality condition in which the dissolved oxygen present in water is insufficient to provide the oxygen requirements of aerobic organisms. Water devoid of oxygen is known as *anoxic*.

III.3 What are the factors influencing the concentration of dissolved oxygen?

The concentration of DO in an aquatic environment is controlled by many interrelated variables, including stream temperature, salinity, barometric pressure, turbulence, respiration, photosynthesis, and biological and chemical oxygen demanding reactions. To simplify, these factors can be divided two categories: 1) those that define the capacity of the water to hold DO (DO saturation) and 2) those that affect the percent of that capacity which is actually utilized (% DO saturation).

III.3.1 DO saturation

DO saturation is defined by the mathematical relationship among three variables: atmospheric pressure, temperature, and salinity. Variation in DO saturation is proportional with variation in atmospheric pressure and is inversely proportional with variation in temperature and salinity. Thus, as atmospheric pressure increases so does the concentration of DO at saturation. Because atmospheric pressure decreases as elevation increases, DO at saturation is inversely proportional with elevation. At any one elevation, DO at saturation also will vary based on the presence of low or high pressure storm systems. As water temperature and/or salinity increase, the concentration of DO at saturation decreases. Water temperature varies depending on numerous factors including: latitude, climate, season, presence of springs, shade, and volume of warm water inputs, as examples. Salinity primarily varies based on the degree of oceanic influence.

One of the primary routes by which oxygen dissolves in water is through the diffusion of oxygen across the air-water interface. Atmospheric oxygen exerts a pressure at the air-water interface allowing for the diffusion of oxygen across the boundary until the partial pressure of atmospheric oxygen equals the partial pressure of oxygen in water. The pressure exerted on the air-water interface by oxygen dissolved in water is defined not only by the concentration of oxygen in water, but by the temperature of the water, as well. For example, O_2 molecules become excited and exert a greater partial pressure on the air-water interface when warm then they do when cool. Thus, the warming of a waterbody serves to slow or even reverse the diffusion of oxygen from the air to the water column.

With respect to salinity, one can visualize water as including H_2O molecules and the spaces between them. The spaces between the H_2O molecules allow for various other molecules to be dissolved in water. If the spaces between the H_2O molecules are filled with molecules such as salts, then the number of spaces available for oxygen is reduced. Salinity is a measure of salts and is generally used to define the gradient between freshwater, brackish water, and saltwater systems. An aquatic system with a high salinity (e.g., the ocean) will naturally have a lower DO concentration at saturation than will a freshwater system with little or no salinity.

III.3.2 Percent Saturation

In the natural environment, there are several other factors at play besides the effects of atmospheric pressure, temperature, and salinity. For example, photosynthesis, turbulence, respiration, organic decomposition, and oxygen demanding chemical reactions also effect the concentration of DO in an aquatic system. These factors do not control the capacity of an aquatic system to hold oxygen in solution (DO saturation). Instead, they affect the percentage of the capacity that is actually utilized (percent saturation).

The photosynthesis of aquatic plants, algae, and cynobacteria has a profound effect on the oxygen content of water. Photosynthetic organisms use carbon dioxide to convert the energy contained in sunlight into carbohydrates and oxygen. Aquatic photosynthetic organisms release their oxygen (a waste product) to the water column, temporarily increasing the DO concentration of the water. Areas in which the substrate, light, nutrients and temperature favor the growth of aquatic photosynthetic organisms may see large increases in DO during the late afternoon when the effects of photosynthesis have accumulated through the day. Such areas may be naturally present in an aquatic system (e.g., wetlands; lakes; and slow moving, shallow river reaches) or promoted by anthropogenic activities (e.g., nutrient enrichment, shade removal, reduction in flow, or reduction in water depth through sediment deposition).

The contribution of oxygen to the water column as a result of photosynthesis occurs only during the daylight hours when photosynthesis is active. This source of oxygen is not present during the night when in the absence of sunlight photosynthesis does not occur. The result is a notable cyclical DO pattern where DO is low in the pre-dawn hours, increases slowly during the morning, reaches a peak prior to sunset, and then declines through the night. This is called a *diel* cycle.

The term *turbulence* refers to a physical process in which the air-water interface is disturbed. Turbulence serves to increase the transfer of oxygen across the air-water interface by increasing the surface area of the interface either at the surface of the water or in the form of bubbles of air entrained within the water column (e.g., as occurs at waterfalls or through mechanical mixing). Turbulence can serve to either decrease or increase the transfer of oxygen to the water column depending on whether the water is supersaturated or subsaturated and whether or not air is entrained in the water column.

The respiration of aquatic organisms requires oxygen for the process of converting carbohydrates into energy for growth and reproduction. It also results in the release of carbon dioxide as a waste product. The oxygen fueling the respiration of aquatic organisms comes from the water column and as described above is extracted using specialized structures or methods (e.g., gills). Respiration exerts a continual pressure on dissolved oxygen supplies.

The decomposition of organic matter in the aquatic environment is a complex process involving numerous organisms and chemical reactions. Biological oxygen demand is a measure of the pressure exerted on dissolved oxygen supplies by the biological decomposition of organic molecules. Numerous species of micro-organisms are involved in the process of biological decomposition.

Chemical oxygen demand is a measure of the pressure exerted on dissolved oxygen supplies by the chemical oxidation of organic molecules. Some of the reactions are initiated by biological activity. The chemical reactions typically at play in an aquatic environment include: carbonaceous deoxygenation, nitrogenous deoxygenation, nitrification, and methantrophy. Appendix C includes an excerpt from the Shasta River TMDL (NCRWQCB 2006) summarizing these processes.

III.4 Conceptual Model for DO

The USEPA's CADDIS (Causal Analysis/Diagnostic Decision Information System) has produced a conceptual model for dissolved oxygen depicting the potential linkages between and among various environmental and anthropogenic factors.

As depicted in Figure 1, the causal pathways potentially resulting in dissolved oxygen impairment include: 1) channel alteration; 2) land cover alteration; 3) water impoundment; and, 4) chemical, organic matter, and nutrient loading. Increased stream temperatures, increased ionic strength, and/or increased sediment loading are interacting stressors that can further exacerbate DO impairment. The biotic responses of concern include changes in behavior, increased mortality, impairment of invertebrate assemblages, impairment of fish assemblages, and other biological impairments. Increased susceptibility to disease, decreased growth, and decreased fecundity are also biotic responses of concern, though not specifically indicated in this model. A more complete conceptual model is included in Appendix D.

The following is USEPA's written explanation of the conceptual model

> "Certain human activities, such as agricultural, residential, and industrial practices, can contribute to DO depletion (or, less frequently, DO supersaturation), and subsequent biological impairment. These practices may directly introduce chemical contaminants, organic loading, and nutrients to streams, via point and non-point sources such as wastewater treatment plant effluents, fertilizers, animal wastes, landfills, and septic systems. Increases in these substances can increase chemical and biochemical oxygen demand, most notably due to increased respiration of plants and especially microbes.
>
> Physical alteration of the stream channel, through impoundments or channel alterations, can contribute to low dissolved oxygen concentrations in several ways. For example, an impoundment downstream of a location will slow water velocities and increase water depths, which will tend to reduce turbulence and lower incorporation of oxygen into the water column via aeration, as well as reduce diffusion of oxygen from the atmosphere. Channel incision also reduces oxygen diffusion due to decreases in surface-to-volume ratio with increasing stream depth. An impoundment upstream of a location (upper far right of diagram) may reduce DO levels if downstream water releases come from deeper, oxygen-depleted waters of the reservoir (i.e., if they are hypolimnetic), but may

increase DO levels if discharges are highly turbulent; whether DO levels increase or decrease will depend on impoundment size and type of release.

Land cover alterations also may reduce stream DO levels by altering in-stream physical characteristics. For example, decreases in riparian vegetation often associated with these activities can reduce large woody debris inputs to the channel, reducing turbulence and aeration; homogenization of stream substrates can have similar effects. In addition these alterations may increase delivery of chemical contaminants, organic material, and nutrients to streams with surface runoff.

In addition to these processes discussed above, DO concentrations are closely linked to several other stressors...Nutrient enrichment stimulates oxygen-generating (photosynthesis) and oxygen-depleting (respiration) processes. DO levels also are affected by water temperature, ionic strength, and dissolved solids: oxygen solubility decreases as these parameters increase, reducing the amount of available DO in the water. Increased bedded sediment can decrease interstitial flow, reducing oxygen availability for sediment-dwelling organisms, and decreases in water velocity can lower oxygen delivery rates.

DO concentrations directly impact abiotic and biotic stream environments. Low DO...affects the oxidation and reduction (redox) reactions which determine the bioavailability of many inorganic compounds, as well as biologically important materials such as nitrogen and sulfur. For example, lower redox potential (↓ Eh) may decrease the release of precipitated metals, which actually may benefit organisms by reducing bioavailability); however, it also may increase the release of precipitated phosphates, encouraging the proliferation of nitrogen-fixing cyanobacteria and potentially altering food resources for fish and invertebrate assemblages.

The most direct effect of low DO is respiratory distress in biota, which may be exacerbated by relatively rapid fluctuations in available DO. During periods of low DO, some species may increase movement to enhance ventilation across gill structures, attempt to gulp air from the surface, or gather around photosynthesizing plants. Respiratory stress can cause low DO-sensitive taxa [e.g., EPT taxa, or Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddis flies), and salmonid fishes] to decrease; often these taxa are considered indicators of good water quality. Decreases in low DO-sensitive life stages also are potential indicators. Conversely, more tolerant organisms (e.g., cyprinids, amphipods, and chironomids with hemoglobin) and life stages may increase. Increased populations of plant-breathers (e.g., insects that can obtain air from plants, such as certain beetle larvae) and air-breathers (e.g., insects that can carry air bubbles with them underwater) also may be observed. If DO depletion is significant enough, widespread fish kills may occur.

> Although biological impairments related to dissolved oxygen usually result from insufficient DO levels, too much DO, or supersaturation, also may pose a problem in certain situations. This supersaturation may result from extremely high levels of oxygen-generating photosynthesis, or from extremely high turbulence and aeration downstream of impoundments. Ultimately, these rapid or large increases in DO may affect organisms by contributing to stressful fluctuations in DO levels, altering redox potentials and bioavailability of potentially toxic substances (e.g., metals), or leading to gas bubble disease (a condition indicated by gas bubbles forming under skin and around eyes) (CADDIS 2007)."

With respect to the kind of activities generally found in the North Coast Region, the conceptual model highlights the importance of evaluating and controlling anthropogenic inputs of chemicals, nutrients, and organic rich wastes. But, it also highlights the importance of evaluating and managing the effects of:

- ✓ Anthropogenic alteration to the natural pattern and range of flows, including stormwater management, groundwater protection, and control of water impoundment and withdrawal;
- ✓ Anthropogenic sources of erosion and sediment delivery;
- ✓ Anthropogenic loss of channel forming materials (e.g., large woody debris);
- ✓ Alteration of the stream channel, such as through gravel mining;
- ✓ Disturbance to wetlands, the flood plain and riparian zone;
- ✓ Anthropogenic sources of nutrients, organic matter, warm water and their delivery to a waterbody, including the discharge of agricultural return flows; and,
- ✓ Threat of loss or alteration (e.g., reduction in flow or increase in temperature) of cold water springs.

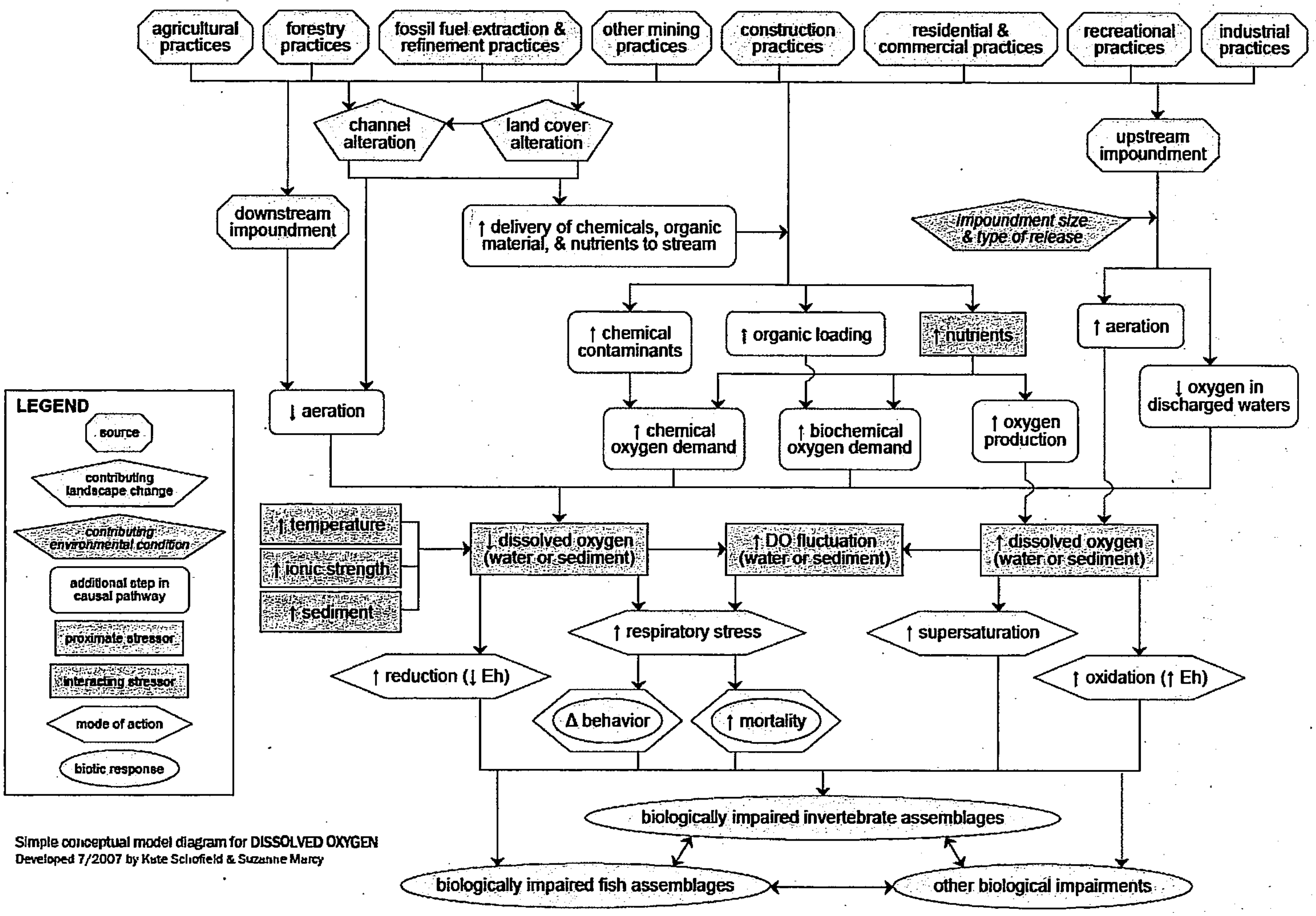
III.5 How is dissolved oxygen measured?

Dissolved oxygen measurements were historically collected as grab samples and analyzed in the field using the Winkler or modified Winkler method. The method requires careful sampling to avoid aeration, acid fixation, and slow titration to measure a change in test color. During the 1950 and 1960s when the State of California engaged in extensive water quality monitoring, one sample per site was typically collected during a sampling trip with site sample times varying across the hours of the work day.

More recently, DO has been measured using a datasonde data logger (datasonde). The Regional Water Board, for example, owns several datasondes used both by Regional Water Board staff and other local partners for specific field studies. A datasonde measures the current resulting from the electrochemical reduction of oxygen diffusing through a selective membrane (HACH 2008a). It is capable of collecting and storing data at intervals over several days. There are issues with calibration drift and biofouling of the membrane when the device is deployed for multiple days, making quality assurance a particularly important aspect of the data collection effort. The advantage of the datasonde over the Winkler method is that data can be collected over a 24-hour period (or longer). Thus, with this sampling method, it is possible to ascertain the true daily minimum DO value, since it often occurs at night.

Even more recently, dissolved oxygen data collection methods have been further improved with the development of Luminescent Dissolved Oxygen technology.. The use of this new technology is not yet widespread. But, it is expected to replace the earlier membrane-based probes in the coming year (Fadness 2008). Luminescent Dissolved Oxygen technology has a thicker membrane than its predecessor and is thus less susceptible to biofouling. It is also reported to have the ability to hold a calibration without drift (HACH 2008b). Data can be collected with this device at intervals over a 7-day period (or longer), thus allowing for assessment not only of the daily minimum, but daily and weekly averages, as well.

Figure 1 CADDIS Conceptual Model for DO



Simple conceptual model diagram for DISSOLVED OXYGEN
Developed 7/2007 by Kate Schofield & Suzanne Marcy

CHAPTER IV.
FISHERIES OF THE NORTH COAST REGION

As described by Moyle (2002) the North Coast Region is divided into two zoogeographic provinces representing two distinct fauna: the Klamath Province and the North Coast Province. The Klamath Province includes the Upper Klamath Subprovince, the Lower Klamath Subprovince, the Rogue River Subprovince, and the Klamath-Pit fishless area. The North Coast Province includes all the rivers draining to the Pacific Ocean north of the Klamath River basin to the Oregon border, as well as those south of the Klamath River to San Francisco Bay.

IV.1 Klamath Province

Moyle (2002) describes the native fishes of the Upper Klamath Province as primarily freshwater dispersants "most having their closet relatives in the Great Basin." A freshwater dispersant is a species that arrived in its present location from a freshwater route or has evolved in place from a distant saltwater ancestor (Moyle 2002). Freshwater dispersants in the Upper Klamath Province arrived from the Great Basin due to a time in geologic history when an ancestor of the Snake River, now draining through the Columbia River, previously flowed through the Klamath Region (Aalto et al. 1998 as cited by Moyle 2002). The native fishes of the Upper Klamath Province include three species of sucker; three species of cyprinids (i.e., blue chub, Klamath tui chub, speckled dace); three species of sculpin; several species of salmonid (e.g., bull trout, rainbow trout, redband trout, coastal rainbow trout, and the now extinct Chinook salmon); and three species of lamprey (Moyle 2002). Of these, the Klamath River lamprey, Lost River sucker, shortnose sucker, and slender sculpin are at risk of extinction (Moyle 2002). The slender sculpin, however, only occurs in Klamath and Agency lakes in Oregon.

The Lower Klamath Province includes 21 native species of fish including: three species of lamprey, two species of sturgeon, one cyprinid (speckled dace), one sucker, two species of smelt, six species of salmonid (the pink salmon now extinct), one stickleback, four species of sculpin, and one flounder. Of these, the river lamprey, green sturgeon, eulachon, longfin smelt, chum salmon, coho salmon, and cutthroat trout are at risk of extinction (Moyle 2002).

The Rogue River Subprovince contains the same saltwater dispersant species as in the lower Klamath River and the only native freshwater dispersant is the Klamath smallscale sucker (Moyle 2002). A saltwater dispersant is a species that lives in the freshwater environment; but, it either can live some portion of its life in saltwater or has immediate ancestors that did. The saltwater dispersants found in California are anadromous or had ancestors who were anadromous (Moyle 2002).

The Klamath-Pit fishless area is comprised of a large region of lava geology and scrubby forest and no flowing waterbody (Moyle 2002). Much of the rainfall to this area feeds underground springs that form the Fall River, a tributary to the Pit River (Moyle 2002).

IV.2 North Coast Province

The rivers of the North Coast Province each have slightly different zoogeographic histories; but, Moyle (2002) describes them as having more faunal similarities than differences. Moyle (2002) highlights the following North Coast basins: Tomales Bay, Russian River, Gualala River, Garcia River, Navarro River, Big River, Noyo River, Mattole River, Bear River, Eel River, Mad River, Little River, Redwood Creek, and the Smith River. Of these, only the Tomales Bay resides outside of the boundaries of the North Coast Region.

The native fish common to most of these rivers include: Pacific lamprey, coho salmon, rainbow trout, threespine stickleback, staghorn sculpin, coastrange sculpin, and prickly sculpin. Of these, Moyle (2002) lists the coho salmon at risk of extinction.

The Russian River uniquely includes several species of fish also endemic to the Sacramento-San Joaquin basins of the Central Valley, including: hardhead, hitch, Sacramento pikeminnow, California roach, Sacramento sucker, longfin smelt, tule perch, riffle sculpin, and starry flounder (Moyle 2002). Moyle (2002) describes the Russian River as having "captured" much of the Central Valley fauna. California roach are also found in the Gualala and Navarro Rivers (Moyle 2002). The Sacramento sucker has made its way into the Navarro, Big, Bear, Eel, and Mad Rivers and Redwood Creek (Moyle 2002).

Moyle (2002) identifies those species at risk of extinction in the North Coast Province as including:

- River lamprey (in the Russian and Eel rivers),
- Pacific brook lamprey (in the Russian and Eel rivers),
- Hitch (in the Russian River),
- Eulachon (in the Mad River, Redwood Creek, and Smith River),
- Longfin smelt (in the Russian River),
- Coho salmon (throughout the Province),
- Chinook salmon (in the Russian, Mattole, Bear, Eel, Mad, Little, and Smith Rivers, and Redwood Creek),
- Tule perch (in the Russian River), and
- Tidewater goby (in the Eel River, Redwood Creek, and Smith River).

The green sturgeon and longfin smelt are already extinct in the Eel River; pink salmon are extinct in the Russian River, Eel River, and Mad River; and Chinook salmon is extinct in the Garcia River (Moyle 2002).

IV.3 Individual Life Histories

The following is a list of native fishes identified as being at risk of extinction in the North Coast Region, including both the Klamath Province and the North Coast Province (Moyle 2002). While they share the status of being at risk, they also represent a range of fish species and life histories. What follows is a discussion of the individual life histories and

DO requirements, to the degree that they are known. Predictably, the DO requirements of salmonids are the most well understood and represent the largest part of the discussion. Because coldwater DO objectives have generally been developed based on the requirements of salmonids, the information below is intended to confirm whether or not DO objectives developed to protect salmonids will protect the other fishes at risk, as well.

- Salmonids (chum salmon, coho salmon, Chinook salmon, cutthroat trout);
- Lamprey (Klamath River lamprey, river lamprey, Pacific brook lamprey);
- Sucker (Lost River sucker, shortnose sucker);
- Green sturgeon;
- Hitch;
- Smelt (eulachon and longfin smelt);
- Tule perch; and
- Tidewater goby.

IV.3.1 Salmon

The present distribution and abundance of salmonids "have been strongly shaped by Pleistocene events. In northern and mountain areas, they followed the advance and retreat of continental glaciers, rapidly colonizing new steams and lakes" (Moyle 2002). Moyle (2002) asserts that salmonids thrive in dynamic environments. But, the water must be fairly cool (<22°C maximum) and well oxygenated (Moyle 2002). Moyle (2002) opines that because they have twice as much genetic material as most fishes, salmonids respond rapidly to evolutionary pressures.

Salmonids are anadromous fish, being born in freshwater, migrating to the ocean where they feed and mature, and returning to their natal freshwater stream to reproduce. Salmonids typically die after spawning in fresh water. Salmonid eggs are laid in a nest (i.e., redd) that the female digs in the gravel. The eggs are fertilized externally and the developing embryos covered with gravel as protection. After the yolk sac fry or alevin hatch, they remain in the interstices of the gravel until ready for emergence to the water column. Juvenile fish grow in freshwater until ready for outmigration to the ocean. They remain in the estuary where they develop osmoregulation facilities capable of life in the ocean. Once in the ocean they feed and grow before reaching sexual maturity. Some salmonids complete their sexual maturation in the freshwater of their natal stream. Others return to their natal stream ready to spawn.

Salmonid species differ in the timing of their life cycle stages, as well as the specific habitat niches they inhabit while in the freshwater environment. For example, spring Chinook enter a river system in the spring while fall Chinook enter a river system in the fall. However, both species wait until water flows increase and water temperatures decline in the fall before building redds and laying eggs. Other salmonid species arrive throughout the fall and winter for spawning. By June, the fry of all salmonid species have emerged from the gravel and begun their life in the water column. The length of time juvenile fish remain in freshwater before outmigrating to the ocean varies from several months to several years.

IV.3.1.1 Coho Salmon

In California, coho salmon (*Oncorhynchus kisutch*) have a fairly strict 3 year life cycle with about half of its life spent in freshwater and the other half in the ocean (Moyle 2002). Coho adults migrate upstream for spawning after heavy fall or winter rains breach the sandbars of coastal streams allowing the fish to enter. Coho choose smaller coastal streams or the tributaries of larger coastal streams for spawning. They continue upstream when stream flows are rising or falling; though, not necessarily when the streams are in full flood (Moyle 2002). Redd locations generally are at the head of riffles, just below a pool, "where water changes from smooth to turbulent flow and there is abundant medium to small gravel" (Moyle 2002). Embryos hatch after 8-12 weeks of incubation, time being "inversely related to water temperature" (Moyle 2002).

After emergence, fry find quiet stream margins to feed and shelter before establishing territories. Nielsen (1992a, 1992b, and 1994) as cited by Moyle 2002, documented a complicated division of territories amongst coho juveniles, including distinctions between those she called estuarine, margin, thalweg, and early pulse juveniles. All are as their name implies: "early pulse juveniles show two pulses of growth, one in spring and one in autumn (Moyle 2002)."

The outmigration of juveniles begins between March and May. The triggers include: "rising or falling water levels, day length, water temperature, food densities, phase of the moon, and dissolved oxygen levels" (Moyle 2002). Migrants transform into silvery smolts often lingering for a period in the estuary while adjustments are made to their osmoregulatory system (Moyle 2002).

IV.3.1.2 Chinook Salmon

In California, Chinook salmon (*Oncorhynchus tshawytscha*) are often described by the timing of their freshwater migration: fall-run, late fall-run, winter-run, and spring-run (Moyle 2002). Widely recognized runs in the North Coast Region include: Smith River fall run (and spring run), Klamath-Trinity fall run, Klamath-Trinity spring run, Klamath late fall run, Redwood Creek fall run, Little River fall run, Mad River fall run, Humboldt Bay tributary fall run, Eel River fall run, Bear River fall run, Mattole River fall run, and Garcia River fall run (Moyle 2002). Stream-type Chinook are fish that migrate upstream before reaching sexual maturity, as well as juveniles that spend more than 1 year in freshwater before outmigrating (Moyle 2002). Ocean-type Chinook are fish that spawn immediately upon migrating upstream, as well as juveniles that spend less than 1 year in freshwater before outmigrating (Moyle 2002).

A fall-run Chinook is an ocean-type Chinook, entering the big rivers of the Klamath and North Coast Provinces in the late summer and early fall, and spawning in the lowland reaches within a few days to weeks or arrival (Moyle 2002). Juveniles emerge from the gravel in spring and move downstream within a few months to rear in the mainstem or estuary before going out to sea (Moyle 2002).

A spring-run Chinook is a stream-type Chinook, entering the Smith, Klamath or Eel River in the spring or early summer, going as far upstream as it can, and holding in deep, cold pools until spawning in the early fall (Moyle 2002). The juveniles rear for 3-15 months depending on flow conditions (Moyle 2002). Spring-run Chinook are considerably less abundant that fall-run Chinook because of the presence of dams, blocking much of their historical mid-elevation habitat (Moyle 2002).

IV.3.1.3 Chum Salmon

In California, small runs of chum salmon were historically present in streams from the Sacramento River north (Moyle 2002). Today, small runs of chum salmon continue in the Smith, Klamath and Trinity Rivers. Chum salmon are generally ocean-type salmon, spending little time in freshwater, and most of that often in the estuary. Chum salmon enter freshwater in the late fall with optimal spawning temperatures of 7.2-12.8 °C and oxygen levels greater than 80% saturation (Moyle 2002).

IV.3.1.4 Cutthroat Trout

In California, coastal cutthroat trout live in the coastal drainages from the Eel River north (Moyle 2002). Coastal cutthroat trout are more strongly tied to fresh water than most anadromous fishes, leaving freshwater only in the summer months, if at all, and returning to overwinter in freshwater (Moyle 2002). They live primarily in small, low-gradient coastal streams and estuaries where temperatures are cool (<18 °C), well-shaded, and there is abundant cover (Moyle 2002). They especially avoid waters with DO <5 mg/L (Moyle 2002). Embryo survival can be reduced to less than 10% with DO levels lower than 6.9 mg/L (Moyle 2002). Cutthroat trout migrate upstream in August-October following the first substantial rainfall (Moyle 2002). Embryos hatch after 6-7 weeks of incubation and alevin remain in the gravel for an additional 1-2 weeks (Moyle 2002), emerging from March to June (Moyle 2002).

IV.3.1.5 DO requirements of early life stages

In her review of scientific literature on the subject of DO requirements for salmonids, Regional Water Board staff Carter (2005) found that the early life stages of salmonids (embryos and alevins) are particularly vulnerable to poor water quality conditions because of their relative immobility within the gravel and their underdeveloped ability to extract oxygen from the environment. The effects of low DO on fish eggs and larvae include: respiratory dependence, retarded growth, reduced yolk sac absorption, developmental deformities, and mortality (Davis 1975).

The DO present in the intragravel environment is a function of many chemical, physical, and biological factors, including: the DO concentration of the overlying water, water temperature, substrate size and porosity, biochemical oxygen demand, sediment oxygen demand, the gradient and velocity of the stream, channel configuration, and depth of water (Carter 2005). In streams with substantial groundwater inflows, however, DO concentrations and flow patterns of intragravel water may not relate in the usual way to substrate composition and permeability (Bjornn and Reiser 1991). In fact, Bjornn and Reiser (1991) determine that unhatched embryos can extract the necessary oxygen from the air within a dewatered redd, as long as the environment is otherwise moist.

Koski (1965), as cited by USEPA (1986), found that even within the same redd, intragravel DO concentrations varied 5 or 6 mg/L in 30 coho salmon redds studied in 3 small, unlogged, forested watersheds. But, the average intraredd DO concentration was about 2 mg/L below that of the overlying water while the minimum concentrations averaged about 3 mg/L below those of the overlying water. USEPA (1986) recommends ambient water quality objectives be set 3 mg/L higher than intragravel DO requirements to ensure protection of embryos and alevin.

In its review of the scientific literature, ODEQ (1995), as cited by Carter (2005), found that the mortality of salmonid embryos held at a constant 10 °C began to increase dramatically as DO concentrations were reduced below 3 mg/L. Silver et al. (1963) as cited by Carter (2005) found that survival of a large percentage of embryos was possible even at 2.5 mg/L by a reduction in respiration rates. But, this resulted in a concurrent reduction in growth and development rates.

Embryo survival rates have been correlated with DO concentration: 62 % survival of steelhead embryos at 9.25 mg/L DO and 16% survival at 2.6 mg/L DO (Coble 1961 as cited by Carter 2005). But, at temperatures suitable to Chinook salmon incubation, percent survival remained high as DO concentrations were reduced from 11 mg/L to 3.5 mg/L (Eddy 1971 as cited by Carter 2005). The number of days to hatching increased, however, while the mean dry weight of the fry decreased substantially (Eddy 1971 as cited by Carter 2005).

Salmonid embryos were found to be smaller than normal and hatching either delayed or premature when DO was less than saturation throughout development (Bjorrn and Reiser 1991). Shumway et al. (1964), as cited by Carter (2005), found that the median time to hatching decreased and size of fry increased as DO levels increased.

Once embryos hatch, alevin reside in the intragravel environment until their yolk sac is absorbed and they are ready to emerge from the gravel as fry. To some degree, they are able to move between particles within the intragravel environment to locate preferred water quality conditions. The Washington State Department of Ecology (WDOE 2002), as cited by Carter (2005), found that alevin showed a strong preference for DO concentrations of 8-10 mg/L, avoiding areas where DO was 4-6 mg/L.

Bjornn and Reiser (1991), suggest that an average intragravel DO concentration of 8 mg/L allows for good embryo and alevin survival. Davis (1975), as cited by Carter (2005), concludes that 9.75 mg/L is necessary for full protection of larvae and mature eggs. USEPA (1986) determines that no production impairment is expected when intragravel DO conditions average 8 mg/L. The daily minimum intragravel DO should not be reduced below 6 mg/L.

IV.3.1.6 DO requirements to support juvenile growth

As described by Carter (2005) food conversion efficiency is related to DO concentrations and the process becomes less efficient when DO is less than 4-4.5 mg/L (ODEQ 1995 as cited by Carter 2005). Bjornn and Reiser (1991) as cited by Carter (2005) state that growth, food conversion efficiency, and swimming performance are adversely affected when DO concentrations are less than 5 mg/L. Brett and Blackburn (1981) as cited by Carter (2005) demonstrated that both coho and sockeye salmon growth is strongly dependent on DO concentration up to 5 mg/L. Growth rates are independent of DO at concentrations greater than 5 mg/L, however. Herrmann et al. (1962) as cited by Carter (2005), concluded that a reduction in the mean oxygen levels from 8.3 mg/L to 6 and 5 mg/L resulted in slight decreases in food consumption and growth. USEPA (1986) as cited by Carter 2005) calculated no reduction in growth at DO concentrations of 8 an 9 mg/L and 1% reduction in growth at 7 mg/L, with reductions in growth rates seen above 6 mg/L generally not statistically significant.

IV.3.1.7 DO requirements to support swimming

Davis (1975), as cited by Carter 2005, reviewed numerous studies and reported no impairment to rearing salmonids if DO concentrations averaged 9 mg/L, while at levels of 6.5 mg/L, "the average member of the community will exhibit symptoms of oxygen distress." Davis et al. (1963) as cited by Carter 2005, reported maximum sustained swimming speeds of wild juvenile coho salmon held in the laboratory were reduced when DO dropped below saturation at water temperatures between 10-20 °C. WDOE (2002), as cited by Carter 2005, concluded that swimming fitness is maximized when the daily minimum DO levels are above 8 mg/L.

IV.3.1.8 DO preference

Field and laboratory studies have found that avoidance reactions in juvenile salmonids consistently occur at concentrations of 5 mg/L and lower, with some indication that avoidance is triggered at concentrations as high as 6 mg/L (Carter 2005). Spoor (1990), as cited by Carter 2005, concluded that brook trout will avoid oxygen concentrations below 4 mg/L and preferred oxygen levels of 5 mg/L or higher. Salmonid mortality occurs when DO concentrations are below 3 mg/L for periods longer than 3.5 days (USEPA 1986, as cited by Carter 2005).

IV.3.2 Lamprey

Lamprey are a jawless fish from the family *Petromyzontidae* that generally feed on the blood and body fluids that they extract with their sucker-like mouth from live fish (Moyle 2002). This "predatory" phase of the Pacific lamprey is spent in the ocean, except for those species that are landlocked (Moyle 2002).

Pacific lamprey spawning usually begins in early March and lasts through late June (Moyle 2002). There are variations to this schedule. And, in the larger rivers (Klamath, Trinity, and Eel) there may be both spring and fall runs, similar to salmon (Moyle 2002).

Adult lamprey migrate from the ocean to freshwater where a male and female build a nest together in the gravel (Moyle 2002). After the eggs are laid and fertilized, embryos develop and hatch in about 19 days at 15 °C (Moyle 2002). The ammocoetes are washed downstream to a muddy or sand-bottomed backwater where they burrow in the sediment, tail down (Moyle 2002). They remain in the sediment as filter feeders while they undergo a metamorphosis to become adult lamprey (Moyle 2002). Metamorphosis takes from 5-7 years (Moyle 2002).

There is some evidence of temperature requirements of lamprey. But, little information is available regarding dissolved oxygen requirements, though ammocoete development is impaired under very low DO concentrations (Goodman 2008). Of primary concern to lamprey conservation are activities that may directly disturb ammocoetes, result in sedimentation of quiescent stream reaches, or cause localized dewatering (USFWS 2007). DO conditions suitable to support salmonids are believed to be adequate for lamprey, as well (Goodman 2008).

IV.3.3 Sucker

The Lost River sucker (*Catostomus luxatus*) and shortnose sucker (*Chasmistes brevirostris*) are two native species of the upper Klamath basin. Both sucker species are endangered and belong to a "part of a group of suckers that are large, long-lived, late-maturing, and live in lakes and reservoirs but spawn primarily in streams; collectively, they are commonly referred to as lake suckers" (NRC 2004). Lake suckers differ from most other suckers in having terminal or subterminal mouths that open more forward than down, an apparent adaptation for feeding on zooplankton rather than suctioning food from the substrate (Scoppettone and Vinyard 1991 as cited by NRC 2004). Historically, Lost River suckers and shortnose suckers occurred in the Lost River and upper Klamath River and their tributaries, especially Tule Lake, Upper Klamath Lake, Lower Klamath Lake, Sheepy Lake, and their tributaries (Moyle 2002 and USFWS 2002 as cited by NRC 2004).

The adult suckers reach sexual maturity between years 4 and 6 for the shortnose sucker (USFWS 2007c) and 5 and 14 for the Lost River sucker (USFWS 2007b). They spawn in river riffle and run habitat from February through May in gravel and cobble substrate with moderate flows and depths less than 4 feet (USFWS 2007b and 2007c). Sucker larvae move out of the gravel soon after hatching and generally drift downstream to the lake environment where they disperse in the near shore areas (Cooperman and Markle 2004 as cited by USFWS 2007a; USFWS 2007b). Larval habitat is best described as shallow, nearshore, and vegetated in both rivers and lakes, except Clear Lake and Gerber Reservoir which lack vegetation (Klamath Tribe 1991, Markle and Simon 1994, and Reiser et al. 2001 as cited by NRC 2004). Adult suckers select water depths of 3-15 feet, their strongest preference appears to be for 5-11 feet (Reiser et al. 2001 and USFWS 2002 as cited by NRC 2004). Adult Lost River suckers have been aged to 43 years while shortnose suckers have been aged to 33 years (NRC 2004). The lake suckers spawn numerous times over their life time producing millions of eggs, a life history strategy necessary due to the high natural mortality of the young fish and the low natural mortality of the older adult fish (NRC 2004).

With respect to water quality, Woodhouse et al. (2004) synthesized several studies in the Lost River basin to determine appropriate thresholds for Lost River and shortnose suckers. In summary, water quality threshold values include:

- DO > 2.3 mg/L (based on LC_{50} in shortnose sucker larvae);

- pH < 9.5 (based on critical maxima in shortnose sucker adults);
- Water temperature < 30.3 °C (based on LC50 in shortnose sucker juveniles);
- Un-ionized ammonia < 0.48 mg/L (based on LC_{50} in Lost River sucker larvae and shortnose sucker juveniles).

Staff concludes that DO conditions suitable for the protection of salmonids will adequately protect suckers, as well.

IV.3.4 Green Sturgeon

The green sturgeon (*Acipsenser medirostris Ayres*) is a long-lived anadromous fish that spends most of its time in ocean waters with feeding forays to bays and estuaries (NMFS 2009). Both adults and juveniles are benthic feeders eating shrimp, mollusks, amphipods and small fish (Moyle 2002). The green sturgeon migrates into freshwater systems to spawn. In the North Coast Region, green sturgeon are primarily found in the Klamath and Trinity rivers; though, they will occasionally be seen in the Eel River which once supported a spawning run (Moyle 2002).

Green sturgeon enter the Klamath River system between February and late July with a spawning period of March to July and a peak from mid-March to mid-June (Moyle 2002). They spawn in deep, fast water where eggs are broadcast and externally fertilized (Moyle 2002). Juveniles remain in freshwater for up to 3 years before migrating to the ocean. Water quality requirements for the green sturgeon are unknown; but, a small amount of silt will prevent the eggs from clumping together and thus reduce viability (Moyle 2002). Gulf of Mexico sturgeon were found in locations in the Suwannee River estuary ranging from 6.0 to 9.8 mg/L DO with an average of 7.5 mg/L DO (Harris et al. 2005). Eggs were found in areas of the Suwannee River with DO exceeding 5.0 mg/L (Sulak and Clugston 1998). Campbell and Goodman (2004) exposed juvenile shortnose sturgeon, an Atlantic species, to varying laboratory conditions and derived LC50s ranging from 2.2-3.1 mg/L DO depending on the accompanying salinity, temperature, and age of the fish. Younger fish were more sensitive to low DO than older fish.

NMFS 2009 lists as threats to California's green sturgeon:

- ✓ Insufficient freshwater flow rates in spawning areas,
- ✓ Contaminants (e.g., pesticides),
- ✓ Bycatch of green sturgeon in fisheries,
- ✓ Potential poaching (e.g., for caviar),
- ✓ Entrainment by water projects,
- ✓ Influence of exotic species,
- ✓ Small population size,
- ✓ Impassable barriers, and
- ✓ Elevated water temperatures.

Staff concludes that DO requirements designed to protect salmonids will reasonably protect sturgeon, as well.

IV.3.5 Smelt

The eulachon (*Thaleichthys pacificus*) and longfin smelt (*Spirinchus thaleichthys*) are both in the smelt family *Osmeridae* and are anadromous fish. Within the North Coast River, the eulachon has been found historically in the Klamath River, as well as in the Mad River, Redwood Creek, and the Smith River while the longfin smelt has been found in Humboldt Bay, the Eel River estuary, the Klamath river estuary, and the Russian River estuary (Moyle 2002).

The eulachon is the largest example of the smelt family (Moyle 2002). It is a very oily fish, also sometimes called the candlefish because of its historic use when dried to be burned as a candle. It is an anadromous fish, spending most of its life at sea and then spawning in the lower reaches of coastal rivers (Moyle 2002). Eulachon return to freshwater between December and May in their third year and their migration appears to be timed with river temperatures between 4-8 °C (Moyle 2002). Migrating fish seldom travel farther than 12 km up river, the fish keeping to the river bottom and shallow river edges (Moyle 2002). Spawning occurs where temperatures are between 4-10 °C, velocities are moderate, and substrate consists of pea-sized gravel or gravel mixed with sand, wood or other debris (Moyle 2002). Fertilization is external with females producing an average of 25,000 eggs (Moyle 2002). Eggs have two membranes, the outer one of which ruptures when the egg hits the channel bottom. This allows the sticky edges to adhere to the substrate where the larvae will hatch in 2-3 weeks. The larvae are quickly washed out to sea (Moyle 2002).

Moyle (2002) states "given the extended ocean life phase of eulachon and the apparently sporadic nature of their abundance in recent years, it is likely that oceanic conditions may be important determinants of the size of spawning runs." He continues "eulachon are sensitive to a number of environmental factors and their recent decline in California streams may be the result of changes in water quality or spawning habitat in the lower reaches of rivers" (Moyle 2002).

Longfin smelt have a wide salinity and temperature range, reflecting their ability to occupy various estuarine niches depending on the time of year and life cycle stage (Moyle 2002). They spawn in freshwater over sandy or gravel substrates, rocks and aquatic plants as early as November and up through the month of June (Moyle 2002). Embryos hatch in 40 days at temperatures of 7 °C, the newly hatched larvae drift quickly down to the estuary (Moyle 2002). Larvae metamorphose into juveniles after 30-60 days from hatching, depending on the temperature (Moyle 2002). Most adult longfin smelt die after spawning (Moyle 2002).

Pientka and Parrish (2002) found that in a comparison of habitat use by Atlantic salmon and rainbow smelt, the two occupied similar thermal habitat. But, Atlantic salmon generally chose habitat with higher DO concentrations. Staff concludes that DO objectives designed to protect salmonids will be protective of smelt, as well.

IV.3.6 Tule Perch

The UC Cooperative Extension, Fish Web Site lists Bodega Bay, Gualala River-Salmon Creek watershed (i.e., coastal streams from the Gualala River to Salmon Creek in

Sonoma County), and Russian River as locations in the North Coast Region where tule perch are found (UCCE 2009). They prefer low elevation lakes, streams, and estuarine environments, requiring well oxygenated water with temperatures below 22 °C and have high salinity tolerances (UCCE 2009). Numeric DO criteria for tule perch were not immediately available. However, Moyle (2002) notes that yellow perch can survive DO levels of less than 1 mg/L.

In rivers, tule perch occupy deep pools with complex cover, particularly overhanging vegetation (UCCE 2009). In lakes, they tend towards deep water with a slight current, as well as near stands of tule (UCCE 2009). Tule perch bear live young in emergent vegetation during the period of May to June (UCCE 2009). The young grow rapidly in the first 18 months and may reach up to 7 years of age, though the majority live about 5 years (UCCE 2009).

Staff conclude that tule perch are likely to be well-protected by DO objectives designed to protect salmonids.

IV.3.7 Hitch

Hitch (*Lavinia exilicauda*) are in the minnow family (Cyprinidae) and are closely related to California roach (Moyle 2002). Hitch are widespread in warm, low-elevation lakes, sloughs, and slow-moving stretches of river, and in clear, low-gradient streams (Moyle 2002). They also have wide temperature and salinity tolerances, e.g. up to 38 °C and 9 ppt, respectively (Moyle 2002).

Adult fish are pelagic, feeding on algae, insects, and/or zooplankton (Moyle 2002). But, juveniles are found in shallow-water habitat under the protection of vegetation such as tule where they eat insect larvae and pupae and planktonic crustaceans (Moyle 2002). Spawning takes place in riffles of streams tributary to lakes, rivers and sloughs, after flows increase in response to spring rains (Moyle 2002). In Clear Lake, spawning migrations take place from mid-March through May and occasionally into June (Moyle 2002). Females release their eggs over clean gravel where 1-5 males then fertilize them. Eggs sink into the gravel, absorb water, and swell up to 4 times their original size to lodge in the gravel (Moyle 2002). Hitch eggs hatch in 3-7 days and larvae become free-swimming in another 3-4 days (Moyle 2002). In Clear Lake, juveniles quickly move into the lake, allowing spawning in tributaries that otherwise dry up as the summer proceeds (Moyle 2002). Hitch are not aggressive swimmers and can be barred from habitat by small dams and other structures (Moyle 2002).

Moyle (2002) lists the probable factors influencing the declining status of hitch in the North Coast Region to include:

- ✓ Loss of adequate spawning flows in spring months (because of dams and diversions);
- ✓ Loss of summer rearing and holding habitat;
- ✓ Pollution; and,
- ✓ Predation by nonnative fishes.

No information could be found with respect to the DO requirements of hitch. But, because of their wide temperature and salinity tolerances, staff assumes that DO thresholds also range widely making hitch far less sensitive to DO than salmonids.

IV.3.8 Tidewater Goby

The tidewater goby (*Eucyclogobius newberryi*) is endemic to California, found in lagoons of coastal streams throughout the North Coast Region up to the Smith River (Moyle 2002). Tidewater gobies prefer well-oxygenated, brackish, cool waters with salinities less than 10 ppt (Moyle 2002). They are generally absent from lagoons that stagnate or stratify (Moyle 2002). Tidewater gobies live about 1 year with reproduction occurring throughout the year, though little spawning occurs from December through March (Moyle 2002). The male creates a vertical burrow in which fertile eggs are laid (Moyle 2002). Male tidewater gobies prefer relatively unconsolidated, clean, coarse sand and begin digging in April or May after lagoons close to the ocean (Swift et al. 1989; Swenson 1995 as cited by USFS 2007). The male guards the embryos for 9-11 days, after which the larvae emerge from the burrow and join the benthos (Moyle 2002). Juvenile/adults fish prefer sand, mud, gravel and silt, particularly is association with submerged vegetation for cover from predators (Stillwater Sciences 2006). Tidewater gobies are found at DO concentrations ranging from 0.2 mg/L to 15.5 mg/L (Tetra Tech Inc. 2000, Irwin and Soltz 1984, and Chamberlain 2006 as cited by Stillwater Sciences 2006) with some evidence that higher densities are found between 2-4 mg/L DO (Tetra Tech Inc. 2000 as cited by Stillwater Sciences 2006).

Moyle (2002) notes the effects of upstream logging on tidewater goby habitat, including increased sedimentation and increased severity of high-flow events. He also notes that where estuaries have been permanently breached with jetties, tidewater gobies are absent.

Staff concludes that DO objectives designed to protect salmonids will also protect tidewater gobies.

IV.4 Summary

In summary, there a number of native fish species of the North Coast Region that are at risk of extinction, including species of: salmonids, lamprey, sucker, sturgeon, hitch, smelt, perch, and goby. These fishes occupy a variety of freshwater and estuarine habitats, some of them overlapping with other native species. The life cycles vary considerably with some species spending a majority of their lives in freshwater and others in the ocean. Yet, the information staff has been able to gather on the DO and/or other water quality requirements of each of the species of interest suggests that DO objectives designed to protect salmonids likely will protect the other native species, as well, even for those species with extended larval stages such as the lamprey. This brief assessment is intended only to confirm that the general bias towards salmonids in the establishing of water quality objectives is, at least for DO, warranted.

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CHAPTER V.
ASSESSMENT OF EXISTING DO OBJECTIVES AND RECOMMENDATIONS

The purpose of this chapter is to assess the continued appropriateness of the existing DO objectives and determine what revisions and/or updates are required to ensure full protection of water quality and beneficial uses. To this end, staff has conducted the following analyses:

1. Compared the existing life cycle DO objectives to USEPA guidance on the development of ambient water quality criteria for DO and the other scientific literature as presented in Chapter IV; and,
2. Evaluated 4 lines of evidence regarding the appropriateness of the existing Table 3-1 DO objectives as representations of background, including the results of the Klamath River TMDL for DO.

V.1 Assessment of Life Cycle DO Objectives

As described in Chapter II, the life cycle DO objectives are given in the Basin Plan as daily minimum objectives specific to the beneficial uses they are each designed to protect. For example, in waterbodies designated as WARM, MAR, or SAL, an ambient water quality objective of 5.0 mg/L is applied. In waterbodies designated as COLD, an ambient water quality objective of 6.0 mg/L is applied. And, in waterbodies designated as SPWN, an ambient water quality objective of 7.0 mg/L is applied, except during critical periods of spawning and egg incubation when an ambient water quality objective of 9.0 mg/L is applied.

Staff compared the freshwater life cycle DO objectives (i.e., for WARM, COLD, and SPWN) as they are currently given in the Basin Plan to USEPA guidance on the development of freshwater ambient water quality criteria for DO (USEPA 1986). Because USEPA's freshwater guidance is over 20 years old, staff further compared the COLD and SPWN objectives to a survey of scientific literature conducted in-house in 2005 (Carter 2005). Carter (2005) surveyed the effects of DO on salmonids by life stage. It is incorporated here by reference and included in Appendix E and has been previously peered reviewed. It is summarized in Chapter IV along with other scientific literature regarding the life cycle requirements of salmonids and other native North Coast fish species.

Staff compared the saltwater life cycle DO objectives (i.e., for MAR and SAL) as they are currently given in the Basin Plan to USEPA guidance on the development of saltwater ambient water quality criteria for DO (USEPA 2000). The saltwater guidance was developed for the Atlantic coast from Cape Cod to Cape Hatteras, only. As such staff referred to the Southern California Coastal Water Research Project's (SCCWRP) assessment of USEPA (2000) for insight on the application of USEPA (2000) to Pacific waters (SCCWRP 2003). Though no DO objective for the protection of the EST[6]

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[6] The estuarine habitat (EST) beneficial use includes uses of water that support estuarine ecosystems including, but not limited to, preservation or enhancement of estuarine habitats, vegetation, fish, shellfish, or wildlife (e.g., estuarine mammals, waterfowl, shorebirds).

beneficial use is currently given in the Basin Plan, staff considered USEPA (2000) and SCCWRP (2003) with respect to estuarine protection, as well.

V.1.1 Comparison of Freshwater Life Cycle DO Objectives to USEPA (1986)

USEPA (1986) reviewed the scientific literature for the effects of various DO concentrations on mortality, growth, reproduction, early life stages, behavior, and swimming ability of both salmonid and non-salmonid fish species. It further reviewed the effects of various DO concentrations on macroinvertebrates, though concluded that DO suitable to support salmonids would adequately protect macroinvertebrates, as well. USEPA (1986) is incorporated by reference as a primary scientific source and is included as Appendix ??

Largely based on growth and survival data, generalization of response curve shape and assumed applicability of laboratory responses to natural populations, USEPA (1986) developed four levels of risk as given in Table 1: no, slight, moderate, and severe production impairment.

Table 1: USEPA's (1986) DO concentrations (mg/L) equivalent to qualitative levels of effect

	Salmonid waters		Nonsalmonid waters		Invertebrates
	Embryo and larval stages*	Other life stages	Early life stages	Other life stages	
No production impairment	11 (8)	8	6.5	6	8
Slight production impairment	9 (6)	6	5.5	5	5
Moderate production impairment	8 (5)	5	5	4	
Severe production impairment	7 (4)	4	4.5	3.5	
Limit to avoid acute mortality	6 (3)	3	4	3	4

*Values within parentheses represent the DO concentration required within the intragravel environment. Values without parentheses represent the DO concentration estimated as necessary to achieve the required intragravel DO.

USEPA (1986) recommended national DO criteria. But, it provided guidance for the development of local criteria, as well. In the development of local criteria, USEPA (1986) recommended that "if slight production impairment or a small but undefinable risk of moderate production impairment is unacceptable" then continuous exposure conditions should use the *no production impairment* values developed from the scientific literature as means and the *slight production impairment* values as minima. Staff concludes that slight or moderate impairment is unacceptable in North Coast waterbodies because of the risk of extinction facing several native fish species. USEPA recommendations for each life cycle stage, described below, are based on this premise.

USEPA (1986) also recommended the use of a 7-day averaging period for embryonic, larval, and early life stages because of the sensitivity of these life stages. USEPA (1986) further said that "other life stages can probably be adequately protected by 30-day averages." Staff recommends the use of a 7-day averaging period for all life stages because of the risk of extinction facing several native fish species. The discussion below is based on this premise, as well.

V.1.1.1 Coldwater Criteria for Early Life Stages (SPWN)

As given in Table 1, USEPA (1986) recommended for sensitive coldwater populations for which slight or no production impairment is acceptable, daily minimum DO conditions for early life stages based on slight production impairment values:

- ✓ ≥6.0 mg/L in the intragravel environment and
- ✓ ≥9.0 mg/L in the water column.

USEPA (1986) further recommended 7-day average DO conditions for early life stages based on no production impairment values:

- ✓ ≥8.0 mg/L in the intragravel environment and
- ✓ ≥11.0 mg/L in the water column.

Daily Minimum Requirement

The Basin Plan gives as the SPWN life cycle requirement a daily minimum DO condition ≥ 9.0 mg/L in the water column. The Basin Plan does not include a 7-day average limit; nor, are there requirements specific to the intragravel environment.

The 9.0 mg/L daily minimum SPWN requirement given in the Basin Plan applies to the period of "critical spawning and egg incubation." The calendar dates during which "critical spawning and egg incubation" occur are not included in the Basin Plan. Further, this period as defined does not include the time after egg incubation when the yolk-sac fry or alevin still reside in the intragravel environment. For the period of yolk-sac absorption—and the rest of the year—the Basin Plan includes a daily minimum SPWN requirement of 7.0 mg/L.

USEPA (1986) arrived at the 9.0 mg/L daily minimum DO requirement in the water column based on the findings of Koski (1965) in which the minimum intragravel concentrations averaged for 3 small, unlogged, forested watersheds was 3.0 mg/L below the overlying water. Thus, to ensure sensitive early life stages a minimum of 6.0 mg/L DO in the intragravel environment, the overlying water column must be at least 9.0 mg/L. A SPWN DO requirement of 7.0 mg/L during yolk-sac absorption and prior to fry emergence may result in intragravel DO conditions as low as 4.0 mg/L as a daily minimum. WDOE (2002) as cited by Carter (2005) found that alevin avoided areas where DO was 4-6 mg/L.

To ensure adequate protection of early life stages in the intragravel environment, staff recommends eliminating the 7.0 mg/L daily minimum SPWN requirement as under protective. Staff further recommends expanding the period of time in which the 9.0 mg/L daily minimum SPWN requirement is applied to include all early life stages prior to emergence.

7-day Average Requirement

The existing DO objectives do not include a 7-day average objective to protect the processes spawning and early development from DO stress due to multiple days of depressed DO. USEPA (1986) recommends criteria that include average limitations and Regional Water Board staff concur. Because of the risk of extinction facing several native fish species in the North Coast Region, staff recommends a 7-day average requirement based on the "no production impairment" value given in Table 1. This is a moving 7-day average of 11.0 mg/L DO in the water column based on seven consecutive daily averages. The water column DO objective for coldwater spawning is based on an estimate of the DO required in the water column to ensure adequate DO in the intragravel environment where developing eggs and alevin reside.

Intragravel Requirement

As described in Chapter III, common DO monitoring tools include the 1) Winkler titration conducted in the field using a grab sample and 2) a datasonde which automatically collect continuous data over 24-hours or longer. Common tools and methods of intragravel DO field sampling have not yet been fully developed or broadly used (Fadness 2009). Further, monitoring the intragravel environment during spawning, egg incubation, and early development risks the possibility of 1) direct harm to eggs and/or alevin and/or 2) an unfavorable alteration of the redd environment.

As such, staff does not recommend adding intragravel DO requirements to the Basin Plan at this time. Instead, staff recommends water column criteria that are 3 mg/L greater than the DO concentration required in the intragravel environment to protect eggs and pre-emergence life stages. DO conditions in the intragravel environment must be an average of 8.0 mg/L to ensure no production impairment of threatened and endangered species. As described by USEPA (1986), 11.0 mg/L DO in the water column is necessary to ensure an average of 8.0 mg/L DO in the intragravel environment.

Location and Timing of SPWN

The current objectives for SPWN are developed specifically for the protection of salmonids. The location and timing of spawning is different for each of the native species of fishes at risk of extinction in the North Coast Region. Yet, with respect to DO requirements, it appears that objectives developed to protect salmonids will be reasonably protective of the other species, as well, including early life stages. This is not only because of the greater salmonid sensitivity to DO conditions then many other native species of fish. But, it is also because most of the North Coast Region is designated as providing the SPWN beneficial use based on the historic and/or existing use of North Coast estuaries and rivers by salmonids. Because of the widespread use of North Coast streams by salmonids, other fish species with geographically narrower freshwater ranges will benefit from the broad application of the SPWN objective.

According to Moyle (2002), salmonid spawning and incubation generally occurs in the North Coast Region from mid-September to early June. The Hoopa Valley Tribe has established in its water quality control plan a spawning and incubation period of

September 15 through June 4 based on studies in the Trinity River. This period reasonably coincides with expected spawning and incubation throughout the Region.

For the purpose of DO, staff recommends that objectives designed to protect the SPWN beneficial use be applied in all waterbodies listed for SPWN and during the period of the year in which salmonid spawning and incubation is or has historically occurred, estimated as September 15 through June 4.

V.1.1.2 Coldwater Criteria for Other Life Stages (COLD)

As given in Table 1, USEPA (1986) recommended for sensitive populations of juvenile and adult coldwater fish for which little or no production impairment is acceptable, daily minimum DO conditions ≥6.0 mg/L in the water column. USEPA (1986) further recommended 7- or 30-day average DO conditions ≥8.0 mg/L in the water column.

Daily Minimum Requirement

The Basin Plan gives as the COLD life cycle requirement a daily minimum DO condition ≥ 6.0 mg/L in the water column. This is in accordance with USEPA (1986) guidance and the findings of Carter (2005), as described in Chapter IV. As such, staff recommends no changes to this objective.

7-day Average Requirement

The Basin Plan does not currently include a 7- or 30-day average limit. The absence of an average DO requirement could result in multiple days in which the daily minimum DO objective is met and therefore compliance is achieved. Yet, water quality conditions are stressful to aquatic organisms due to a regularity of exposure to DO conditions that allows for slight production impairment. Because of the number of species at risk of extinction in the North Coast Region, Staff recommends a 7-day average as more protective than a 30-day average. Staff proposes the addition to the Basin Plan of a 7-day average of the daily minimums ≥8.0 mg/L. This is in accordance with USEPA (1986), as well as the findings of Carter (2005). This is a moving 7-day average of DO in the water column based on 7 consecutive daily minimums.

V.1.1.3 Warm Water Criteria (WARM)

The Basin Plan currently assigns a daily minimum DO concentration of 5.0 mg/L as the life cycle DO objective for the protection of WARM. This is implemented as an instantaneous minimum. There is no accompanying average limit to protect against the chronic effects of DO stress. Further, there is no SPWN DO objective specifically developed to protect early life stages of warm water species.

The WARM DO objective applies in only two waterbodies in the North Coast Region: the Bray Hydrologic Subarea in the Butte Valley Hydrologic Area and Tule Lake Hydrologic Subarea of the Lost River Hydrologic Area. Both are contained within the Klamath River watershed. With the exception of these two waterbodies, all the other North Coast waterbodies designated as WARM are also designated as COLD. As the DO objectives associated with the protection of COLD are more stringent than those associated with the protection of WARM, the COLD DO objectives apply in all the other

North Coast basins. Only in those waterbodies for which a Use Attainability Analysis is successfully conducted in the future will the application of the WARM DO objective ever expand.

The Bray Hydrologic Subarea is in the Butte Valley Hydrologic Area, a closed basin approximately 18 miles long from north to south and with a maximum width of 13 miles. The Butte Valley floor is an ancestral lake bed that encompasses an area of about 130 square miles. Volcanic rocks surround the valley and underlie it at depths of about 400 to 1,500 feet. Streams drain into the valley from the west, and the water either infiltrates permeable deposits or flows into Meiss Lake, which is a small remnant of the large lake that once filled the valley. Discharge from the valley is by subsurface flow through fractured volcanic rocks to adjacent basins (USGS 1995).

The Tule Lake Hydrologic Subarea is in the Lost River Hydrologic Area. Much of the native hydrology of the basin has been modified for the purpose of agricultural irrigation and the management of wildlife preserves. Summer flows in Tule Lake are dominated by agricultural return flows. As described in Chapter IV, two species of endangered suckers reside in the Lost River Hydrologic Area.

USEPA (1986) recommended 5.5 mg/L DO as a daily minimum and 6.5 mg/L as a 7- or 30-day average to protect against production impairment of early life stages of warm water fish. It further recommended 5.0 mg/L DO as a daily minimum and 6.0 mg/L as a 7- or 30-day to protect against production impairment of other life stages of warm water fish (USEPA 1986).

With respect to the general population of warm water fish, the existing 5.0 mg/L DO objective as a daily minimum appears to adequately protect against significant production impairment. The addition of a 7-day or 30-day average of 6.0 mg/L would further protect against the chronic effects of DO stress. As described above, USEPA (1986) recommends a 7-day average to protect sensitive species or life stages. Staff recommends the application of 6.0 mg/L as a 7-day moving average of the daily minimum to ensure maximum protection, due to the presence of the endangered suckers in the Lost River Hydrologic Area.

With respect to the early life stages of warm water fish, staff has considered several lines of thought in its attempt to determine an appropriate approach to the protection of the early life stages of warm water fish. These include: 1) consideration of the structure of beneficial uses as given in the Basin Plan; 2) the range of applicability of the WARM DO objective; and 3) the range of accuracy of the datasonde for the measurement of DO.

The Basin Plan does not currently distinguish between SPWN objectives designed to protect coldwater species and those necessary to protect warm water species. For this purpose, the Basin Plan might ideally include a SPWN (cold) and a SPWN (warm) to adequately make the distinction. At present, only a SPWN designation is given and is designed to protect coldwater organisms. In the absence of a revision to the beneficial uses, the Basin Plan might otherwise include a SPWN DO objective for the protection of warm water species with an explanation in the Basin Plan as to its specific applicability to streams designated as WARM, only.

The fish species most affected by the designation of WARM and SPWN to protect warm water fishes, are the endangered suckers of the Lost River Hydrologic Subarea. This is because there are only two subareas of the Region in which WARM DO objectives apply, the Lost River Hydrologic Subarea being one of them. As described in Chapter IV, Woodhouse et al. (2004) identified a threshold of greater than 2.3 mg/L DO for the protection of endangered suckers, based on an LC_{50} for shortnose sucker larvae. This is in essence an early life cycle criteria and is less stringent than the 5.5 mg/L DO recommended by USEPA (1986).

The Hydrolab datasonde is reported to have an accuracy of ±0.2 mg/L for measurements < 20 mg/L DO. The difference between 5.0 and 5.5 mg/L as a daily minimum and 6.0 and 6.5 mg/L as a 7-day mean is not large. But, it is a difference which standard monitoring equipment is capable of distinguishing.

Staff concludes in the weighing of these pieces of information that the early life stages of warm water fish in the Lost River Hydrologic Subarea and Bray Hydrologic Subarea are adequately protected with a WARM DO objective of 5.0 mg/L as a daily minimum and 6.0 mg/L as a 7-day mean. The addition of a separate SPWN objective for the protection of warm water species appears unwarranted at this time. Staff recommend that in the event that any waterbodies of the North Coast are dedesignated for COLD and the WARM objectives as recommended here no longer appear to protect early life stages of the warm water species of concern in those basins, then consideration of a subcategory of the SPWN beneficial use for the protection of warm water species should be given. Further, DO objectives for the protection of early life stages of warm water fish should be developed under this new subcategory.

V.1.1.4 MAR, SAL, and EST

The Basin Plan currently assigns a daily minimum DO concentration of 5.0 mg/L as the life cycle DO objective for the protection of MAR and SAL. It does not include a life cycle DO objective for the protection of EST; though, all of the waterbodies designated as EST are also designated as COLD and SPWN and thus the life cycle DO objectives for these beneficial uses apply. There are 13 individually named hydrologic areas/subareas for which MAR is an existing designated use, including:

- Smith River Plain Hydrologic Subarea,
- Crescent City Harbor,
- Klamath Glen Hydrologic Subarea,
- Orick Hydrologic Subarea,
- Big Lagoon Hydrologic Area,
- Little River Hydrologic Area (in the Trinidad Hydrologic Unit),
- Humboldt Bay,
- Bodega Bay Hydrologic Area,
- Estero Americano Hydrologic Area,

- Estero de San Antonio Hydrologic Area,
- Ocean waters,
- Bays, and
- Estuaries.

There are also 4 hydrologic areas/subareas for which MAR is a potential designated use, including: Blue Lake Hydrologic Area, Ferndale Hydrologic Area, minor coastal streams, and saline wetlands. With the exception of ocean waters, all the hydrologic areas/subareas designated as MAR are stream reaches in which freshwater and saline water influences are present.

Only the Russian Gulch Hydrologic Area is listed as providing the SAL beneficial use. But, staff believes this to be a typographical error; and, it will be corrected through another basin planning amendment process. Saline wetlands are designated as potentially providing the SAL beneficial use.

The Basin Plan also requires for coastal waters that DO concentrations not at any time be depressed more than 10% from that which occurs naturally. This applies to saline waters only, and is derived from the State's Ocean Plan (Resolution No. 90-27) as revised in 1990 and included in Table 3-1 of the Basin Plan. Also included in Table 3-1 are site-specific DO objectives of 6.0 mg/L as a daily minimum for Bodega Bay and Humboldt Bay.

USEPA does not have specific criteria recommendations for Pacific Coast saltwater environments. But, USEPA (2000) recommends criteria for the saltwater environments of the Atlantic Coast which are useful for comparison. USEPA (2000) recommends 2.3 mg/L DO as the criterion minimum concentration (CMC) to ensure juvenile and adult survival, applied as a 1-hour average. It also recommends 4.8 mg/L DO as the criterion continuous concentration (CCC) to ensure no negative effects on growth, applied as a 4-day average. From this, USEPA (2003) as cited by SCCWRP (2003) has developed criteria specific to the Chesapeake Bay. SCCWRP (2003) considered both USEPA (2000) and USEPA (2003) in its contemplation of DO criteria for Newport Bay in southern California. The work of USEPA (2000), USEPA (2003) and SCCWRP (2003) apply to stream reaches with both freshwater and saline water influences.

In its comparison of USEPA (2000) and USEPA (2003) to the conditions in Newport Bay, SCCWRP (2003) made the following observations:

- Phytoplankton are the dominant primary producers in the Chesapeake Bay and in many other systems where DO concentrations have been studied (Cloern 2001 as cited by SCCWRP 2003). Macroalgae, on the other hand, are the primary producers in the Newport Bay system. The relationships among nutrient loading, primary production, and DO availability must be better understood for macroalgae systems prior to determining the applicability of USEPA (2000) and USEPA (2003) to west coast systems.

- West coast estuaries differ from those of the east coast in terms of the physical structure of the water column. In river-dominated estuaries such as the Chesapeake and many other East and Gulf Coast systems with significant year round freshwater flow, the interface between the warm fresh water and the cold, denser seawater is a major contributing factor to vertical stratification while these phenomena may be limited in west coast systems with minor freshwater summer flows. The difference in flows also results in differences in average channel depths and widths, as well as other physical estuarine characteristics.

SCCWRP (2003) also observed that "low DO availability often occurs in conjunction with other anthropogenic stressors that accompany increased development. These additional factors, which include increased pathogen prevalence, fishing pressure, sediment loads, increase and altered freshwater inputs, and hydrodynamic modifications (Breitburg 2002 as cited by SCCWRP 2003), may interact synergistically with hypoxia to negatively impact aquatic resources."

With these things in mind, staff recommends the retention of the existing 5.0 mg/L DO objective for MAR and SAL and 6.0 mg/L DO objective for Bodega Bay and Humboldt Bay as more than adequate protection of these beneficial uses and locations. This is based on the fact that direct application of USEPA (2000) and USEPA (2003) is not yet demonstrated for west coast systems; however, USEPA (2000) results in criteria recommendations less stringent than 5.0 mg/L and 6.0 mg/L as daily minima.

In addition, staff recommends the future study of North Coast bays and estuaries, with consideration of the variety of factors that combine from upstream activities to impact the estuarine environment, including the potential development of a plan specifically designed to protect the resources of North Coast bays and estuaries. Within this context, staff proposes the potential for revision and expansion of the MAR and SAL DO objectives (as well as other related objectives) and the development of a numeric EST DO objective (as well as other related objectives), as new data is developed and insights garnered.

In the mean time, staff recommends the adoption of a narrative DO objective for the protection of the Region's bays and estuaries which is modeled after the one contained in the Santa Ana Regional Water Board's Basin Plan, protecting among other resources, Newport Bay. That narrative objective reads: "The dissolved oxygen content of enclosed bays and estuaries shall not be depressed to levels that adversely affect beneficial uses as a result of controllable water quality factors." Staff recommends this narrative objective as a tool for ensuring that the study of individual bays or estuaries can lead to the appropriate protections until such time as the revision of the numeric objectives is proven necessary and is accomplished.

V.1.2 Summary of Staff Recommendations for Revision of Life Cycle Objectives

1. *SPWN*: To ensure adequate protection of early life stages in the intragravel environment, staff recommends eliminating the 7.0 mg/L daily minimum SPWN requirement as under protective. Staff further recommends expanding the period

of time in which the 9.0 mg/L daily minimum SPWN requirement is applied to include all early life stages prior to emergence.

2. *SPWN:* Because of the risk of extinction facing several native fish species in the North Coast Region, staff recommends a 7-day average requirement based on the "no production impairment" value given in Table 1. This is a moving 7-day average of 11.0 mg/L DO in the water column based on seven consecutive daily averages.
3. *SPWN:* Staff does not recommend adding intragravel DO requirements to the Basin Plan at this time. Instead, staff recommends water column criteria that are 3 mg/L greater than the DO concentration required in the intragravel environment to protect eggs and pre-emergence life stages, as described above.
4. *SPWN:* Staff recommends that objectives designed to protect the SPWN beneficial use be applied in all waterbodies listed for SPWN and during the period of the year in which salmonid spawning and incubation is or has historically occurred, estimated as September 15 through June 4.
5. *COLD:* Staff recommends no changes to the existing daily minimum DO objective for COLD.
6. *COLD:* Staff recommends the addition to the Basin Plan of a 7-day average of the daily minimums ≥8.0 mg/L. This is a moving 7-day average of DO in the water column based on 7 consecutive daily minimums.
7. *WARM:* Staff recommends the addition to the Basin Plan of 6.0 mg/L as a 7-day moving average of the daily minimum.
8. *MAR, SAL, and EST:* Staff recommends the retention of the existing 5.0 mg/L DO objective for MAR and SAL and 6.0 mg/L DO objective for Bodega Bay and Humboldt Bay as adequate protection of these beneficial uses and locations.
9. *MAR, SAL and EST:* Staff recommends that the Board consider in the next triennial review prioritizing the future study of North Coast bays and estuaries, with consideration of the variety of factors that combine from upstream activities to impact the estuarine environment. Staff further recommends that the outcome of this study include the development of a plan specifically designed to protect the resources of North Coast bays and estuaries. Within this context, staff proposes the potential for revision and expansion of the MAR and SAL DO objectives (as well as other related objectives) and the development of a numeric EST DO objective (as well as other related objectives).
10. *MAR, SAL and EST:* Staff recommends the adoption of a narrative DO objective for the protection of the Region's bays and estuaries as follows: "The dissolved oxygen content of enclosed bays and estuaries shall not be depressed to levels that adversely affect beneficial uses as a result of controllable water quality factors."

V.2 Assessment of Background DO Objectives

The framework of the Basin Plan is based on the logic that protection of water quality in the North Coast is best provided by prohibiting the point source discharge of waste. Some exceptions to this framework are included in the Basin Plan for the Lost River and for the Mad, Eel, and Russian rivers from October 1 through May 14. In all other streams and all other times of the year, the point source discharge of waste is prohibited.

The DO objectives included in the Basin Plan compliment this framework by requiring that for all the streams named in Table 3-1 of the Basin Plan, background ambient water quality conditions for DO be maintained. To accomplish this end, the Table 3-1 DO objectives are established at what was understood in 1975 to be background levels. For those waterbodies not named in Table 3-1 of the Basin Plan, the alternative protection strategy was to establish DO objectives designed to protect aquatic fish and wildlife resources (i.e., life cycle DO objectives).

Staff has assessed the Table 3-1 DO objectives to determine if they are established at levels understood today to represent background conditions. The assessment highlights several lines of evidence indicating that the Table 3-1 DO objectives do not depict background conditions and require updating.

V.2.1 Table 3-1 DO Objectives

The Table 3-1 DO objectives were developed for individually named waterbodies throughout the Region and include 58 separate entries. As described in Chapter II, they are based on background conditions as measured by extensive regional sampling in the 1950s and 1960s collected by a range of partners including federal, state and local agencies. The Department of Water Resources published the data in annual bulletins beginning with data from 1951. Generally, the data are monthly grab samples that were collected during day light hours and analyzed in the field using the Winkler titration method.

As a result of this sampling, the majority of the listed waterbodies (71%) were assigned a background DO objective of 7.0 mg/L as a daily minimum. This includes all of the listed waterbodies in the North Coastal Basin (100%) and 58% of the listed waterbodies in the Klamath River Basin. Exceptions to this norm are listed in Table 2 below so as to indicate the range of background DO objectives contained in the Basin Plan.

V.2.2 Grab sampling versus continuous monitoring

The first line of evidence that the background DO objectives require updating is based on a general observation about the relationship between grab samples and the diurnal fluctuation of DO in many freshwater systems. As described in Chapter III, DO fluctuates temporally and spatially as a result of numerous factors, including both natural and anthropogenic factors. A grab sample provides only a snapshot of the DO condition at that location at a given moment in time.

Table 2: Background DO Objectives from Table 3-1 of the Basin Plan

Hydrologic Area	Waterbody	DO Objective (mg/L)
Lost River HA	Clear Lake Reservoir and Upper Lost River	5.0
	Lower Lost River	5.0
	Tule Lake	5.0
	Lower Klamath Lake	5.0
Shasta Valley HA	Lake Shastina	6.0
Salmon River HA	All streams	9.0
Middle Klamath River HA	Klamath River below Iron Gate Dam	8.0
Lower Trinity River HA	Trinity River	8.0
	Other streams	9.0
Lower Klamath River HA	Klamath River	8.0
	Other streams	8.0
Ilinois River HA	All streams	8.0
Winchuck River HU	All streams	8.0
Smith River HU	Smith River-Main Forks	8.0
Smith River Plain HSA	Smith River	8.0
Eureka Plain HU	Humboldt Bay	6.0
Russian River HU	Bodega Bay	6.0
All other Hydrologic Areas	Waterbodies listed in Table 3-1	7.0

For the period of time when ambient water quality data was routinely collected during daylight hours by grab sample, the results could reasonably be compared to the Table 3-1 objectives for compliance and other purposes. This is because the Table 3-1 objectives were developed from data collected in the same manner. However, Regional Water Board staff more recently began collecting ambient DO data using continuous monitoring probes (datasondes). These datasondes collect data at a preset interval over the course of a day or longer and electronically record the results. The outcome is a continuous DO dataset that shows the pattern and range of DO fluctuation over the course of 24 hours, including the minimum DO condition generally observed during the night. The night time, minimum DO condition had previously been excluded from most DO datasets, including those that were used to calculate the Table 3-1 DO objectives. Comparison of the night time minimum DO condition as measured by a continuous monitoring probe to the Table 3-1 objectives identified as daily minimums can be misleading.

A cursory review of DWR's hydrologic data reports from the 1950s and 1960s indicates that the DO data often indicated fully saturated or supersaturated conditions during the day. This suggests that night time conditions were often subsaturated. To illustrate this point, Summers and Engle (1993), as cited by SCCWRP (2003), found that single, daytime instantaneous measures of DO detected hypoxia only 20% of the time that it was known to occur based on 31 days of continuous sampling in the Gulf of Mexico. While this statistic is unlikely to apply to freshwater streams in the North Coast, it nonetheless illustrates the disconnect between day time measurements and the detection of low DO.

V.2.3 Historic landuse

The second line of evidence that the background DO objectives require updating is based on a general observation regarding the history of landuse in the North Coast Region prior to and including the period of the 1950s and 1960s. Commercial scale mining and logging operations began in areas throughout California, including the North Coast Region in the mid- to late 1800s. This was followed by dam building and agricultural enterprises, as well as urban development. By the 1950s and 1960s, areas of the North Coast Region were undergoing their second wave of timber cutting; by that time with the use of tractors and other heavy equipment which left a significant foot print on the landscape and downstream watercourses. Though the point source discharge of waste from urban development has been very localized in the North Coast Region, other direct effects on water quality from stream channel modification, road building, dam building, and gravel mining, as examples, have been felt in the North Coast Region for over a century. Further, the indirect effects known as nonpoint source pollution emanating from agricultural runoff, wetland reclamation, sedimentation, water diversions, and the like have also been felt in the North Coast for over a century.

As depicted in Figure 1 (CADDIS conceptual model for DO), these activities affect the availability of DO in aquatic systems. Thus, by the 1950s and 1960s, it is likely that DO was already altered from its natural state and measurements made during this time probably did not represent true background conditions in all locations.

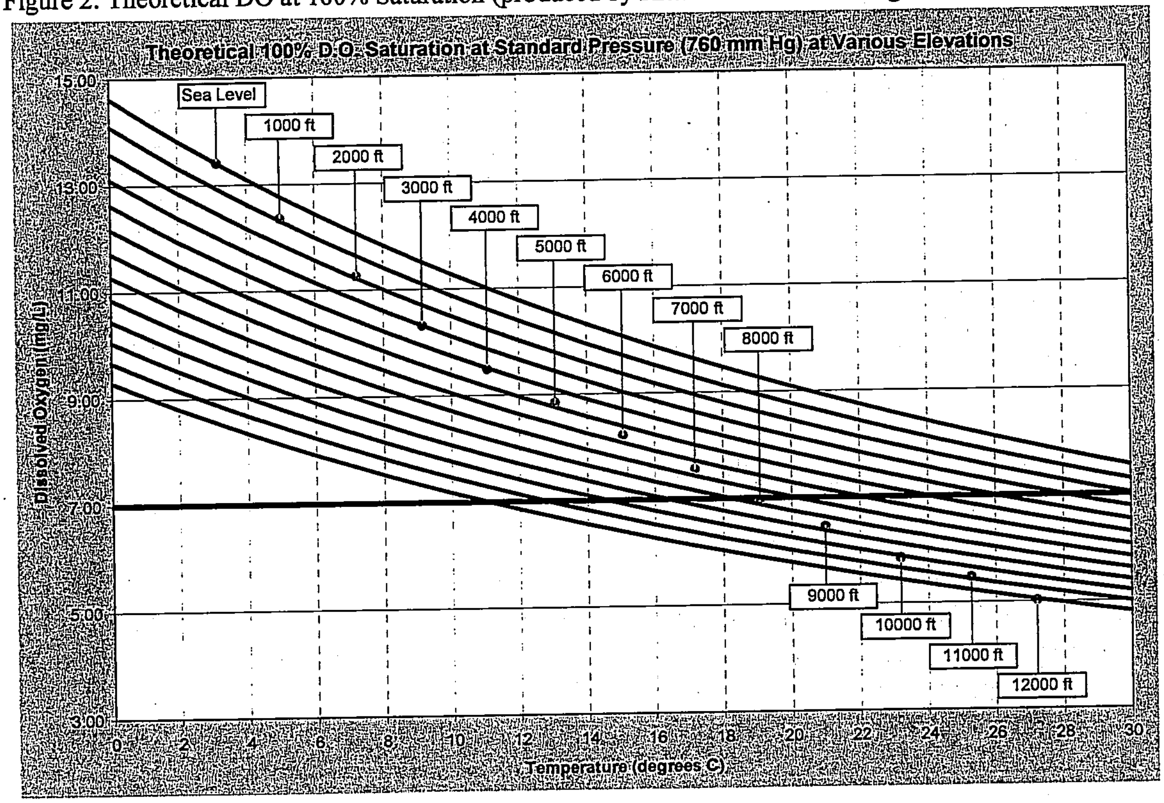
V.2.4 DO at saturation

The third line of evidence that the background DO objectives require updating is based on an assessment of the theoretical DO concentrations possible within North Coast waterbodies at 100% and 85% DO saturation. Staff calculated the theoretical DO concentrations under varying temperatures and elevations to produce Figure 2 (100% saturation) and Figure 3 (85% saturation). Figure 3 indicates staff's rough estimate of the minimum DO concentrations that occur as a result of the natural fluctuation in DO concentrations resulting from photosynthesis, respiration, turbulence, and biological and chemical oxidation. Staff assumed this to be reasonably represented by a DO saturation of 85%. Figure 2 indicates the minimum DO concentrations possible in the absence of these moderating factors, as represented by 100% saturation. The calculations were made using standard pressure (760 mm Hg) and assuming freshwater conditions.

For the purpose of assessment, staff identified a temperature of 22 °C as reasonably representing the maximum temperature supporting salmonids. At this temperature, Figure 2 indicates that those locations greater than 7000 feet in elevation do not achieve a minimum DO concentration of 7.0 mg/L under standard pressure. As a point of comparison, most of the watersheds in the North Coast Region are less than 6000 feet in elevation, with the exception of locations within the Klamath River and Trinity River basins. But, at 85% saturation and 22 °C, Figure 3 indicates that locations greater than 3000 feet do not achieve a minimum of 7.0 mg/L. This suggests that at standard pressure the freshwater locations in the Humboldt Bay watersheds and the Gualala-Salmon-Bodega Bay watersheds can reasonably be expected to achieve a minimum DO concentration of 7.0 mg/L, even when stream temperatures are high. But, for those locations throughout the Region that exceed 3000 feet, experience a diurnal fluctuation in DO, and experience periodic high stream temperatures, a minimum DO concentration of 7.0 mg/L may not consistently be possible, particularly during summer nights.

As a point of comparison, Blodgett (1971) reports for the period of 1951-1968 monthly mean temperatures in the Region that are ≤10 °C, suggesting that temperatures are generally low enough to ensure background DO conditions ≤7.0 mg/L. But, the average *maximum* temperature for this period is 25 °C with a range of 16-34 °C. This indicates that background DO conditions ≤7.0 mg/L are periodically impossible. The period 1951-1968 is the same period from which DO data was collected and analyzed for the purpose of developing background DO objectives for the original Basin Plan. As such, staff conclude that even at the time of their development, the background DO objectives in Table 3-1 were not consistently achievable during summer nights at higher elevations.

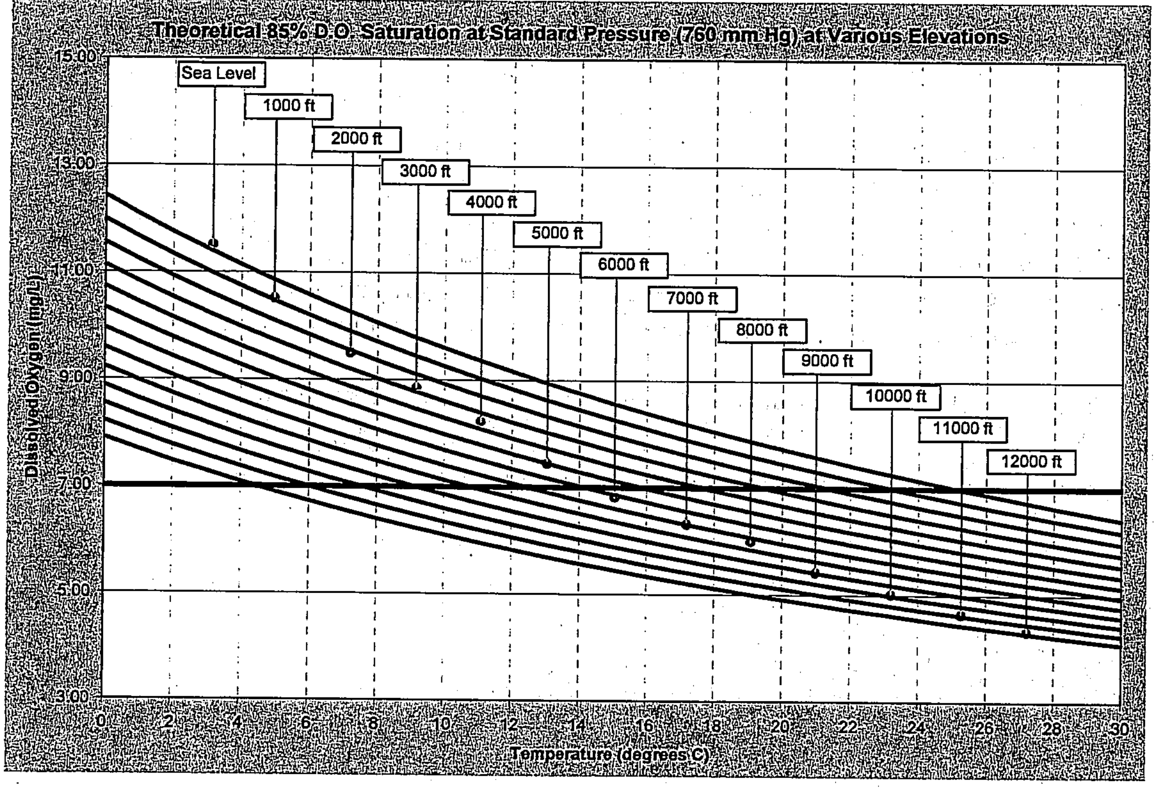
Figure 2: Theoretical DO at 100% Saturation (produced by Rich Fadness of the Regional Water Board)



V.2.5 Klamath River TMDL for DO

The fourth line of evidence that the background DO objectives require updating is based on the modeling conducted for the Klamath River Total Maximum Daily Load (TMDL) for DO. The Klamath River has been listed on the 303(d) list as impaired for DO, as well as other parameters. Water quality model simulations of natural baseline conditions in the Klamath River, detailed below, estimated minimum DO conditions below the existing and proposed life cycle DO objectives and below the existing background DO objectives for the river.

Figure 3: Theoretical DO at 85% (produced by Rich Fadness of the Regional Water Board)



V.2.5.1 Klamath River Water Quality Modeling

To support TMDL development for the Klamath River system, the need for an integrated receiving water hydrodynamic and water quality modeling system was identified. A model for the Klamath River had already been developed by PacifiCorp to support studies for the Federal Energy Regulatory Commission hydropower relicensing process (PacifiCorp 2005) when this project commenced. The version of the model available in 2004 is hereafter referred to as the *PacifiCorp Model*. The Regional Water Board, Oregon Department of Environmental Quality (ODEQ), and USEPA determined that this existing *PacifiCorp Model* would provide the optimal basis, after making some enhancements, for TMDL model development. The *PacifiCorp Model* uses hydrodynamic and water quality models with a proven track record in the environmental arena and has already been reviewed by most stakeholders in the Klamath River watershed. Additionally, it can be directly compared to ODEQ, Regional Water Board and Tribal water quality criteria.

Description of the Model

The original *PacifiCorp Model* consisted of Resource Management Associates (RMA) RMA-2 and RMA-11 models and the U.S. Army Corps of Engineers' CE-QUAL-W2 model. The RMA-2 and RMA-11 models were applied for Link River (which is the stretch of the Klamath River from Upper Klamath Lake to Keno Dam), Keno Dam to J.C. Boyle Reservoir, Bypass/Full Flow Reach, and Iron Gate Dam to Turwar (See Figures 4 and 5). RMA-2 simulates hydrodynamics while RMA-11 represents water quality processes. The CE-QUAL-W2 model was applied for Lake Ewauna-Keno Dam, J.C. Boyle Reservoir, Copco Reservoir, and Iron Gate Reservoir. CE-QUAL-W2 is a two-dimensional, longitudinal/vertical (laterally averaged), hydrodynamic and water quality model (Cole et al. 2003). For the purposes of TMDL development, enhancements to the RMA/CE-QUAL-W2 portions of the PacifiCorp model were made in the following areas: BOD/organic matter (OM) unification, algae representation in Lake Ewauna, Monod-type continuous Sediment Oxygen Demand (SOD) and OM decay, pH simulation in RMA, OM-dependent light extinction simulation in RMA, reaeration formulations, and dynamic OM partitioning.

Since the estuarine portion of the Klamath River (Turwar to the Pacific Ocean) was not included in the original *PacifiCorp Model*, one of the first updates made was to include an estuarine model. From a review of available data for the estuary, it was apparent that hydrodynamics and water quality within the estuary are highly variable spatially and temporally and are greatly influenced by time of year, river flow, tidal cycle, and location of the estuary mouth (which changes due to sand bar movement). Additionally, transect temperature and salinity data in the lower estuary showed significant lateral variability, as did DO to a lesser extent. Therefore, USEPA's Environmental Fluid Dynamics Code (EFDC), which is a full 3-D hydrodynamic and water quality model, was selected to model the complex estuarine environment.

EFDC is capable of predicting hydrodynamics, nutrient cycles, DO, temperature, and other parameters and processes pertinent to the TMDL development effort for the estuarine section. It is capable of representing the highly variable flow and water quality conditions within years and between years for the estuary. As with RMA-2, RMA-11, and CE-QUAL-W2, EFDC has a proven record in the environmental arena and model results can be directly compared to ODEQ, Regional Water Board and Tribal water quality criteria. A major advantage of EFDC is that it is USEPA-endorsed and supported and available freely in the public domain.

The combination of the *PacifiCorp Model* (RMA and CE-QUAL-W2), with enhancements, and the EFDC model for the estuary resulted in the Klamath River model used for TMDL development. Table x-x identifies the modeling elements applied to each river segment. These segments are depicted graphically in Figures 4 and 5. Linkages between the different modeling segments were made by transferring time-variable flow and water quality from one model to the next (e.g., output from the Link River model became input for the Lake Ewauna-Keno Dam model).

Figure 4: Model segments in Oregon and Northern California

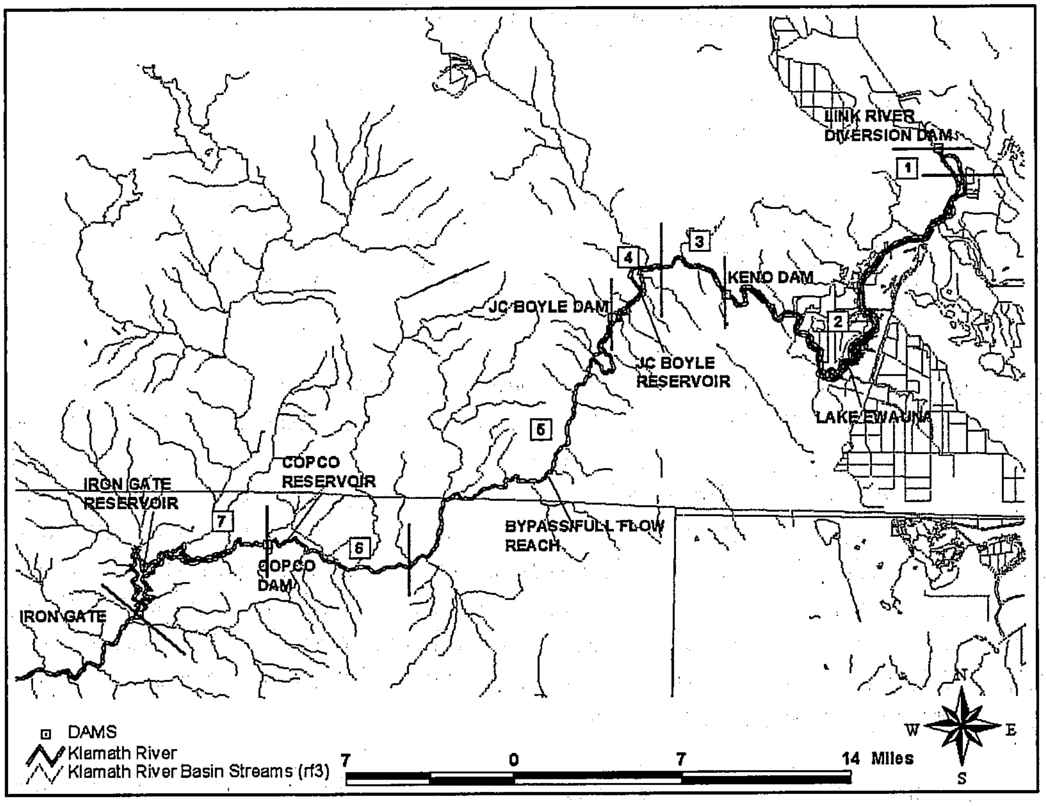


Figure 5: Model segments in California

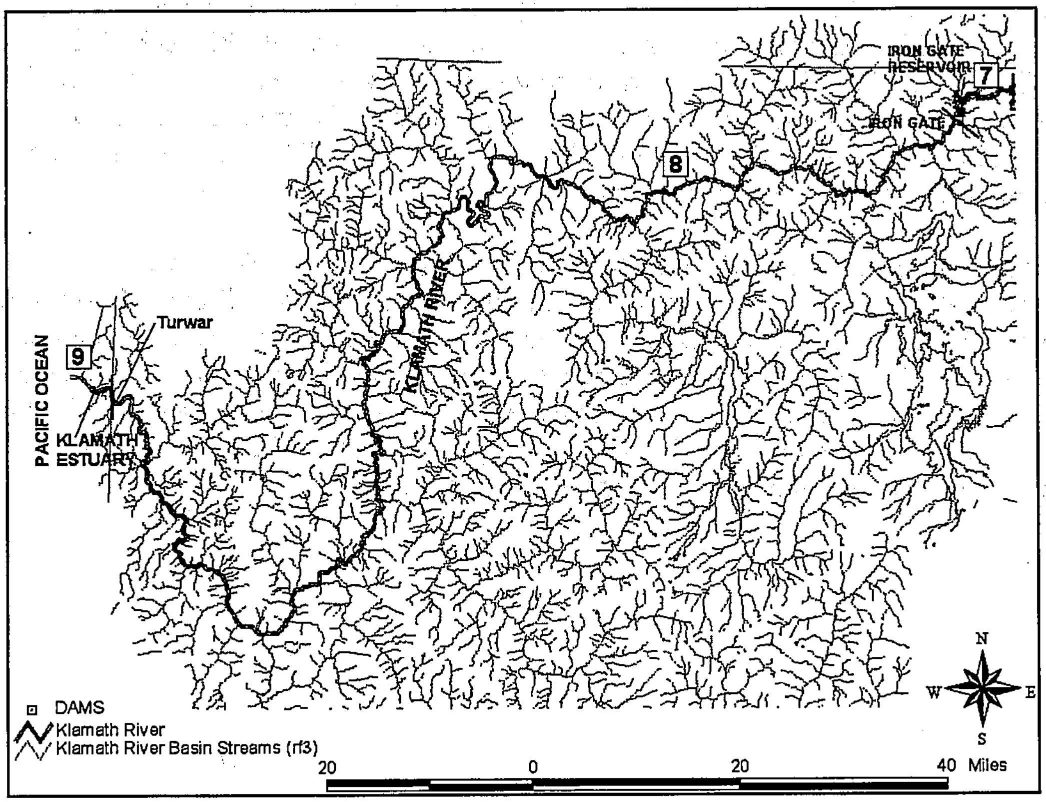


Table 3. Models applied to each Klamath River and estuary segment

Modeling Segment #	Modeling Segment	Segment Type	Model(s)	Dimensions
1	Link River	River	RMA-2/RMA-11	1-D
2	Lake Ewauna-Keno Dam	Reservoir	CE-QUAL-W2	2-D
3	Keno Dam to J.C. Boyle Reservoir	River	RMA-2/RMA-11	1-D
4	J.C. Boyle Reservoir	Reservoir	CE-QUAL-W2	2-D
5	Bypass/Full Flow Reach	River	RMA-2/RMA-11	1-D
6	Copco Reservoir	Reservoir	CE-QUAL-W2	2-D
7	Iron Gate Reservoir	Reservoir	CE-QUAL-W2	2-D
8	Iron Gate Dam to Turwar	River	RMA-2/RMA-11	1-D
9	Turwar to Pacific Ocean	Estuary	EFDC	3-D

Following model calibration and verification exercises, the model was run to simulate DO concentrations under estimated natural baseline conditions (i.e., T1BSR). Variables were adjusted and natural boundary conditions estimated for this simulation. Most importantly, the T1BSR model run simulates a free-flowing river without any dams. The Klamath River TMDL Staff Report, including extensive documentation of the water quality models, was peer reviewed in February 2009.

V.2.5.3 Natural Conditions Baseline - Background Loads

The Klamath River TMDL models were applied to characterize natural baseline water quality conditions of the Klamath River. In estimating the natural baseline water quality conditions of the Klamath River the following characteristics about the Klamath River watershed were incorporated.

The underlying geology in much of the Upper Klamath basin is of volcanic origin. Soils derived from this rock type are naturally high in phosphorus (Walker 2001). Through natural erosion and leaching processes these soils contribute a high background phosphorous load to Upper Klamath basin waters. In a nutrient loading study conducted by Rykbost and Charlton (2001), monitoring of several natural artesian springs in the upper Klamath basin were characterized by high levels of nitrogen and phosphorus, demonstrating the high natural background loading of nutrients. Upper Klamath Lake has long been noted for its eutrophic condition and demonstrated presence of high levels of organic matter (algae), including nitrogen fixing blue-green algae (Kann and Walker 2001). This nutrient and organic-matter rich Upper Klamath Lake water is the headwaters source of the Klamath River.

Within the Klamath Mountains Province of the mid- and lower-Klamath River, the underlying geology is not volcanic, and therefore does not tend to have the high levels of nitrogen and phosphorus characteristic of the Upper Klamath basin. Consequently, the tributaries that drain to the Klamath River within this province have considerably lower nutrient concentrations. As a result, the quality of the Klamath River generally improves as it flows from the Upper Klamath basin to the Pacific Ocean.

Alkalinity is a measure of the ability of water to neutralize acids. In the natural environment, alkalinity comes primarily from the dissolution of carbonate rocks. Carbonate rock sources are rare in much of the Klamath basin due to its volcanic origin. As a result, the Klamath River has a relatively low alkalinity (<100 mg/L). The low alkalinity provides for a weak buffering capacity of Klamath River water. Photosynthetic activity removes carbon dioxide in the water (in the form of carbonic acid) which increases the water pH. Natural alkalinity serves as a buffer to minimize the photosynthetically induced increase in pH. In low alkalinity waters such as the Klamath River, this buffering capacity is frequently exceeded and high pH values are observed during daytime hours when photosynthesis is occurring. The large daily variation of pH observed in the Klamath River is caused by photosynthetic activity in the low alkalinity water.

Further exacerbating the effect of the naturally productive and weakly buffered system is the presence of regionally high ambient summer air temperatures, and the resulting high heat load to the shallow and predominantly un-shaded Upper Klamath Lake. These naturally warm waters are the source of the Klamath River. In addition, the east-west aspect of much of the Klamath River also makes it prone to heating, even within the steep gorges of some reaches of the river.

In summary, the high ambient air temperatures, coupled with the high levels of biological productivity and respiration that is enhanced by the high levels of biostimulatory nutrients, yield large volumes of organic matter, seasonally high water temperatures, daily low dissolved oxygen, and high pH levels. All of these water quality conditions can be extremely stressful to many forms of aquatic life. These natural background heat, nutrient, and organic matter loads to the Klamath River underscore the very limited capacity of the river to assimilate anthropogenic pollutant sources.

V.2.5.2 Natural Baseline Conditions (T1BSR)

In order to fully evaluate applicable water quality standards, it was necessary to simulate natural baseline conditions throughout the Klamath River. The natural baseline conditions scenario (T1BSR) simulated the Klamath River from Upper Klamath Lake to the Pacific Ocean in the absence of all dams. The Klamath River model for this scenario used a different configuration than that for the current conditions. The entire length of the river from Upper Klamath Lake to just upstream of the estuary was simulated using the riverine RMA model. No CE-QUAL-W2 modeling segments were included since the natural configuration includes no impoundments.

The Upper Klamath Lake boundary condition for the model was based on the existing Upper Klamath Lake TMDL (ODEQ 2002). Specifically, median concentrations for water quality constituents and existing temperature were applied at the outlet and based on 1995 Upper Klamath Lake model output. Flow from Upper Klamath Lake was set at existing conditions, in order to maintain consistency with the existing conditions scenario. The flow balance for the current conditions model (when dams are present) and the reservoir operations limit the ability to represent natural flows. It should be noted that results for two model runs: one that used current conditions flows from Upper Klamath

Lake and one that used estimated flows from a natural regime (USBR 2005), were compared and not found to be substantially different.

Permitted point sources were removed from the model (i.e., both flow and water quality contributions were removed). The Lost River Diversion Channel (LRDC) and Klamath Straits Drain (KSD) were represented using current conditions flow, however, their water quality and temperature were set to be the same as Upper Klamath Lake. Current flow was again used to maintain consistency with the current conditions scenario in order to calculate pollutant load reductions, and associated TMDL load allocations, necessary to meet water quality standards. For tributaries to the Klamath River in California, natural and TMDL conditions were represented, depending on the tributary.

In summary, the key components of the natural conditions baseline scenario are:

- Representation of the river with no dams;
- The Upper Klamath Lake (UKL) boundary condition based on existing UKL TMDL compliant conditions;
- Absence of all point sources;
- LRDC and KSD represented using current conditions flow, but water quality set equal to UKL TMDL compliant conditions; and
- California tributaries flow and water quality conditions set at estimated natural and existing TMDL compliant conditions.

The model simulation was run for the year 2000.

V.2.5.3 Discussion of Results

The results of the model simulation of natural background DO conditions are expressed as hourly measures of DO at key locations throughout the watershed beginning at the Oregon-California state line and continuing down through the estuary. Upon plotting the simulated data for individual sites, TMDL staff determined that the natural background simulation indicated periods of noncompliance with the existing Table 3-1 background DO objectives. Figures 6 illustrates the hourly fluctuations of simulated DO throughout the year downstream of Iron Gate Dam as compared to the 8.0 mg/L DO currently applicable at that site. Graphic representations of data fro other sites are included in Appendix G. These figures show that in the absence of anthropogenic influences (e.g., dams, point source discharges, and non-point source discharges) DO is regularly less than 8.0 mg/L for some portion of the time between the months of June and September.

Staff conducted another assessment to compare simulated natural DO to proposed life cycle DO requirements to determine whether or not these objectives could be met under natural conditions. Figure 7 illustrates the hourly fluctuations in simulated DO throughout the year downstream of Iron Gate Dam on the Klamath River as compared to the updated life cycle DO requirements. Graphic representations of data for other sites on the Klamath River are included in Appendix H.

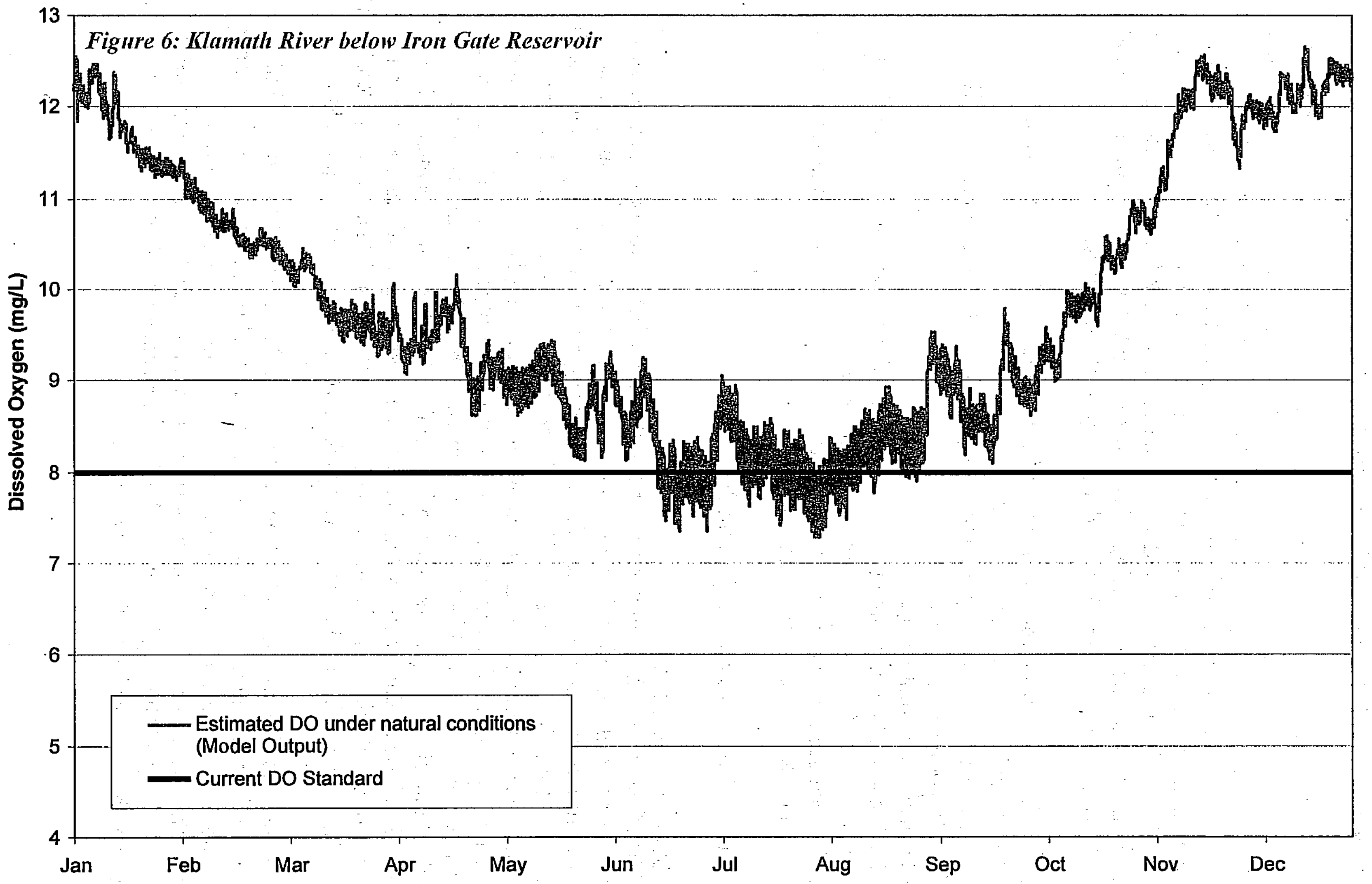


Figure 6: Klamath River below Iron Gate Reservoir

Figures 7: Estimated daily minimum DO under natural conditions (TIBSR) as compared to proposed life cycle requirements: Downstream of Iron Gate Dam on the Klamath River.

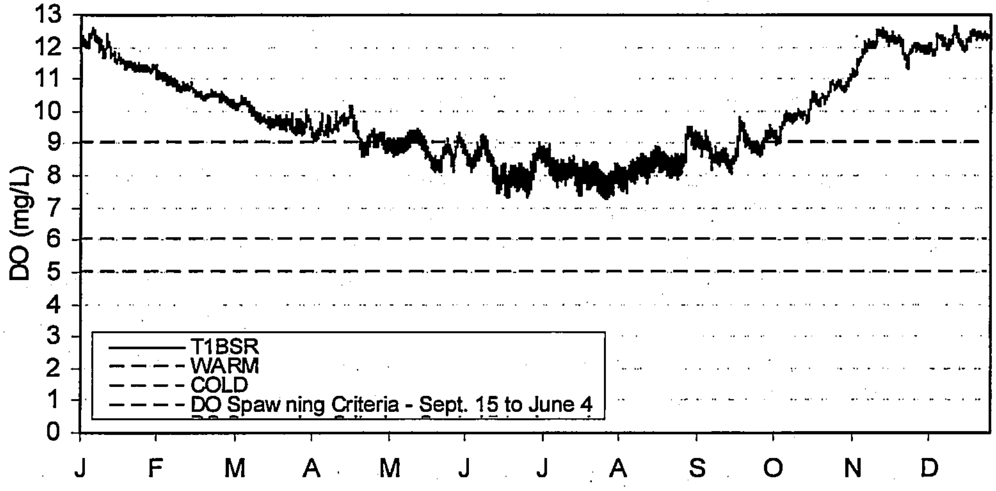
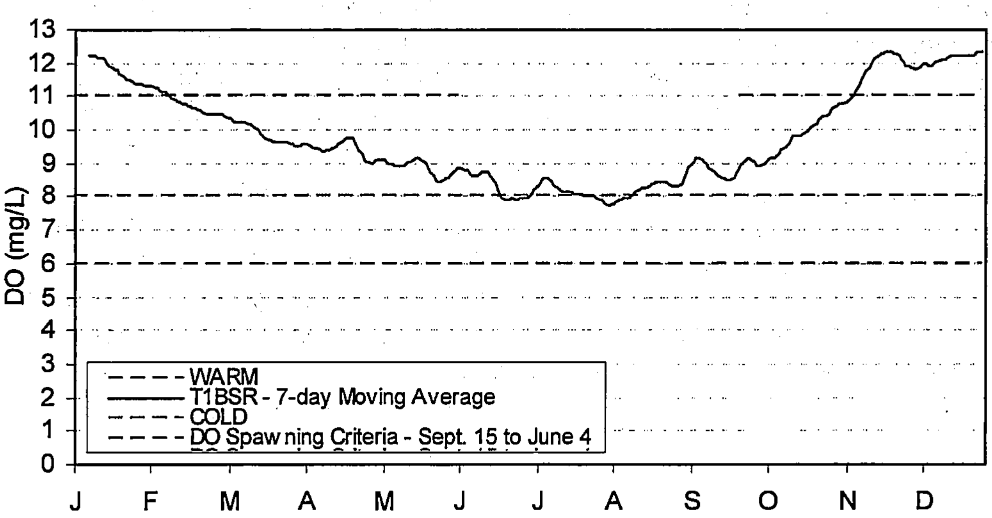


Figure 8: Estimated 7-day average DO under natural conditions (T1BSR) as compared to proposed life cycle requirements: Downstream of Iron Gate Dam on the Klamath River.



These figures show that in the absence of anthropogenic influences (e.g., dams, point source discharges, and non-point source discharges) simulated ambient water quality conditions achieve the daily minimum DO requirements for warm water fish (5.0 mg/L) and cold water fish (6.0 mg/L) throughout the year. It is during the spawning season (including early development), estimated to last from September 15 through June 4, that simulated water quality conditions do not appear to consistently meet updated life cycle requirements (9.0 mg/L during spawning, egg incubation, and early development).

During the first couple of weeks of the spawning season (e.g., estimated as September 15 through September 30), simulated DO at most of the stations is less than 9.0 mg/L. But, it varies from 9.0 mg/L by less than 1 mg/L (≥8.0 mg/L). Similarly, simulated DO at stations from the state line and to the confluence with the Scott River begins to decrease below 9.0 mg/L in April and downstream of the Scott River beginning in May. Again, the variance from 9.0 mg/L is generally no more than 1 mg/L (≥8.0 mg/L).

More dramatic, however, is the comparison of simulated natural background DO conditions to 7-day moving average life cycle requirements, specifically the spawning requirements. In this comparison, simulated ambient water quality does not meet the 11.0 mg/L 7-day average at individual stations for 3-6 months of the 7 ½ month period in which it is required, depending on the station. As a general matter, the weekly average DO appears to reach a peak in late October, plateau through early January and then begin to steadily decrease until reaching a low in late July/early August. Weekly average DO then begins to increase again until reaching a peak in late October. The increases and decreases in seasonal DO appear to be primarily a function of temperature.

Staff has developed two hypotheses to explain the high degree of dissimilarity between DO under natural conditions and 7-day average spawning requirements.

1. The Klamath River has historically had large runs of anadromous fishes with diverse life histories (NRC 2004). Coho salmon, spring-run Chinook salmon and summer steelhead in particular depended heavily on tributaries to complete their life cycles and sustain their populations (NRC 2004). The mainstem Klamath River water quality conditions may not ever have been optimal for these stream-type salmonids. But, their large dependence on higher quality tributary conditions may have ensured their success in the basin until the degradation of tributary conditions were well underway. If this is the case, then the protection of DO and temperature refugia is paramount to the protection of salmonids.
2. The 7-day average 11 mg/L DO water quality criteria is designed to ensure that there exists in the intragravel environment a 7-day average DO condition of 8 mg/L. USEPA (1986) recommends adding 3 mg/L to the intragravel requirement to calculate an appropriate water column requirement based on the findings of Koski (1965). But, the average intraredd DO concentration as measured by Koski (1965) was about 2 mg/L below that of the overlying water with intraredd variation of 5 or 6 mg/L (Koski 1965). In high gradient streams with little embeddedness or sediment oxygen demand, a lower correction factor may be appropriate. There is no information at present by which to alter the 3 mg/L correction factor.

V.2.6 Summary of Staff Observations regarding the Revision of Background DO Objectives

1. The data used to develop the background DO objectives contained in Table 3-1 of the Basin Plan were collected by grab sample during day light hours, frequently missing the true daily minimum DO conditions more often experienced during the night. Nonetheless, the Table 3-1 DO objectives are identified as daily minimum objectives.

2. DO monitoring is often done using a datasonde DO probe that is capable of recording DO concentrations over the course of 24 hours or longer. The daily minimum values obtained from a continuous DO dataset is not reasonably comparable to DO objectives based on day time data.
3. The background DO objectives contained in the Table 3-1 of the Basin Plan represent DO conditions as measured during the 1950s and 1960s when the landuse history of the North Coast Region had already resulted in water quality impacts, likely including impacts to DO.
4. Most of the waterbodies listed in Table 3-1 of the Basin Plan are required to meet a 7.0 mg/L DO objective. The capacity of water to hold DO at saturation is affected by temperature, atmospheric pressure, and salinity. At standard pressure in freshwater, water at high elevations and during high temperatures does not always have the capacity to hold 7.0 mg/L of DO, even at 1005 saturation.
5. Modeling conducted in support of the Klamath River TMDL for DO and other parameters demonstrates that in the absence of anthropogenic sources and activities (i.e., under natural conditions), various locations throughout the Klamath River are unable to consistently meet the background DO objectives as they are listed in Table 3-1 of the Basin Plan.
6. The protection of tributaries that provide cold water and DO refugia may be important, particularly in waterbodies unable to meet life cycle DO objectives due to natural conditions, such as the Klamath River.
7. There is some reason to believe that the 3 mg/L factor used to convert intragravel requirements to water column objectives may be over protective in some areas.

CHAPTER VI. ALTERNATIVES

Staff has evaluated the efficacy of several options, known as Alternatives, to determine the best means of addressing the issues raised in this staff report. In summary, the issues to be addressed are as follows:

1. Since the development of the DO objectives in 1975, several native fish species have become at risk of extinction.
2. The life cycle DO objectives do not adequately protect against the effects of multiple days or weeks of low DO conditions.
3. The SPWN DO objective is underprotective of pre-emergent fry.
4. The background DO objectives are outdated in light of new sampling capabilities that allow for continuous monitoring over a 24-hour period or longer.

The California Environmental Quality Act (CEQA) requires consideration of at least two alternatives, including a "no action" alternative. For the purpose of this analysis, staff has developed 3 alternatives. They are 1) No action; 2) Adoption of revised DO objectives specific to the Klamath River only; and, 3) Adoption of revised DO objectives for the whole region.

VI.1 No Action Alternative

With respect to DO, the "no action" alternative is to retain the DO objectives as written in the Basin Plan without update or revision. The No Action Alternative would leave Table 3-1 unchanged, including background DO objectives developed based on grab sample data from the 1950s and 1960s. As an example, the background DO objectives would be retained for the Klamath River, even given the results of the Klamath River TMDL for DO demonstrating that natural conditions (in the absence of anthropogenic effects) result in periodic DO concentrations less than the given objectives. The life cycle DO objectives would continue to protect against acute effects. But, they would provide no protection against the chronic effects of DO stress, including reduced reproductive success, reduced growth, and increased susceptibility to disease. The background DO objectives would continue to apply instead of life cycle DO objectives in those waterbodies listed in Table 3-1.

VI. 2 Klamath River Alternative

This alternative would retain the existing DO objectives for the whole Region *except* the Klamath River. In this alternative, the site-specific DO objectives included in Table 3-1 of the Basin Plan would be updated for the Middle Klamath River HA and the Lower Klamath River HA based on the results of modeling conducted in support of the TMDL for DO. Specifically, new minimum and 50% lower limits would be derived from the output of the model run that was designed to depict the Klamath River under natural conditions, including a natural stream channel configuration (e.g., without dams), natural concentrations of nutrients and organic matter, and natural temperatures.

In favor of this alternative is that DO objectives for the Klamath River would provide a more accurate representation of background conditions than the DO objectives currently contained in Table 3-1. In particular, the daily minimum DO objectives would represent true daily minimums such that continuous monitoring data over 24-hours or longer could reasonably be compared to the objectives for determining compliance and other purposes. Further, the Regional Water Board would be able to demonstrate to USEPA that the source reductions as calculated in the Klamath River TMDL would result in compliance with the DO objectives, a demonstration that could not be made in the absence of their revision.

This alternative, however, would leave threatened and endangered species under-protected during some times of the year and during some life cycle stages in some of the other waterbodies of the Region. This is because the life cycle DO objectives, not being updated, would continue to protect against the acute effects of DO depletion, only. For the other waterbodies included in Table 3-1 of the Basin Plan, except for the Klamath River, the DO objectives would continue to provide a poor representation of daily minimum background conditions, making assessment of compliance and/or impairment difficult.

VI.3 Region-wide Alternative

There are three main components of the existing DO objectives: the life cycle DO objectives, the background DO objectives, and the relationship between the two. The Region-wide Alternative includes several sub-alternatives related to the revision of each of these main components.

VI.3.1 Region-wide Alternative—Revision of the Life Cycle DO Objectives

If some revision is otherwise to be made to the DO objectives, then one of the most simple and straightforward elements of the revision is to update the life cycle DO objectives based on the recommendations in USEPA (1986). An update to the life cycle DO objectives would include:

- The addition of 7-day average limits for SPWN and COLD as described in Chapter V;
- The elimination of the 7.0 mg/L daily minimum SPWN objective as under-protective;
- The expansion of the period in which the 9.0 mg/L daily minimum SPWN objective applies to ensure protection of pre-emergent fry; and,
- The addition of a 7-day average limit for WARM.
- The addition of a narrative objective for EST.

In updating the life cycle DO objectives in this way, the Basin Plan would provide for the range of DO conditions required of aquatic species in the Region.

VI.3.2 Region-wide Alternative—Revision of the Background DO Objectives

The staff report clearly demonstrates the need to update the background DO objectives. To leave Table 3-1 without revision would jeopardize the integrity of the monitoring and compliance programs. The project of updating the background DO objectives, however, is a very difficult one.

VI.3.2.1 Modeling

One option is to model background DO conditions for each waterbody listed in Table 3-1. The experience gained from the Shasta River and Klamath River TMDLs for DO, as well as the Laguna TMDL for DO now underway, could help to streamline the data collection and modeling effort. Nonetheless, the time and expense in modeling DO conditions in each waterbody listed in Table 3-1 would be tremendous and require a significant redirection in staff priorities.

VI.3.2.2 Estimate Natural Background using Percent Saturation and Natural Temperatures

Another option is to rely on the observation that DO in healthy streams and rivers approaches saturation, fluctuating slightly due to the natural processes associated with photosynthesis and decomposition (Deas and Orlob 1999). The range of fluctuation in saturation in such a system is generally defined as 80-100% (Hauer and Hill 2007; SFBRWQCB 2007; Moyle 2008). With this information, it is possible to establish DO concentrations representative of background conditions based on what would be expected at a given percent saturation. To calculate background DO concentrations in this way, one would need to establish the appropriate percent saturation representative of background conditions, the natural receiving water temperatures at a given site, site salinity, and site barometric pressure.

Percent Saturation Representative of Background Conditions

There are numerous regions, states and countries that utilize percent saturation as a water quality criterion for DO. For example, Region 2 (San Francisco Bay) requires that the median DO concentration for any three consecutive months not be less than 80% of the DO content at saturation (SFBRWQCB 2007). It further states that in areas unaffected by waste discharges, a level of about 85% of oxygen saturation exists (SFBRWQCB 2007). Region 3 (Central Coast) requires that median values not fall below 85% saturation as a result of controllable water quality conditions (CCRWQCB 1994). Region 5 (Central Valley) requires that for those surface water bodies outside the legal boundaries of the Delta, the monthly median of the mean daily DO concentration shall not fall below 85% of saturation in the main water mass (CVRWQCB 2007). It further requires that for water bodies unable to meet concentration-based DO objectives due to natural conditions, DO must be maintained at or above 95% of saturation (CVWQCB 2007). Finally, Region 8 (Santa Ana) requires that waste discharges shall not cause the median DO concentration to fall below 85% of saturation (SARRWQCB 2008).

The State of Oregon applies a 90% saturation criterion in those COLD waterbodies unable to meet concentration-based limits due to conditions of barometric pressure, altitude and temperature, and 95% saturation in SPWN waterbodies under the same conditions. The Hoopa Valley Tribe applies a 90% saturation criterion under natural receiving water temperatures in those COLD and SPWN waterbodies unable to meet concentration-based limits due to natural conditions. The National Rivers Authority of England requires DO in their RE1 waterbodies (very high quality, suitable for all fisheries) to be at or above 80% of saturation (NRA 1994).

Staff propose that the DO concentration at or above 85% of saturation at natural receiving water temperatures reasonably represents the daily minimum DO expected under natural conditions. Staff bases this proposal on the following:

1. 85% of saturation falls within the range of saturation values (80-100%) expected to represent natural background.
2. ODEQ (1995) called a Technical Advisory Committee, chaired by Gary Chapman of USEPA, to review its water quality objectives for DO. The Technical Advisory Committee concluded that Oregon's former water quality criteria of 90% and 95% of saturation were too conservative because natural conditions in some streams will cause DO levels to fall below 90%.
3. Davis (1975) demonstrated that few members of a salmonid population will show the effects of oxygen stress if DO is at or above 85% saturation at temperatures up to 20°C and 93% of saturation at temperatures up to 25°C, suggesting that a percent saturation less than 85% may cause harm at higher temperatures. Because of the threatened and endangered status of some salmonid species in the North Coast Region, staff believes it necessary to provide at least the protection afforded by 85% of saturation, recognizing that natural systems do not provide "ideal" conditions at all times. See Chapter IV regarding the DO tolerances and adaptive behavior of salmonids and other fishes.
4. Many streams in the North Coast Region have been affected by elevated stream temperatures due to sedimentation, flow reductions, agricultural return flows, loss of riparian shade, and other factors. Because DO fluctuates as a result of variation in temperature, and some of the waterbodies in the North Coast Region are listed on the 303(d) list for temperature impairments, staff propose that background DO objectives be calculated not based on existing stream temperatures, but natural stream temperatures. This approach makes biological sense since an organism's metabolic rate increases with increased temperature thereby increasing its DO requirement at the same time that DO at saturation is falling. And, it provides a margin of safety to better ensure that a background DO objective calculated in this way is reasonably conservative and protective. A discussion of techniques for such an analysis is included below.

Natural Receiving Water Temperatures

A variety of common techniques are available for estimation of natural stream temperatures at a given site. Reasonable estimates of natural temperatures can be developed by comparison with reference streams, simple calculations, or use of computer models. Though a number of techniques may be applied, the most appropriate technique will depend on the site-specific conditions of the location of interest. Factors that may require a more in-depth analysis are:

- significant alteration of natural hydrologic conditions,
- unique hydrologic features such as springs or cold tributaries,
- estuarine environments, and
- thermal stratification.

Defining the alteration of thermal influences

The first step in estimating natural stream temperatures is to identify the drivers of stream temperature that have been altered from natural conditions. Stream temperature drivers include solar radiation, advection of cold water, bed conduction, convection, and evaporation. Once the altered stream temperature drivers have been identified, the effects of those alterations can be assessed using the tools described below.

Comparison with reference streams

Reference streams can be helpful for estimating natural temperatures if the reference stream closely resembles the location of interest in a natural state. Headwater stream reaches and mainstem trunk stream reaches are two types of stream environments that are particularly suited for this type of analysis, if shade and meteorological conditions are comparable.

Headwater streams are suited to these types of comparisons because they are close to the stream source, groundwater. Groundwater is typically constant year round, and generally defines the lower temperature limit for streams in the summer months. The lower reaches of mainstem trunk streams (e.g., the mainstem Eel River at Alderpoint) are also suited to these types of comparisons because they typically represent temperatures that are in equilibrium with heat sources and sinks. Maximum stream temperatures of the lower reaches of major rivers are typically very similar in the summer months. Stream reaches in between the headwaters and lower mainstem stream reaches are only suited for comparison with reference streams if the riparian, hydrologic, and meteorologic conditions are comparable from the headwaters to the location of interest, and there are no unique thermal or hydrologic conditions present.

Simple Calculations

The use of simple calculations can be useful in estimating natural steam temperatures. The mixing equation, $Q_{ds}*T_{ds} = Q_{us}*T_{us} + Q_{trib}*T_{trib}$ (where the Qs represent flows, Ts represent temperatures, ds denotes downstream, us denotes upstream, and trib denotes tributary temperatures and flows) is a helpful equation for calculating the change in temperature downstream of a confluence of two streams. Similarly, Cafferata (1990) demonstrated that a modified version of Brown's equation gives a reasonable estimate of temperature change due to alteration of solar exposure for short stream reaches, where the conditions in the reach are homogeneous.

Computer models

Many computer models have been developed with the ability to calculate stream temperatures. Some of these models were developed for other purposes and only calculate temperature in order to calculate other water quality related processes, while others were specifically developed with stream temperature applications in mind. Either type of model can be used to estimate stream temperatures if all the relevant processes and factors are accounted for in the model. For instance, some models do not take into account riparian shade, while others do.

One of the more commonly used simple stream temperature model is SSTEMP, maintained by the USGS. SSTEMP is considered a simple model because it requires no compiler or complicated input files. The calculation scheme is also simple, relying on daily average input data to estimate daily average stream temperatures for a single reach. Accordingly, SSTEMP is well-suited for simple thermal situations. It can be used to evaluate changes in channel geometry, vegetation, meteorologic conditions, and changes in flow. A limitation of the SSTEMP model is that because the input data are daily averages, the model does not perform well when the model is evaluating a reach that represents significantly more or less than one day's travel time. Also, the SSTEMP model does not perform well if the reach in question encompasses drastic differences of shade, flow, channel geometry, or meteorology within it.

Deterministic computer models are useful in situations where a reach of stream, or a stream network, requires a more sophisticated analysis. These models are designed to accommodate variable conditions in time and space, which requires that those variables be defined in time and space. The definition of those conditions requires large amounts of data. To use a deterministic model to estimate natural temperatures, the natural condition of each factor that influences stream temperatures must be estimated over the entire time and spatial extent of the analysis.

The Klamath TMDL temperature analysis is an example of the use of deterministic models to estimate natural temperatures. In that analysis, natural temperatures were estimated by defining the estimated natural conditions of the Klamath River and calculating the temperatures that would result from those conditions using the RMA-2 and RMA-11 models. Estimates of natural flows from Upper Klamath Lake and downstream tributaries were developed to define natural hydrologic conditions. Similarly, the natural, un-dammed geometry of the Klamath River was used to define the natural channel geometry. Finally, shade and meteorological conditions were assumed to be effectively natural.

Assessment of this Alternative—Percent Saturation

The benefit of calculating background DO objectives based on percent saturation and natural receiving water temperatures is that it does not require an abundance of DO data or extensive DO modeling. This is important because the DO dataset for the North Coast Region is very sparse and unevenly distributed. A very significant effort and prioritization of monitoring resources would be required to collect sufficient data to populate a DO water quality model and test its efficacy. This is hampered by the relatively few datasonde data loggers available for deployment at any given time. Further, the modeling exercise itself could require significant time and resources in its development, tuning, running, and testing. The Klamath River TMDL is an example of the effort that could be required.

The challenge of calculating background DO objectives using this technique is that it requires the estimate of natural receiving water temperatures. This exercise, like that of DO modeling, requires the availability of data; and, may require a significant amount of data if a more complex temperature model is required. However, temperature data is much more readily available throughout the North Coast Region then is DO data and much more readily obtained, if necessary. In addition, as described above, there are some simple ways in which such an estimate could be developed.

An additional challenge of calculating background DO objectives using this technique is that it might not reasonably apply to streams and rivers that have DO-related attributes that are uncharacteristic of most other North Coast streams. For example, 85% of saturation might not reasonably represent the natural diurnal fluctuation in DO in a low gradient, widely meandering, wetland complex with large solar exposure and high summer temperatures. In this example, a background DO objective might more reasonably be developed as a site specific objective based on the unique attributes of the system.

VI.3.3 Region-wide Alternative—Life Cycle or Background Precedence?

The Basin Plan currently only requires the application of life cycle DO objectives in those streams not otherwise listed in Table 3-1 of the Basin Plan. The result of this structure is that few of the Region's waterbodies are required to meet life cycle DO objectives. This is significant because the background DO objectives are given as a daily minimum and the annual average of monthly means. This allows for compliant conditions to include multiple days and weeks of significantly depressed DO, even during critical periods of spawning, egg incubation and early life stage development. Without a change to this relationship, the SPWN beneficial use will continue to be under-protected in most of the Region's waterbodies.

An alternative is to reverse the relationship between the life cycle DO objectives and background DO objectives. In this scenario, the life cycle DO objectives would take precedence and only for those waterbodies in which natural conditions prevent the attainment of the life cycle objectives would background DO objectives apply.

There are several benefits to this alternative. First, the life cycle DO objectives—as long as they are updated—would provide adequate protection to all the beneficial uses, including protection of threatened and endangered species, sensitive species, and sensitive life stages. Second, the life cycle DO objectives are based on decades of robust science, voluminous data, and peer review. The background DO objectives, on the other hand, will necessarily be based on limited data and provide only an estimate of background conditions.

The challenge of implementing this alternative is in determining whether or not natural conditions are preventing the attainment of life cycle DO objectives in a given waterbody. In a memorandum dated November 5, 1997, the Director of the EPA Office of Science and Technology (Davies 1997) specified a policy for "establishing site specific aquatic life criteria equal to natural background:"

> "States and Tribes may establish site specific numeric aquatic life water quality criteria by setting the criteria value equal to *natural* background. Natural background is defined as background concentration due *only* to non-anthropogenic sources, i.e., non-man-made sources. In setting criteria equal to

natural background the state or tribe should, at a minimum, include in their water quality standards:

1. a definition of natural background consistent with the above;
2. a provision that site specific criteria can be set equal to natural background; and
3. a procedure for determining natural background, or alternatively, a reference in their water quality standards to another document describing the binding procedure that will be used."

USEPA Region 9, in its review and approval of the Hoopa Valley Tribe's water quality standards, required that the "natural conditions" clause included in its standards not be implemented until an approvable procedure for determining "natural conditions" was identified. As such, staff believes it necessary to establish a procedure here.

VI.3.3.1 Procedure for determining if natural conditions prevent attainment of objectives

There are essentially three steps to determining if natural conditions prevent the attainment of life cycle DO objectives.

The first step is to confirm that water quality conditions in a waterbody do not meet the life cycle DO objectives. This is accomplished by conducting continuous monitoring during the weeks or months in which noncompliance is expected, establishing a quantitative record of noncompliance. It is understood that periodic noncompliance with life cycle DO objectives might occur even in waterbodies in which life cycle DO objectives are typically met. For example, prolonged drought, extreme flooding and sedimentation, or excessive organic loading after a fire could result in extraordinary or unusual conditions that depress DO temporarily. Periodic noncompliance such as this, a temporary and unusual circumstance, do not constitute reason to calculate a new DO objective based on percent saturation. It is the intention of this alternative that only long-lived noncompliance resulting from permanent natural conditions characteristic of the basin constitute a reason for recalculation (e.g., phosphorus-rich geology, extensive wetland complexes, or ephemeral stream flow). As such, the DO data collected with the intention of proving noncompliance with life cycle DO objectives must be assessed within the context of recent climatic and other events temporarily affecting DO.

The second step is to develop a conceptual model of the elements affecting DO in the aquatic system of concern, both anthropogenic and natural. This is accomplished through a combination of both qualitative and quantitative information, as appropriate, including: a general understanding of DO relationships, historical water quality and land use records, and existing data. The result should be a conceptual model similar to that presented in Chapter III in which the site specific characteristics of the waterbody in question are presented and their relationships among each other identified. The intention of this step is to identify all the factors contributing to the pattern and range of DO observed in the basin. At this stage, an estimate of the importance of individual elements with respect to their overall affect on DO is helpful. If existing data and information are available, these estimates could be given as quantities or ranges of quantities. Or, they might be expressed as percentages based on the importance of their influence on DO concentrations.

The third step is to estimate DO concentrations in the waterbody in question under natural conditions. The method used to develop these estimates will depend in large part on the characteristics of the basin. As such, staff can not prescribe a specific method that can with assurance apply in all basins of the Region. Instead, staff can describe the goals of this step and refer the reader to the discussion of the Klamath River TMDL in Chapter V as an example of how this question has been answered for that basin.

The goal of this step is to produce a reasonable estimate of DO resulting only from the influences of natural conditions so as to compare them to the life cycle DO objectives. This is accomplished by choosing a method that produces an equation in which the addition of all anthropogenic and natural sources/conditions influencing DO results in DO concentrations equivalent to those actually measured. The equation produced must be internally logical and consistent with the conceptual model produced in step two. Once anthropogenic sources/conditions are subtracted from the equation, the result should be an estimate of DO concentrations under natural conditions, only. These are then compared to the life cycle DO objectives to determine if life cycle DO objectives can be met.

It is important to keep in mind that the goal of this step is *not* to produce a site-specific objective of unequivocal accuracy. The development of site-specific objectives may be required in some basins where the application of 85% saturation under natural temperature conditions can not reasonably be expected to result in DO concentrations that represent true natural background conditions: estuarine systems, or systems experiencing periodic turnover, for example. Further, there may be basins or locations in the Region where neither life cycle DO objectives nor background DO objectives reasonably apply. For these situations, USEPA has produced guidance on the development of site-specific objectives.

VI.4 Proposed Alternative

Staff propose as the most efficacious alternative the Region-wide revision of the DO objectives, including:

- Revision of the life cycle DO objectives based on USEPA (1986) and other scientific literature as described in Section V.1.3;
- Elimination of the background DO objectives from Table 3-1 except for Humboldt Bay, Bodega Bay, and ocean waters.
- Inclusion of a "natural conditions" clause that allows for the calculation of background DO objectives based on 85% saturation under natural stream temperatures in those waterbodies or reaches of waterbodies where natural conditions prevent the attainment of life cycle DO objectives.

Proposed Basin Plan language is as follows:

"Dissolved oxygen concentrations shall conform to the following life cycle dissolved oxygen requirements.

Beneficial Use	Daily minimum objective (mg/L)	7-day average objective (mg/L)[7]
MAR, SAL	5.0	NA
WARM	5.0	6.0
COLD[8]	6.0	8.0
SPWN[9]	9.0	11.0

Dissolved oxygen concentrations in Humboldt Bay and Bodega Bay shall conform to a daily minimum objective of 6.0 mg/L. As required of the Ocean Plan, dissolved oxygen concentrations shall not at any time be depressed more than 10 percent from that which occurs naturally in ocean waters.

Upon approval from the Executive Officer, in those waterbodies for which the life cycle DO requirements are unachievable due to natural conditions[10], site specific background DO requirements can be applied as water quality objectives by calculating the daily minimum DO necessary to maintain 85% saturation under site salinity, site atmospheric pressure, and natural receiving water temperatures.[11] In no event may controllable factors reduce the daily minimum DO below 6.0 mg/L.

For the protection of estuarine habitat (EST), the dissolved oxygen content of enclosed bays and estuaries shall not be depressed to levels adversely affecting beneficial uses as a result of controllable water quality factors."

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[7] A 7-day moving average is calculated by taking the average of each set of seven consecutive daily averages.

[8] Water quality objectives designed to protect COLD-designated waters are based on the life cycle requirements of salmonids but apply to all waters designated in Table 2-1 of the Basin Plan as COLD regardless of the presence or absence of salmonids.

[9] Water quality objectives designed to protect SPWN-designated waters apply to all fresh waters designated in Table 2-1 of the Basin Plan as SPWN in those reaches and during those periods of time when spawning, egg incubation, and larval development are occurring or have historically occurred. The period of spawning, egg incubation, and emergence generally occur in the North Coast Region between the dates of September 15 and June 4.

[10] Natural conditions are conditions or circumstances affecting the physical, chemical, or biological integrity of water that are not influenced by past or present anthropogenic activities.

[11] The method(s) used to estimate natural temperatures for a given waterbody or stream length must be approved by the Executive Officer and may include, as appropriate, comparison with reference streams, simple calculation, or computer models.

CHAPTER VII. MONITORING PLAN

Monitoring is required to determine the environmental condition of a waterbody, its ability to support beneficial uses, and the degree of compliance with the Basin Plan, including water quality objectives. With respect to the proposed revisions to the Basin Plan for DO, monitoring should include measurements for:

1. DO, temperature, and salinity in the water column and
2. Atmospheric pressure at water column measuring stations.

Water quality data generally are collected in the region for one of three purposes: 1) to measure compliance with a discharge permit, 2) to identify water quality impairments requiring 303(d) listing, or 3) as a part of a specific study.

Regional Water Board staff issue National Pollutant Discharge Elimination System (NPDES) permits as well as Waste Discharge Requirements (WDR) for the control of both point source and stormwater discharges. Instream DO measurements are required upstream and downstream of a discharge. The upstream measurement is intended to represent ambient conditions while the downstream measurement is intended to reflect the impact of the discharge on the ambient condition. A violation of the water quality objectives results if the upstream measurement meets the water quality objective and the downstream measurement does not; or, if the upstream measurement does not meet the water quality objective and the downstream measurement is less than the upstream measurement. Staff recommends that:

1. DO measurements be continuous measurements collected less than or equal to once every hour within a 24-hour day. A reasonable break in the monitoring schedule should be allowed for the purpose of maintaining or replacing monitoring equipment.
2. DO weekly averages be calculated from the daily means of a moving 7-day period. Fewer than 7 daily means may be allowable in any 7-day period for the calculation of a weekly average to be acceptable.
3. The period of monitoring be adjusted based on site specific information indicating that less frequent monitoring will provide equivalent results.
4. Upstream monitoring be outside the sphere of influence of the discharge in question. It should also be outside the influence of any other known upstream point source discharges, if possible.
5. Downstream monitoring be established downstream of the discharge outfall a sufficient distance to ensure that the effects on DO of the discharge (e.g., conversion of organic matter, uptake of nutrients) are adequately captured. This determination may require a short field trial or simple modeling exercise.

Regional Water Board staff also implements the Surface Water Ambient Monitoring Program (SWAMP) in the North Coast Region. Annual data, including DO data, is collected from individual watersheds on a rotation. The SWAMP program maintains several datasondes and is capable of collecting continuous measurements over multiple days.

The data collected through SWAMP are used, in conjunction with data from other sources, to assess the condition of the Region's waterbodies, including the identification of waterbodies that are impaired and require listing on the Clean Water Act (CWA) 303(d) list. There are three waterbodies in the North Coast Region currently listed on the 303(d) list for impairments due to reduced DO: the Klamath River mainstem from the Oregon border to the estuary, the Shasta River Hydrological Area, and Laguna de Santa Rosa in the Russian River watershed. A Total Maximum Daily Load (TMDL) to correct the problem has been developed and adopted for the Shasta River. TMDLs for the Klamath River and Laguna de Santa Rosa are currently under development.

There are numerous other waterbodies in the Region, however, that are listed as impaired due to excess nutrients, elevated stream temperatures, and/or pH. These are indicators that often result in or are suggestive of excessive primary production and may impact DO concentration and saturation. These require further monitoring. Staff recommends that:

1. Waterbodies with impairments due to pH, ammonia, temperature, or nutrients should also be monitored for DO.
2. DO monitoring should be conducted on a continuous basis with measurements recorded less than or equal to once every hour within a 24-hour day and for at least a 7-day period. Simultaneously, temperature, salinity, and atmospheric pressure should also be collected to allow for the calculation of percent DO saturation.
3. The Regional Water Board should develop and distribute guidelines for the appropriate placement, maintenance, and reading of monitoring devices for the purpose of ensuring the collection of representative samples.

Finally, Regional Water Board staff and/or its cooperators occasionally conduct special water quality studies, which result in the collection of DO data or modeling. Such special studies might include investigations and analyses to: respond to complaint; support an enforcement action; support the 303(d) listing process; support the development of a TMDL; or otherwise determine compliance with the Basin Plan, permit, or TMDL. Occasionally, Regional Water Board staff participates in area-wide monitoring projects led by another agency, but including a water quality goal, which we serve. Staff recommend that:

1. Data collected under these auspices be included in a Region-wide ambient water quality database for future reference and analysis.
2. DO data be collected in a manner consistent with the proposed DO objective, including the percent DO saturation criteria, if adopted.

CHAPTER VIII.
IMPLEMENTATION PLAN

The Regional Water Boards adopt and implement water quality control plans for the protection and enhancement of water quality in the region, as required by the Porter-Cologne Water Quality Control Act (Porter-Cologne Act). In 1971 the North Coast Regional Water Quality Control Board first adopted two Interim Basin Plans, one for the Klamath Basin (1a) and the second for the North Coast Basin (1b). In 1975, the two plans were revised and went through another adoption process. In 1988 the two individual Basin Plans were combined into one plan, referred to since as the Water Quality Control Plan for the North Coast Region (Basin Plan). The Basin Plan has been amended numerous times since then most recently in 2007. The existing DO objectives have been in place since the Basin Plan was approved in 1975.

SWRCB (2004) describes the planning authority under Porter-Cologne to extend to any activity or factor that may affect water quality, including waste discharges, saline intrusion, reduction of waste assimilative capacity caused by reduction in water quantity, hydrogeologic modifications, watershed management projects, and land use. It further makes clear that all dischargers are subject to regulation under the Porter-Cologne Act including both point and nonpoint source dischargers (SWRCB 2004).

VIII. 1 Activities of Concern with respect to DO

The conceptual model for DO (Figure 1 and Appendix D) specifically identifies the following activities as influencing the presence of DO in an aquatic system: agricultural practices, forestry practices, fossil fuel extraction and refinement practices, other mining practices, construction practices, residential and commercial practices, recreational practices, and industrial practices. These activities have the potential to act as sources of: fire ash and smoke, animal wastes, mining wastes, septic system leachate, landfill leachate, fertilizers, vehicle emissions, industrial emissions, sewage treatment plant effluent, industrial effluent, stormwater discharge, and other historic or existing sources. In addition, these activities have the potential to alter environmental conditions in such as way as to alter the natural cycle of DO availability. For example, the installation of impoundments, alteration of land cover, alteration of the stream channel, increase in temperature, or increase in sediment delivery can impact the functioning of DO in an aquatic system.

As such, the conceptual model illustrates the importance of developing management measures designed to:

- Reduce the threat of the discharge of anthropogenic sources of nutrients, and organic matter including the discharge of agricultural return flows,
- Reduce the threat of discharge of warm water to a waterbody, including the discharge of agricultural return flows;
- Reduce the threat of anthropogenic sources of erosion and sediment delivery;
- Reduce the threat of direct alteration of the stream channel, such as through gravel mining;

- Reduce the threat of disturbance to wetlands, the flood plain and riparian zone;
- Reduce the threat of anthropogenic alteration to the natural pattern and range of flows, including stormwater management, groundwater protection, and control of water impoundment and withdrawal;
- Reduce the threat of loss or alteration (e.g., reduction in flow or increase in temperature) of cold water springs; and,
- Increase the availability of channel forming material (e.g., large woody debris) in the stream channel, riparian zone, and floodplain.

It further illustrates the importance of developing management measures designed to control vehicle and industrial emissions. This task, however, is out of the range of the Regional Water Board's authority.

VIII.2 Regulatory Program

The cornerstones of the Regional Water Board's regulatory program are the 1) waste discharge prohibition,2) the Waste Discharge Requirement (WDR), and 3) waivers of WDRs. As an example of the waste discharge prohibition, the Regional Water Board prohibits the discharge of wastes to all the waters of the Region except the Lost River and it further prohibits waste discharge to the Mad, Eel, and Russian Rivers during the period of May 15 through September 30 and under specific flow regimes. The Regional Water Board can issue exceptions to this prohibition, if necessary. The Regional Water Board can also issue new prohibitions to address specific water quality issues, as needed.

WDRs allow the discharge of waste to a water of the North Coast Region; but, they identify the pollutants of concern and the discharge limits necessary to ensure the protection of water quality, including compliance with the ambient water quality objectives and antidegradation policies of the Basin Plan. WDRs can be issued as individual permits (e.g., for a particular facility), group permits (e.g., for facilities within a particular watershed), or general permits (e.g., for facilities conducting a particular activity). The Regional Water Board also has the option to issue a waiver of requirements for facilities whose operations meet certain conditions if it is in the public interest.

VIII.2.1 Nonpoint Source Program

In 1988, the SWRCB issued a Nonpoint Source Policy outlining a three-tiered program by which nonpoint source pollution was to be controlled in the State. The first tier of the program called upon landowners to voluntarily comply with the Basin Plan, including compliance with water quality objectives. The Nonpoint Source Policy was updated in 2004 and more plainly made clear the obligation of the Regional Water Board to ensure compliance with the Basin Plan, even from nonpoint sources of pollution.

In 2000, the SWRCB developed a strategy for prioritizing those sources of nonpoint source pollution requiring immediate state attention. The "Plan for California's Nonpoint Source Pollution Control Program" (SWRCB 2000) identifies 6 categories of activities requiring priority management for the control of nonpoint source pollution in the state, including:

1. Agriculture;
2. Forestry;
3. Urban areas;
4. Marinas and recreational boating;
5. Hydromodification; and
6. Wetlands, riparian areas and vegetated treatment systems.

For these 6 categories of activities, the SWRCB (2000) further identifies 61 management measures to be implemented over a 15 year schedule, beginning in the 1998.

VIII.2.2 Existing Programs

The Regional Water Board currently implements a number of programs that reasonably and adequately address water quality issues such as DO. These include programs designed to control:

- Discharge of waste to waters of the State either directly or via stormwater discharges. These discharges are regulated under the National Pollutant Discharge Elimination System (NPDES) program.
- Discharge of waste as a result of timber operations.
- Discharge of waste as a result of dredging, filling, or other activities in wetlands that meet the federal definition of wetlands (410 certification program)
- Discharges of waste to land (Chapter 15 Program and Non-Chapter 15 Permitting, Surveillance, and Enforcement Program)

VIII.2.2.1 NPDES Permitting, Surveillance, and Enforcement

The National Pollutant Discharge Elimination System (NPDES) program is a federal program which has been delegated to the State of California for implementation. NPDES permits, sometimes also referred to as Waste Discharge Requirements (WDRs), are issued to regulate the discharge of municipal wastewater or industrial process, cleaning, or cooling wastewaters, commercial wastewater, treated groundwater from cleanup projects, or other wastes to surface waters only. All municipalities within the North Coast Region which discharge wastewater to surface waters are currently regulated by NPDES permits issued by the Regional Water Board. Non-municipal waste discharges typically regulated by NPDES permits in the North Coast Region include: canneries, fish hatcheries, wineries and other food processing plants, groundwater cleanup projects, hardboard manufacturing plants, pulp mills, sawmills, and gravel operations.

VIII.2.2.2 NPDES Stormwater

The goal of the Storm Water Program is to prevent or minimize the discharge of pollutants contained in storm water runoff to waters of the state. Common pollutants contained in storm water runoff include:

- Sediment: construction or other activities expose and loosen soils, while vehicles break-up pavement. Excessive sediment in water can effect the respiration, growth and reproduction of aquatic organisms, cause aesthetic impacts to receiving streams and affect spawning habitat of salmonids.

- Nutrients: Sources include fertilizer, lawn clippings, and car exhaust which contain nutrients like phosphorous and nitrogen. An overabundance of nutrients can accelerate the growth of algae and affect the availability of DO.
- Heavy metals and toxic chemicals: Sources of cars (brake pads, engine wear, etc) pesticides and herbicides. Maintaining and cleaning transportation vehicles can release solvents, paint, rust, and lead.. These chemicals may poison organisms or cause serious birth defects.
- Bacteria: Sources include failing septic tanks, sewer overflows, decaying organic material and the improper disposal of household pet fecal material. Some bacteria found in stormwater runoff can result in disease. Beach closures result from high bacteria levels.

There are three statewide NPDES stormwater permits issued by the SWRCB and implemented by individual Regional Water Boards. These permits are for the control of stormwater runoff from 1) industrial facilities, 2) construction sites, and 3) municipalities. The NPDES Stormwater permit program is implemented as a phased program in which facilities implement best management practices and monitor and improve management practices, as monitoring data indicates the need.

VIII.2.2.3 Land Disposal Program

The California Code of Regulations (CCR) Title 23 (Chapter 15) contains the regulatory requirements for hazardous waste. The Chapter 15 Program regulates the discharge to land of certain sold and liquid wastes. These wastes include municipal solid waste, hazardous wastes, designated wastes, and nonhazardous and inert sold wastes. In general, these wastes cannot be discharged directly to the ground surface without impacting groundwater or surface water, and therefore must be contained in waste management units (e.g., landfills) to isolate them from the environment.

The Non-Chapter 15 Permitting, Surveillance and Enforcement Program is a State mandated program under which Waste Discharge Requirements are issued to regulate the discharge of municipal, industrial, commercial and other wastes to land only. If the waste discharge consists only of non-process storm water, it may be regulated under the NPDES Stormwater program. The discharge of waste to surface water (rivers, streams, lakes, wetlands, drains, and the Pacific Ocean) is regulated under the NPDES Permitting, Surveillance, and Enforcement program.

All municipalities within the North Coast Region which discharge wastewaters to land are currently regulated by Waste Discharge Requirements issued by the Regional Water Board. Industrial, commercial, or other operations which discharge to municipal or other publicly owned wastewater collection systems are not required to obtain Waste Discharge Requirements under this program, but must comply with waste discharge requirements issued by the appropriate public entity.

Non-municipal waste discharges typically regulated by Waste Discharge Requirements under the Non-Chapter 15 Permitting, Surveillance and Enforcement program within the North Coast Region include: dairies, mines, mobile home parks, sawmills, and wineries.

VIII.2.2.4 Timber Operations

The Regional Water Board has been regulating discharges from logging and associated activities since 1972 which is consistent with the abundance of timber and water resources in the North Coast Region. The North Coast Region includes 12 % of the State's land area yet produces 48% of the private timber harvested within the State and 40% of the State's total runoff.

Timber harvesting activities with the greatest potential to impact waters of the State include: felling, yarding, and hauling of trees; road construction and reconstruction; watercourse crossing construction, reconstruction, or removal, herbicide applications, broadcast burning and other site preparation activities. Excessive soil erosion and sediment delivery associated with these activities can impact the beneficial uses of water by: 1) silting over fish spawning habitat; 2) clogging drinking water intakes; 3) filling pools creating shallower, wider, and warmer stream, and increasing downstream flooding; 4) creating unstable stream channels; and 5) losing riparian habitat. Timber harvesting in the riparian zone can adversely affect stream temperatures by removing stream shading which is especially a concern for temperature impaired waterbodies. Removal of large diameter trees in the riparian zone also adverse affects the amount of large woody debris available for the development of the complex instream features necessary to support pool development and predator protection.

Landowners must apply for coverage under a General Waste Discharge Requirement (WDR) for Discharges Related to Timber Harvest Activities on Non-Federal Land, categorical waiver of WDRs, an individual waiver of WDRs, or a Watershed-wide WDR. Most public lands involved in timber harvest activities within the North Coast Region are under the jurisdiction of the U.S. Forest Service. The Regional Water Board and the USFS entered into a Management Agency Agreement in 1981 to formalize the program that would be implemented to overseeing water quality protection on USFS timber sales. In 2004, the RWB adopted a five-year conditional waiver to regulate USFS timber sales. Forest Service and Regional Water Board staff is currently developing a approach for the Regional Water Board's consideration on the regulatory process that will be used to for both timber sales as well as the other land uses (e.g. road construction and maintenance, grazing, etc) that occur on the USFS holdings.

VIII.2.2.5 401 Certification

Anyone proposing to conduct a project that requires a federal permit or involves dredge or fill activities that may result in a discharge to U.S. surface waters and/or waters of the state are required to obtain a Clean Water Act (CWA) Section 401 Water Quality Certification and/or Waste Discharge Requirements (Dredge/Fill Projects) from the Regional Water Board, verifying that the project activities will comply with state water quality standards. The most common federal permit for dredge and fill activities is a CWA Section 404 permit issued by the Army Corps of Engineers.

Section 401 of the CWA grants each state the right to ensure that the State's interests are protected on any federally permitted activity occurring in or adjacent to waters of the state. In California, the Regional Water Boards are the agency mandated to ensure protection of the State's waters. So if a proposed project requires a U.S. Army Corps of Engineers CWA Section 404 permit, falls under other federal jurisdiction, and has the potential to impact waters of the state, the Regional Water Board will regulate the project and associated activities through a Water Quality Certification determination (Section 401).

However, if a proposed project does not require a federal permit, but does involve dredge or fill activities that may result in a discharge to waters of the state, the Regional Water Board has the option to regulate the project under its state authority in the form of WDRs or a waiver of WDRs. In addition, California Department of Fish and Game (DFG) may regulate the project through the Streambed Alteration Agreement process. DFG issues Streambed Alteration Agreements when project activities have the potential to impact intermittent and perennial streams, rivers, or lakes.

VIII.2.2.6 Total Maximum Daily Loads

The Regional Water Board develops and implements Total Maximum Daily Loads (TMDLs) for water bodies listed as impaired on the 303(d) list. A draft of the 2008 305(b) and 303(d) integrated report is available for public review at http://www.waterboards.ca.gov/northcoast/water_issues/programs/tmdls/303d/. Waterbodies listed as impaired due to reduced DO include: Lower Eel River, Klamath River, Green Valley Creek in the Russian River watershed, and the Laguna de Santa Rosa in the Russian River watershed. Waterbodies listed as impaired due to elevated nutrients include: Estero Americano and Americano Creek, Stemple Creek and Estero de San Antonio, Butte Valley in the Klamath River watershed, Klamath River, Tule Lake and Mt. Dome Hydrologic Subarea of the Klamath River watershed, and the Laguna de Santa Rosa. The Regional Water Board has approved a TMDL for the DO in the Shasta River, including an implementation plan. USEPA has established a TMDL for nutrients for the Lost River for which no implementation plan yet exists.

The Regional Water Board is responsible for developing and implementing the source control measures necessary to achieve the calculated total maximum daily load allowable to meet water quality objectives as expressed in a TMDL. Because it is concurrently under development with this DO objective revision, the TMDL for the Klamath River is designed to achieve revised DO objectives as described in this staff report.

VIII.2.3 Policies Currently Under Development

The Regional and State Water Boards are in the process of developing a variety of additional policies to address emerging water quality issues confronting the state. Below is a discussion of a few of the policies currently under development that may play a role in the control of activities affecting ambient DO.

VIII.2.3.1 Streams and Wetlands System Protection Policy

Staffs of the North Coast and San Francisco Bay Regional Water Quality Control Boards are developing amendments to their respective Basin Plans that will protect stream and wetlands systems, including measures to protect riparian areas and floodplains. The goals of the proposed Stream and Wetland System Protection Policy are:

- To achieve water quality standards and protect beneficial uses of waters of the state
- To protect drinking water through natural water quality enhancement and protection of groundwater recharge zones
- To restore habitat and protect aquatic species and wildlife
- To enhance flood protection through natural functions of stream and wetlands systems
- To restore the associated recreational opportunities, green spaces and neighborhood amenities that water resources provide
- To protect property values and community welfare by protecting natural environments
- To encourage local watershed planning and support local oversight of water resources
- To improve Regional Water Board permitting and program efficiency

It is the aim of the "Stream and Wetland System Protection Policy" to achieve these goals by protecting and restoring the physical characteristics of stream and wetlands systems—stream channels, wetlands, riparian areas, and floodplains—including their connectivity and natural hydrologic regimes. The Policy will clarify that stream and wetlands system protection and restoration are viable forms of pollution prevention in all land use settings, and that the strategies of pollutant source control and stream and wetlands system protection need to be integrated to complete the entire watershed water quality management strategy. The Policy will be based on sound scientific principles and will develop reasonable methods to protect water quality.

It is staff's intent that a single "Stream and Wetland System Protection Policy" be proposed for Basin Plan adoption in the North Coast and San Francisco Bay Regions to improve regulatory consistency between the two interlocking regions. The Policy may serve as a model for other Regional Water Board's consideration and for the state as a whole in the protection of water quality. The Policy, as envisioned by staff, will promote regulatory efficiency by linking to existing relevant permit conditions and provisions in 401 water quality certifications, timber harvesting plans (THPs), waste discharge requirements (WDRs), WDR waivers, and stormwater National Pollutant Discharge Elimination System (NPDES) permits. The Policy will also promote general efficiency by linking to the Regional Water Boards' monitoring programs (e.g., Surface Water Ambient Monitoring Program) and grants program. The Policy will provide incentives for local jurisdictions to develop watershed management plans that can be used by project applicants to offset impacts to stream and wetlands functions when on-site avoidance of impacts is impossible. In this way the Policy will create a vehicle for working with local jurisdictions to develop effective implementation strategies consistent with local stakeholder interests.

VIII.2.3.2 North Coast Instream Flow Policy

Water Code section 1259.4, which was added by Assembly Bill 2121 (Stats. 2004, ch. 943, §3), requires the State Water Board to adopt principles and guidelines for maintaining instream flows in northern California coastal streams as part of state policy for water quality control, for the purposes of water right administration. The State Water Resources Control Board issued in January 2008 a draft "Policy for Maintaining Instream Flows in Northern California Coastal Streams." The State Water Board held public workshops and received written comment on the draft policy. They are conducting additional technical analysis before finalizing the plan for Board adoption.

As described in the draft:

> "The policy establishes principles and guidelines for maintaining instream flows for the protection of fishery resources. It does not specify the terms and conditions that will be incorporated into water right permits, licenses, and registration. It prescribes protective measures regarding the season of diversion, minimum bypass flow, and maximum cumulative diversion. Site-specific studies may be conducted to evaluate whether alternative protective criteria could be applied. The policy also limits construction of new on stream dams and contains measures to ensure that approval of new on stream dams does not adversely affect instream flows needed for fishery resources. The policy provides for a watershed-based approach to evaluate the effects of multiple diversions on instream flows within a watershed as an alternative to evaluating water diversion projects on an individual basis. Enforcement requirements contained in this policy include a framework for compliance assurance, prioritization of enforcement cases, and descriptions of enforcement actions. The policy contains guidelines for evaluating whether a proposed water diversion, in combination with existing diversions in a watershed, may affect instream flows needed for the protection of fishery resources." (Division of Water Rights 2007)

VIII.2.3.3 Agricultural Waiver Policy

On its webpage, the State Water Board describes the irrigated lands regulatory program as it is implemented in the state, including agricultural waivers (SWRCB 2009).

> "Over the years, the Regional Water Boards issued waivers for over 40 categories of discharges. Although waivers are always conditional, the historic waivers had few conditions. Senate Bill 390, signed into law on October 6, 1999, required the Regional Water Boards to review their existing waivers and to renew them or replace them with WDRs. Under Senate Bill 390, waivers not reissued automatically expired on January 1, 2003.
>
> Discharges from agricultural lands include irrigation return flow, flows from tile drains, and storm water runoff. These discharges can affect water quality by

> transporting pollutants including pesticides, sediment, nutrients, salts (including selenium and boron), pathogens, and heavy metals from cultivated fields into surface waters. Many surface water bodies are impaired because of pollutants from agricultural sources. Groundwater bodies have also suffered pesticide, nitrate and salt contamination. Statewide, approximately 9,493 miles of rivers/stream and some 513,130 acres of lake/reservoirs are listed on the 303(d) list as being impaired by irrigated agriculture…
>
> To control and assess the effects of discharges from irrigated agricultural lands, the Los Angeles, Central Coast, Central Valley, and San Diego Regional Water Quality Control Boards have adopted comprehensive conditional waivers. An estimated 80,000 growers, who cultivate over 9 million acres, are subject to conditional waivers in these regions. These Regional Water Boards have made significant strides to implement their waiver programs and are committed to continue their efforts to work with the agricultural community to protect and improve water quality. The number of acres and agricultural operations will increase as other Regional Water Boards adopt conditional waivers for discharges from irrigated agricultural land. Regional Water Boards 1, 2, 6, and 8 have no immediate plans to adopt waivers for agricultural discharges, but may do so eventually to implement TMDLs."

VIII.2.3.4 Prohibition of Excess Sediment

A committee of Regional Water Board members and staff has been developing a Basin Plan amendment designed to control the discharge of excess sediment into waters of the state in the North Coast Region by adopting a Prohibition of Excess Sediment and developing an implementation plan. A copy of the revised draft language is available on the website (http://www.waterboards.ca.gov/northcoast/water_issues/programs/basin_plan/sediment_amendment.shtml).

As currently written, the implementation plan calls for the prevention and minimization of any new sources of excess sediment and the inventory, prioritization, control, and monitoring of existing sources of excess sediment. The term excess sediment is currently defined as "soil, rock, and/or sediments (e.g., sand, silt, or clay) discharged to waters of the state in an amount that could be deleterious to beneficial uses or cause a nuisance" (NCRWQCB 2007). The types of anthropogenic activities that could result in a discharge of excess sediment from point or nonpoint sources include but are not limited to: construction; mining; agriculture, including ranching, grazing, and farming; dairies and other types of confined animal operations; road construction, reconstruction, maintenance and decommissioning; timber harvesting; and other earth-disturbing activities.

VIII.2.3.5 Surface Water Rights Program

The Division of Water Rights within the State Boards is responsible for 1) reviewing and issuing permits for the right to appropriate water and 2) maintaining a record of riparian water users (SWRCB 2000). To ensure that water rights decisions do not deleteriously affect water quality in a given region, Water Rights is obligated to ensure that any water right permit it issues complies with the Basin Plan for that region.

The Regional Water Boards establish the beneficial uses[12] of waterbodies within their respective regions and the water quality objectives (e.g., narrative and numeric criteria) necessary to support those beneficial uses. The North Coast Regional Water Board has in the last several years begun to see the availability of adequate instream flows as a critical component of water quality and the protection of beneficial uses. Specifically, the listing of several species of fishes as threatened or endangered under state and federal law has highlighted the need for adequate flows to support the proper functioning of stream and wetland systems; creation and maintenance of high quality habitat; and the stabilization of water quality dynamics. This has led, as an example, to the specific consideration of flow r in the Scott and Shasta River Total Maximum Daily Loads (TMDL) for the protection of instream temperatures threatened by the withdrawal of water from cold water sources. There are other examples, as well, of North Coast streams where the reduction or seasonal loss of instream flows plays a significant role in the listed status of cold water fishes and other beneficial use impairment (e.g., Klamath River). Lastly, there are examples of streams where landscape modifications have increased flows and rates of flooding, also causing impacts to beneficial uses (e.g., Russian River, Freshwater Creek).

VIII.2.3.6 <u>Groundwater Management Program</u>

A discussion of the groundwater management program in the state is included here even though it does not fall under the purview of the State or Regional Water Board. The purpose is to provide a general description of how groundwater resources are managed in the state and to identify opportunities for the Regional Water Board to support activities in the North Coast Region which can result in improved groundwater monitoring and management.

In 2003 the Department of Water Resources issued an update to Bulletin 118 reviewing California's groundwater. Regarding groundwater management in the state, it said:

> "In 1914, California created a system of appropriating surface water rights through a permitting process (Stat 1913, ch. 586), but groundwater use has never been regulated by the State. Though the regulation of groundwater has been considered on several occasions, the California Legislature has repeatedly held that groundwater management should remain a local responsibility (Sax 2002). Although they are treated differently legally, groundwater and surface water are closely interconnected in the hydrologic cycle. Use of one resource will often affect the other, so that effective groundwater management must consider surface water supplies and uses (DWR 2003)."

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[12] The term "beneficial use" is used here based on the definition contained in the Porter-Cologne Water Quality Control Act: "Beneficial uses" of the waters of the state that may be protected against quality degradation include but are not limited to, domestic, municipal, agricultural and industrial supply, power generation, recreation, aesthetic enjoyment, navigation and preservation and enhancement of fish, wildlife, and other aquatic resources or preserves. (CWC §13050(f))

Of the many findings, DWR (2003) highlights the fact that 27 counties in California have adopted groundwater ordinances. In all but three cases, restricting out-of-county uses appears to be the only purpose (DWR 2003). An ordinance adopted in Glenn County, however, establishes more comprehensive management objectives. Counties within the North Coast Region for which a groundwater ordinance has been adopted include: Siskiyou, Modoc, Shasta, Glenn, Lake, and Mendocino. North Coast counties for which no groundwater ordinance exists include: Del Norte, Humboldt, Trinity, Sonoma and Marin.

DWR (2003) made ten major recommendations for the purpose of improving the state's management of groundwater resources:

1. Local or regional agencies should develop groundwater management plans if groundwater constitutes part of their water supply.
2. The State of California should continue programs to provide technical and financial assistance to local agencies to develop monitoring programs, management plans, and groundwater storage projects to more efficiently use groundwater resources and provide a sustainable supply for multiple beneficial uses.
3. DWR should continue to work with local agencies to more accurately define historical overdraft and to more accurately predict future water shortages that could result in overdraft.
4. Groundwater management agencies should work with land use agencies to inform them of the potential impacts various land use decisions may have on groundwater, and to identify, prioritize, and protect recharge areas.
5. DWR should publish a report by December 31, 2004 that identifies those groundwater basins or sub basins that are being managed by local or regional agencies and those that are not, and should identify how local agencies are using groundwater resources and protecting groundwater quality.
6. Water managers should include an evaluation of water quality in a groundwater management plan, recognizing that water quantity and water quality are inseparable.
7. Water transfers that involve groundwater (of surface water that will be replaced with groundwater) should be consistent with groundwater management in the source areas that will assure the long term sustainability of the groundwater resource.
8. Continue to support coordinated management of groundwater and surface water supplies and integrated management of groundwater quality and groundwater quantity.
9. Local, State, and federal agencies should improve data collection and analysis to better estimate groundwater basin conditions used in Statewide and local water supply reliability planning.
10. Increase coordination and sharing of groundwater data among local, State, and federal agencies and improve data dissemination to the public.

VIII.3 Recommendations to the Regional Water Board for Implementation

As a result of its analysis of the activities associated with impacts to DO, the regulatory programs currently in place, and the polices under development, staff have identified the following list of general actions as necessary to achieve ambient DO water quality objectives.

1. Update the DO limits contained in all NPDES permits and WDRs with the new DO objectives when the permits come up for renewal. Calculate DO limits for all new NPDES permits and WDRS based on the revised DO objectives. Ensure permit writers are familiar with the basis for the DO objective revisions.
2. Implement all approved nutrient and DO TMDLs as they are currently written. Following implementation and based on adaptive monitoring results, consider updating approved nutrient and DO TMDLs based on revised DO objectives, as appropriate. All DO and nutrient TMDLs under development and yet to be developed must be based on the revised DO objectives.
3. Continue implementing the "Plan for California's Nonpoint Source Pollution Control Program" with emphasis on management measures specific to agriculture; forestry; urban areas; marinas and recreational boating; hydromodification; and wetlands, riparian areas and vegetated treatment systems. Ensure staff in the Nonpoint Source Unit is familiar with the basis for the DO revisions.
4. Only provide 401 Certification to those projects demonstrating an ability to meet new ambient water quality objectives for DO. Ensure staff responsible for 401 certifications is familiar with the basis for the DO revisions.
5. Prioritize the identification and permitting (or removal) of currently unpermitted instream impoundments.
6. Support the finalization and adoption of the "Stream and Wetland System Protection Policy," including adoption of a narrative objective and implementation measures for the protection of the pattern and range of flows necessary to protect beneficial uses. If the Regional Water Board does not elect to adopt the policy as developed by staff in its entirety, staff recommends the Regional Water Board consider adoption of the narrative objective and implementation measures for flow.
7. Support the finalization and adoption of the "North Coast Instream Flow Policy," including protective measures regarding the season of diversion, minimum bypass flow, and maximum cumulative diversion. Continue to provide guidance to State Water Board staff on compliance with the Basin Plan, including protection from further impairment in 303(d) listed streams and enforcement of the policy for unpermitted water diverters. If the policy is not adopted by the State Water Board, staff recommends the issue be considered as a priority issue for the North Coast Board during the next Triennial Review process.
8. Prioritize the development of an agricultural policy including development of a general WDR and companion conditional waiver to address issues of chemical, organic matter, and nutrient loading; discharge of agricultural return flows; and stream channel, stream bank and riparian zone protections from activities such as water diversion, grazing, planting/harvesting, irrigation, and road building.

9. Support the finalization and adoption of the "Prohibition of Excess Sediment" at either the region wide or watershed scale, including measures to prevent and minimize new sources of sediment and inventory, prioritize, control, and monitor existing sources of excess sediment. The policy should be brought before the Regional Water Board for their consideration before the end of the 2007-2010 Triennial Review period.
10. Support the conduct of local research regarding the relationship between groundwater basins and surface water basins in the North Coast Region, including basin delineation, flow data, water quality data, and water use information. Review the existing groundwater management plans in Siskiyou, Modoc, Shasta, Glenn, Lake and Mendocino counties. Develop a strategy for protecting surface water quality from impairment due to the loss or alteration of cold groundwater inputs to North Coast rivers. Encourage Del Norte, Humboldt, Trinity, Sonoma and Marin counties to develop groundwater management plans.
11. Prioritize for grant funding projects that demonstrate management techniques in concert with those described in Section VIII.1.

In addition, staff have identified a series of specific management measures, as adapted from the Shasta River TMDL Implementation Plan and included in Table 4 that could be implemented by land managers and others.

Table 4: Implementation Measures for Land Managers and Others

Responsible Party	**Actions to Achieve Revised Ambient Dissolved Oxygen Water Quality Objectives**
	Range and Riparian Land Management
Parties conducting grazing activities	Landowners should employ land stewardship practices and activities that minimize, control, and preferably prevent discharges of fine sediment, nutrients, and other oxygen consuming materials to waters of the North Coast Region. Landowners should also employ land stewardship practices and activities that minimize, control, and preferably prevent elevated solar radiation loads from affecting waters of the North Coast rivers and their tributaries. Those that oversee and manage grazing and range land activities in the North Coast Region should implement the applicable management measures for agriculture and grazing from the following sources: • *Policy for the Implementation and Enforcement of the Nonpoint* Source *Pollution Control Program* (NPS Policy) (SWRCB 2004 or as amended). • Recovery *Strategy for California Coho Salmon* (Coho Recovery Strategy) (CDFG 2004)
Natural Resource Conservation Service (NRCS) and Resource Conservation Districts (RCDs)	Assist landowners and mangers in developing and implementing management practices that minimize, control and preferably prevent discharges of fine sediment, nutrients and other oxygen consuming materials, as well as elevated solar radiation loads from affecting waters of the North Coast Region. Assist landowners in developing and implementing a monitoring program to evaluate and document implementation and effectiveness of the range and riparian management actions taken by the landowner.
California Department of Fish and Game (CDFG)	Assist landowners in developing and implementing management practices that minimize, control, and preferably prevent discharges of fine sediment, nutrients and other oxygen consuming materials as well as elevated solar radiation loads from affecting waters of the North Coast. Administer the Coho Recovery Strategy.
North Coast Regional Water Quality Control Board (Regional Water Board)	Work cooperatively with the Natural Resources Conservation Service and Resource Conservation Districts to develop appropriate management plans, identify grant funding, and support public outreach efforts. The Regional Water Board shall address the removal and suppression of vegetation that provides shade to a water body through development of a Stream and Wetland System Protection Policy. This will be a comprehensive, region-wide riparian policy that will address the importance of shade on instream water temperatures and will potentially propose riparian setbacks and buffer widths. The Policy will likely propose new regulations and guidelines, and will therefore take the form of an amendment to the Basin Plan. Other actions under this section may be modified for consistency with this policy, once adopted. With funding already available through a grant from the U.S. EPA, Regional Water Board staff is scheduled to develop this Policy for Regional Water Board consideration by the end of the 2007-2010 Triennial Review period.. The Regional Water Board shall take appropriate permitting actions as necessary to address the removal and suppression of vegetation that provides

Responsible Party	**Actions to Achieve Revised Ambient Dissolved Oxygen Water Quality Objectives**
	shade to a water body in the North Coast Region. Such actions may include, but are not limited to, prohibitions, waste discharge requirements (WDRs) or waivers of WDRs for grazing and rangeland activities, farming activities near water bodies, stream bank stabilization activities, and other land uses that may remove and/or suppress vegetation that provides shade to a water body.
	Tailwater Return Flows
Irrigators	Those that oversee and manage tailwater discharges from irrigated lands in North Coast rivers and tributaries, which may include landowners, lessees, and land managers (collectively referred to as irrigators), should employ land stewardship and irrigation management practices and activities that minimize, control, and preferably prevent discharges of fine sediment, nutrients and other oxygen consuming materials, and elevated water temperatures from affecting waters of the North Coast Region. Irrigators should implement the applicable management measures for tailwater return flows from the following sources: • Policy *for the Implementation and Enforcement of the Nonpoint Source Pollution Control Program* (NPS Policy) (SWRCB 2004 or as amended). • *Recovery Strategy for California Coho Salmon* (Coho Recovery Strategy) (CDFG 2004). In addition, landowners may develop and implement management measures suitable for their site-specific conditions.
NRSC and RCDs	Assist irrigators in developing and implementing management practices that minimize, control and preferably prevent discharges of fine sediment, nutrients and other oxygen consuming materials, and elevated water temperatures from affecting waters of the North Coast Region.
CDFG	Assist irrigators in developing and implementing management practices that minimize, control, and preferably prevent discharges of fine sediment, nutrients and other oxygen consuming materials, and elevated water temperatures from affecting waters of the North Coast Region. Administer the Coho Recovery Strategy.
Regional Water Boards	Evaluate the effectiveness of tailwater management actions and develop recommendations for the most effective regulatory vehicle to bring tailwater discharges into compliance with water quality standards, the TMDLs, and the NPS Policy. Should efforts fail to be implemented or effective, the Regional Water Board's Executive Officer may require irrigators, on a site specific as-needed basis, to develop, submit, and implement, upon review, comment and approval by the Regional Water Board's Executive Officer, a tailwater management plan designed to prevent discharges of fine sediment, nutrients and other oxygen consuming materials, and elevated solar radiation loads from affecting waters of the Shasta River and its tributaries.
	Water Use and Flow
Water Diverters	Water diverters should employ water management practices and activities that

Responsible Party	**Actions to Achieve Revised Ambient Dissolved Oxygen Water Quality Objectives**
	result in increased **dedicated cold water instream flow** in the rivers and tributaries of the North Coast Region. Water diverters should participate in and implement applicable flow-related measures outlined in the following sources: • *Policy for the Implementation and Enforcement of the Nonpoint Source Pollution Control Program* (NPS Policy) (SWRCB 2004 or as amended). • Recovery *Strategy for California Coho Salmon* (Coho Recovery Strategy) (CDFG 2004). This recommended flow measure does not alter or reallocate water rights within the North Coast Region's waterbodies, nor does it bind the Regional Water Board in future TMDLs, the State Water Board's Division of Water Rights in any water rights decision, or state and federal courts.
NRSC and RCDs	Assist water diverters in developing and implementing management practices that increase dedicated cold water instream flows in the North Coast Region.
CDFG	Assist water diverters in developing and implementing management practices that increase dedicated cold water instream flows in the North Coast Region. Administer the Coho Recovery Strategy.
Regional Water Board	Work cooperatively with water diverters, RCDs, CDFG and DWR, wholly or in part, to establish monitoring and reporting programs to gauge implementation and effectiveness of the actions taken by responsible parties.
Irrigation Control Structures, Flashboard Dams, and other Minor Impoundments (Collectively referred to as minor impoundments)	
Individual Irrigators Irrigation Districts Department of Water Resources (DWR) Others owning, operating, managing, or anticipating construction of minor impound	Irrigation districts, individual irrigators, and others that own, operate, manage, or anticipate constructing instream minor impoundments or other structures capable of blocking, impounding, or otherwise impeding the free flow of water in the North Coast Region shall comply with one or more of the following measures: • Permanently remove minor impoundments • Re-engineer existing impoundments to decrease surface area of impoundment. • Not construct new impoundments unless they can be shown to have positive effects to the beneficial uses of Individual Irrigators
NRSC and RCDs	Assist in developing and implementing minor impoundment removal, re-engineering or initial design work for compliance with water quality standards, the TMDLs, and the NPS Policy.
CDFG	Assist in developing and implementing the removal, re-engineering, or limitation on the construction of minor impoundments in the North Coast Region. Administer the Coho Recovery Strategy.
Regional Water Boards	Work with CDFG to establish monitoring and reporting elements of their programs in order to gage their effectiveness. Include appropriate conditions in Clean Water Act water quality certification permits for minor impoundment removal or re-engineering activities that comply with water quality standards, the TMDL, and the NPS Policy.
Urban and Suburban Runoff	

Responsible Party	**Actions to Achieve Revised Ambient Dissolved Oxygen Water Quality Objectives**
Cities Other landowners with suburban runoff	Cities and other landowners with suburban runoff should implement the applicable measures from the NPS Policy.
RWQCB	Work cooperatively with responsible parties to implement their plan, including appropriate management measures and reasonable time schedules which minimize, control, and preferably prevent discharges of fine sediment, nutrients and other oxygen consuming materials and elevated temperature waste discharge from affecting waters of the North Coast Region.
Activities on Federal Lands	
USFS	The USFS shall consistently implement the best management practices for timber harvest activities, grazing, and other activities included in the: • *Water Quality Management for Forest System Lands in California, Best Management Practices* (USFS 2000) or as amended as long as equivalent or better water quality protections are required.
Regional Water Board	Continue its involvement with the USFS to periodically reassess the mutually agreed upon goals of the 1981 Management Agency Agreement between the SWRCB and the USFS. Work with the USFS to draft and finalize a regulatory program (WDR/conditional waiver).
BLM	BLM shall implement best management grazing strategies that are detailed in a joint management agency document titled: • Riparian Management, TR 1737-14, Grazing Management for Riparian-Wetland Areas, USDI-BLM, USDA-FS (1997).
Regional Water Board	The Regional Water Board will work with the BLM to draft and finalize a WDR/conditional waiver.
Timber Harvest Activities on Non-Federal Lands	
Private parties conducting timber harvest	Parties conducting timber harvest activities should employ land stewardship practices that minimize, control, and preferably prevent discharges of fine sediment, nutrients and other oxygen consuming materials from affecting waters of the North Coast Region. Landowners should also employ land stewardship practices and activities that prevent to the maximum extent possible, elevated solar radiation loads from affecting waters of the North Coast Region's rivers and their Class I[13] and Class II tributaries[14].
CDF	Ensure timber operations in the North Coast Region are in compliance with the water quality standards, the TMDLs, and NPS Policy.
Regional Water Boards	The Regional Water Board shall use appropriate permitting and enforcement tools to regulate discharges from timber harvest activities in the North Coast Region, including, but not limited to: Participation in the CDF timber harvest review and approval process.

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[13] A Class I stream is watercourse which contains domestic water supplies including springs on site and/or within 100 feet downstream of the operation area and/or have fish always or seasonally present onsite, including habitat to sustain fish migration and spawning. Class I streams include historically fish-bearing streams.

[14] A Class II stream is a watercourse which has fish always or seasonally present offsite within 1000 feet downstream; and/or contains aquatic habitat for non-fish aquatic species. Class II waters do not include Class III waters that are directly tributary to Class I waters.

Responsible Party	**Actions to Achieve Revised Ambient Dissolved Oxygen Water Quality Objectives**
	Use of general or specific WDRs and waivers of WDRs, if applicable, to regulate timber harvest activities on private lands in the North Coast Region. If the California Forest Practice Rules (Title 14 CCR Chapters 4, 4.5 and 10) are changed in a manner that reduces water quality protections, the Regional Water Board shall require plan submitters to maintain the level of water quality protection provided by the 2006 Forest Practice Rules.
California Department of Transportation Activities	
CalTrans	Caltrans shall implement the requirements of its stormwater program.
Regional Water Board	Complete an initial evaluation of the Caltrans Stormwater Program. Continue periodic reviews of the program to assure ongoing compliance.

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APPENDIX A

pH

The pH shall conform to those limits listed in Table 3-1. For waters not listed in Table 3-1 and where pH objectives are not prescribed, the pH shall not be depressed below 6.5 nor raised above 8.5. Changes in normal ambient pH levels shall not exceed 0.2 units in waters with designated marine (MAR) or saline (SAL) beneficial uses nor 0.5 units within the range specified above in fresh waters with designated COLD or WARM beneficial uses.

Dissolved Oxygen

Dissolved oxygen concentrations shall conform to those limits listed in Table 3-1. For waters not listed in Table 3-1 and where dissolved oxygen objectives are not prescribed the dissolved oxygen concentrations shall not be reduced below the following minimum levels at any time.

Waters designated WARM, MAR, or SAL	5.0 mg/l
Waters designated COLD	6.0 mg/l
Waters designated SPWN	7.0 mg/l
Waters designated SPWN during critical spawning and egg incubation periods	9.0 mg/l

Bacteria

The bacteriological quality of waters of the North Coast Region shall not be degraded beyond natural background levels. In no case shall coliform concentrations in waters of the North Coast Region exceed the following:

In waters designated for contact recreation (REC-1), the median fecal coliform concentration based on a minimum of not less than five samples for any 30-day period shall not exceed 50/100 ml, nor shall more than ten percent of total samples during any 30-day period exceed 400/100 ml (State Department of Health Services).

At all areas where shellfish may be harvested for human consumption (SHELL), the fecal coliform concentration throughout the water column shall not exceed 43/100 ml for a 5-tube decimal dilution test or 49/100 ml when a three-tube decimal dilution test is used (National Shellfish Sanitation Program, Manual of Operation).

Temperature

Temperature objectives for COLD interstate waters, WARM interstate waters, and Enclosed Bays and Estuaries are as specified in the "Water Quality Control Plan for Control of Temperature in the Coastal and Interstate Waters and Enclosed Bays of California" including any revisions thereto. A copy of this plan is included verbatim in the Appendix Section of this Plan. In addition, the following temperature objectives apply to surface waters:

The natural receiving water temperature of intrastate waters shall not be altered unless it can be demonstrated to the satisfaction of the Regional Water Board that such alteration in temperature does not adversely affect beneficial uses.

At no time or place shall the temperature of any COLD water be increased by more than 5°F above natural receiving water temperature.

At no time or place shall the temperature of WARM intrastate waters be increased more than 5°F above natural receiving water temperature.

Toxicity

All waters shall be maintained free of toxic substances in concentrations that are toxic to, or that produce detrimental physiological responses in human, plant, animal, or aquatic life. Compliance with this objective will be determined by use of indicator organisms, analyses of species diversity, population density, growth anomalies, bioassays of appropriate duration, or other appropriate methods as specified by the Regional Water Board.

The survival of aquatic life in surface waters subjected to a waste discharge, or other controllable water quality factors, shall not be less than that for the same water body in areas unaffected by the waste discharge, or when necessary for other control water that is consistent with the requirements for "experimental water" as described in "**Standard Methods for the Examination of Water and Wastewater**", 18th Edition (1992). As a minimum, compliance with this objective as stated in the previous sentence shall be evaluated with a 96-hour bioassay.

In addition, effluent limits based upon acute bioassays of effluents will be prescribed. Where appropriate, additional numerical receiving water objectives for specific toxicants will be established as sufficient data become available, and source control of toxic substances will be encouraged.

TABLE 3-1

SPECIFIC WATER QUALITY OBJECTIVES FOR NORTH COAST REGION

	Specific Conductance (micromhos) @ 77°F		Total Dissolved Solids (mg/l)		Dissolved Oxygen (mg/l)			Hydrogen Ion (pH)		Hardness (mg/l)	Boron (mg/l)	
Waterbody[1]	90% Upper Limit[3]	50% Upper Limit[2]	90% Upper Limit[3]	50% Upper Limit[2]	Min	90% Lower Limit[3]	50% Lower Limit[2]	Max	Min	50% Upper Limit[2]	90% Upper Limit[3]	50% Upper Limit[2]
Lost River HA												
Clear Lake Reservoir & Upper Lost River	300	200			5.0		8.0	9.0	7.0	60	0.5	0.1
Lower Lost River	1000	700			5.0		-	9.0	7.0	-	0.5	0.1
Other Streams	250	150			7.0		8.0	8.4	7.0	50	0.2	0.1
Tule Lake	1300	900			5.0		-	9.0	7.0	400	-	-
Lower Klamath Lake	1150	850			5.0		-	9.0	7.0	400	-	-
Groundwaters [4]	1100	500			-		-	8.5	7.0	250	0.3	0.2
Butte Valley HA												
Streams	150	100			7.0		9.0	8.5	7.0	30	0.1	0.0
Meiss Lake	2000	1300			7.0		8.0	9.0	7.5	100	0.3	0.1
Groundwaters [4]	800	400			-		-	8.5	6.5	120	0.2	0.1
Shasta Valley HA												
Shasta River	800	600			7.0		9.0	8.5	7.0	220	1.0	0.5
Other Streams	700	400			7.0		9.0	8.5	7.0	200	0.5	0.1
Lake Shastina	300	250			6.0		9.0	8.5	7.0	120	0.4	0.2
Groundwaters [4]	800	500			-		-	8.5	7.0	180	1.0	0.3
Scott River HA												
Scott River	350	250			7.0		9.0	8.5	7.0	100	0.4	0.1
Other Streams	400	275			7.0		9.0	8.5	7.0	120	0.2	0.1
Groundwaters [4]	500	250			-		-	8.0	7.0	120	0.1	0.1
Salmon River HA												
All Streams	150	125			9.0		10.0	8.5	7.0	60	0.1	0.0
Middle Klamath River HA												
Klamath River above Iron Gate Dam including Iron Gate & Copco Reservoirs	425	275			7.0		10.0	8.5	7.0	60	0.3	0.2
Klamath River below Iron Gate Dam	350	275			8.0		10.0	8.5	7.0	80	0.5	0.2
Other Streams	300	150			7.0		9.0	8.5	7.0	60	0.1	0.0
Groundwaters [4]	750	600			-		-	8.5	7.5	200	0.3	0.1
Applegate River HA												
All Streams	250	175			7.0		9.0	8.5	7.0	60	-	-
Upper Trinity River HA												
Trinity River [5]	200	175			7.0		10.0	8.5	7.0	80	0.1	0.0
Other Streams	200	150			7.0		10.0	8.5	7.0	60	0.0	0.0
Clair Engle Lake and Lewiston Reservoir	200	150			7.0		10.0	8.5	7.0	60	0.0	0.0

TABLE 3-1 (CONTINUED)

SPECIFIC WATER QUALITY OBJECTIVES FOR NORTH COAST REGION

	Specific Conductance (micromhos) @ 77°F		Total Dissolved Solids (mg/l)		Dissolved Oxygen (mg/l)			Hydrogen Ion (pH)		Hardness (mg/l)	Boron (mg/l)	
Waterbody[1]	90% Upper Limit[3]	50% Upper Limit[2]	90% Upper Limit[3]	50% Upper Limit[2]	Min	90% Lower Limit[3]	50% Lower Limit[2]	Max	Min	50% Upper Limit[2]	90% Upper Limit[3]	50% Upper Limit[2]
Hayfork Creek												
Hayfork Creek	400	275			7.0		9.0	8.5	7.0	150	0.2	0.1
Other Streams	300	250			7.0		9.0	8.5	7.0	125	0.0	0.0
Ewing Reservoir	250	200			7.0		9.0	8.0	6.5	150	0.1	0.0
Groundwaters [4]	350	225			-		-	8.5	7.0	100	0.2	0.1
S.F. Trinity River HA												
S.F. Trinity River	275	200			7.0		10.0	8.5	7.0	100	0.2	0.0
Other Streams	250	175			7.0		9.0	8.5	7.0	100	0.0	0.0
Lower Trinity River HA												
Trinity River	275	200			8.0		10.0	8.5	7.0	100	0.2	0.0
Other Streams	250	200			9.0		10.0	8.5	7.0	100	0.1	0.0
Groundwaters [4]	200	150			-		-	8.5	7.0	75	0.1	0.1
Lower Klamath River HA												
Klamath River	300[6]	200[6]			8.0		10.0	8.5	7.0	75[6]	0.5[6]	0.2[6]
Other Streams	200[6]	125[6]			8.0		10.0	8.5	6.5	25[6]	0.1[6]	0.0[6]
Groundwaters [4]	300	225			-		-	8.5	6.5	100	0.1	0.0
Illinois River HA												
All Streams	200	125			8.0		10.0	8.5	7.0	75	0.1	0.0
Winchuck River HU												
All Streams	200[6]	125[6]			8.0		10.0	8.5	7.0	50[6]	0.0[6]	0.0[6]
Smith River HU												
Smith River-Main Forks	200	125			8.0		11.0	8.5	7.0	60	0.1	0.1
Other Streams	150[6]	125[6]			7.0		10.0	8.5	7.0	60[6]	0.1[6]	0.0[6]
Smith River Plain HSA												
Smith River	200[6]	150[6]			8.0		11.0	8.5	7.0	60[6]	0.1[6]	0.0[6]
Other Streams	150[6]	125[6]			7.0		10.0	8.5	6.5	60[6]	0.1[6]	0.0[6]
Lakes Earl & Talawa	-	-			7.0		9.0	8.5	6.5	-	-	-
Groundwaters [4]	350	100			-		-	8.5	6.5	75	1.0	0.0
Crescent City Harbor	-	-										
Redwood Creek HU												
Redwood Creek	220[6]	125[6]	115[6]	75[6]	7.0	7.5	10.0	8.5	6.5			
Mad River HU												
Mad River	300[6]	150[6]	160[6]	90[6]	7.0	7.5	10.0	8.5	6.5			
Eureka Plain HU												
Humboldt Bay	-	-	-	-	6.0	6.2	7.0	8.5	7			
Eel River HU												
Eel River	375[6]	225[6]	275[6]	140[6]	7.0	7.5	10.0	8.5	6.5			
Van Duzen River	375	175	200	100	7.0	7.5	10.0	8.5	6.5			

TABLE 3-1 (CONTINUED)

SPECIFIC WATER QUALITY OBJECTIVES FOR NORTH COAST REGION

	Specific Conductance (micromhos) @ 77°F		Total Dissolved Solids (mg/l)		Dissolved Oxygen (mg/l)			Hydrogen Ion (pH)		Hardness (mg/l)	Boron (mg/l)	
Waterbody[1]	90% Upper Limit[3]	50% Upper Limit[2]	90% Upper Limit[3]	50% Upper Limit[2]	Min	90% Lower Limit[3]	50% Lower Limit[2]	Max	Min	50% Upper Limit[2]	90% Upper Limit[3]	50% Upper Limit[2]
South Fork Eel River	350	200	200	120	7.0	7.5	0.0	8.5	6.5			
Middle Fork Eel River	450	200	230	130	7.0	7.5	10.0	8.5	6.5			
Outlet Creek	400	200	230	125	7.0	7.5	10.0	8.5	6.5			
Cape Mendocino HU												
Bear River	390[6]	255[6]	240[6]	150[6]	7.0	7.5	10.0	8.5	6.5			
Mattole River	300[6]	170[6]	170[6]	105[6]	7.0	7.5	10.0	8.5	6.5			
Mendocino Coast HU												
Ten Mile River	-	-	-	-	7.0	7.5	10.0	8.5	6.5			
Noyo River	185[6]	150[6]	120[6]	105[6]	7.0	7.5	10.0	8.5	6.5			
Jug Handle Creek	-	-	-	-	7.0	7.5	10.0	8.5	6.5			
Big River	300[6]	195[6]	190[6]	130[6]	7.0	7.5	10.0	8.5	6.5			
Albion River	-	-	-	-	7.0	7.5	10.0	8.5	6.5			
Navarro River	285[6]	250[6]	170[6]	150[6]	7.0	7.5	10.0	8.5	6.5			
Garcia River	-	-	-	-	7.0	7.5	10.0	8.5	6.5			
Gualala River	-	-	-	-	7.0	7.5	10.0	8.5	6.5			
Russian River HU												
(upstream)[8]	320	250	170	150	7.0	7.5	10.0	8.5	6.5			
(downstream)[9]	375[6]	285[6]	200[6]	170[6]	7.0	7.5	10.0	8.5	6.5			
Laguna de Santa Rosa	-	-	-	-	7.0	7.5	10.0	8.5	6.5			
Bodega Bay	-	-	-	-	6.0	6.2	7.0	8.5	7			
Coastal Waters[10]	-	-	-	-	11	11	11	12	12			

[1] Water bodies are grouped by hydrologic unit (HU), hydrologic area (HA), or hydrologic subarea (HSA).

[2] 50% upper and lower limits represent the 50 percentile values of the monthly means for a calendar year. 50% or more of the monthly means must be less than or equal to an upper limit and greater than or equal to a lower limit.

[3] 90% upper and lower limits represent the 90 percentile values for a calendar year. 90% or more of the values must be less than or equal to an upper limit and greater than or equal to a lower limit.

[4] Value may vary depending on the aquifer being sampled. This value is the result of sampling over time, and as pumped, from more than one aquifer.

[5]

Daily Average Not to Exceed	Period	River Reach
60°F	July 1 - Sept. 14	Lewiston Dam to Douglas City Bridge
56°F	Sept. 15 - Oct. 1	Lewiston Dam to Douglas City Bridge
56°F	Oct. 1 - Dec. 31	Lewiston Dam to confluence of North Fork Trinity River

[6] Does not apply to estuarine areas.

[7] pH shall not be depressed below natural background levels.

[8] Russian River (upstream) refers to the mainstem river upstream of its confluence with Laguna de Santa Rosa.

[9] Russian River (downstream) refers to the mainstem river downstream of its confluence with Laguna de Santa Rosa.

[10] The State's Ocean Plan applies to all North Coast Region coastal waters.

[11] Dissolved oxygen concentrations shall not at any time be depressed more than 10 percent from that which occurs naturally.

[12] pH shall not be changed at any time more than 0.2 units from that which occurs naturally.

\- no water body specific objective available.

APPENDIX B

TABLE 2-1: BENEFICIAL USES OF WATERS OF THE NORTH COAST REGION

HU/HA/ HSA	HYDROLOGIC UNIT/AREA/ SUBUNIT/DRAINAGE FEATURE	BENEFICIAL USES																										
		MUN	AGR	IND	PRO	GWR	FRSH	NAV	POW	REC1	REC2	COMM	WARM	COLD	ASBS	SAL	WILD	RARE	MAR	MIGR	SPWN	SHELL	EST	AQUA	CUL	FLD	WET	WQE
101.00	**Winchuck River Hydrologic Unit**																											
	Winchuck River	E	E	E	P		E	E	P	E	E	E		E			E	E		E	E			P				
102.00	**Rogue River Hydrologic Unit**																											
102.20	Ilinois River Hydrologic Area	E	E	E	P		E	E	E	E	E	E		E			E	E		E	E			E				
102.30	Applegate River Hydrologic Area	E	E	E	E		E	E	P	E	E	E		E			E	E		E	E			P				
103.00	**Smith River Hydrologic Unit**																											
103.10	Lower Smith River Hydrologic Area																											
103.11	Smith River Plain Hydrologic Subarea	E	E	E	P		E	E		E	E	E		E			E	E	E	E	E		E	P	E			
	Lake Talawa	P					E	E		E	E	E	E	E			E	E		E				P	E			
	Lake Earl	E	E	E			E	E		E	E	E	E	E			E	E		E				P	E			
	Crescent City Harbor						E	E		E	E	E	P	E			E	E	E	E		E		E				
103.12	Rowdy Creek Hydrologic Subarea	E	E	E	P		E	E	P	E	E	E		E			E	E		E	E			P				
103.13	Mill Creek Hydrologic Subarea	E	E	E	P		E	E	P	E	E	E		E			E	E		E	E			P				
103.20	South Fork Smith River Hydrologic Area	E	E	E	P		E	E	E	E	E	E		E			E	E		E	E			P	E			
103.30	Middle Fork Smith River Hydrologic Area	E	E	E	P		E	E	E	E	E	E		E			E	E		E	E			E	P			
103.40	North Fork Smith River Hydrologic Area	E	E	E	P		E	E	E	E	E	E		E			E	E		E	E			P				
103.50	Wilson Creek Hydrologic Area	E	E	E	P		E	E	E	E	E	E		E			E	E		E	E			P	E			
105.00	**Klamath River Hydrologic Unit**																											
105.10	Lower Klamath River Hydrologic Area																											
105.11	Klamath Glen Hydrologic Subarea	E	E	P	P	E	E	E	P	E	E	E	E	E			E	E	E	E	E	E	E	P	E			
105.12	Orleans Hydrologic Subarea	E	E	E	P	E	E	E	P	E	E	E	E	E			E	E		E	E	P		P	E			
105.20	Salmon River Hydrologic Area																											
105.21	Lower Salmon Hydrologic Subarea	E	E	E	P		E	E	P	E	E	E		E			E	E		E	E	P		P	E			
105.22	Wooley Creek Hydrologic Subarea	E	P	E	P	E	E	E	P	E	E	E		E			E	E		E	E	P		P	E			
105.23	Sawyers Bar Hydrologic Subarea	E	E	E	P		E	E	P	E	E	E		E			E	E		E	E	P		P				
105.24	Cecilville Hydrologic Subarea	E	E	E	P		E	E	P	E	E	E		E			E	E		E	E	P		P				

TABLE 2-1: BENEFICIAL USES OF WATERS OF THE NORTH COAST REGION

HU/HA/ HSA	HYDROLOGIC UNIT/AREA/ SUBUNIT/DRAINAGE FEATURE	BENEFICIAL USES																										
		MUN	AGR	IND	PRO	GWR	FRSH	NAV	POW	REC1	REC2	COMM	WARM	COLD	ASBS	SAL	WILD	RARE	MAR	MIGR	SPWN	SHELL	EST	AQUA	CUL	FLD	WET	WQE
105.30	Middle Klamath River Hydrologic Area																											
105.31	Ukonom Hydrologic Subarea	E	E	E	E	E	E	E	P	E	E	E	E	E			E	E		E	E			P	E			
105.32	Happy Camp Hydrologic Subarea	E	E	E	E	E	E	E	P	E	E	E	E	E			E	E		E	E			P	E			
105.33	Seiad Valley Hydrologic Subarea	E	E	E	E	E	E	E	P	E	E	E	E	E			E	E		E	E			P	E			
105.35	Beaver Creek Hydrologic Subarea	E	E	E	E	E	E	E	P	E	E	E	E	E			E	E		E	E			P				
105.36	Hornbrook Hydrologic Subarea	E	E	E	E	E	E	E	P	E	E	E	E	E			E	E		E	E			P				
105.37	Iron Gate Hydrologic Subarea	P	P	P	P		E	E	E	E	E	E	E	E			E	E		E	E	E		E				
105.38	Copco Lake Hydrologic Subarea	E	E	E	P		E	E	E	E	E	E	E	E			E	E		E	E			E				
105.40	Scott River Hydrologic Area																											
105.41	Scott Bar Hydrologic Subarea	E	E	E	P	E	E	E	E	E	E	E		E			E	E		E	E			P				
105.42	Scott Valley Hydrologic Subarea	E	E	E	P	E	E	E	E	E	E	E		E			E	E		E	E			E				
105.50	Shasta Valley Hydrologic Area																											
	Shasta River & Tributaries	E	E	E	P	E	E	E	P	E	E	E	E	E			E	E		E	E			E				
	Lake Shastina	P	E	P	P	E	E	E		E	E		E	E			E			P				P				
	Lake Shastina Tributaries	E	E	E	P	E	E	P	P	E	E	E	E	E			E			E	E			P				
105.80	Butte Valley Hydrologic Area																											
105.81	Macdoel-Dorris Hydrologic Subarea	E	E	P	P				E	E	E	E	E	E			E	E		E	E			P				
	Meiss Lake	E	E	P	P	E				P	E		E	E			E							P				
105.82	Bray Hydrologic Subarea	E	E						P	E	E	E	E				E	E		E	E			P				
105.83	Tennant Hydrologic Subarea	E	E	P	P	E	E		P	E	E	P	P	E			E	P		E	E			P				

TABLE 2-1: BENEFICIAL USES OF WATERS OF THE NORTH COAST REGION

HU/HA/ HSA	HYDROLOGIC UNIT/AREA/ SUBUNIT/DRAINAGE FEATURE	BENEFICIAL USES																										
		MUN	AGR	IND	PRO	GWR	FRSH	NAV	POW	REC1	REC2	COMM	WARM	COLD	ASBS	SAL	WILD	RARE	MAR	MIGR	SPWN	SHELL	EST	AQUA	CUL	FLD	WET	WQE
105.90	Lost River Hydrologic Area																											
105.91	Mount Dome Hydrologic Subarea	P	E	P	P	E	E		P	P	E	P	E	E			E	E		E	E			P				
105.92	Tule Lake Hydrologic Subarea	P	E	P	P	E	E			P	E	E	E	P			E	E		E	E			P				
105.93	Clear Lake Hydrologic Subarea	P	E	P	P	E	E	P	P	E	E	E	E	E			E	E		E	E	P		P				
105.94	Boles Hydrologic Subarea	P	E	P	P	E	E		P	P	E	E	E	E			E	E		E	E	P		P				
	Trinity River Hydrologic Unit																											
106.10	Lower Trinity River Hydrologic Area																											
106.11	Hoopa Hydrologic Subarea	E	E	E	P	E	E	E	P	E	E	E		E			E	E		E	E	P		P	E			
106.12	Willow Creek Hydrologic Subarea	E	E	E	P	E	E	E	E	E	E	E		E			E	E		E	E	P		P				
106.13	Burnt Ranch Hydrologic Subarea	E	E	E	P	E	E	E	P	E	E	E		E			E	E		E	E	P		E				
106.14	New River Hydrologic Subarea	E	E	E	P	E	E	E	P	E	E	E		E			E	E		E	E	P		P				
106.15	Helena Hydrologic Subarea	E	E	E	P	E	E	E	P	E	E	E		E			E	E		E	E	P		P				
106.20	South Fork Trinity River Hydrologic Area																											
106.21	Grouse Creek Hydrologic Subarea	E	E	E	P	E	E	E	P	E	E	E		E			E	E		E	E			P				
106.22	Hyampom Hydrologic Subarea	E	E	E	P	E	E	P	E	E	E	E		E			E	E		E	E			P				
106.23	Forest Glen Hydrologic Subarea	E	E	E	P	E	E	P	P	E	E	E		E			E	E		E	E			P				
106.24	Corral Creek Hydrologic Subarea	E	E	E	P	E	E	E	P	E	E	E		E			E	E		E	E			P				
106.25	Hayfork Valley Hydrologic Subarea	E	E	E	E	E	E		P	E	E	E		E			E	E		E	E			P				
	Ewing Reservoir	E		P	P			E		P	E	E	E	E			E	E						P				
106.30	**Middle Trinity Hydrologic Area**																											
106.31	Douglas City Hydrologic Subarea	E	E	E	P	E	E	E	P	E	E	E		E			E	E		E	E			P				
106.32	Weaver Creek Hydrologic Subarea	E	E	E	P	E	E	E	P	E	E	E		E			E	E		E	E			E				

TABLE 2-1: BENEFICIAL USES OF WATERS OF THE NORTH COAST REGION

HU/HA/ HSA	HYDROLOGIC UNIT/AREA/ SUBUNIT/DRAINAGE FEATURE	BENEFICIAL USES																										
		MUN	AGR	IND	PRO	GWR	FRSH	NAV	POW	REC1	REC2	COMM	WARM	COLD	ASBS	SAL	WILD	RARE	MAR	MIGR	SPWN	SHELL	EST	AQUA	CUL	FLD	WET	WQE
106.40	Upper Trinity River Hydrologic Area																											
	Trinity Lake (formerly Clair Engle Lake)	E	E	E	E	E	E	E	E	E	E	E	E	E			E	E		P	E			P				
	Lewiston Reservoir	E	E	P	P	E	E	E	E	E	E	E	P	E			E	E		P	E			E				
	Trinity River	E	E	P	P	E	E	E	P	E	E	E		E			E	E		E	E			E				
107.00	**Redwood Creek Hydrologic Unit**																											
107.10	Orick Hydrologic Area	E	E	E	P	E		E	P	E	E	E		E			E	E	E	E	E		E	P	E			
107.20	Beaver Hydrologic Area	E	E	E	P	E		E	P	E	E	E		E			E	E		E	E			P				
107.30	Lake Prairie Hydrologic Area	E	E	E	P	E		E	P	E	E	E		E			E	E		E	E			P				
108.00	**Trinidad Hydrologic Unit**																											
108.10	Big Lagoon Hydrologic Area	E	E	E	P	E	E	E		E	E	E		E	E		E	E	E	E	E		E	P	E			
108.20	Little River Hydrologic Area	P	E	E	P	E	E	E		P	E	E		E			E	E	E	E	E		E	P	E			
109.00	**Mad River Hydrologic Unit**																											
109.10	Blue Lake Hydrologic Area	E	E	E	E	E	E	E	P	E	E	E		E			E	E	P	E	E		E	E	E			
109.20	North Fork Mad River Hydrologic Area	E	E	E	E	E	E	E	P	E	E	E		E			E	E		E	E			P				
109.30	Butler Valley Hydrologic Area	E	E	E	E	E	E	E	P	E	E	E		E			E	E		E	E			P	E			
109.40	Ruth Hydrologic Area	E	E	E	E	E	E	E	E	E	E	E	E	E			E	E		E	E			P				
110.00	**Eureka Plain Hydrologic Unit**																											
	Jacoby Creek	E	E	E	P	E	E	E	P	E	E	E		E			E	E		E	E		E*	P	E			
	Freshwater Creek	E	E	E	P	E	E	E	P	E	E	E		E			E	E		E	E		E*	E	E			
	Elk River	E	E	E	P	E	E	E	P	E	E	E		E			E	E		E	E		E*	P				
	Salmon Creek	E	E	E	P	E	E	E	P	E	E	E		E			E	E		E	E		E*	P	E			
	Humboldt Bay	E	E	E	P		E	E	P	E	E	E		E			E	E	E	E	E	E	E*	E	E			

TABLE 2-1: BENEFICIAL USES OF WATERS OF THE NORTH COAST REGION

HU/HA/ HSA	HYDROLOGIC UNIT/AREA/ SUBUNIT/DRAINAGE FEATURE	BENEFICIAL USES																										
		MUN	AGR	IND	PRO	GWR	FRSH	NAV	POW	REC1	REC2	COMM	WARM	COLD	ASBS	SAL	WILD	RARE	MAR	MIGR	SPWN	SHELL	EST	AQUA	CUL	FLD	WET	WQE
111.00	**Eel River Hydrologic Unit**																											
111.10	Lower Eel River Hydrologic Area																											
111.11	Ferndale Hydrologic Subarea	E	E	E	P	E	E	E	P	E	E	E		E			E	E	P	E	E	E	E	P	E			
111.12	Scotia Hydrologic Subarea	E	E	E	P	E	E	E	P	E	E	E		E			E	E		E	E			P				
111.13	Larabee Creek Hydrologic Subarea	E	E	E	P	E	E	E	P	E	E	E		E			E	E		E	E			P				
111.20	Van Duzen River Hydrologic Area																											
111.21	Hydesville Hydrologic Subarea	E	E	E	P	E	E	E	P	E	E	E	E	E			E	E		E	E			P	E			
111.22	Bridgeville Hydrologic Subarea	E	E	E	P	E	E	E	E	E	E	E	E	E			E	E		E	E			P				
111.23	Yager Creek Hydrologic Subarea	E	E	E	P	E	E		P	E	E	E	E	E			E	E		E	E			E	E			
111.30	South Fork Eel River Hydrologic Area																											
111.31	Weott Hydrologic Subarea	E	E	E	P	E	E	E	P	E	E	E	E	E			E	E		E	E			P				
111.32	Benbow Hydrologic Subarea	E	E	E	P	E	E	E	P	E	E	E	E	E			E	E		E	E			P				
111.33	Laytonville Hydrologic Subarea	E	E	E	P	E	E	E	P	E	E	E	E	E			E	E		E	E			P				
111.40	Middle Fork Eel River Hydrologic Area																											
111.41	Sequoia Hydrologic Subarea	E	E	E	P	E	E	E	E	E	E	E	E	E			E	E		E	E			P				
111.42	Spy Rock Hydrologic Subarea	E	E	E	P	E	E	E	E	E	E	E	E	E			E	E		E	E			P				
111.50	North Fork Eel River Hydrologic Area	E	E	E	P	E	E	E	E	E	E	E	E	E			E	E		E	E			P				
111.60	Upper Main Eel River Hydrologic Area																											
111.61	Outlet Creek Hydrologic Subarea	E	E	E	P	E		E	P	E	E	E	E	E			E	E		E	E			E				
111.62	Tomki Creek Hydrologic Subarea	E	E	E	P	E	E	E	P	E	E	E	E	E			E	E		E	E			E				
111.63	Lake Pillsbury Hydrologic Subarea	E	E	E	P	E	E	E	E	E	E	E	E	E			E	E		E	E			E				

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HU/HA/ HSA	HYDROLOGIC UNIT/AREA/ SUBUNIT/DRAINAGE FEATURE	BENEFICIAL USES																										
		MUN	AGR	IND	PRO	GWR	FRSH	NAV	POW	REC1	REC2	COMM	WARM	COLD	ASBS	SAL	WILD	RARE	MAR	MIGR	SPWN	SHELL	EST	AQUA	CUL	FLD	WET	WQE
111.70	Middle Fork Eel River Hydrologic Area																											
111.71	Eden Valley Hydrologic Subarea	E	E	E	P		E	E	P	E	E	E	E	E			E	E		E	E			E				
111.72	Round Valley Hydrologic Subarea	E	E	E	P	E	E	E	P	E	E	E	P	E			E	E		E	E			E				
111.73	Black Butte River Hydrologic Subarea	E	E	E	P		E	E	E	E	E	E	E	E			E	E		E	E			P				
111.74	Wilderness Hydrologic Subarea	E	E	E	P		E	E	E	E	E	E	E	E			E	E		E	E			P				
112.00	**Cape Mendocino Hydrologic Unit**																											
112.10	Oil Creek Hydrologic Area	P	E	E	P		E		P	E	E	E		E			E	E		E	E		E	E	E			
112.20	Capetown Hydrologic Area	E	E	E	P	E	E	E	P	E	E	E		E			E	E		E	E			P	E			
112.30	Mattole River Hydrologic Area	E	E	E	P	E	E	E	P	E	E	E	P	E			E	E		E	E		E	E				
113.00	**Mendocino Coast Hydrologic Unit**																											
113.10	Rockport Hydrologic Area	E	E	E	P	E	E	E	P	E	E	E		E			E	E		E	E		E	P				
113.11	Usal Creek Hydrologic Subarea	E	P	P	P	E	E	E	P	E	E	E		E			E	E		E	E							
113.12	Wages Creek Hydrologic Subarea	E	E	E	P	E	E	E	P	E	E	E		E			E	E		E	E							
113.13	Ten Mile River Hydrologic Subarea	E	E	E	P	E	E	E	P	E	E	E		E			E	E		E	E		E	P				
113.20	Noyo River Hydrologic Area	E	E	E	P	E	E	E	E	E	E	E		E			E	E		E	E		E	E				
113.30	Big River Hydrologic Area	E	E	E	P	E	E	E	P	E	E	E		E			E	E		E	E		E	P				
113.40	Albion River Hydrologic Area	E	E	E	P	E	E	E	P	E	E	E		E			E	E		E	E		E	P				
113.50	Navarro River Hydrologic Area	E	E	E	P	E	E	E	P	E	E	E		E			E	E		E	E		E	P				
113.60	Pt Arena Hydrologic Area																											
113.61	Greenwood Creek Hydrologic Subarea	E	E	E	P	E	E	E	P	E	E	E		E			E	E		E	E		E	P				
113.62	Elk Creek Hydrologic Subarea	P	P	E	P	E	E	E	P	E	E	E		E			E	E		E	E		E	P				
113.63	Alder Creek Hydrologic Subarea	E	E	E	P	E	E	E	P	E	E	E		E			E	E		E	E		E	P				
113.64	Brush Creek Hydrologic Subarea	E	E	E	P	E	E	E	P	E	E	E		E			E	E		E	E		E	P				

TABLE 2-1: BENEFICIAL USES OF WATERS OF THE NORTH COAST REGION

HU/HA/ HSA	HYDROLOGIC UNIT/AREA/ SUBUNIT/DRAINAGE FEATURE	BENEFICIAL USES																										
		MUN	AGR	IND	PRO	GWR	FRSH	NAV	POW	REC1	REC2	COMM	WARM	COLD	ASBS	SAL	WILD	RARE	MAR	MIGR	SPWN	SHELL	EST	AQUA	CUL	FLD	WET	WQE
113.70	Garcia River Hydrologic Area	E	E	E	P		E	E	P	E	E	E		E			E	E		E	E		E	P				
113.80	Gualala River Hydrologic Area																											
113.81	North Fork Gualala Hydrologic Subarea	E	E	E	P	E	E	E	P	E	E	E		E			E	E		E	E			E				
113.82	Rockpile Creek Hydrologic Subarea	E	E	E	P	E		E	P	E	E	E	E	E			E	E		E	E		E	P				
113.83	Buckeye Creek Hydrologic Subarea	E	E	E	P	E		E	P	E	E	E	E	E			E	E		E	E			P				
113.84	Wheatfield Fork Hydrologic Subarea	E	E	E	P	E		E	P	E	E	E	E	E			E	E		E	E			P				
113.85	Gualala Hydrologic Subarea	E	E	E	P	E	E	E	P	E	E	E	E	E			E	E		E	E			P				
113.90	Russian Gulch Hydrologic Area	E	E	E	P	E				E	E	P		E		E	E			E	E			E				
114.00	**Russian River Hydrologic Unit**																											
114.10	Lower Russian River Hydrologic Area																											
114.11	Guerneville Hydrologic Subarea	E	E	E	P	E	E	E	P	E	E	E	E	E			E	E		E	E	P	E	P				
114.12	Austin Creek Hydrologic Subarea	E	E	E	P	E		E	P	E	E	E	E	E			E	E		E	E			P				
114.20	Middle Russian River Hydrologic Area																											
114.21	Laguna Hydrologic Subarea	P	E	E	P	E	E	E	E	E	E	E	E	E			E	E		E	E	P		P				
114.22	Santa Rosa Hydrologic Subarea	E	E	E	P	E		E	P	E	E	E	E	E			E	E		E	E	P		P				
114.23	Mark West Hydrologic Subarea	E	E	E	P	E	E	E	P	E	E	E	E	E			E	E		E	E	P		P				
114.24	Warm Springs Hydrologic Subarea	E	E	E	P	E	E	E	E	E	E	E	E	E			E	E		E	E			E				
114.25	Geyserville Hydrologic Subarea	E	E	E	P	E	E	E	P	E	E	E	E	E			E	E		E	E	P		P				
114.26	Sulphur Creek Hydrologic Subarea	E	E	E	P	E		E	P	E	E	E	E	E			E	E		E	E			P				

TABLE 2-1: BENEFICIAL USES OF WATERS OF THE NORTH COAST REGION

HU/HA/ HSA	HYDROLOGIC UNIT/AREA/ SUBUNIT/DRAINAGE FEATURE	BENEFICIAL USES																										
		MUN	AGR	IND	PRO	GWR	FRSH	NAV	POW	REC1	REC2	COMM	WARM	COLD	ASBS	SAL	WILD	RARE	MAR	MIGR	SPWN	SHELL	EST	AQUA	CUL	FLD	WET	WQE
114.30	Upper Russian River Hydrologic Area																											
114.31	Ukiah Hydrologic Subarea	E	E	E	P	E	E	E	E	E	E	E	E	E			E	E		E	E	P		P				
114.32	Coyote Valley Hydrologic Subarea	E	E	E	P	E	E	E	E	E	E	E	E	E			E	E		E	E			P				
114.33	Forsythe Creek Hydrologic Subarea	E	E	E	P	E		E	P	E	E	E	E	E			E	E		E	E			P				
115.00	**Bodega Hydrologic Unit**																											
115.10	Salmon Creek Hydrologic Area	E	E	E	P	E		E		E	E	E		E			E	E		E	E	P	E	P				
115.20	Bodega Harbor (or Bay) Hydrologic Area	E	E	E	P	E		E		E	E	E		E			E	E	E	E	E	E		E				
115.30	Estero Americano Hydrologic Area	E	E	E	P	E		E		E	E	E		E			E	E	E	E	E	P	E	P				
115.40	Estero de San Antonio Hydrologic Area	E	E	E	P	E		E		E	E	E		E			E	E	E	E	E	P	E	P				
	Minor Coastal Streams (not listed above**)	E	P	P	P	P	P	P		P	P	E	P	P			E	E	P	P	P		E	P	P			
	Ocean Waters			P	P			E		E	E	E			P		E	E	E	E	E	E		E				
	Bays			P	P			E		P	E	E	P	E			E	P	E	E	E	E	P	P	P			
	Saline Wetlands			P		P	P	P		P	P	P	P	P		P	P	P	P	P	P	P	P	P	P	P	E	P
	Freshwater Wetlands	P	P	P		P	P	P		P	P	P	P	P			P	P		P	P	P	P	P	P	P	E	P
	Estuaries	P	P	P	P		P	E	P	E	E	P	P	E			E	P	E	E	E	E	E	P	P			
	Groundwater	E	E	E	P																			P	E			

Waterbodies are grouped by hydrologic unit (HU) or hydrologic area (HA).

*EST use applies only to the estuarine portion of the waterbody as defined in Chapter 2. **Permanent and intermittent P = Potential E = Existing

APPENDIX C

CHAPTER 4. DISSOLVED OXYGEN SOURCE AND LINKAGE ANALYSIS

4.1 Introduction

This chapter identifies the processes that affect dissolved oxygen concentrations of the Shasta River and its tributaries and establishes a linkage between these processes and measured dissolved oxygen concentrations. First, the various processes that can affect dissolved oxygen concentrations in a surface waterbody are reviewed. Secondly, the chapter identifies the anthropogenic sources (or factors) that are affecting these processes and controlling dissolved oxygen concentrations in the Shasta River and its tributaries. The contributions from these sources are then quantified in Chapter 7.

4.1.1 Processes Affecting Dissolved Oxygen in Surface Waters

Dissolved oxygen levels in surface waters are controlled by a number of interacting processes (Figure 4.1), including:

- Photosynthesis;
- Respiration;
- Carbonaceous deoxygenation within the water column ;
- Nitrogenous deoxygenation ;
- Nitrification;
- Reaeration;
- Sediment oxygen demand; and
- Methanotrophy.

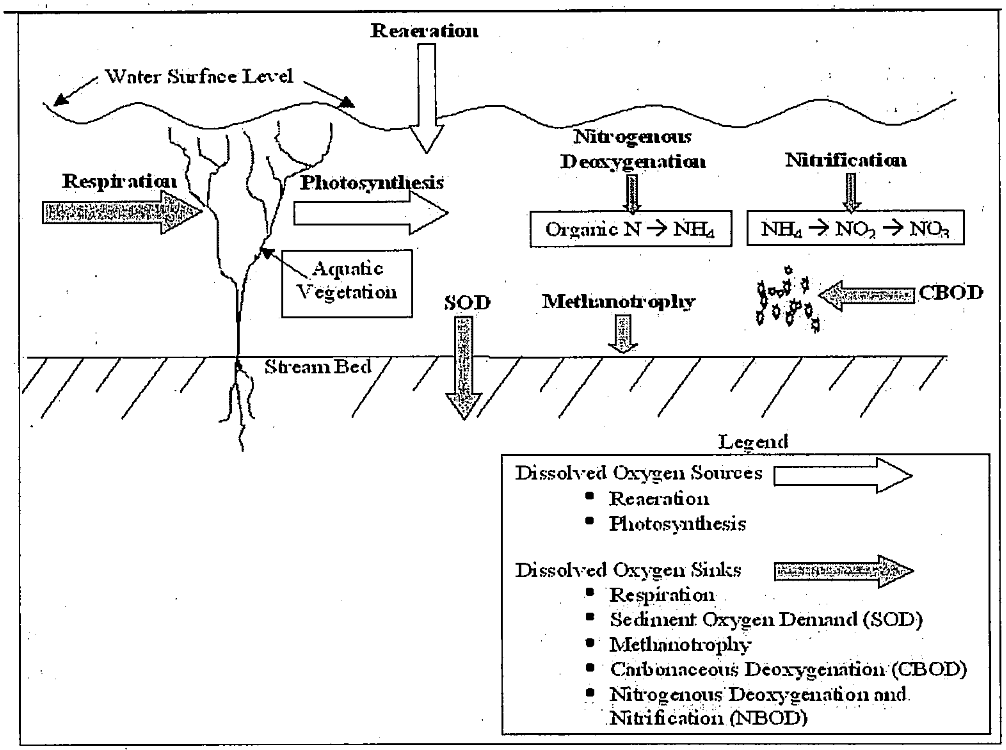


Figure 4.1: Physical, Chemical, and Biological Processes Affecting Dissolved Oxygen in Surface Water Bodies

- *Photosynthesis* is the process by which solar energy is stored as chemical energy in organic molecules. In this process, oxygen is liberated and carbon dioxide is sequestered.
- The organic matter produced by photosynthesis then serves as an energy source for nearly all other living organisms in the reverse processes of respiration and *decomposition* whereby oxygen is bonded with other elements.
- *Carbonaceous deoxygenation* is the technical term for decomposition, involving the consumption of oxygen by bacteria during the breakdown of organic material. Carbon dioxide is released as a byproduct of carbonaceous deoxygenation. When this oxidation is exerted on carbonaceous organic material that is suspended in the water column, it is measured as biochemical oxygen demand (BOD), typically measured as the amount of oxygen consumed during a five-day test period (BOD_5).
- *Nitrogenous deoxygenation* involves the conversion of organic nitrogen to ammonia (NH_4^+) by bacteria, a process that consumes oxygen.
- *Nitrification* is the process by which ammonia is oxidized to nitrite (NO^{2-}) and subsequently to nitrate (NO^{3-}); a process that also consumes oxygen.
- *Reaeration* is the process whereby atmospheric oxygen is transferred to a waterbody.
- *Sediment oxygen demand* refers to the consumption of oxygen by sediment and organisms (such as bacteria and invertebrates) through both the decomposition of organic matter and respiration by plants, bacteria, and invertebrates. Simplistically, sediment oxygen demand is carbonaceous deoxygenation and respiration occurring in the sediments.
- *Methanotrophy* is the process by which methane (CH_4) is biologically oxidized in aerobic environments, a process that consumes oxygen and forms carbon dioxide and water. Methanotrophy can occur in sediments and at the sediment-water interface. Where methanotrophy occurs, it can be measured as part of the overall sediment oxygen demand.

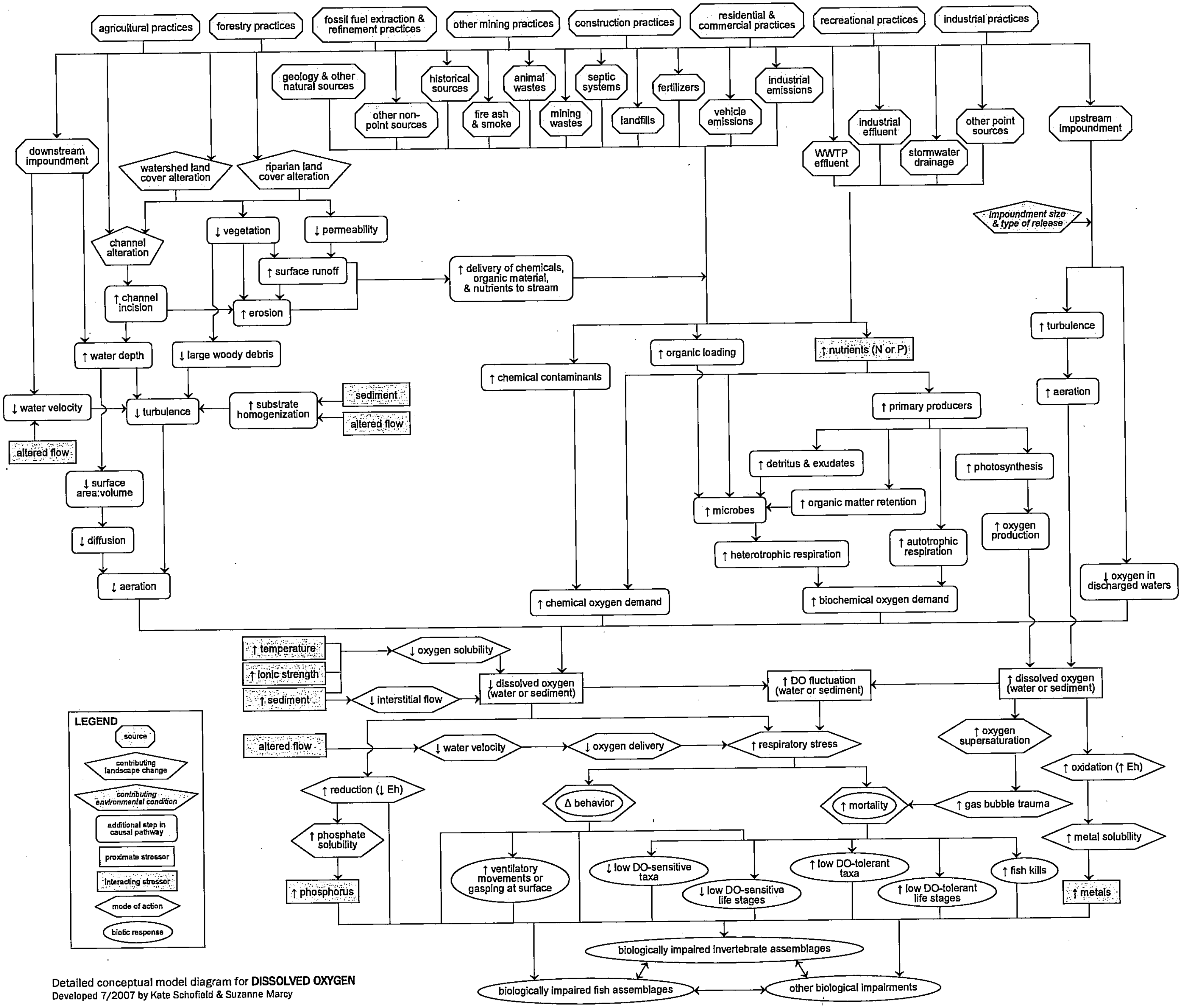
In addition to these processes, dissolved oxygen concentrations are affected by water temperature, salinity, and atmospheric pressure. Oxygen is soluble, or "dissolved" in water. The solubility of oxygen is a function of water temperature, salinity, and atmospheric pressure; decreasing with rising temperature and salinity, and increasing with rising atmospheric pressure. At sea level (1 atm of pressure) fresh water has a saturation dissolved oxygen concentration of about 14.6 mg/L at 0°C and 8.2 mg/L at 25°C. The connection between dissolved oxygen concentration and water temperature is important given the fact that the Shasta River is impaired by both high water temperatures and low dissolved oxygen concentrations.

4.2 Sources of Information

Much of the data and information used in the development of the dissolved oxygen TMDL was collected during the summers of 2002, 2003, and 2004 by Regional Water Board staff, with assistance from the U.S. Geological Survey and UC Davis Aquatic Ecosystems Analysis Laboratory. These data included:

- Hourly dissolved oxygen measurements at 16 sites;
- Hourly temperature measurements at 19 sites;

APPENDIX D



Detailed conceptual model diagram for **DISSOLVED OXYGEN**
Developed 7/2007 by Kate Schofield & Suzanne Marcy

APPENDIX E

The Effects of Dissolved Oxygen on Steelhead Trout, Coho Salmon, and Chinook Salmon Biology and Function by Life Stage

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August 2005

Introduction

Adequate concentrations of dissolved oxygen in fresh water streams are critical for the survival of salmonids. Fish have evolved very efficient physiological mechanisms for obtaining and using oxygen in the water to oxygenate the blood and meet their metabolic demands (WDOE 2002). However, reduced levels of dissolved oxygen can impact growth and development of different life stages of salmon, including eggs, alevins, and fry, as well as the swimming, feeding and reproductive ability of juveniles and adults. Such impacts can affect fitness and survival by altering embryo incubation periods, decreasing the size of fry, increasing the likelihood of predation, and decreasing feeding activity. Under extreme conditions, low dissolved oxygen concentrations can be lethal to salmonids.

Literature reviewed for this analysis included EPA guidance, other states' standards, reports that compiled and summarized existing scientific information, and numerous laboratory studies. When possible, species-specific requirements were summarized for the following life stages: migrating adults, incubation and emergence, and freshwater rearing and growth. The following information applies to salmonids in general, with specific references to coho, Chinook, steelhead, and other species of salmonids as appropriate.

EFFECTS OF LOW DISSOLVED OXYGEN CONCENTRATIONS ON SALMONIDS

Adult Migration

Reduced concentrations of dissolved oxygen can negatively affect the swimming performance of migrating salmonids (Bjornn and Reiser 1991). The upstream migration by adult salmonids is typically a stressful endeavor. Sustained swimming over long distances requires high expenditures of energy and therefore requires adequate levels of dissolved oxygen. Migrating adult Chinook salmon in the San Joaquin River exhibited an avoidance response when dissolved oxygen was below 4.2 mg/L, and most Chinook waited to migrate until dissolved oxygen levels were at 5 mg/L or higher (Hallock et al. 1970).

Incubation/Emergence

Low levels of dissolved oxygen can be directly lethal to salmonids, and can also have sublethal effects such as changing the rate of embryological development, the time to hatching, and size of emerging fry (Spence et al. 1996). The embryonic and larval stages of salmonid development are especially susceptible to low dissolved oxygen levels as their ability to extract oxygen is not fully developed and their relative immobility inhibits their ability to migrate to more favorable conditions. The dissolved oxygen requirements for successful incubation of embryos and emergence of fry is tied to intragravel dissolved oxygen levels. Intragravel dissolved oxygen is typically a function of many chemical, physical, and hydrological variables, including: the dissolved oxygen concentration of the overlying stream water, water temperature, substrate size and porosity, biochemical oxygen demand of the intragravel water, sediment oxygen demand, the gradient and velocity of the stream, channel configuration, and depth of water. As a result the dissolved oxygen concentration within the gravels can be depleted causing problems for salmonid embryos and larvae, even when overlying surface water oxygen levels are suitable (USEPA 1986a).

Studies note that water column dissolved oxygen concentrations are typically estimated to be reduced by 1-3 mg/L as water is transmitted to redds containing developing eggs and larvae (WDOE 2002). USEPA (1986a) concluded that dissolved oxygen levels within the gravels should be considered to be at least 3 mg/L lower than concentrations in the overlying water. ODEQ (1995) expect the loss of an average of 3 mg/L dissolved oxygen from surface water to the gravels.

Incubation mortality

Phillips and Campbell (1961, as cited by Bjornn and Reiser 1991) concluded that intragravel dissolved oxygen must average 8 mg/L for embryos and alevins to survive well. After reviewing numerous studies Davis (1975) states that a dissolved oxygen concentration of 9.75 mg/L is fully protective of larvae and mature eggs, while at 8 mg/L the average member of the incubating population will exhibit symptoms of oxygen distress, and at 6.5 mg/L a large portion of the incubating eggs may be affected. Bjornn and Reiser (1991) reviewed numerous references and recommend that dissolved oxygen should drop no lower than 5 mg/L, and should be at or near saturation for successful incubation.

In a review of several laboratory studies, ODEQ (1995) concluded that at near optimum (10°C) constant temperatures acute mortality to salmonid embryos occurs at relatively low concentrations of dissolved oxygen, near or below 3 mg/L. Field studies reviewed by ODEQ (1995) demonstrate that embryo survival is low when the dissolved oxygen content in the gravels drops near or below 5 mg/L, and survival is greater at 8 mg/L.

Silver et al. (1963) performed a study with Chinook salmon and steelhead trout, rearing eggs at various constant dissolved oxygen concentrations and water velocities. They found that steelhead embryos held at 9.5°C and Chinook salmon embryos held at 11°C experienced complete mortality at dissolved oxygen concentrations of 1.6 mg/L. Survival of a large percentage of embryos reared at oxygen levels as low as 2.5 mg/L appeared to be possible by reduction of respiration rates and consequent reduction of growth and development rates.

In a field study Cobel (1961) found that the survival of steelhead embryos was correlated to intragravel dissolved oxygen in the redds, with higher survival at higher levels of dissolved oxygen. At 9.25 mg/L survival was 62%, but survival was only 16% at 2.6 mg/L. A laboratory study by Eddy (1971) found that Chinook salmon survival at 10.4 mg/L (13.5 °C) was approximately 67%, however at dissolved oxygen levels of 7.3 mg/L (13.5 °C) survival dropped to 49-57.6%. At temperatures more suitable for Chinook incubation (10.5 °C) Eddy (1971) found the percent survival remained high (over 90%) at dissolved oxygen levels from 11 mg/L to 3.5 mg/L; however, as dissolved oxygen levels decreased, the number of days to hatching increased and the mean dry weight of the fry decreased substantially. WDOE (2002) also points out that the studies above did not consider the act of emerging through the redds, and the metabolic requirements to emerge would be expected to be substantial. Therefore, it is likely that higher oxygen levels may be needed to fully protect hatching and emergence, than to just support hatching alone.

Incubation growth

Embryos can survive when dissolved oxygen is below saturation (and above a critical level), but development typically deviates from normal (Bjornn and Reiser 1991). Embryos were found to be smaller than normal, and hatching either delayed or premature, when dissolved oxygen was below saturation throughout development (Doudoroff and Warren 1965, as cited by Bjornn and Reiser 1991).

Garside (1966) found the number of days it took for rainbow trout to go from fertilization to hatching increased as dissolved oxygen concentrations and water temperature decreased. In this study, rainbow trout were incubated at temperatures between 2.5 - 17.5°C and dissolved oxygen levels from 2.5 - 11.3 mg/L. At 10°C and 7.5°C the total time for incubation was delayed 6 and 9 days respectively at dissolved oxygen levels of 2.5 mg/L versus embryos incubated at approximately 10.5 mg/L.

Silver et al. (1963) found that hatching of steelhead trout held at 9.5°C was delayed 5 to 8 days at dissolved oxygen concentrations averaging 2.6 mg/L versus embryos reared at 11.2 mg/L. A smaller delay of hatching was observed at oxygen levels of 4.2 and 5.7 mg/L, although none was apparent at 7.9 mg/L. For Chinook salmon held at 11°C, Silver et al. observed that embryos reared at oxygen levels lower than 11 mg/L experienced a delay in hatching, with the most significant delay in those reared at dissolved oxygen levels of 2.5 mg/L (6 to 9 days). The size of both Chinook and steelhead embryos increased with increases in dissolved oxygen up to 11.2 mg/L. External examination of embryos revealed abnormal structural development in Chinook salmon tested at dissolved oxygen concentrations of 1.6 mg/L, and abnormalities in steelhead trout at concentrations of 1.6 and 2.6 mg/L. The survival of Chinook salmon after hatching was only depressed at the 2.5 mg/L level, the lowest level at which hatching occurred, with lower mortalities occurring at higher velocities. Post hatching survival of steelhead trout could not be determined due to numerous confounding factors.

Shumway et al. (1964) conducted a laboratory study to determine the influence of oxygen concentration and water movement on the growth of steelhead trout and coho salmon embryos. The experiments were conducted at a temperature of 10°C and oxygen levels generally ranging from 2.5 - 11.5 mg/L and flows from 3 to 750 cm/hour. It was concluded that the median time to hatching decreased and size of fry increased as dissolved oxygen levels increased. For example, steelhead trout embryos reared at 2.9 mg/L hatched in approximately 41 days and had a wet weight of 17 mg, while embryos reared at 11.9 mg/L hatched in 36 days and weighed 32.3 mg. The authors found that a reduction of either the oxygen concentration or the water velocity will reduce the size of fry and increase the incubation period, although the affect of various water velocities tested was less than the effect of the different dissolved oxygen concentrations tested.

WDOE (2002) reviewed various references and found that at favorable incubation temperatures a mean oxygen concentration of 10.5 mg/L will result in a 2% reduction in growth. At other oxygen concentrations, growth is reduced as follows: 8% reduction at oxygen levels of 9 mg/L, 10% reduction at 7 mg/L, and a 25% reduction at 6 mg/L.

Incubation avoidance/preference
Alevin showed a strong preference for oxygen concentrations of 8 - 10 mg/L and moved through the gravel medium to these concentrations, avoiding concentrations from 4 - 6 mg/L (WDOE 2002).

Emergence mortality
"The hatching time, size, and growth rate of developing embryos is proportional to the dissolved oxygen concentrations up to 8 mg/L or greater. The ability of fry to survive their natural environment may be related to the size of fry at hatch (ODEQ 1995)." McMahon (1983) recommends dissolved oxygen levels be ≥ 8 mg/L for high survival and emergence of fry. In a review of controlled field and lab studies on emergence, WDOE (2002) states that average intragravel oxygen concentrations of 6 - 6.5 mg/L and lower can cause stress and mortality in developing embryos and alevin. It is also noted that field studies on emergence consistently cite intragravel oxygen concentrations of 8 mg/L or greater as being associated with or necessary for superior health and survival, oxygen concentrations below 6 - 7 mg/L result in a 50% reduction in survival through emergence, and oxygen concentrations below 5 mg/L result in negligible

survival. According to various laboratory studies, the threshold for complete mortality of emerging salmonids is noted to occur between 2 - 2.5 mg/L (WDOE 2002).

After reviewing numerous literature sources, the USEPA (1986a) concluded that the embryonic and larval stages of salmonid development will experience no impairment when water column dissolved oxygen concentrations are 11 mg/L. This translates into an intragravel dissolved oxygen concentration of 8 mg/L (USEPA assumes a 3 mg/L loss between the surface water and gravels). Table 1 from the USEPA (1986a) lists the water column and intragravel dissolved oxygen concentrations associated with various health effects. These health affects range from no production impairment to acute mortality.

Table 1: Dissolved oxygen concentrations and their effects salmonid embryo and larval stages (USEPA, 1986a).

Level of Effect	Water Column DO (mg/L)	Intragravel DO (mg/L)
No Production Impairment	11	8*
Slight Production Impairment	9	6*
Moderate Production Impairment	8	5*
Severe Production Impairment	7	4*
Limit to Avoid Acute Mortality	6	3*

* A 3 mg/L loss is assumed between the water column dissolved oxygen levels and those intragravel.

Freshwater Rearing and Growth

Swimming and activity

Salmonids are strong active swimmers requiring highly oxygenated waters (Spence 1996), and this is true during the rearing period when the fish are feeding, growing, and avoiding predation. Salmonids may be able to survive when dissolved oxygen concentrations are low (<5 mg/L), but growth, food conversion efficiency, and swimming performance will be adversely affected (Bjornn and Reiser 1991). Davis (1975) reviewed numerous studies and reported no impairment to rearing salmonids if dissolved oxygen concentrations averaged 9 mg/L, while at oxygen levels of 6.5 mg/L "the average member of the community will exhibit symptoms of oxygen distress", and at 4 mg/L a large portion of salmonids may be affected. Dahlberg et al. (1968) state that at temperatures near 20°C any considerable decrease in the oxygen concentration below 9 mg/L (the air saturation level) resulted in some reduction of the final swimming speed. They found that between dissolved oxygen concentrations of 7 to 2 mg/L the swimming speed of coho declined markedly with the decrease in dissolved oxygen concentration.

In a laboratory study, Davis et al. (1963) reported that the maximum sustainable swimming speeds of wild juvenile coho salmon were reduced when dissolved oxygen dropped below saturation at water temperatures of 10, 15, and 20°C. Air-saturation values for these dissolved oxygen concentrations were cited as 11.3, 10.2, and 9.2 mg/L respectively. They found that the maximum sustained swimming speeds (based on first and second swimming failures at all temperatures) were reduced by 3.2 - 6.4%, 5.9 - 10.1%, 9.9 - 13.9%, 16.7 - 21.2%, and 26.6 - 33.8% at dissolved oxygen concentrations of 7, 6, 5, 4, and 3 mg/L respectively. The authors also conducted tests on juvenile Chinook salmon and found that the percent reductions from maximum swimming speed at temperatures ranging from 11 to 15°C were greater than those for juvenile coho. At the dissolved oxygen concentrations listed above swimming speeds were decreased by 10%, 14%, 20%, 27%, and 38% respectively.

WDOE (2002) reviewed various data and concluded that swimming fitness of salmonids is maximized when the daily minimum dissolved oxygen levels are above 8 - 9 mg/L. Jones et al. (1971, as cited by USEPA 1986a) found the swimming speed of rainbow trout was decreased 30% from maximum at dissolved oxygen concentrations of 5.1 mg/L and 14°C. At oxygen levels of 3.8 mg/L and a temperature of 22°C, they found a 43% reduction in the maximum swimming speed.

Growth

In a review of constant oxygen exposure studies WDOE (2002) concluded salmonid growth rates decreased less than 10% at dissolved oxygen concentrations of 8 mg/L or more, less than 20% at 7 mg/L, and generally less than 22% at 5 - 6 mg/L. Herrmann (1958) found that the mean percentage of weight gain in juvenile coho held at constant dissolved oxygen concentrations was 7.2% around 2 mg/L, 33.6% at 3 mg/L, 55.8% near 4 mg/L, and 67.9% at or near 5 mg/L. In a laboratory study Fischer (1963) found that the growth rates of juvenile coho exposed to constant oxygen concentrations ranging from 2.5 to 35.5 mg/L (fed to satiation, temperature at approximately 18 °C) dramatically decreased with decreases in the oxygen concentration below 9.5 mg/L (air saturation level). WDOE (2002) concludes that a monthly or weekly average concentration of 9 mg/L, and a monthly average of the daily minimum concentrations should be at or above 8 - 8.5 mg/L to have a negligible effect (5% or less) on growth and support healthy growth rates.

Food conversion efficiency is related to dissolved oxygen levels and the process becomes less efficient when oxygen concentrations are below 4 - 4.5 mg/L (ODEQ 1995). Bjornn and Reiser (1991) state that growth, food conversion efficiency, and swimming performance are adversely affected when dissolved oxygen concentrations are <5 mg/L. The USEPA (1986a) reviewed growth data from a study conducted by Warren et al. (1973) where tests were conducted at various temperatures to determine the growth of coho and Chinook. USEPA cites that, with the exception of tests conducted at 22 °C, the results supported the idea that the effects of low dissolved oxygen become more severe at higher temperatures.

Brett and Blackburn (1981) performed a laboratory study to determine the growth rate and food conversion efficiency of young coho and sockeye salmon fed full rations. Tests were performed at dissolved oxygen concentrations ranging from 2 to 15 mg/L at a constant temperature of 15°C, the approximate optimum temperature for growth of Pacific Salmon. Both species showed a strong dependence of growth on the environmental oxygen concentrations when levels were below 5 mg/L. For coho, zero growth was observed at dissolved oxygen concentrations of 2.3 mg/L. The mean value for maximum coho growth occurred at 4 mg/L, and at dissolved oxygen concentrations above this level growth did not appear to be dependant on the dissolved oxygen. Sockeye displayed zero growth at oxygen levels of 2.6 mg/L, and reached the zone of independence (growth not dependant on dissolved oxygen levels) at 4.2 mg/L. Brett and Blackburn (1981) conclude that the critical inflection from oxygen dependence to independence occurs at 4 - 4.2 mg/L for coho and sockeye.

Herrmann et al. (1962) studied the influence of various oxygen concentrations on the growth of age 0 coho salmon held at 20 °C. Coho were held in containers at a constant mean dissolved oxygen level ranging from 2.1 - 9.9 mg/L and were fed full rations. The authors concluded that oxygen concentrations below 5 mg/L resulted in a sharp decrease in growth and food consumption. A reduction in the mean oxygen levels from 8.3 mg/L to 6 and 5 mg/L resulted in slight decreases in food consumption and growth. Weight gain in grams per gram of food consumed was slightly depressed at dissolved oxygen concentrations near 4 mg/L, and were markedly reduced at lower concentrations. At oxygen levels of 2.1 and 2.3 mg/L, many fish died and the surviving fish lost weight and consumed very little food.

USEPA (1986a) calculated the median percent reduction in growth rate of Chinook and coho salmon fed full rations at various dissolved oxygen concentrations. They calculated no reduction in growth at dissolved oxygen concentrations of 8 and 9 mg/L, and a 1% reduction in growth at 7 mg/L for both species. At 6 mg/L Chinook and coho growth were reduced by 7% and 4% respectively. Dissolved oxygen levels of 4 mg/L result in a 29% reduction in growth for Chinook salmon and 21% reduction in growth for coho. At 3 mg/L there was a 47% decrease in Chinook growth and a 37% reduction in coho growth. USEPA (1986a) states that due to the variability inherent in growth studies the reductions in growth rates seen above 6 mg/L are not usually statistically significant, while reductions in growth at dissolved oxygen levels below 4 mg/L are considered severe.

Avoidance and preference

Salmonids have been reported to actively avoid areas with low dissolved oxygen concentrations, which is likely a useful protective mechanism that enhances survival (Davis 1975). Field and laboratory studies have found that avoidance reactions in juvenile salmonids consistently occur at concentrations of 5 mg/L and lower, and there is some indication that avoidance is triggered at concentrations as high as 6 mg/L. Therefore these dissolved oxygen levels should be considered a potential barrier to the movement and habitat selection of salmonids (WDOE 2002).

Spoor (1990) performed a laboratory study on the distribution of fingerling brook trout in dissolved oxygen concentration gradients. Sixteen gradients between 1 and 8.9 mg/L were used for the study to determine what level of dissolved oxygen is preferred by the brook trout. It was found that in the absence of a gradient with dissolved oxygen concentrations at 6 mg/L or more throughout the system, the fish moved freely without showing preference or avoidance. Movement from low to higher oxygen concentrations were noted throughout the study. Fish moved away from water with dissolved oxygen concentrations from 1 - 1.9 mg/L within one hour, moved away from water with dissolved oxygen concentrations of 2 - 2.9 mg/L within 1 - 2 hours, and moved away more slowly from concentrations of 3 - 3.9 mg/L. From his study, Spoor (1990) concluded that brook trout will avoid oxygen concentrations below 4 mg/L, and preferred oxygen levels of 5 mg/L or higher.

Whitmore et al. (1960) performed studies with juvenile coho and Chinook salmon to determine their avoidance reaction to dissolved oxygen concentration of 1.5, 3 , 4.5, and 6 mg/L at variable river water temperatures. Juvenile Chinook salmon showed marked avoidance of oxygen concentrations near 1.5, 3, and 4.5 mg/L in the summer at mean temperatures ranging from 20.7 - 22.8°C, but no avoidance to levels near 6 mg/L at a mean temperature of 18.4°C. Chinook did not show as strong an avoidance to these oxygen levels in the fall when water temperatures were lower, ranging from 11.8 - 13.2°C. Chinook showed little avoidance of dissolved oxygen concentrations near 4.5 mg/L during the fall, and no avoidance to concentrations near 6 mg/L. In all cases avoidance became progressively larger with reductions in the oxygen concentration below 6 mg/L. Seasonal differences of avoidance are most likely due to differences in water temperature. At temperatures ranging from 18.4 - 19°C juvenile coho salmon showed some avoidance to all of the above oxygen concentrations, including 6 mg/L. Their behavior was more erratic than that of Chinook, and their avoidance of concentrations near 4.5 mg/L and lower was not as pronounced at corresponding temperatures. The juvenile coho often started upon entering water with low dissolved oxygen and then darted around until they found their way out of the experimental channel.

USEPA (1986a) performed a literature review and cites the effects of various dissolved oxygen concentrations on salmonid life stages other than embryonic and larval (Table 2). These effects range from no impairment at 8 mg/L to acute mortality at dissolved oxygen levels below 3 mg/L.

Table 2: Dissolved oxygen concentrations and their effects on salmonid life stages other than embryonic and larval (USEPA 1986a).

Level of Effect	Water Column DO (mg/L)
No Production Impairment	8
Slight Production Impairment	6
Moderate Production Impairment	5
Severe Production Impairment	4
Limit to Avoid Acute Mortality	3

Lethality

Salmonid mortality begins to occur when dissolved oxygen concentrations are below 3 mg/L for periods longer than 3.5 days (USEPA 1986a). A summary of various field study results by WDOE (2002) reports that significant mortality occurs in natural waters when dissolved oxygen concentrations fluctuate the range of 2.5 - 3 mg/L. Long-term (20 - 30 days) constant exposure to mean dissolved oxygen concentrations below 3 - 3.3 mg/L is likely to result in 50% mortality of juvenile salmonids (WDOE 2002). According to a short-term (1 - 4 hours) exposure study by Burdick et al. (1954, as cited by WDOE, 2002), in warm water (20 - 21°C) salmonids may require daily minimum oxygen levels to remain above 2.6 mg/L to avoid significant (50%) mortality. From these and other types of studies, WDOE (2002) concluded that juvenile salmonid mortality can be avoided if daily minimum dissolved oxygen concentration remain above 3.9 mg/L, and the monthly or weekly average of minimum concentrations remains above 4.6 mg/L.

EFFECTS OF HIGH TOTAL DISSOLVED GAS CONCENTRATIONS ON SALMONIDS

High levels of total dissolved gas (TDG), including dissolved oxygen, can be harmful to salmonids and other fish and result in "gas bubble disease". This occurs when dissolved gases in their circulatory system come out of solution and form bubbles which block the flow of blood through the capillary vessels (USEPA 1986b). There are several ways TDG supersaturation can occur, including excessive algal photosynthesis which can create supersaturated dissolved oxygen conditions (USEPA 1986b). Thus, to protect salmonids and other freshwater fish the USEPA has set criteria for TDG stating that levels should not exceed 110% of the saturation value.

Numerous studies have been conducted to determine the mortality rate of salmonids exposed to various levels of TDG. Mesa et al. (2000) conducted laboratory experiments on juvenile Chinook and steelhead, exposing them to different levels of TDG and found no fish died when held at 110% TDG for up to 22 days. When fish were exposed to 120% TDG, 20% of juvenile Chinook died within 40 to 120 hours while 20% of juvenile steelhead died within 20 to 35 hours. At TDG levels of 130% Chinook mortality reached 20% after 3 to 6 hours and steelhead mortality was 20% after 5 to 7 hours. Gale et al. (2001) held adult female spring Chinook at mean TDG levels ranging from 114.1% to 125.5% and found the time to first mortality ranged from 10 to 68 hours.

USEPA (1986b) discusses various studies on the effects of TDG on salmonids. The following studies are all cited from the USEPA 1986 water quality criteria document. Bouck et al. (1975) found TDG levels of 115% and above to be acutely lethal to most species of salmonids, and levels of 120% TDG are rapidly lethal to all salmonids. Conclusions drawn from Ebel et al. (1975) and Rulfison and Abel (1971) include the following:

- Adult and juvenile salmonids confined to shallow water (1 m) with TDG levels above 115% experience substantial levels of mortality.
- Juvenile salmonids exposed sublethal levels TDG supersaturation are able to recover when returned to normally saturated water, while adults do not recover and generally die.

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APPENDIX F

United States
Environmental Protection
Agency

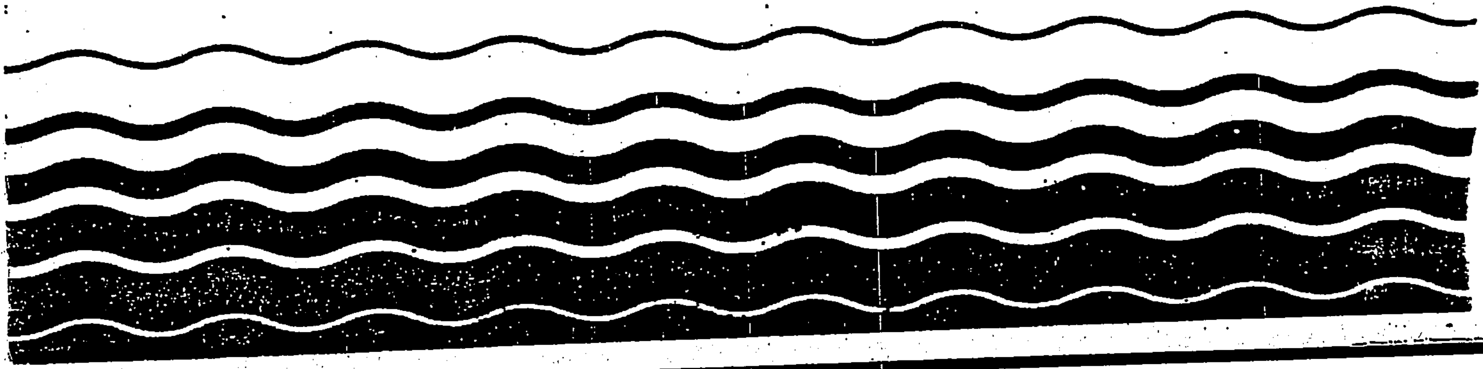
Office of Water
Regulations and Standards
Criteria and Standards Division
Washington, DC 20460

EPA 440/5-86-003
April 1986

Water

EPA

Ambient Water Quality Criteria for Dissolved Oxygen



Ambient Aquatic Life Water Quality Criteria for Dissolved Oxygen

(Freshwater)

U.S. Environmental Protection Agency
Office of Research and Development
Environmental Research Laboratories
Duluth, Minnesota
Narragansett, Rhode Island

NOTICES

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Ambient Water Quality Criteria for Dissolved Oxygen

FRESHWATER AQUATIC LIFE

I. Introduction

A sizable body of literature on the oxygen requirements of freshwater aquatic life has been thoroughly summarized (Doudoroff and Shumway, 1967, 1970; Warren et al., 1973; Davis, 1975a,b; and Alabaster and Lloyd, 1980). These reviews and other documents describing the dissolved oxygen requirements of aquatic organisms (U.S. Environmental Protection Agency, 1976; International Joint Commission, 1976; Minnesota Pollution Control Agency, 1980) and more recent data were considered in the preparation of this document. The references cited below are limited to those considered to be the most definitive and most representative of the preponderance of scientific evidence concerning the dissolved oxygen requirements of freshwater organisms. The guidelines used in deriving aquatic life criteria for toxicants (Federal Register, 45 FR 79318, November 28, 1980) are not applicable because of the different nature of the data bases. Chemical toxicity data bases rely on standard 96-h LC50 tests and standard chronic tests; there are very few data of either type on dissolved oxygen.

Over the last 10 years the dissolved oxygen criteria proposed by various agencies and researchers have generally reflected two basic schools of thought. One maintained that a dynamic approach should be used so that the criteria would vary with natural ambient dissolved oxygen minima in the waters of concern (Doudoroff and Shumway, 1970) or with dissolved oxygen requirements of fish expressed in terms of percent saturation (Davis, 1975a,b). The other maintained that, while not ideal, a single minimum allowable concentration should adequately protect the diversity of aquatic life in fresh waters (U.S. Environmental Protection Agency, 1976). Both approaches relied on a simple minimum allowable dissolved oxygen concentration as the basis for their criteria. A simple minimum dissolved oxygen concentration was also the most practicable approach in waste load allocation models of the time.

Expressing the criteria in terms of the actual amount of dissolved oxygen available to aquatic organisms in milligrams per liter (mg/l) is considered more direct and easier to administer compared to expressing the criteria in terms of percent saturation. Dissolved oxygen criteria expressed as percent saturation, such as discussed by Davis (1975a,b), are more complex and could often result in unnecessarily stringent criteria in the cold months and potentially unprotective criteria during periods of high ambient temperature or at high elevations. Oxygen partial pressure is subject to the same temperature problems as percent saturation.

The approach recommended by Doudoroff and Shumway (1970), in which the criteria vary seasonally with the natural minimum dissolved oxygen concentrations in the waters of concern, was adopted by the National Academy of Sciences and National Academy of Engineering (NAS/NAE, 1973). This approach has some merit, but the lack of data (natural minimum concentrations) makes its application difficult, and it can also produce unnecessarily stringent or unprotective criteria during periods of extreme temperature.

The more simplistic approach to dissolved oxygen criteria has been supported by the findings of a select committee of scientists specifically established by the Research Advisory Board of the International Joint Commission to review the dissolved oxygen criterion for the Great Lakes (Magnuson et al., 1979). The committee concluded that a simple criterion (an average criterion of 6.5 mg/l and a minimum criterion of 5.5 mg/l) was preferable to one based on percent saturation (or oxygen partial pressure) and was scientifically sound because the rate of oxygen transfer across fish gills is directly dependent on the mean difference in oxygen partial pressure across the gill. Also, the total amount of oxygen delivered to the gills is a more specific limiting factor than is oxygen partial pressure per se. The format of this otherwise simple criterion was more sophisticated than earlier criteria with the introduction of a two-concentration criterion comprised of both a mean and a minimum. This two-concentration criteria structure is similar to that currently used for toxicants (Federal Register, 45 FR 79318, November 28, 1980). EPA agrees with the International Joint Commission's conclusions and will recommend a two-number criterion for dissolved oxygen.

The national criteria presented herein represent the best estimates, based on the data available, of dissolved oxygen concentrations necessary to protect aquatic life and its uses. Previous water quality criteria have either emphasized (Federal Water Pollution Control Administration, 1968) or rejected (National Academy of Sciences and National Academy of Engineering, 1972) separate dissolved oxygen criteria for coldwater and warmwater biota. A warmwater-coldwater dichotomy is made in this criterion. To simplify discussion, however, the text of the document is split into salmonid and nonsalmonid sections. The salmonid-nonsalmonid dichotomy is predicated on the much greater knowledge regarding the dissolved oxygen requirements of salmonids and on the critical influence of intergravel dissolved oxygen concentration on salmonid embryonic and larval development. Nonsalmonid fish include many other coldwater and coolwater fish plus all warmwater fish. Some of these species are known to be less sensitive than salmonids to low dissolved oxygen concentrations. Some other nonsalmonids may prove to be at least as sensitive to low dissolved oxygen concentrations as the salmonids; among the nonsalmonids of likely sensitivity are the herrings (Clupeidae), the smelts (Osmeridae), the pikes (Esocidae), and the sculpins (Cottidae). Although there is little published data regarding the dissolved oxygen requirements of most nonsalmonid species, there is apparently enough anecdotal information to suggest that many coolwater species are more sensitive to dissolved oxygen depletion than are warmwater species. According to the American Fisheries Society (1978), the term "coolwater fishes" is not vigorously defined, but it refers generally to those species which are distributed by temperature preference between the "coldwater" salmonid communities to the north and the more diverse, often centrarchid-dominated "warmwater" assemblages to the south. Many states have more stringent dissolved oxygen standards for colder waters, waters that contain either salmonids, nonsalmonid coolwater fish, or the sensitive centrarchid, the smallmouth bass.

The research and sociological emphasis for dissolved oxygen has been biased towards fish, especially the more economically important species in the family Salmonidae. Several authors (Doudoroff and Shumway, 1970; Davis, 1975a,b) have discussed this bias in considerable detail and have drawn similar conclusions regarding the effects of low dissolved oxygen on freshwater invertebrates. Doudoroff and Shumway (1970) stated that although some invertebrate species are about as sensitive as the moderately susceptible fishes, all invertebrate species need not be protected in order to protect the food source for fisheries because many invertebrate species, inherently more tolerant than fish, would increase in abundance. Davis (1975a,b) also concluded that invertebrate species would probably be adequately protected if the fish populations are protected. He stated that the composition of invertebrate communities may shift to more tolerant forms selected from the resident community or recruited from outside the community. In general, stream invertebrates that are requisite riffle-dwellers probably have a higher dissolved oxygen requirement than other aquatic invertebrates. The riffle habitat maximizes the potential dissolved oxygen flux to organisms living in the high water velocity by rapidly replacing the water in the immediate vicinity of the organisms. This may be especially important for organisms that exist clinging to submerged substrate in the riffles. In the absence of data to the contrary, EPA will follow the assumption that a dissolved oxygen criterion protective of fish will be adequate.

One of the most difficult problems faced during this attempt to gather, interpret, assimilate, and generalize the scientific data base for dissolved oxygen effects on fish has been the variability in test conditions used by investigators. Some toxicological methods for measuring the effects of chemicals on aquatic life have been standardized for nearly 40 years; this has not been true of dissolved oxygen research. Acute lethality tests with dissolved oxygen vary in the extreme with respect to types of exposure (constant vs. declining), duration of exposure (a few hours vs. a week or more), type of endpoint (death vs. loss of equilibrium), type of oxygen control (nitrogen stripping vs. vacuum degassing), and type of exposure chamber (open to the atmosphere vs. sealed). In addition there are the normal sources of variability that influence standardized toxicity tests, including seasonal differences in the condition of test fish, acclimation or lack of acclimation to test conditions, type and level of feeding, test temperature, age of test fish, and stresses due to test conditions. Chronic toxicity tests are typically of two types, full life cycle tests or early life stage tests. These have come to be rather rigorously standardized and are essential to the toxic chemical criteria established by EPA. These tests routinely are assumed to include the most sensitive life stage, and the criteria then presume to protect all life stages. With dissolved oxygen research, very few tests would be considered legitimate chronic tests; either they fail to include a full life cycle, they fail to include both embryo and larval stages, or they fail to include an adequate period of post-larval feeding and growth.

Instead of establishing year-round criteria to protect all life stages, it may be possible to establish seasonal criteria based on the life stages present. Thus, special early life stage criteria are routinely accepted for salmonid early life stages because of their usual intergravel environment. The same concept may be extended to any species that appear to have more stringent dissolved oxygen requirements during one period of their life history. The flexibility afforded by such a dichotomy in criteria carries with it the responsibility to accurately determine the presence or absence of the more sensitive stages prior to invocation of the less stringent criteria. Such presence/absence data must be more site-specific than national in scope, so that temperature, habitat, or calendar specifications are not possible in this document. In the absence of such site-specific determinations the default criteria would be those that would protect all life stages year-round; this is consistent with the present format for toxic chemical criteria.

II. Salmonids

The effects of various dissolved oxygen concentrations on the well-being of aquatic organisms have been studied more extensively for fish of the family Salmonidae (which includes the genera Coregonus, Oncorhynchus, Prosopium, Salmo, Salvelinus, Stenodus, and Thymallus) than for any other family of organisms. Nearly all these studies have been conducted under laboratory conditions, simplifying cause and effect analysis, but minimizing or eliminating potentially important environmental factors, such as physical and chemical stresses associated with suboptimal water quality, as well as competition, behavior, and other related activities. Most laboratory studies on the effects of dissolved oxygen concentrations on salmonids have emphasized growth, physiology, or embryonic development. Other studies have described acute lethality or the effects of dissolved oxygen concentration on swimming performance.

A. Physiology

Many studies have reported a wide variety of physiological responses to low dissolved oxygen concentrations. Usually, these investigations were of short duration, measuring cardiovascular and metabolic alterations resulting from hypoxic exposures of relatively rapid onset. While these data provide only minimal guidance for establishing environmentally acceptable dissolved oxygen concentrations, they do provide considerable insight into the mechanisms responsible for the overall effects observed in the entire organism. For example, a good correlation exists between oxygen dissociation curves for rainbow trout blood (Cameron, 1971) and curves depicting the reduction in growth of salmonids (Brett and Blackburn, 1981; Warren et al., 1973) and the reduction in swimming ability of salmonids (Davis et al., 1963). These correlations indicate that the blood's reduced oxygen loading capacity at lower dissolved oxygen concentrations limits the amount of oxygen delivered to the tissues, restricting the ability of fish to maximize metabolic performance.

In general, the significance of metabolic and physiological studies on the establishment of dissolved oxygen criteria must be indirect, because their applicability to environmentally acceptable dissolved oxygen concentrations requires greater extrapolation and more assumptions than those required for data on growth, swimming, and survival.

B. Acute Lethal Concentrations

Doudoroff and Shumway (1970) summarized studies on lethal concentrations of dissolved oxygen for salmonids; analysis of these data indicates that the test procedures were highly variable, differing in duration, exposure regime, and reported endpoints. Only in a few cases could a 96-hr LC50 be calculated. Mortality or loss of equilibrium usually occurred at concentrations between 1 and 3 mg/l.

Mortality of brook trout has occurred in less than one hour at 10°C at dissolved oxygen concentrations below 1.2 mg/l, and no fish survived exposure at or below 1.5 mg/l for 10 hours (Shepard, 1955). Lethal dissolved oxygen concentrations increase at higher water temperatures and longer exposures. A 3.5 hr exposure killed all trout at 1.1 and 1.6 mg/l at 10 and 20°C, respectively (Downing and Merkens, 1957). A 3.5-day exposure killed all trout at 1.3 and 2.4 mg/l at 10 and 20°C, respectively. The corresponding no-mortality levels were 1.9 and 2.7 mg/l. The difference between dissolved oxygen concentrations causing total mortality and those allowing complete survival was about 0.5 mg/l when exposure duration was less than one week. If the period of exposure to low dissolved oxygen concentrations is limited to less than 3.5 days, concentrations of dissolved oxygen of 3 mg/l or higher should produce no direct mortality of salmonids.

More recent studies confirm these lethal levels in chronic tests with early life stages of salmonids (Siefert et al., 1974; Siefert and Spoor, 1973; Brooke and Colby, 1980); although studies with lake trout (Carlson and Siefert, 1974) indicate that 4.5 mg/l is lethal at 10°C (perhaps a marginally acceptable temperature for embryonic lake trout).

C. Growth

Growth of salmonids is most susceptible to the effects of low dissolved oxygen concentrations when the metabolic demands or opportunities are greatest. This is demonstrated by the greater sensitivity of growth to low dissolved oxygen concentrations when temperatures are high and food most plentiful (Warren et al., 1973). A total of more than 30 growth tests have been reported by Herrmann et al. (1962), Fisher (1963), Warren et al. (1973), Brett and Blackburn (1981), and Spoor (1981). Results of these tests are not easily compared because the tests encompass a wide range of species, temperatures, food types, and fish sizes. These factors produced a variety of control growth rates which, when combined with a wide range of test durations and fish numbers, resulted in an array of statistically diverse test results.

The results from most of these 30-plus tests were converted to growth rate data for fish exposed to low dissolved oxygen concentrations and were compared to control growth rates by curve-fitting procedures (JRB Associates, 1984). Estimates of growth rate reductions were similar regardless of the type of curve employed, but the quadratic model was judged to be superior and was used in the growth rate analyses contained in this document. The apparent relative sensitivity of each species to dissolved oxygen depletion may be influenced by fish size, test duration, temperature, and diet. Growth rate data (Table 1) from these tests with salmon and trout fed unrestricted rations indicated median growth rate reductions of 7, 14, and 25 percent for fish held at 6, 5, and 4 mg/l, respectively (JRB Associates, 1984). However, median growth rate reductions for the various species ranged from 4 to 9 percent at 6 mg/l, 11 to 17 percent at 5 mg/l, and 21 to 29 percent at 4 mg/l.

Table 1. Percent reduction in growth rate of salmonids at various dissolved oxygen concentrations expressed as the median value from n tests with each species (calculated from JRB Associates, 1984).

Dissolved Oxygen (mg/l)	Species (number of tests)					
	Chinook Salmon (6)	Coho Salmon (12)	Sockeye Salmon (1)	Rainbow Trout (2)	Brown Trout (1)	Lake Trout (2)
9	0	0	0	0	0	0
8	0	0	0	1	0	0
7	1	1	2	5	1	2
6	7	4	6	9	6	7
5	16	11	12	17	13	16
4	29	21	22	25	23	29
3	47	37	33	37	36	47
Median Temp. (°C)	15	18	15	12	12	12

Considering the variability inherent in growth studies, the apparent reductions in growth rate sometimes seen above 6 mg/l are not usually statistically significant. The reductions in growth rate occurring at dissolved oxygen concentrations below about 4 mg/l should be considered severe; between 4 mg/l and the threshold of effect, which variably appears to be between 6 and 10 mg/l in individual tests, the effect on growth rate is moderate to slight if the exposures are sufficiently long.

Within the growth data presented by Warren et al. (1973), the greatest effects and highest thresholds of effect occurred at high temperatures (17.8 to 21.7°C). In two tests conducted at about 8.5°C, the growth rate reduction at 4 mg/l of dissolved oxygen averaged 12 percent. Thus, even at the maximum feeding levels in these tests, dissolved oxygen levels down to 5 mg/l probably have little effect on growth rate at temperatures below 10°C.

Growth data from Warren et al. (1973) included chinook salmon tests conducted at various temperatures. These data (Table 2) indicated that growth tests conducted at 10-15°C would underestimate the effects of low dissolved oxygen concentrations at higher temperatures by a significant margin. For example, at 5 mg/l growth was not affected at 13°C but was reduced by 34 percent if temperatures were as high as 20°C. Examination of the test temperatures associated with the growth rate reductions listed in Table 1 shows that most data represent temperatures between 12 and 15°C. At the higher temperatures often associated with low dissolved oxygen concentrations, the growth rate reductions would have been greater if the generalizations of the chinook salmon data are applicable to salmonids in general. Coho salmon growth studies (Warren et al., 1973) showed a similar result over a range of temperatures from 9 to 18°C, but the trend was reversed in two tests near 22°C (Table 3). Except for the 22°C coho tests, the coho and chinook salmon results support the idea that effects of low dissolved oxygen become more severe at higher temperatures. This conclusion is supported by data on largemouth bass (to be discussed later) and by the increase in metabolic rate produced by high temperatures.

Table 2. Influence of temperature on growth rate of chinook salmon held at various dissolved oxygen concentrations (calculated from Warren et al., 1973; JRB Associates, 1984).

Dissolved Oxygen (mg/l)	Percent Reduction in Growth Rate at					
	8.4°C	13.0°C	13.2°C	17.8°C	18.6°C	21.7°C
9	0	0	0	0	0	0
8	0	0	0	0	2	0
7	0	0	4	0	8	2
6	0	0	8	5	19	14
5	0	0	16	16	34	34
4	7	4	25	33	53	65
3	26	22	36	57	77	100

Table 3. Influence of temperature on growth rate of coho salmon held at various dissolved oxygen concentrations (calculated from Warren et al., 1973; JRB Associates, 1984).

Dissolved Oxygen (mg/l)	Percent Reduction in Growth Rate at					
	8.6°C	12.9°C	13.0°C	18.0°C	21.6°C	21.8°C
10	0	0	0	0	0	0
9	0	0	0	5	0	0
8	0	1	2	10	0	0
7	1	4	6	17	0	6
6	4	10	13	27	0	1
5	9	18	23	38	0	7
4	17	29	36	51	4	19
3	28	42	51	67	6	37

Effects of dissolved oxygen concentration on the growth rate of salmonids fed restricted rations have been less intensively investigated. Thatcher (1974) conducted a series of tests with coho salmon at 15°C over a wide range of food consumption rates at 3, 5, and 8 mg/l of dissolved oxygen. The only significant reduction in growth rate was observed at 3 mg/l and food consumption rates greater than about 70 percent of maximum. In these studies, Thatcher noted that fish at 5 mg/l appeared to expend less energy in swimming activity than those at 8 mg/l. In natural conditions, where fish may be rewarded for energy expended defending preferred territory or searching for food, a dissolved oxygen concentration of 5 mg/l may restrict these activities.

The effect of forced activity and dissolved oxygen concentration on the growth of coho salmon was studied by Hutchins (1974). The growth rates of salmon fed to repletion at a dissolved oxygen concentration of 3 mg/l and held at current velocities of 8.5 and 20 cm/sec were reduced by 20 and 65 percent, respectively. At 5 mg/l, no reduction of growth rate was seen at the slower velocity, but a 15 percent decrease occurred at the higher velocity.

The effects of various dissolved oxygen concentrations on the growth rate of coho salmon (~ 5 cm long) in laboratory streams with an average current velocity of 12 cm/sec have been reported by Warren et al. (1973). In this series of nine tests, salmon consumed aquatic invertebrates living in the streams. Results at temperatures from 9.5° to 15.5°C supported the results of earlier laboratory studies; at higher growth rates (40 to 50 mg/g/day), dissolved oxygen levels below 5 mg/l reduced growth rate, but at lower growth rates (0 to 20 mg/g/day), no effects were seen at concentrations down to 3 mg/l.

The applicability of these growth data from laboratory tests depends on the available food and required activity in natural situations. Obviously, these factors will be highly variable depending on duration of exposure, growth rate, species, habitat, season, and size of fish. However, unless effects of these variables are examined for the site in question, the laboratory results should be used. The attainment of critical size is vital to the smolting of anadromous salmonids and may be important for all salmonids if size-related transition to feeding on larger or more diverse food organisms is an advantage. In the absence of more definitive site-specific, species-specific growth data, the data summary in Tables 1, 2, and 3 represent the best estimates of the effects of dissolved oxygen concentration on the potential growth of salmonid fish.

D. Reproduction

No studies were found that described the effects of low dissolved oxygen on the reproduction, fertility, or fecundity of salmonid fish.

E. Early Life Stages

Determining the dissolved oxygen requirements for salmonids, many of which have embryonic and larval stages that develop while buried in the gravel of streams and lakes, is complicated by complex relationships between the dissolved oxygen supplies in the gravel and the overlying water. The dissolved oxygen supply of embryos and larvae can be depleted even when the dissolved oxygen concentration in the overlying body of water is otherwise acceptable. Intergravel dissolved oxygen is dependent upon the balance between the combined respiration of gravel-dwelling organisms, from bacteria to fish embryos, and the rate of dissolved oxygen supply, which is dependent upon rates of water percolation and convection, and dissolved oxygen diffusion.

Water flow past salmonid eggs influences the dissolved oxygen supply to the microenvironment surrounding each egg. Regardless of dissolved oxygen concentration in the gravel, flow rates below 100 cm/hr directly influence the oxygen supply in the microenvironment and hence the size at hatch of salmonid fish. At dissolved oxygen levels below 6 mg/l the time from fertilization to hatch is longer as water flow decreases (Silver et al., 1963; Shumway et al., 1964).

The dissolved oxygen requirements for growth of salmonid embryos and larvae have not been shown to differ appreciably from those of older salmonids. Under conditions of adequate water flow (≥100 cm/hr), the weight attained by salmon and trout larvae prior to feeding (swimup) is decreased less than 10 percent by continuous exposure to concentrations down to 3 mg/l (Brannon, 1965; Chapman and Shumway, 1978). The considerable developmental delay which occurs at low dissolved oxygen conditions could have survival and growth implications if the time of emergence from gravel, or first feeding, is critically related to the presence of specific food organisms, stream flow, or other factors (Carlson and Siefert, 1974; Siefert and Spoor, 1974). Effects of low dissolved oxygen on early life stages are probably most significant during later embryonic development when critical dissolved oxygen concentrations are highest (Alderdice et al., 1958) and during the first few months post-hatch when growth rates are usually highest. The latter authors studied the effects of 7-day exposure of embryos to low dissolved oxygen at various stages during incubation at otherwise high dissolved oxygen concentrations. They found no effect of 7-day exposure at concentrations above 2 mg/l (at a water flow of 85 cm/hr).

Embryos of mountain whitefish suffered severe mortality at a mean dissolved oxygen concentration of 3.3 mg/l (2.8 mg/l minimum) and some reduction in survival was noted at 4.6 mg/l (3.8 mg/l minimum); at 4.6 mg/l, hatching was delayed by 1 to 2 weeks (Sieffert et al., 1974). Delayed hatching resulted in poorer growth at the end of the test, even at dissolved oxygen concentrations of 6 mg/l.

Evaluating intergravel dissolved oxygen concentrations is difficult because of the great spatial and temporal variability produced by differences in stream flow, bottom topography, and gravel composition. Even within the same redd, dissolved oxygen concentrations can vary by 5 or 6 mg/l at a given time (Koski, 1965). Over several months, Koski repeatedly measured the dissolved oxygen concentrations in over 30 coho salmon redds and the overlying stream water in three small, forested (unlogged) watersheds. The results of these measurements indicated that the average intraredd dissolved oxygen concentration was about 2 mg/l below that of the overlying water. The minimum concentrations measured in the redds averaged about 3 mg/l below those of the overlying water and probably occurred during the latter period of intergravel development when water temperatures were warmer, larvae larger, and overlying dissolved oxygen concentrations lower.

Coble (1961) buried steelhead trout eggs in streambed gravel, monitored nearby intergravel dissolved oxygen and water velocity, and noted embryo survival. There was a positive correlation between dissolved oxygen concentration, water velocity, and embryo survival. Survival ranged from 16 to 26 percent whenever mean intergravel dissolved oxygen concentrations were below 6 mg/l or velocities were below 20 cm/hr; at dissolved oxygen concentrations above 6 mg/l and velocities over 20 cm/hr, survival ranged from 36 to 62 percent. Mean reductions in dissolved oxygen concentration between stream and intergravel waters averaged about 5 mg/l as compared to the 2 mg/l average reduction observed by Koski (1965) in the same stream. One explanation for the different results is that the intergravel water flow may have been higher in the natural redds studied by Koski (not determined) than in the artificial redds of Coble's investigation. Also, the density of eggs near the sampling point may have been greater in Coble's simulated redds.

A study of dissolved oxygen concentrations in brook trout redds was conducted in Pennsylvania (Hollander, 1981). Brook trout generally prefer areas of groundwater upwelling for spawning sites (Witzel and MacCrimmon, 1983). Dissolved oxygen and temperature data offer no indication of groundwater flow in Hollender's study areas, however, so that differences between water column and intergravel dissolved oxygen concentrations probably represent intergravel dissolved oxygen depletion. Mean dissolved oxygen concentrations in redds averaged 2.1, 2.8, and 3.7 mg/liter less than the surface water in the three portions of the study. Considerable variation of intergravel dissolved oxygen concentration was observed between redds and within a single redd. Variation from one year to another suggested that dissolved oxygen concentrations will show greater intergravel depletion during years of low water flow.

Until more data are available, the dissolved oxygen concentration in the intergravel environment should be considered to be at least 3 mg/l lower than the oxygen concentration in the overlying water. The 3 mg/l differential is assumed in the criteria, since it reasonably represents the only two available studies based on observations in natural redds (Koski, 1965; Hollender, 1981). When siltation loads are high, such as in logged or agricultural watersheds, lower water velocity within the gravel could additionally reduce dissolved oxygen concentrations around the eggs. If either greater or lesser differentials are known or expected, the criteria should be altered accordingly.

F. Behavior

Ability of chinook and coho salmon to detect and avoid abrupt differences in dissolved oxygen concentrations was demonstrated by Whitmore et al. (1960). In laboratory troughs, both species showed strong preference for oxygen levels of 9 mg/l or higher over those near 1.5 mg/l; moderate selection against 3.0 mg/l was common and selection against 4.5 and 6.0 mg/l was sometimes detected.

The response of young Atlantic salmon and brown trout to low dissolved oxygen depended on their age; larvae were apparently unable to detect and avoid water of low dissolved oxygen concentration, but fry 6-16 weeks of age showed a marked avoidance of concentrations up to 4 mg/l (Bishai, 1962). Older fry (26 weeks of age) showed avoidance of concentrations up to 3 mg/l.

In a recent study of the rainbow trout sport fishery of Lake Taneycomo, Missouri, Weithman and Haas (1984) have reported that reductions in minimum daily dissolved oxygen concentrations below 6 mg/l are related to a decrease in the harvest rate of rainbow trout from the lake. Their data suggest that lowering the daily minimum from 6 mg/l to 5, 4, and 3 mg/l reduces the harvest rate by 20, 40, and 60 percent, respectively. The authors hypothesized that the reduced catch was a result of reduction in feeding activity. This mechanism of action is consistent with Thatcher's (1974) observation of lower activity of coho salmon at 5 mg/l in laboratory growth studies and the finding of Warren et al. (1973) that growth impairment produced by low dissolved oxygen appears to be primarily a function of lower food intake.

A three-year study of a fishery on planted rainbow trout was published by Heimer (1984). This study found that the catch of planted trout increased during periods of low dissolved oxygen in American Falls reservoir on the Snake River in Idaho. The author concluded that the fish avoided areas of low dissolved oxygen and high temperature and the increased catch rate was a result of the fish concentrating in areas of more suitable oxygen supply and temperature.

G. Swimming

Effects of dissolved oxygen concentrations on swimming have been demonstrated by Davis et al. (1963). In their studies, the maximum sustained swimming speeds (in the range of 30 to 45 cm/sec) of juvenile coho salmon were reduced by 8.4, 12.7, and 19.9 percent at dissolved oxygen concentrations of 6, 5, and 4 mg/l, respectively. Over a temperature range from 10 to 20°C, effects were slightly more severe at cooler temperatures. Jones (1971) reported 30 and 43 percent reductions of maximal swimming speed of rainbow trout at dissolved oxygen concentrations of 5.1 (14°C) and 3.8 (22°C) mg/l, respectively. At lower swimming speeds (2 to 4 cm/sec), coho and chinook salmon at 20°C were generally able to swim for 24 hours at dissolved oxygen concentrations of 3 mg/l and above (Katz et al., 1958). Thus, the significance of lower dissolved oxygen concentrations on swimming depends on the level of swimming performance required for the survival, growth, and reproduction of salmonids. Failure to escape from predation or to negotiate a swift portion of a spawning migration route may be considered an indirect lethal effect and, in this regard, reductions of maximum swimming performance can be very important. With these exceptions, moderate levels of swimming activity required by salmonids are apparently little affected by concentrations of dissolved oxygen that are otherwise acceptable for growth and reproduction.

H. Field Studies

Field studies of salmonid populations are almost non-existent with respect to effects of dissolved oxygen concentrations. Some of the systems studied by Ellis (1937) contained trout, but of those river systems in which trout or other salmonids were most likely (Columbia River and Upper Missouri River) no stations were reported with dissolved oxygen concentrations below 5 mg/l, and 90 percent of the values exceeded 7 mg/l.

III. Non-Salmonids

The amount of data describing effects of low dissolved oxygen on non-salmonid fish is more limited than that for salmonids, yet must cover a group of fish with much greater taxonomic and physiological variability. Salmonid criteria must provide for the protection and propagation of 38 species in 7 closely related genera; the non-salmonid criteria must provide for the protection and propagation of some 600 freshwater species in over 40 diverse taxonomic families. Consequently, the need for subjective technical judgment is greater for the non-salmonids.

Many of the recent, most pertinent data have been obtained for several species of Centrarchidae (sunfish), northern pike, channel catfish, and the fathead minnow. These data demonstrate that the larval stage is generally the most sensitive life stage. Lethal effects on larvae have been observed at dissolved oxygen concentrations that may only slightly affect growth of juveniles of the same species.

A. Physiology

Several studies of the relationship between low dissolved oxygen concentrations and resting oxygen consumption rate constitute the bulk of the physiological data relating to the effect of hypoxia on nonsalmonid fish. A reduction in the resting metabolic rate of fish is generally believed to represent a marked decrease in the scope for growth and activity, a net decrease in the supply of oxygen to the tissues, and perhaps a partial shift to anaerobic energy sources. The dissolved oxygen concentration at which reduction in resting metabolic rate first appears is termed the critical oxygen concentration.

Studies with brown bullhead (Grigg, 1969), largemouth bass (Cech et al., 1979), and goldfish and carp (Beamish, 1964), produced estimates of critical dissolved oxygen concentrations for these species. For largemouth bass, the critical dissolved oxygen concentrations were 2.8 mg/l at 30°C, < 2.6 mg/l at 25°C, and < 2.3 mg/l at 20°C. For brown bullheads the critical concentration was about 4 mg/l. Carp displayed critical oxygen concentrations near 3.4 and 2.9 mg/l at 10 and 20°C, respectively, and goldfish critical concentrations of dissolved oxygen were about 1.8 and 3.5 mg/l at 10 and 20°C, respectively. A general summary of these data suggest critical dissolved oxygen concentrations between 2 and 4 mg/l, with higher temperatures usually causing higher critical concentrations.

Critical evaluation of the data of Beamish (1964) suggest that the first sign of hypoxic stress is not the decrease in oxygen consumption, but rather an increase, perhaps as a result of metabolic cost of passing an increased ventilation volume over the gills. These increases were seen in carp at 5.8 mg/l at 20°C and at 4.2 mg/l at 10°C.

B. Acute Lethal Concentrations

Based on the sparse data base describing acute effects of low dissolved oxygen concentrations on nonsalmonids, many non-salmonids appear to be considerably less sensitive than salmonids. Except for larval forms, no non-salmonids appear to be more sensitive than salmonids. Spoor (1977) observed lethality of largemouth bass larvae at a dissolved oxygen concentration of 2.5 mg/l after only a 3-hr exposure. Generally, adults and juveniles of all species studied survive for at least a few hours at concentrations of dissolved oxygen as low as 3 mg/l. In most cases, no mortality results from acute exposures to 3 mg/l for the 24- to 96-h duration of the acute tests. Some non-salmonid fish appear to be able to survive a several-day exposure to concentrations below 1 mg/l (Moss and Scott, 1961; Downing and Merkens, 1957), but so little is known about the latent effects of such exposure that short-term survival cannot now be used as an indication of acceptable dissolved oxygen concentrations. In addition to the unknown latent effects of exposure to very low dissolved oxygen concentrations, there are no data on the effects of repeated short-term exposures. Most importantly, data on the tolerance to low dissolved oxygen concentrations are available for only a few of the numerous species of non-salmonid fish.

C. Growth

Stewart et al. (1967) conducted several growth studies with juvenile largemouth bass and observed reduced growth at 5.9 mg/l and lower concentrations. Five of six experiments included dissolved oxygen concentrations between 5 and 6 mg/l; dissolved oxygen concentrations of 5.1 and 5.4 mg/l produced reductions in growth rate of 20 and 14 percent, respectively, but concentrations of 5.8 and 5.9 mg/l had essentially no effect on growth. The efficiency of food conversion was not reduced until dissolved oxygen concentrations were much lower, indicating that decreased food consumption was the primary cause of reduced growth.

When channel catfish fingerlings held at 8, 5, and 3 mg/l were fed as much as they could eat in three daily feedings, there were significant reductions in feeding and weight gain (22 percent) after a 6 week exposure to 5 mg/l (Andrews et al., 1973). At a lower feeding rate, growth after 14 weeks was reduced only at 3 mg/l. Fish exposed to 3 mg/l swam lethargically, fed poorly and had reduced response to loud noises. Raible (1975) exposed channel catfish to several dissolved oxygen concentrations for up to 177 days and observed a graded reduction in growth at each concentration below 6 mg/l. However, the growth pattern for 6.8 mg/l was comparable to that at 5.4 mg/l. He concluded that each mg/l increase in dissolved oxygen concentrations between 3 and 6 mg/l increased growth by 10 to 13 percent.

Carlson et al. (1980) studied the effect of dissolved oxygen concentration on the growth of juvenile channel catfish and yellow perch. Over periods of about 10 weeks, weight gain of channel catfish was lower than that of control fish by 14, 39, and 54 percent at dissolved oxygen concentrations of 5.0, 3.4, and 2.1 mg/l, respectively. These differences were produced by decreases in growth rate of 5, 18, and 23 percent (JRB Associates, 1984), pointing out the importance of differentiating between effects on weight gain and effects on growth rate. When of sufficient duration, small reductions in growth rate can have large effects on relative weight gain. Conversely, large effects on growth rate may have little effect on annual weight gain if they occur only over a small proportion of the annual growth period. Yellow perch appeared to be more tolerant to low dissolved oxygen concentrations, with reductions in weight gain of 2, 4, and 30 percent at dissolved oxygen concentrations of 4.9, 3.5, and 2.1 mg/l, respectively.

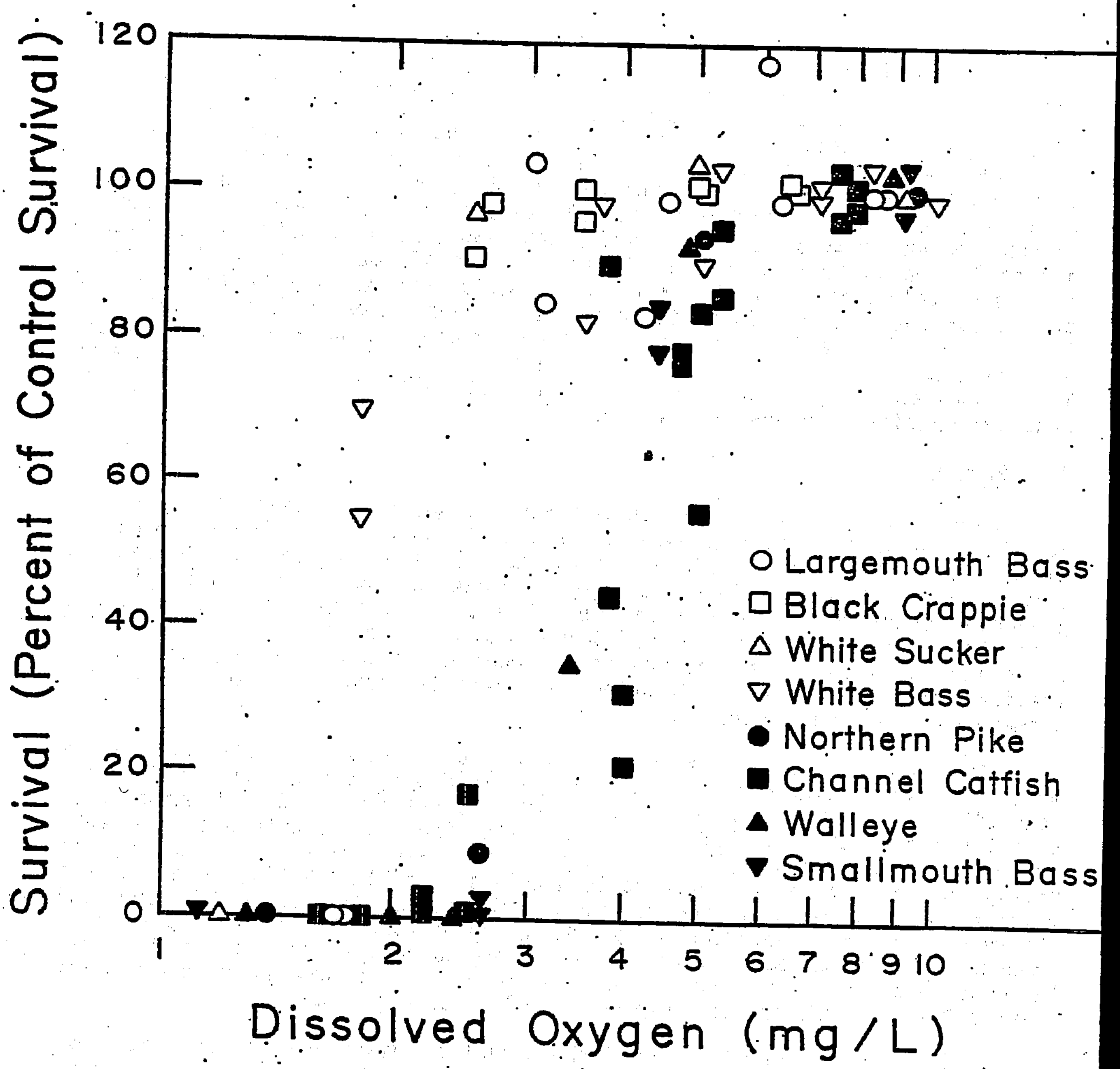

Figure 1. Effect of continuous exposure to various mean dissolved oxygen concentrations on survival of embryonic and larval stages of eight species of nonsalmonid fish. Minima recorded in these tests averaged about 0.3 mg/l below the mean concentrations.

The data of Stewart et al. (1967), Carlson et al. (1980), and Adelman and Smith (1972) were analyzed to determine the relationship between growth rate and dissolved oxygen concentration (JRB Associates, 1984). Yellow perch appeared to be very resistant to influences of low dissolved oxygen concentrations, northern pike may be about as sensitive as salmonids, while largemouth bass and channel catfish are intermediate in their response (Table 4). The growth rate relations modeled from Adelman and Smith are based on only four data points, with none in the critical dissolved oxygen region from 3 to 5 mg/l. Nevertheless, these growth data for northern pike are the best available for nonsalmonid coldwater fish. Adelman and Smith observed about a 65 percent reduction in growth of juvenile northern pike after 6-7 weeks at dissolved oxygen concentrations of 1.7 and 2.6 mg/l. At the next higher concentration (5.4 mg/l), growth was reduced 5 percent.

Table 4. Percent reduction in growth rate of some nonsalmonid fish held at various dissolved oxygen concentrations expressed as the median value from n tests with each species (calculated from JRB Associates, 1984).

Dissolved Oxygen (mg/l)	Species (number of tests)			
	Northern Pike (1)	Largemouth Bass (6)	Channel Catfish (1)	Yellow Perch (1)
9	0	0	0	0
8	1	0	0	0
7	4	0	1	0
6	9	0	3	0
5	16	1	7	0
4	25	9	13	0
3	35	17	20	7
2	--	51	29	22
Median Temp (°C)	19	26	25	20

Brake (1972) conducted a series of studies on juvenile largemouth bass in two artificial ponds to determine the effect of reduced dissolved oxygen concentration on consumption of mosquitofish and growth during 10 2-week exposures. The dissolved oxygen in the control pond was maintained near air-saturation (8.3 to 10.4 mg/l) and the other pond contained mean dissolved oxygen concentrations from 4.0 to 6.0 mg/l depending upon the individual test. The temperature, held near the same level in both ponds for each test, ranged from 13 to 27°C. Food consumption and growth rates of the juvenile bass, maintained on moderate densities of forage fish, increased with temperature and decreased at the reduced dissolved oxygen concentrations except at 13°C. Exposure to that temperature probably slowed metabolic processes of the bass so much that their total metabolic rates were not limited by dissolved oxygen except at very low concentrations. These largemouth bass studies clearly support the idea that higher temperatures exacerbate the adverse effects of low dissolved oxygen on the growth rate of fish (Table 5). Comparisons of Brake's pond studies with the laboratory growth studies of Stewart et al. (1967) suggest that laboratory growth studies may significantly underestimate the adverse effect of low dissolved oxygen on fish growth. Stewart's six studies with largemouth bass are summarized in Table 4 and Brake's data are presented in Table 5. All of Stewart's tests were conducted at 26°C, about the highest temperature in Brake's studies, but comparison of the data show convincingly that at dissolved oxygen concentrations between 4 and 6 mg/l the growth rate of bass in ponds was reduced 17 to 34 percent rather than the 1 to 9 percent seen in the laboratory studies. These results suggest that the ease of food capture in laboratory studies may result in underestimating effects of low dissolved oxygen on growth rates in nature.

Table 5. Effect of temperature on the percent reduction in growth rate of largemouth bass exposed to various dissolved oxygen concentrations in ponds (after Brake, 1972; JRB Associates, 1984).

Temperature (°C)	Percent Reduction in Growth Rate at		
	4.2 ± 0.2 mg/l	4.9 ± 0.2 mg/l	5.8 ± 0.2 mg/l
13.3	0	--	--
13.6	--	--	7
16.3	--	18	--
16.7	--	--	15
18.1	--	19	--
18.6	--	34	--
18.7	18	--	--
23.3	26	--	--
26.7	--	--	17
27.4	31	--	--

Brett and Blackburn (1981) reanalyzed the growth data previously published by other authors for largemouth bass, carp, and coho salmon in addition to their own results for young coho and sockeye salmon. They concluded for all species that above a critical level ranging from 4.0 to 4.5 mg/l, decreases in growth rate and food conversion efficiency were not statistically significant in these tests of relatively short duration (6 to 8 weeks) under the pristine conditions of laboratory testing. EPA believes that a more accurate estimate of the dissolved oxygen concentrations that have no effect on growth and a better estimate of concentration:effect relationships can be obtained by curve-fitting procedures (JCB Associates, 1984) and by examining these results from a large number of studies. Brett and Blackburn added an additional qualifying statement that it was not the purpose of their study to seek evidence on the acceptable level of dissolved oxygen in nature because of the problems of environmental complexity involving all life stages and functions, the necessary levels of activity to survive in a competitive world, and the interaction of water quality (or lack of it) with varying dissolved oxygen concentrations. Their cautious concern regarding the extrapolation to the real world of results obtained under laboratory conditions is consistent with that of numerous investigators.

D. Reproduction

A life-cycle exposure of the fathead minnow beginning with 1- to 2-month old juveniles was conducted and effects of continuous low dissolved oxygen concentrations on various life stages indicated that the most sensitive stage was the larval stage (Brungs, 1971). No spawning occurred at 1 mg/l, and the number of eggs produced per female was reduced at 2 mg/l but not at higher concentrations. Where spawning occurred, the percentage hatch of embryos (81-89 percent) was not affected when the embryos were exposed to the same concentrations as their parents. Hatching time varied with temperature, which was not controlled, but with decreasing dissolved oxygen concentration the average incubation time increased gradually from the normal 5 to nearly 8 days. Mean larval survival was 6 percent at 3 mg/l and 25 percent at 4 mg/l. Mean survival of larvae at 5 mg/l was 66 percent as compared to 50 percent at control dissolved oxygen concentrations. However, mean growth of surviving larvae at 5 mg/l was about 20 percent lower than control larval growth. Siefert and Herman (1977) exposed mature black crappies to constant dissolved oxygen concentrations from 2.5 mg/l to saturation and temperatures of 13-20°C. Number of spawnings, embryo viability, hatching success, and survival through swim-up were similar at all exposures.

E. Early Life Stages

Larval and juvenile non-salmonids are frequently more sensitive to exposures to low dissolved oxygen than are other life stages. Peterka and Kent (1976) conducted semi-controlled experiments at natural spawning sites of northern pike, bluegill, pumpkinseed, and smallmouth bass in Minnesota. Dissolved oxygen concentrations were measured 1 and 10 cm from the bottom, with observations being made on hatching success and survival of embryos, sac larvae, and, in some instances, larvae. Controlled exposure for up to 8 hours was performed *in situ* in small chambers with the dissolved oxygen controlled by nitrogen stripping. For all species tested, tolerance to short-term exposure to low concentrations decreased from embryonic to larval stages. Eight-hour exposure of embryos and larvae of northern pike to dissolved oxygen concentrations caused no mortality of embryos at 0.6 mg/l but was 100 percent lethal to sac-larvae and larvae. The most sensitive stage, the larval stage, suffered complete mortality following 8 hours at 1.6 mg/l; the next higher concentration, 4 mg/l, produced no mortality. Smallmouth bass were at least as sensitive, with nearly complete mortality of sac-larvae resulting from 6-hour exposure to 2.2 mg/l, but no mortality occurred after exposure to 4.2 mg/l. Early life stages of bluegill were more hardy, with embryos tolerating 4-hour exposure to 0.5 mg/l, a concentration lethal to sac-larvae; sac-larvae survived similar exposure to 1.8 mg/l, however. Because the most sensitive stage of northern pike was the later larval stage, and because the younger sac-larval stages of smallmouth bass and bluegill were the oldest stages tested, the tests with these latter species may not have included the most sensitive stage. Based on these tests, 4 mg/l is tolerated, at least briefly, by northern pike and may be tolerated by smallmouth bass, but concentrations as high as 2.2 mg/l are lethal.

Several studies have provided evidence of mortality or other significant damage to young non-salmonids as a result of a few weeks exposure to dissolved oxygen concentrations in the 3 to 6 mg/l range. Siefert et al. (1973) exposed larval northern pike to various dissolved oxygen concentrations at 15 and 19°C and observed reduced survival at concentrations as high as 2.9 and 3.4 mg/l. Most of the mortality at these concentrations occurred at the time the larvae initiated feeding. Apparently the added stress of activity at that time or a greater oxygen requirement for that life stage was the determining factor. There was a marked decrease in growth at concentrations below 3 mg/l. In a similar study lasting 20 days, survival of walleye embryos and larvae was reduced at 3.4 mg/l (Siefert and Spoor, 1974), and none survived at lower concentrations. A 20 percent reduction in the survival of smallmouth bass embryos and larvae occurred at a concentration of 4.4 mg/l (Siefert et al., 1974) and at 2.5 mg/l all larvae died in the first 5 days after hatching. At 4.4 mg/l hatching occurred earlier than in the controls and growth among survivors was reduced. Carlson and Siefert (1974) concluded that concentrations from 1.7 to 6.3 mg/l reduced the growth of early stages of the largemouth bass by 10 to 20 percent. At concentrations as high as 4.5 mg/l, hatching was premature and feeding was delayed; both factors could indirectly influence survival, especially if other stresses were to occur simultaneously. Carlson et al. (1974) also observed that embryos and larvae of channel catfish are sensitive to low dissolved oxygen during 2- or 3-week exposures. Survival at 25°C was slightly reduced at 5 mg/l and significantly reduced at 4.2 mg/l. At 28°C survival was slightly reduced at 3.8, 4.6, and 5.4 mg/l; total mortality occurred at 2.3 mg/l. At all reduced dissolved oxygen concentrations at both temperatures, embryo pigmentation was lighter, incubation period was extended, feeding was delayed, and growth was reduced. No effect of dissolved oxygen concentrations as low as 2.5 mg/l was seen on survival of embryonic and larval black crappie (Sieffert and Herman, 1977). Other tolerant species are the white bass and the white sucker, both of which evidenced adverse effect to embryo larval exposure only at dissolved oxygen concentrations of 1.8 and 1.2 mg/l, respectively (Sieffert et al., 1974; Sieffert and Spoor, 1974).

Data (Figure 1) on the effects of dissolved oxygen on the survival of embryonic and larval nonsalmonid fish show some species to be tolerant (largemouth bass, white sucker, black crappie, and white bass) and others nontolerant (channel catfish, walleye, northern pike, smallmouth bass). The latter three species are often included with salmonids in a grouping of sensitive coldwater fish; these data tend to support that placement.

F. Behavior

Largemouth bass in laboratory studies (Whitmore et al., 1960) showed a slight tendency to avoid concentrations of dissolved oxygen of 3.0 and 4.6 mg/l and a definite avoidance of 1.5 mg/l. Bluegills avoided a concentration of 1.5 mg/l but not higher concentrations. The environmental significance of such a response is unknown, but if large areas are deficient in dissolved oxygen this avoidance would probably not greatly enhance survival. Spoor (1977) exposed largemouth bass embryos and larvae to low dissolved oxygen for brief exposures of a few hours. At 23 to 24°C and 4 to 5 mg/l, the normally quiescent, bottom-dwelling yolk-sac larvae became very active and swam vertically to a few inches above the substrate. Such behavior in natural systems would probably cause significant losses due to predation and simple displacement from the nesting area.

G. Swimming

Effects of low dissolved oxygen on the swimming performance of largemouth bass were studied by Katz et al. (1959) and Dahlberg et al. (1968). The results in the former study were highly dependent upon season and temperature, with summer tests at 25°C finding no effect on continuous swimming for 24 hrs at 0.8 ft/sec unless dissolved oxygen concentrations fell below 2 mg/l. In the fall, at 20°C, no fish were able to swim for a day at 2.8 mg/l, and in the winter and 16° no fish swam for 24 hours at 5 mg/l. These results are consistent with those seen in salmonids in that swimming performance appears to be more sensitive to low dissolved oxygen at lower temperatures.

Dahlberg et al. (1968) looked at the effect of dissolved oxygen on maximum swimming speed at temperatures near 25°C. They reported slight effects (less than 10% reduction in maximum swimming speed) at concentrations between 3 and 4.5 mg/l, moderate reduction (16-20%) between 2 and 3 mg/l and severe reduction (30-50%) at 1 to 1.5 mg/l.

H. Field Studies

Ellis (1937) reported results of field studies conducted at 982 stations on freshwater streams and rivers during the months of June through September, 1930-1935. During this time, numerous determinations of dissolved oxygen concentrations were made. He concluded that 5 mg/l appeared to be the lowest concentration which may reasonably be expected to maintain varied warmwater fish species in good condition in inland streams. Ellis (1944) restated his earlier conclusion and also added that his study had included the measurement of dissolved oxygen concentrations at night and various seasons. He did not specify the frequency or proportion of diurnal or seasonal sampling, but the mean number of samples over the 5-year study was about seven samples per station.

Brinley (1944) discussed a 2-year biological survey of the Ohio River Basin. He concluded that in the zone where dissolved oxygen is between 3 and 5 mg/l the fish are more abundant than at lower concentrations, but show a tendency to sickness, deformity, and parasitization. The field results show that the concentration of 5 mg/l seems to represent a general dividing line between good and bad conditions for fish.

A three-year study of fish populations in the Wisconsin River indicated that sport fish (percids and centrarchids) constituted a significantly greater proportion of the fish population at sites having mean summer dissolved oxygen concentrations greater than 5 mg/l than at sites averaging below 5 mg/l (Coble, 1982). The differences could not be related to any observed habitat variables other than dissolved oxygen concentration.

These three field studies all indicate that increases in dissolved oxygen concentrations above 5 mg/l do not produce noteworthy improvements in the composition, abundance, or condition of non-salmonid fish populations, but that sites with dissolved oxygen concentrations below 5 mg/l have fish assemblages with increasingly poorer population characteristics as the dissolved oxygen concentrations become lower. It cannot be stressed too strongly that these field studies lack definition with respect to the actual exposure conditions experienced by the resident populations and the lack of good estimates for mean and minimum exposure concentrations over various periods precludes the establishment of numerical criteria based on these studies. The results of these semi-quantitative field studies are consistent with the criteria derived later in this document.

IV. Invertebrates

As stated earlier, there is a general paucity of information on the tolerance of the many forms of freshwater invertebrates to low dissolved oxygen. Most available data describe the relationship between oxygen concentration and oxygen consumption or short-term survival of aquatic larvae of insects. These data are further restricted by their emphasis on species representative of relatively fast-flowing mountain streams.

One rather startling feature of these data is the apparently high dissolved oxygen requirement for the survival of some species. Before extrapolating from these data one should be cautious in evaluating the respiratory mode(s) of the species, its natural environment, and the test environment. Thus, many nongilled species respire over their entire body surface while many other species are gilled. Either form is dependent upon the gradient of oxygen across the respiratory surface, a gradient at least partially dependent upon the rate of replacement of the water immediately surrounding the organism. Some insects, such as some members of the mayfly genus, Baetis, are found on rocks in extremely swift currents; testing their tolerance to low dissolved oxygen in laboratory apparatus at slower flow rats may contribute to their inability to survive at high dissolved oxygen concentrations. In addition, species of insects that utilize gaseous oxygen, either from bubbles or surface atmosphere, may not be reasonably tested for tolerance of hypoxia if their source of gaseous oxygen is deprived in the laboratory tests.

In spite of these potential problems, the dissolved oxygen requirements for the survival of many species of aquatic insects are almost certainly greater than those of most fish species. Early indication of the high dissolved oxygen requirements of some aquatic insects appeared in the research of Fox et al. (1937) who reported critical dissolved oxygen concentrations for mayfly nymphs in a static test system. Critical concentrations for six species ranged from 2.2 mg/l to 17 mg/l; three of the species had critical concentrations in excess of air saturation. These data suggest possible extreme sensitivity of some species and also the probability of unrealistic conditions of water flow. More recent studies in water flowing at 10 cm/sec indicate critical dissolved oxygen concentrations for four species of stonefly are between 7.3 and 4.8 mg/l (Benedetto, 1970).

In a recent study of 22 species of aquatic insects, Jacob et al. (1984) reported 2-5 hour LC50 values at unspecified "low to moderate" flows in a stirred exposure chamber, but apparently with no flow of replacement water. Tests were run at one or more of five temperatures from 12 to 30°C; some species were tested at only one temperature, others at as many as four. The median of the 22 species mean LC50s was about 3 mg/l, with eight species having an average LC50 below 1 mg/l and four in excess of 7 mg/l. The four most sensitive species were two mayfly species and two caddisfly species. The studies of Fox et al. (1937), Benedetto (1970), and Jacob et al. (1984) were all conducted with European species, but probably have general relevance to North American habitats. A similar oxygen consumption study of a North American stonefly (Kapoor and Griffiths, 1975) indicated a possible critical dissolved oxygen concentration of about 7 mg/l at a flow rate of 0.32 cm/sec and a temperature of 20°C.

One type of behavioral observation provides evidence of hypoxic stress in aquatic insects. As dissolved oxygen concentrations decrease, many species of aquatic insects can be seen to increase their respiratory movements, movements that provide for increased water flow over the respiratory surfaces. Fox and Sidney (1953) reported caddisfly respiratory movements over a range of dissolved oxygen from 9 to 1 mg/l. A dissolved oxygen decrease to 5 mg/l doubled the number of movements and at 1 to 2 mg/l the increase was 3- to 4-fold.

Similar data were published by Knight and Gaufin (1963) who studied a stonefly common in the western United States. Significant increases occurred below 5 mg/l at 16°C and below 2 mg/l at 10°C. Increases in movements occurred at higher dissolved oxygen concentrations when water flow was 1.5 cm/sec than 7.6 cm/sec, again indicating the importance of water flow rate on the respiration of aquatic insects. A subsequent paper by Knight and Gaufin (1965) indicated that species of stonefly lacking gills are more sensitive to low dissolved oxygen than are gilled forms.

Two studies that provide the preponderance of the current data on the acute effects of low dissolved oxygen concentrations on aquatic insects are those of Gaufin (1973) and Nebeker (1972) which together provide reasonable 96-hr LC50 dissolved oxygen concentrations for 26 species of aquatic insects (Table 6). The two studies contain variables that make them difficult to compare or evaluate fully. Test temperatures were 6.4°C in Gaufin's study and 18.5°C in Nebeker's. Gaufin used a vacuum degasser while Nebeker used a 30-foot stripping column that probably produced an unknown degree of supersaturation with nitrogen. The water velocity is not given in either paper, although flow rates are given but test chamber dimensions are not clearly specified. The overall similarity of the test results suggests that potential supersaturation and lower flow volume in Nebeker's tests did not have a significant effect on the results.

Because half of the insect species tested had 96-h LC50 dissolved oxygen concentrations between 3 and 4 mg/l it appears that these species (collected in Montana and Minnesota) would require at least 4 mg/l dissolved oxygen to ensure their survival. The two most sensitive species represent surprisingly diverse habitats, Ephemerella doddsi is found in swift rocky streams and has an LC50 of 5.2 mg/l while the pond mayfly, Callibaetis montanus, has an LC50 of 4.4 mg/l. It is possible that the test conditions represented too slow a flow for E. doddsi and too stressful flow conditions for C. montanus.

Table 6. Acutely lethal concentrations of dissolved oxygen to aquatic insects.

Species	96-h LC50 (mg/l)	Source*
Stonefly		
Acroneuria pacifica	1.6 (H)**	G
Acroneuria lycorias	3.6	N
Acrynopteryx aurea	3.3 (H)	G
Arcynopteryx parallela	< 2 (H)	G
Diura knowltoni	3.6 (L)	G
Nemoura cinctipes	3.3 (H)	G
Pteronarcys californica	3.9 (L)	G
Pteronarcys californica	3.2 (H)	G
Pteronarcys dorsata	2.2	N
Pteronarcella badia	2.4 (H)	G
Mayfly		
Baetisca laurentina	3.5	N
Callibaetis montanus	4.4 (L)	G
Ephemerella doddsi	5.2 (L)	G
Ephemerella grandis	3.0 (H)	G
Ephemerella subvaria	3.9	N
Hexagenia limbata	1.8 (H)	G
Hexagenia limbata	1.4	N
Leptophlebia nebulosa	2.2	N
Caddisfly		
Brachycentrus occidentalis	< 2 (L)	G
Drusinus sp.	1.8 (H)	G
Hydropsyche sp.	3.6 (L)	G
Hydropsyche betteri	2.9 (21°C)	N
Hydropsyche betteri	2.6 (18.5°C)	N
Hydropsyche betteri	2.3 (17°C)	N
Hydropsyche betteri	1.0 (10°C)	N
Lepidostoma sp.	< 3 (H)	G
Limnophilus ornatus	3.4 (L)	G
Neophylax sp.	3.8 (L)	G
Neothremma alicia	1.7 (L)	G
Diptera		
Simulium vittatum	3.2 (L)	G
Tanytarsus dissimilis	< 0.6	N

* G = Gaufin (1973) -- all tests at 6.4°C.
N = Nebeker (1972) -- all tests at 18.5°C except as noted/flow 125 ml/min.

** H = high flow (1000 ml/min); L = low flow (500 ml/min).

Other freshwater invertebrates have been subjected to acute hypoxic stress and their LC50 values determined. Gaufin (1973) reported a 96-h LC50 for the amphipod *Gammarus limnaeus* of < 3 mg/l. Four other crustaceans were studied by Sprague (1963) who reported the following 24-h LC50s: 0.03 mg/l, *Asellus intermedius*; 0.7 mg/l, *Hyalella azteca*; 2.2 mg/l, *Gammarus pseudolimnaeus*; and 4.3 mg/l, *Gammarus fasciatus*. The range of acute sensitivities of these species appears similar to that reported for aquatic insects.

There are few long-term studies of freshwater invertebrate tolerance to low dissolved oxygen concentrations. Both Gaufin (1973) and Nebeker (1972) conducted long-term survival studies with insects, but both are questioned because of starvation and potential nitrogen supersaturation, respectively. Gaufin's data for eight Montana species and 17 Utah species suggest that 4.9 mg/l and 3.3 mg/l, respectively, would provide for 50 percent survival for from 10 to 92 days. Nebeker lists 30-d LC50 values for five species, four between 4.4 and 5.0 mg/l and one < 0.5 mg/l. Overall, these data indicate that prolonged exposure to dissolved oxygen concentrations below 5 mg/l would have deterimental effects on a large proportion of the aquatic insects common in areas like Minnesota, Montana, and Utah. Information from other habitat types and geographic locations would provide a broader picture of invertebrate dissolved oxygen requirements.

A more classic toxicological protocol was used by Homer and Waller (1983) in a study of the effects of low dissolved oxygen on *Daphna magna*. In a 26-d chronic exposure test, they reported that 1.8 mg/l significantly reduced fecundity and 2.7 mg/l caused a 17 percent reduction in final weight of adults. No effect was seen at 3.7 mg/l.

In summarizing the state of knowledge regarding the relative sensitivity of fish and invertebrates to low dissolved oxygen, it seems that some species of insects and other crustaceans are killed at concentrations survived by all species of fish tested. Thus, while most fish will survive exposure to 3 mg/l, many species of invertebrates are killed by concentrations as high as 4 mg/l. The extreme sensitivity of a few species of aquatic inects may be an artifact of the testing environment. Those sensitive species common to swift flowing, coldwater streams may require very high concentrations of dissolved oxygen. On the other hand, those stream habitats are probably among the least likely to suffer significant dissolved oxygen depletion.

Long-term impacts of hypoxia are less well known for invertebrates than for fish. Concentrations adequate to avoid impairment of fish production probably will provide reasonable protection for invertebrates as long as lethal concentrations are avoided.

V. Other Considerations

A. Effects of Fluctuations

Natural dissolved oxygen concentrations fluctuate on a seasonal and daily basis, while in most laboratory studies the oxygen levels are held essentially constant. In two studies on the effects of daily oxygen cycles the authors concluded that growth of fish fed unrestricted rations was markedly less than would be estimated from the daily mean dissolved oxygen concentrations

(Fisher, 1963; Whitworth, 1968). The growth of these fish was only slightly above that attainable during constant exposure to the minimum concentrations of the daily cycles. A diurnal dissolved oxygen pulse to 3 mg/l for 8 hours per day for 9 days, with a concentration of 8.3 mg/l for the remainder of the time, produced a significant stress pattern in the serum protein fractions of bluegill and largemouth bass but not yellow bullhead (Bouck and Ball, 1965). During periods of low dissolved oxygen the fish lost their natural color, increased their ventilation rate, and remained very quiet. At these times food was ignored. Several times, during the low dissolved oxygen concentration part of the cycle, the fish vomited food which they had eaten as much as 12 hours earlier. After comparable exposure of the rock bass, Bouck (1972) observed similar results on electrophoretic patterns and feeding behavior.

Stewart et al. (1967) exposed juvenile largemouth bass to patterns of diurnally-variable dissolved oxygen concentrations with daily minima near 2 mg/l and daily maxima from 4 to 17 mg/l. Growth under any fluctuation pattern was almost always less than the growth that presumably would have occurred had the fish been held at a constant concentration equal to the mean concentration.

Carlson et al. (1980) conducted constant and diurnally fluctuating exposures with juvenile channel catfish and yellow perch. At mean constant concentrations of 3.5 mg/l or less, channel catfish consumed less food and growth was significantly reduced. Growth of this species was not reduced at fluctuations from about 6.2 to 3.6 and 4.9 to 2 mg/l, but was significantly impaired at a fluctuation from about 3.1 to 1 mg/l. Similarly, at mean constant concentrations near 3.5 mg/l, yellow perch consumed less food but growth was not impaired until concentrations were near 2 mg/l. Growth was not affected by fluctuations from about 3.8 to 1.4 mg/l. No dissolved oxygen-related mortalities were observed. In both the channel catfish and the yellow perch experiments, growth rates during the tests with fluctuating dissolved oxygen were considerably below the rate attained in the constant exposure tests. As a result, the fluctuating and constant exposures could not be compared. Growth would presumably have been more sensitive in the fluctuating tests if there had been higher rates of control growth.

Mature black crappies were exposed to constant and fluctuating dissolved oxygen concentrations (Carlson and Herman, 1978). Constant concentrations were near 2.5, 4, 5.5, and 7 mg/l and fluctuating concentrations ranged from 0.8 to 1.9 mg/l above and below these original concentrations. Successful spawning occurred at all exposures except the fluctuation between 1.8 and 4.1 mg/l.

In considering daily or longer-term cyclic exposures to low dissolved oxygen concentrations, the minimum values may be more important than the mean levels. The importance of the daily minimum as a determinant of growth rate is common to the results of Fisher (1963), Stewart (1967), and Whitworth (1968). Since annual low dissolved oxygen concentrations normally occur during warmer months, the significance of reduced growth rates during the period in question must be considered. If growth rates are normally low, then the effects of low dissolved oxygen concentration on growth could be minimal; if normal growth rates are high, the effects could be significant, especially if the majority of the annual growth occurs during the period in question.

B. Temperature and Chemical Stress

When fish were exposed to lethal temperatures, their survival times were reduced when the dissolved oxygen concentration was lowered from 7.4 to 3.8 mg/l (Alabaster and Welcomme, 1962). Since high temperature and low dissolved oxygen commonly occur together in natural environments, this likelihood of additive or synergistic effects of these two potential stresses is a most important consideration.

High temperatures almost certainly increase the adverse effects of low dissolved oxygen concentrations. However, the spotty, irregular acute lethality data base provides little basis for quantitative, predictive analysis. Probably the most complete study is that on rainbow trout, perch, and roach conducted by Downing and Merkens (1957). Because their study was spread over an 18-month period, seasonal effects could have influenced the effects at the various test temperatures. Over a range from approximately 10 to 20°C, the lethal dissolved oxygen concentrations increased by an average factor of about 2.6, ranging from 1.4 to 4.1 depending on fish species tested and test duration. The influence of temperature on chronic effects of low dissolved oxygen concentrations are not well known, but requirements for dissolved oxygen probably increase to some degree with increasing temperature. This generalization is supported by analysis of salmon studies reported by Warren et al. (1973) and the largemouth bass studies of Brake (1972).

Because most laboratory tests are conducted at temperatures near the mid-range of a species temperature tolerance, criteria based on these test data will tend to be under-protective at higher temperatures and over-protective at lower temperatures. Concern for this temperature effect was a consideration in establishing these criteria, especially in the establishing of those criteria intended to prevent short-term lethal effects.

A detailed discussion and model for evaluating interactions among temperature, dissolved oxygen, ammonia, fish size, and ration on the resulting growth of individual fish (Cuenco et al., 1985a,b,c) provides an excellent, in-depth evaluation of potential effects of dissolved oxygen on fish growth.

Several laboratory studies evaluated the effect of reduced dissolved oxygen concentrations on the toxicity of various chemicals, some of which occur commonly in oxygen-demanding wastes. Lloyd (1961) observed that the toxicity of zinc, lead, copper, and monohydric phenols was increased at dissolved oxygen concentrations as high as approximately 6.2 mg/l as compared to 9.1 mg/l. At 3.8 mg/l, the toxic effect of these chemicals was even greater. The toxicity of ammonia was enhanced by low dissolved oxygen more than that of other toxicants. Lloyd theorized that the increases in toxicity of the chemicals were due to increased ventilation at low dissolved oxygen concentrations; as a consequence of increased ventilation, more water, and therefore more toxicant, passes the fish's gills. Downing and Merkens (1955) reported that survival times of rainbow trout at lethal ammonia concentrations increased markedly over a range of dissolved oxygen concentrations from 1.5 to 8.5 mg/l. Ninety-six-hr LC50 values for rainbow trout indicate that ammonia became more toxic with decreasing dissolved oxygen concentrations from 8.6 to 2.6 mg/l (Thurston et al., 1981). The maximum increase in toxicity was by about a factor of 2. They also compared ammonia LC50 values at reduced dissolved oxygen concentrations after 12, 24, 48, and 72 hrs. The shorter the time period, the more pronounced the positive relationship between the LC50 and dissolved oxygen concentration. The authors recommended that dissolved oxygen standards for the protection of salmonids should reflect background concentrations of ammonia which may be present and the likelihood of temporary increases in those concentrations. Adelman and Smith (1972) observed that decreasing dissolved oxygen concentrations increased the toxicity of hydrogen sulfide to goldfish. When the goldfish were acclimated to the reduced dissolved oxygen concentration before the exposure to hydrogen sulfide began, mean 96-hr LC50 values were 0.062 and 0.048 mg/l at dissolved oxygen concentrations of 6 and 1.5 mg/l, respectively. When there was no prior acclimation, the LC50 values were 0.071 and 0.053 mg/l at the same dissolved oxygen concentrations. These results demonstrated a less than doubling in toxicity of hydrogen sulfide and little difference with regard to prior acclimation to reduced dissolved oxygen concentrations. Cairns and Scheier (1957) observed that bluegills were less tolerant to zinc, naphthenic acid, and potassium cyanide at periodic low dissolved oxygen concentrations. Pickering (1968) reported that an increased mortality of bluegills exposed to zinc resulted from the added stress of low dissolved oxygen concentrations. The difference in mean LC50 values between low (1.8 mg/l) and high (5.6 mg/l) dissolved oxygen concentrations was a factor of 1.5.

Interactions between other stresses and low dissolved oxygen concentrations can greatly increase mortality of trout larvae. For example, sublethal concentrations of pentachlorophenol and oxygen combined to produce 100 percent mortality of trout larvae held at an oxygen concentration of 3 mg/l (Chapman and Shumway, 1978). The survival of chinook salmon embryos and larvae reared at marginally high temperatures was reduced by any reduction in dissolved oxygen, especially at concentrations below 7 mg/l (Eddy, 1972).

In general, the occurrence of toxicants in the water mass, in combination with low dissolved oxygen concentration, may lead to a potentiation of stress responses on the part of aquatic organisms (Davis, 1975a,b). Doudoroff and Shumway (1970) recommended that the disposal of toxic pollutants must be controlled so that their concentrations would not be unduly harmful at prescribed, acceptable concentrations of dissolved oxygen, and these acceptable dissolved oxygen concentrations should be independent of existing or highest permitted concentrations of toxic wastes.

C. Disease Stress

In a study of 5 years of case records at fish farms, Meyer (1970) observed that incidence of infection with Aeromonas liquefasciens (a common bacterial pathogen of fish) was most prevalent during June, July, and August. He considered low oxygen stress to be a major factor in outbreaks of Aeromonas disease during summer months. Haley et al. (1967) concluded that a kill of American and threadfin shad in the San Joaquin River occurred as a result of Aeromonas infection the day after the dissolved oxygen was between 1.2 and 2.6 mg/l. In this kill the lethal agent was Aeromonas but the additional stress of the low dissolved oxygen may have been a significant factor.

Wedemeyer (1974) reviewed the role of stress as a predisposing factor in fish diseases and concluded that facultative fish pathogens are continuously present in most waters. Disease problems seldom occur, however, unless environmental quality and the host defense systems of the fish also deteriorate. He listed furunculosis, Aeromonad and Pseudomonad hemorrhagic septicemia, and vibriosis as diseases for which low dissolved oxygen is one environmental factor predisposing fish to epizootics. He stated that to optimize fish health, dissolved oxygen concentrations should be 6.9 mg/l or higher. Snieszko (1974) also stated that outbreaks of diseases are probably more likely if the occurrence of stress coincides with the presence of pathogenic microorganisms.

VI. Conclusions

The primary determinant for the criteria is laboratory data describing effect on growth, with developmental rate and survival included in embryo and larval production levels. For the purpose of deriving criteria, growth in the laboratory and production in nature are considered equally sensitive to low dissolved oxygen. Fish production in natural communities actually may be significantly more, or less, sensitive than growth in the laboratory, which represents only one simplified facet of production.

The dissolved oxygen criteria are based primarily on data developed in the laboratory under conditions which are usually artificial in several important respects. First, they routinely preclude or minimize most environmental stresses and biological interactions that under natural conditions are likely to increase, to a variable and unknown extent, the effect of low dissolved oxygen concentrations. Second, organisms are usually given no opportunity to acclimate to low dissolved oxygen concentrations prior to tests nor can they avoid the test exposure. Third, food availability is unnatural because the fish have easy, often unlimited, access to food without significant energy expenditure for search and capture. Fourth, dissolved oxygen concentrations are kept nearly constant so that each exposure represents both a minimum and an average concentration. This circumstance complicates application of the data to natural systems with fluctuating dissolved oxygen concentrations.

Considering the latter problem only, if the laboratory data are applied directly as minimum allowable criteria, the criteria will presumably be higher than necessary because the mean dissolved oxygen concentration will often be significantly higher than the criteria. If applied as a mean, the criteria could allow complete anoxia and total mortality during brief periods of very low dissolved oxygen or could allow too many consecutive daily minima near the lethal threshold. If only a minimum or a mean can be given as a general criterion, the minimum must be chosen because averages are too independent of the extremes.

Obviously, biological effects of low dissolved oxygen concentrations depend upon means, minima, the duration and frequency of the minima, and the period of averaging. In many respects, the effects appear to be independent of the maxima; for example, including supersaturated dissolved oxygen values in the average may produce mean dissolved oxygen concentrations that are misleadingly high and unrepresentative of the true biological stress of the dissolved oxygen minima.

Because most experimental exposures have been constant, data on the effect of exposure to fluctuating dissolved oxygen concentrations is sketchy. The few fluctuating exposure studies have used regular, repeating daily cycles of an on-off nature with 8 to 16 hours at low dissolved oxygen and the remainder of the 24 hr period at intermediate or high dissolved oxygen. This is an uncharacteristic exposure pattern, since most daily dissolved oxygen cycles are of a sinusoidal curve shape and not a square-wave variety.

The existing data allow a tentative theoretical dosing model for fluctuating dissolved oxygen only as applied to fish growth. The EPA believes that the data of Stewart et al. (1967) suggest that effects on growth are reasonably represented by calculating the mean of the daily cycle using as a maximum value the dissolved oxygen concentration which represents the threshold effect concentration during continuous exposure tests. For example, with an effect threshold of 6 mg/l, all values in excess of 6 mg/l should be averaged as though they were 6 mg/l. Using this procedure, the growth effects appear to be a reasonable function of the mean, as long as the minimum is not lethal. Lethal thresholds are highly dependent upon exposure duration, species, age, life stage, temperature, and a wide variety of other factors. Generally the threshold is between 1 and 3 mg/l.

A most critical and poorly documented aspect of a dissolved oxygen criterion is the question of acceptable and unacceptable minima during dissolved oxygen cycles of varying periodicity. Current ability to predict effects of exposure to a constant dissolved oxygen level is only fair; the effects of regular, daily dissolved oxygen cycles can only be poorly estimated; and predicting the effects of more stochastic patterns of dissolved oxygen fluctuations requires an ability to integrate constant and cycling effects.

Several general conclusions result from the synthesis of available field and laboratory data. Some of these conclusions differ from earlier ones in the literature, but the recent data discussed in this document have provided additional detail and perspective.

- Naturally-occurring dissolved oxygen concentrations may occasionally fall below target criteria levels due to a combination of low flow, high temperature, and natural oxygen demand. These naturally-occurring conditions represent a normal situation in which the productivity of fish or other aquatic organisms may not be the maximum possible under ideal circumstances, but which represent the maximum productivity under the particular set of natural conditions. Under these circumstances the numerical criteria should be considered unattainable, but naturally-occurring conditions which fail to meet criteria should not be interpreted as violations of criteria. Although further reductions in dissolved oxygen may be inadvisable, effects of any reductions should be compared to natural ambient conditions and not to ideal conditions.
- Situations during which attainment of appropriate criteria is most critical include periods when attainment of high fish growth rates is a priority, when temperatures approach upper-lethal levels, when pollutants are present in near-toxic quantities, or when other significant stresses are suspected.

- Reductions in growth rate produced by a given low dissolved oxygen concentration are probably more severe as temperature increases. Even during periods when growth rates are normally low, high temperature stress increases the sensitivity of aquatic organisms to disease and toxic pollutants, making the attainment of proper dissolved oxygen criteria particularly important. For these reasons, periods of highest temperature represent a critical portion of the year with respect to dissolved oxygen requirements.

- In salmonid spawning habitats, intergravel dissolved oxygen concentrations are significantly reduced by respiration of fish embryos and other organisms. Higher water column concentrations of dissolved oxygen are required to provide protection of fish embryos and larvae which develop in the intergravel environment. A 3 mg/l difference is used in the criteria to account for this factor.

- The early life stages, especially the larval stage, of non-salmonid fish are usually most sensitive to reduced dissolved oxygen stress. Delayed development, reduced larval survival, and reduced larval and post-larval growth are the observed effects. A separate early life stage criterion for non-salmonids is established to protect these more sensitive stages and is to apply from spawning through 30 days after hatching.

- Other life stages of salmonids appear to be somewhat more sensitive than other life stages of the non-salmonids, but this difference, resulting in a 1.0 mg/l difference in the criteria for other life stages, may be due to a more complete and precise data base for salmonids. Also, this difference is at least partially due to the colder water temperatures at which salmonid tests are conducted and the resultant higher dissolved oxygen concentration in oxygen-saturated control water.

- Few appropriate data are available on the effects of reduced dissolved oxygen on freshwater invertebrates. However, historical concensus states that, if all life stages of fish are protected, the invertebrate communities, although not necessarily unchanged, should be adequately protected. This is a generalization to which there may be exceptions of environmental significance. Acutely lethal concentrations of dissolved oxygen appear to be higher for many aquatic insects than for fish.

- Any dissolved oxygen criteria should include absolute minima to prevent mortality due to the direct effects of hypoxia, but such minima alone may not be sufficient protection for the long-term persistence of sensitive populations under natural conditions. Therefore, the criteria minimum must also provide reasonable assurance that regularly repeated or prolonged exposure for days or weeks at the allowable minimum will avoid significant physiological stress of sensitive organisms.

Several earlier dissolved oxygen criteria were presented in the form of a family of curves (Doudoroff and Shumway, 1970) or equations (NAS/NAE, 1973) which yielded various dissolved oxygen requirements depending on the qualitative degree of fishery protection or risk deemed suitable at a given site. Although dissolved oxygen concentrations that risk significant loss of fishery production are not consistent with the intent of water quality criteria, a qualitative protection/risk assessment for a range of dissolved oxygen concentrations has considerable value to resource managers. Using qualitative descriptions similar to those presented in earlier criteria of Doudoroff and Shumway (1970) and Water Quality Criteria 1972 (NAS/NAE, 1973), four levels of risk are listed below:

<u>No Production Impairment</u>. Representing nearly maximal protection of fishery resources.

<u>Slight Production Impairment</u>. Representing a high level of protection of important fishery resources, risking only slight impairment of production in most cases.

<u>Moderate Production Impairment</u>. Protecting the persistence of existing fish populations but causing considerable loss of production.

<u>Severe Production Impairment</u>. For low level protection of fisheries of some value but whose protection in comparison with other water uses cannot be a major objective of pollution control.

Selection of dissolved oxygen concentrations equivalent to each of these levels of effect requires some degree of judgment based largely upon examination of growth and survival data, generalization of response curve shape, and assumed applicability of laboratory responses to natural populations. Because nearly all data on the effects of low dissolved oxygen on aquatic organisms relate to continuous exposure for relatively short duration (hours to weeks), the resultant dissolved oxygen concentration-biological effect estimates are most applicable to essentially constant exposure levels, although they may adequately represent mean concentrations as well.

The production impairment values are necessarily subjective, and the definitions taken from Doudoroff and Shumway (1970) are more descriptive than the accompanying terms "slight," "moderate," and "severe." The impairment values for other life stages are derived predominantly from the growth data summarized in the text and tables in Sections II and III. In general, slight, moderate, and severe impairment are equivalent to 10, 20, and 40 percent growth impairment, respectively. Growth impairment of 50 percent or greater is often accompanied by mortality, and conditions allowing a combination of severe growth impairment and mortality are considered as no protection.

Production impairment levels for early life stages are quite subjective and should be viewed as convenient divisions of the range of dissolved oxygen concentrations between the acute mortality limit and the no production impairment concentrations.

Production impairment values for invertebrates are based on survival in both long-term and short-term studies. There are no studies of warmwater species and few of lacustrine species.

The following is a summary of the dissolved oxygen concentrations (mg/l) judged to be equivalent to the various qualitative levels of effect described earlier; the value cited as the acute mortality limit is the minimum dissolved oxygen concentration deemed not to risk direct mortality of sensitive organisms:

1. Salmonid Waters

a. Embryo and Larval Stages

- No Production Impairment = 11* (8)
- Slight Production Impairment = 9* (6)
- Moderate Production Impairment = 8* (5)
- Severe Production Impairment = 7* (4)
- Limit to Avoid Acute Mortality = 6* (3)

(* Note: These are water column concentrations recommended to achieve the required <u>intergravel</u> dissolved oxygen concentrations shown in parentheses. The 3 mg/l difference is discussed in the criteria document.)

b. Other Life Stages

- No Production Impairment = 8
- Slight Production Impairment = 6
- Moderate Production Impairment = 5
- Severe Production Impairment = 4
- Limit to Avoid Acute Mortality = 3

2. Nonsalmonid Waters

a. Early Life Stages

- No Production Impairment = 6.5
- Slight Production Impairment = 5.5
- Moderate Production Impairment = 5
- Severe Production Impairment = 4.5
- Limit to Avoid Acute Mortality = 4

b. Other Life Stages

- No Production Impairment = 6
- Slight Production Impairment = 5
- Moderate Production Impairment = 4
- Severe Production Impairment = 3.5
- Limit to Avoid Acute Mortality = 3

3. Invertebrates

- No Production Impairment = 8
- Some Production Impairment = 5
- Acute Mortality Limit = 4

Added Note

Just prior to final publication of this criteria document, a paper appeared (Sowden and Power, 1985) that provided an interesting field validation of the salmonid early life stage criterion and production impairment estimates. A total of 19 rainbow trout redds were observed for a number of parameters including percent survival of embryos, dissolved oxygen concentration, and calculated intergravel water velocity. The results cannot be considered a rigorous evaluation of the criteria because of the paucity of dissolved oxygen determinations per redd (2-5) and possible inaccuracies in determining percent survival and velocity. Nevertheless, the qualitative validation is striking.

The generalization drawn from Coble's (1961) study that good survival occurred when mean intergravel dissolved oxygen concentrations exceeded 6.0 mg/l and velocity exceeded 20 cm/hr was confirmed; 3 of the 19 redds met this criterion and averaged 29 percent embryo survival. The survival in the other 16 redds averaged only 3.6 percent. The data from the study are summarized in Table 7. The critical intergravel water velocity from this study appears to be about 15 cm/hr. Below this velocity even apparently good dissolved oxygen

Table 7. Survival of rainbow trout embryos as a function of intergravel dissolved oxygen concentration and water velocity (Sowden and Power, 1985) as compared to dissolved oxygen concentrations established as criteria or estimated as producing various levels of production impairment.

Criteria Estimates	Dissolved Oxygen Concentration mg/l		Percent Survival	Water Velocity, cm/hr	Mean Survival (Flow > 15 cm/hr)
	Mean	Minimum			
Exceeded Criteria	8.9	8.0	22.1	53.7	29.0
	7.7	7.0	43.5	83.2	
	7.0	6.4	1.1	9.8	
	6.9	5.4	21.3	20.6	
Slight Production Impairment	7.4	4.1	0.5	7.2	15.6
	7.1	4.3	21.5	16.3	
	6.7	4.5	4.3	5.4	
	6.4	4.2	0.3	7.9	
	6.0	4.2	9.6	17.4	
Moderate Production Impairment	5.8	3.1	13.4	21.6	6.5
	5.3	3.6	5.6	16.8	
	5.2	3.9	0.4	71.0	
Severe Production Impairment	4.6	4.1	0.9	18.3	0.9
	4.2	3.3	0.0	0.4	
Acute Mortality	3.9	2.9	0.0	111.4	0.0
	3.6	2.1	0.0	2.6	
	2.7	1.2	0.0	4.2	
	2.4	0.8	0.0	1.1	
	2.0	0.8	0.0	192.0	

characteristics do not produce reasonable survival. At water velocities in excess of 15 cm/hr the average percent survival in the redds that had dissolved oxygen concentrations that met the criteria was 29.0 percent. There was no survival in redds that had dissolved oxygen minima below the acute mortality limit. Percent survival in redds with greater than 15 cm/hr flow averaged 15.6, 6.5, and 0.9 percent for redds meeting slight, moderate, and severe production impairment levels, respectively.

Based on an average redd of 1000 eggs, these mean percent survivals would be equivalent to 290, 156, 65, 9, and 0 viable larvae entering the environment to produce food for other fish, catch for fishermen, and eventually a new generation of spawners to replace the parents of the embryos in the redd. Whether or not these survival numbers ultimately represent the impairment definitions is moot in the light of further survival and growth uncertainties, but the quantitative field results and the qualitative and quantitative impairment and criteria values are surprisingly similar.

VII. National Criterion

The national criteria for ambient dissolved oxygen concentrations for the protection of freshwater aquatic life are presented in Table 8. The criteria are derived from the production impairment estimates on the preceding page which are in turn based primarily upon growth data and information on temperature, disease, and pollutant stresses. The average dissolved oxygen concentrations selected are values 0.5 mg/l above the slight production impairment values and represent values between no production impairment and slight production impairment. Each criterion may thus be viewed as an estimate of the threshold concentration below which detrimental effects are expected.

Criteria for coldwater fish are intended to apply to waters containing a population of one or more species in the family Salmonidae (Bailey et al., 1970) or to waters containing other coldwater or coolwater fish deemed by the user to be closer to salmonids in sensitivity than to most warmwater species. Although the acute lethal limit for salmonids is at or below 3 mg/l, the coldwater minimum has been established at 4 mg/l because a significant proportion of the insect species common to salmonid habitats are less tolerant of acute exposures to low dissolved oxygen than are salmonids. Some coolwater species may require more protection than that afforded by the other life stage criteria for warmwater fish and it may be desirable to protect sensitive coolwater species with the coldwater criteria. Many states have more stringent dissolved oxygen standards for cooler waters, waters that contain either salmonids, nonsalmonid coolwater fish, or the sensitive centrarchid, the smallmouth bass. The warmwater criteria are necessary to protect early life stages of warmwater fish as sensitive as channel catfish and to protect other life stages of fish as sensitive as largemouth bass. Criteria for early life stages are intended to apply only where and when these stages occur. These criteria represent dissolved oxygen concentrations which EPA believes provide a reasonable and adequate degree of protection for freshwater aquatic life.

The criteria do not represent assured no-effect levels. However, because the criteria represent worst case conditions (i.e., for wasteload allocation and waste treatment plan design), conditions will be better than the criteria

Table 8. Water quality criteria for ambient dissolved oxygen concentration.

	Coldwater Criteria		Warmwater Criteria	
	Early Life Stages[1,2]	Other Life Stages	Early Life Stages[2]	Other Life Stages
30 Day Mean	NA[3]	6.5	NA	5.5
7 Day Mean	9.5 (6.5)	NA	6.0	NA
7 Day Mean Minimum	NA	5.0	NA	4.0
1 Day Minimum[4,5]	8.0 (5.0)	4.0	5.0	3.0

[1] These are water column concentrations recommended to achieve the required intergravel dissolved oxygen concentrations shown in parentheses. The 3 mg/l differential is discussed in the criteria document. For species that have early life stages exposed directly to the water column, the figures in parentheses apply.

[2] Includes all embryonic and larval stages and all juvenile forms to 30-days following hatching.

[3] NA (not applicable).

[4] For highly manipulatable discharges, further restrictions apply (see page 37)

[5] All minima should be considered as instantaneous concentrations to be achieved at all times.

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nearly all the time at most sites. In situations where criteria conditions are just maintained for considerable periods, the criteria represent some risk of production impairment. This impairment would probably be slight, but would depend on innumerable other factors. If slight production impairment or a small but undefinable risk of moderate production impairment is unacceptable, then continuous exposure conditions should use the no production impairment values as means and the slight production impairment values as minima.

The criteria represent annual worst case dissolved oxygen concentrations believed to protect the more sensitive populations of organisms against potentially damaging production impairment. The dissolved oxygen concentrations in the criteria are intended to be protective at typically high seasonal environmental temperatures for the appropriate taxonomic and life stage classifications, temperatures which are often higher than those used in the research from which the criteria were generated, especially for other than early life stages.

Where natural conditions alone create dissolved oxygen concentrations less than 110 percent of the applicable criteria means or minima or both, the minimum acceptable concentration is 90 percent of the natural concentration. These values are similar to those presented graphically by Doudoroff and Shumway (1970) and those calculated from Water Quality Criteria 1972 (NAS/NAE, 1973). Absolutely no anthropogenic dissolved oxygen depression in the potentially lethal area below the 1-day minima should be allowed unless special care is taken to ascertain the tolerance of resident species to low dissolved oxygen.

If daily cycles of dissolved oxygen are essentially sinusoidal, a reasonable daily average is calculated from the day's high and low dissolved oxygen values. A time-weighted average may be required if the dissolved oxygen cycles are decidedly non-sinusoidal. Determining the magnitude of daily dissolved oxygen cycles requires at least two appropriately timed measurements daily, and characterizing the shape of the cycle requires several more appropriately spaced measurements.

Once a series of daily mean dissolved oxygen concentrations are calculated, an average of these daily means can be calculated (Table 9). For embryonic, larval, and early life stages, the averaging period should not exceed 7 days. This short time is needed to adequately protect these often

Table 9. Sample calculations for determining daily means and 7-day mean dissolved oxygen concentrations (30-day averages are calculated in a similar fashion using 30 days data).

	Dissolved Oxygen (mg/l)		
Day	Daily Max.	Daily Min.	Daily Mean
1	9.0	7.0	8.0
2	10.0	7.0	8.5
3	11.0	8.0	9.5
4	12.0[a]	8.0	9.5[b]
5	10.0	8.0	9.0
6	11.0	9.0	10.0
7	12.0[a]	10.0	10.5[c]
Σ		57.0	65.0
1-day Minimum		7.0	
7-day Mean Minimum		8.1	
7-day Mean			9.3

[a] Above air saturation concentration (assumed to be 11.0 mg/l for this example).

[b] (11.0 + 8.0) ÷ 2.

[c] (11.0 +10.0) ÷ 2.

short duration, most sensitive life stages. Other life stages can probably be adequately protected by 30-day averages. Regardless of the averaging period, the average should be considered a moving average rather than a calendar-week or calendar-month average.

The criteria have been established on the basis that the maximum dissolved oxygen value actually used in calculating any daily mean should not exceed the air saturation value. This consideration is based primarily on analysis of studies of cycling dissolved oxygen and the growth of largemouth bass (Stewart et al., 1967), which indicated that high dissolved oxygen levels (> 6 mg/l) had no beneficial effect on growth.

During periodic cycles of dissolved oxygen concentrations, minima lower than acceptable constant exposure levels are tolerable so long as:

1. the average concentration attained meets or exceeds the criterion;
2. the average dissolved oxygen concentration is calculated as recommended in Table 9; and
3. the minima are not unduly stressful and clearly are not lethal.

A daily minimum has been included to make certain that no acute mortality of sensitive species occurs as a result of lack of oxygen. Because repeated exposure to dissolved oxygen concentrations at or near the acute lethal threshold will be stressful and because stress can indirectly produce mortality or other adverse effects (e.g., through disease), the criteria are designed to prevent significant episodes of continuous or regularly recurring exposures to dissolved oxygen concentrations at or near the lethal threshold. This protection has been achieved by setting the daily minimum for early life stages at the subacute lethality threshold, by the use of a 7-day averaging period for early life stages, by stipulating a 7-day mean minimum value for other life stages, and by recommending additio~~nal limits~~ for manipulatable discharges.

The previous EPA criterion for dissolved oxygen published in Quality Criteria for Water (USEPA, 1976) was a minimum of 5 mg/l (usually applied as a 7Q10) which is similar to the current criterion minimum except for other life stages of warmwater fish which now allows a 7-day mean minimum of 4 mg/l. The new criteria are similar to those contained in the 1968 "Green Book" of the Federal Water Pollution Control Federation (FWPCA, 1968).

A. The Criteria and Monitoring and Design Conditions

The acceptable mean concentrations should be attained most of the time, but some deviation below these values would probably not cause significant harm. Deviations below the mean will probably be serially correlated and hence apt to occur on consecutive days. The significance of deviations below the mean will depend on whether they occur continuously or in daily cycles, the former being more adverse than the latter. Current knowledge regarding such deviations is limited primarily to laboratory growth experiments and by extrapolation to other activity-related phenomena.

Under conditions where large daily cycles of dissolved oxygen occur, it is possible to meet the criteria mean values and consistently violate the mean minimum criteria. Under these conditions the mean minimum criteria will clearly be the limiting regulation unless alternatives such as nutrient control can dampen the daily cycles.

The significance of conditions which fail to meet the recommended dissolved oxygen criteria depend largely upon five factors: (1) the duration of the event; (2) the magnitude of the dissolved oxygen depression; (3) the frequency of recurrence; (4) the proportional area of the site failing to meet the criteria; and (5) the biological significance of the site where the event occurs. Evaluation of an event's significance must be largely case- and site-specific. Common sense would dictate that the magnitude of the depression would be the single most important factor in general, especially if the acute value is violated. A logical extension of these considerations is that the event must be considered in the context of the level of resolution of the monitoring or modeling effort. Evaluating the extent, duration, and magnitude of an event must be a function of the spatial and temporal frequency of the data. Thus, a single deviation below the criterion takes on considerably less significance where continuous monitoring occurs than where sampling is comprised of once-a-week grab samples. This is so because based on continuous monitoring the event is provably small, but with the much less frequent sampling the event is not provably small and can be considerably worse than indicated by the sample.

The frequency of recurrence is of considerable interest to those modeling dissolved oxygen concentrations because the return period, or period between recurrences, is a primary modeling consideration contingent upon probabilities of receiving water volumes, waste loads, temperatures, etc. It should be apparent that return period cannot be isolated from the other four factors discussed above. Ultimately, the question of return period may be decided on a site-specific basis taking into account the other factors (duration, magnitude, areal extent, and biological significance) mentioned above. Future studies of temporal patterns of dissolved oxygen concentrations, both within and between years, must be conducted to provide a better basis for selection of the appropriate return period.

In conducting waste load allocation and treatment plant design computations, the choice of temperature in the models will be important. Probably the best option would be to use temperatures consistent with those expected in the receiving water over the critical dissolved oxygen period for the biota.

B. The Criteria and Manipulatable Discharges

If daily minimum ~~disso~~lved oxygen concentrations are perfectly serially correlated, i.e., if the annual lowest daily minimum dissolved oxygen concentration is adjacent in time to the next lower daily minimum dissolved oxygen concentration and one of these two minima is adjacent to the third lowest daily minimum dissolved oxygen concentration, etc., then in order to meet the 7-day mean minimum criterion it is unlikely that there will be more than three or four consecutive daily minimum values below the acceptable 7-day mean minimum. Unless the dissolved oxygen pattern is extremely erratic, it is also unlikely that the lowest dissolved oxygen concentration will be appreciably below the acceptable 7-day mean minimum or that daily minimum values below the 7-day mean minimum will occur in more than one or two weeks each year. For some discharges, the distribution of dissolved oxygen concentrations can be manipulated to varying degrees. Applying the daily minimum to manipulatable discharges would allow repeated weekly cycles of minimum acutely acceptable dissolved oxygen values, a condition of probable stress and possible adverse biological effect. If risk of protection impairment is to be minimized, the application of the one day minimum criterion to manipulatable discharges should either limit the frequency of occurrence of values below the acceptable 7-day mean minimum or impose further limits on the extent of excursions below the 7-day mean minimum. For such controlled discharges, it is recommended that the occurrence of daily minima below the acceptable 7-day mean minimum be limited to 3 weeks per year or that the acceptable one-day minimum be increased to 4.5 mg/l for coldwater fish and 3.5 mg/l for warmwater fish. Such decisions could be site-specific based upon the extent of control, serial correlation, and the resource at risk.

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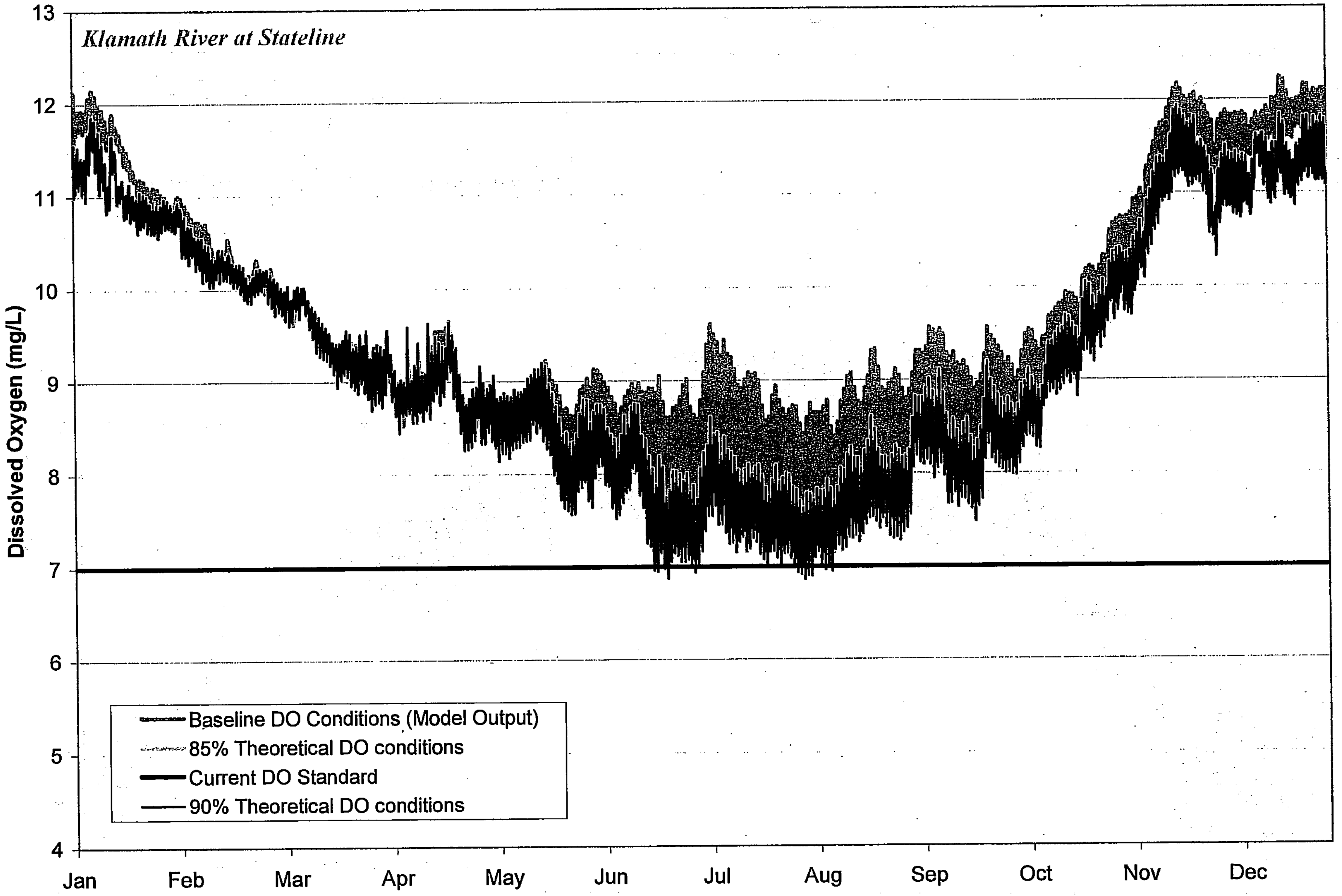
APPENDIX G


Klamath River at Stateline
Dissolved Oxygen (mg/L)
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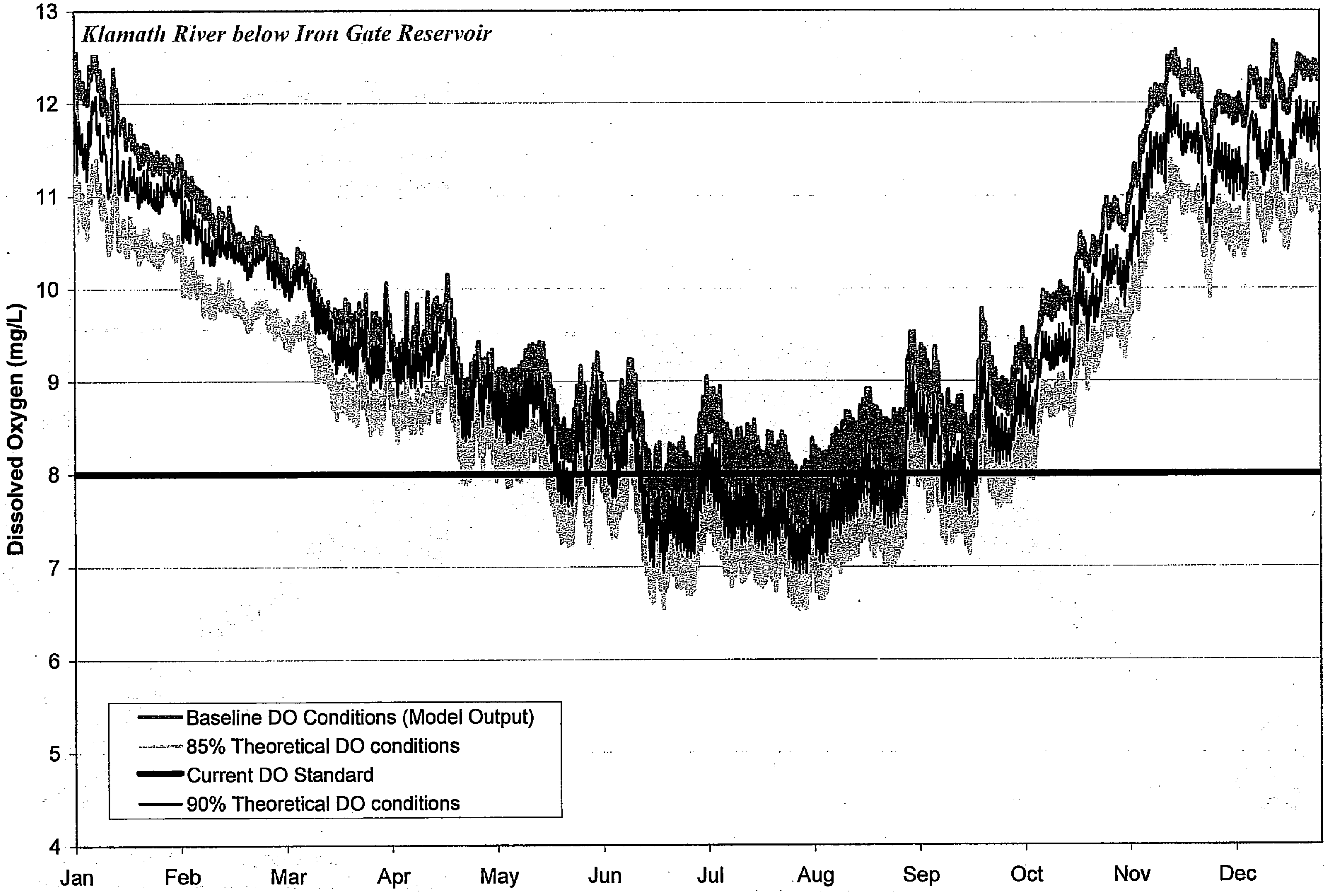
Baseline DO Conditions (Model Output)
85% Theoretical DO conditions
Current DO Standard
90% Theoretical DO conditions


Klamath River below Iron Gate Reservoir
Dissolved Oxygen (mg/L)
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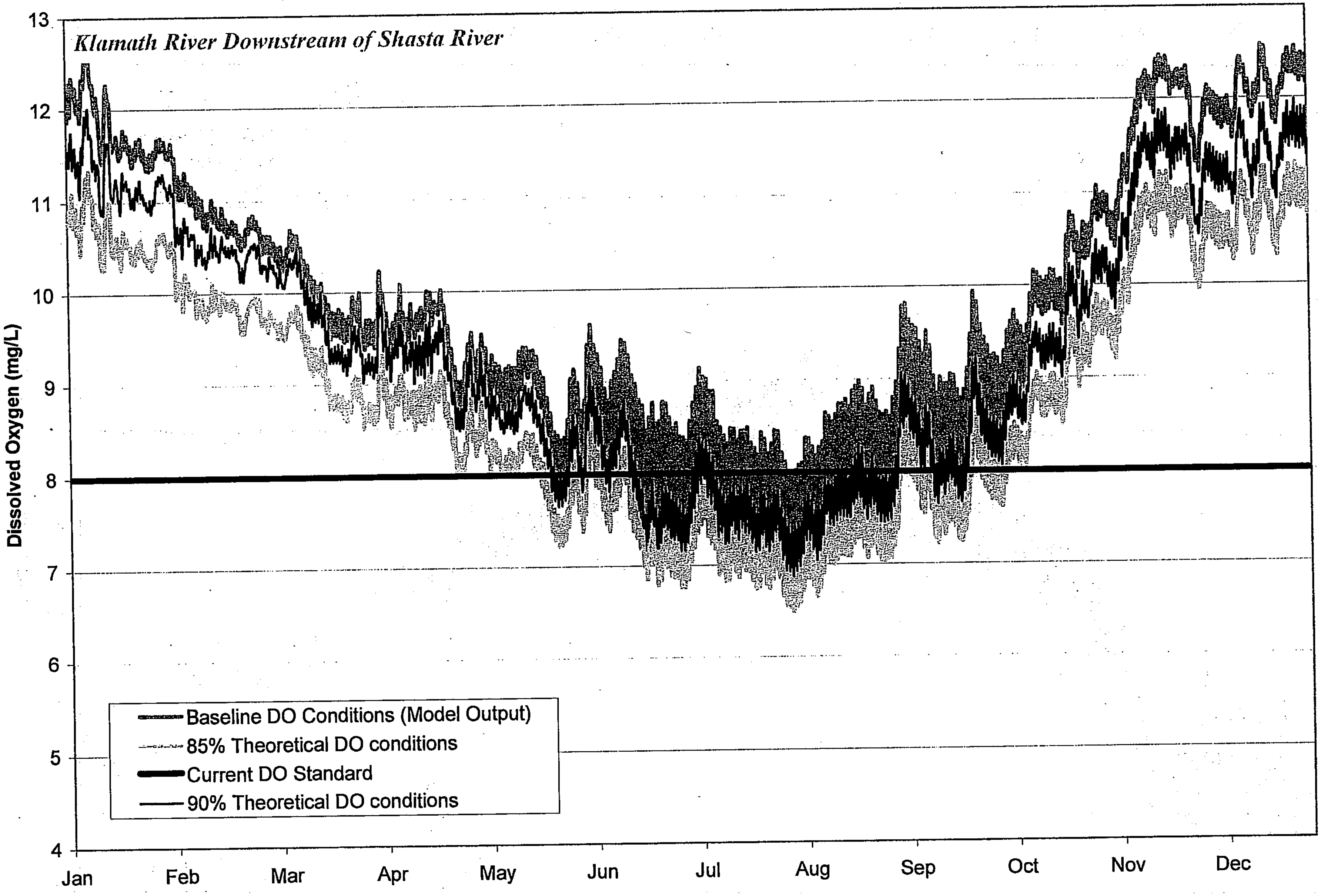
Baseline DO Conditions (Model Output)
85% Theoretical DO conditions
Current DO Standard
90% Theoretical DO conditions

Klamath River Downstream of Shasta River
Dissolved Oxygen (mg/L)
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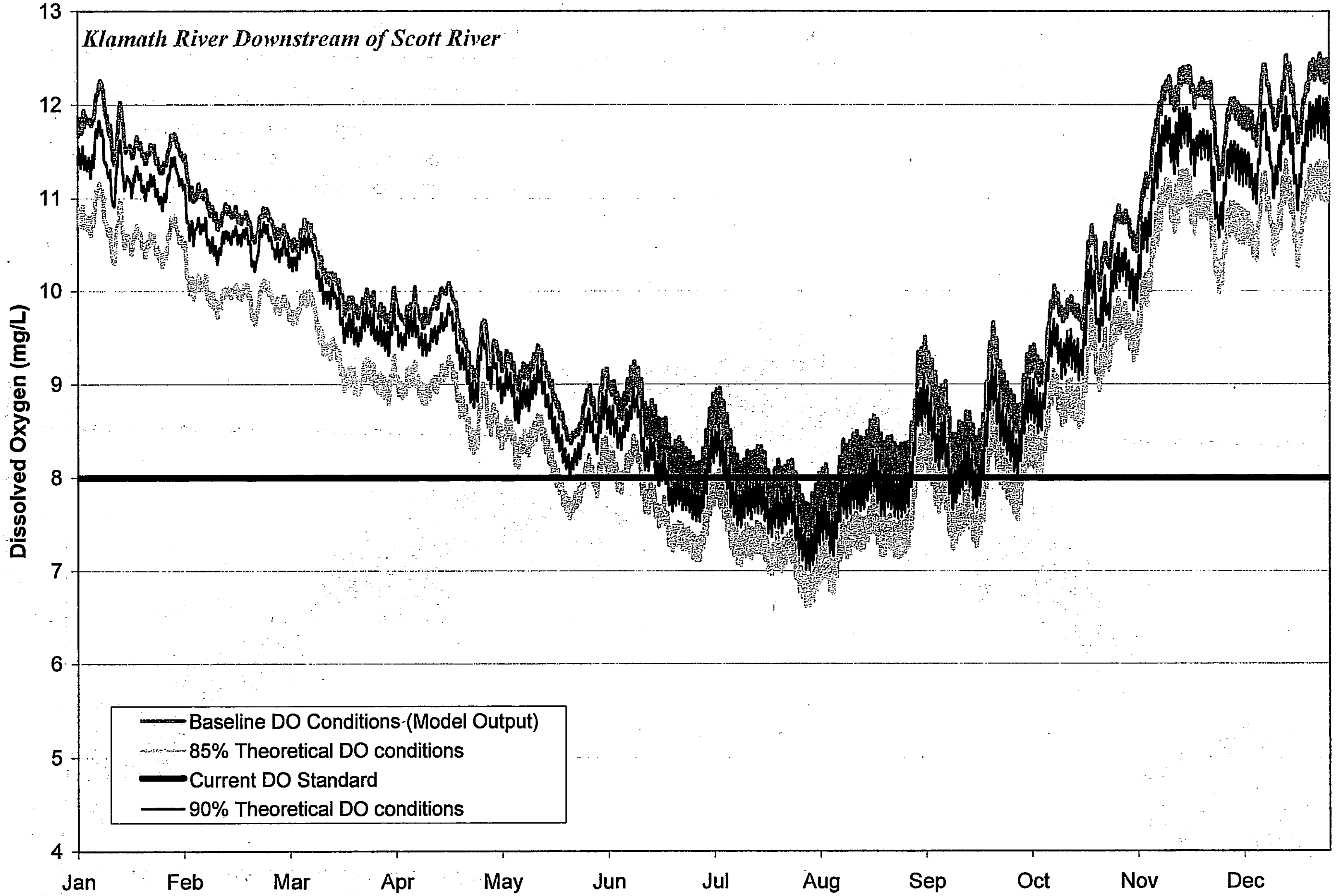
Baseline DO Conditions (Model Output)
85% Theoretical DO conditions
Current DO Standard
90% Theoretical DO conditions


Klamath River Downstream of Scott River
Dissolved Oxygen (mg/L)
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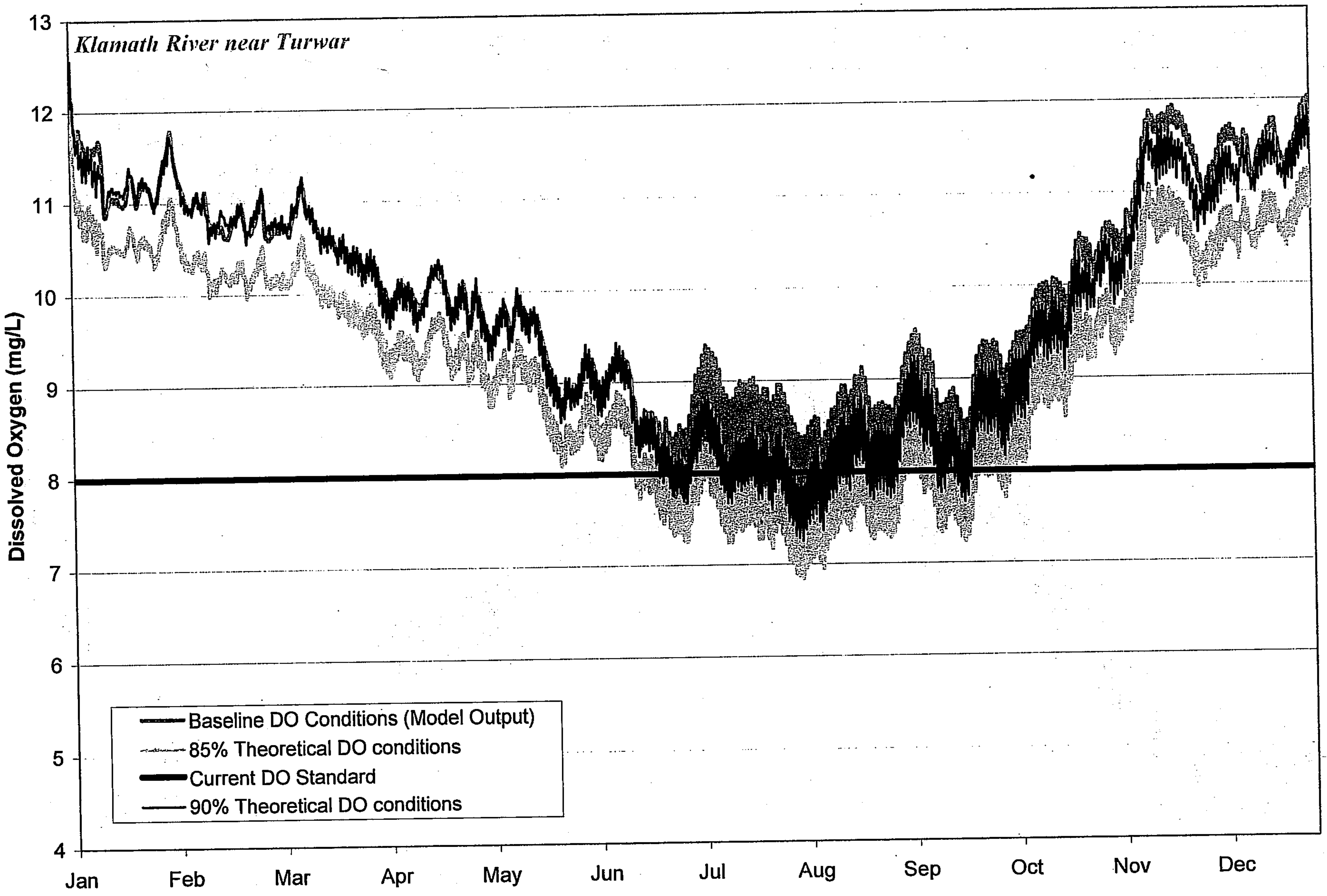
Baseline DO Conditions-(Model Output)
85% Theoretical DO conditions
Current DO Standard
90% Theoretical DO conditions


Klamath River near Turwar
Dissolved Oxygen (mg/L)
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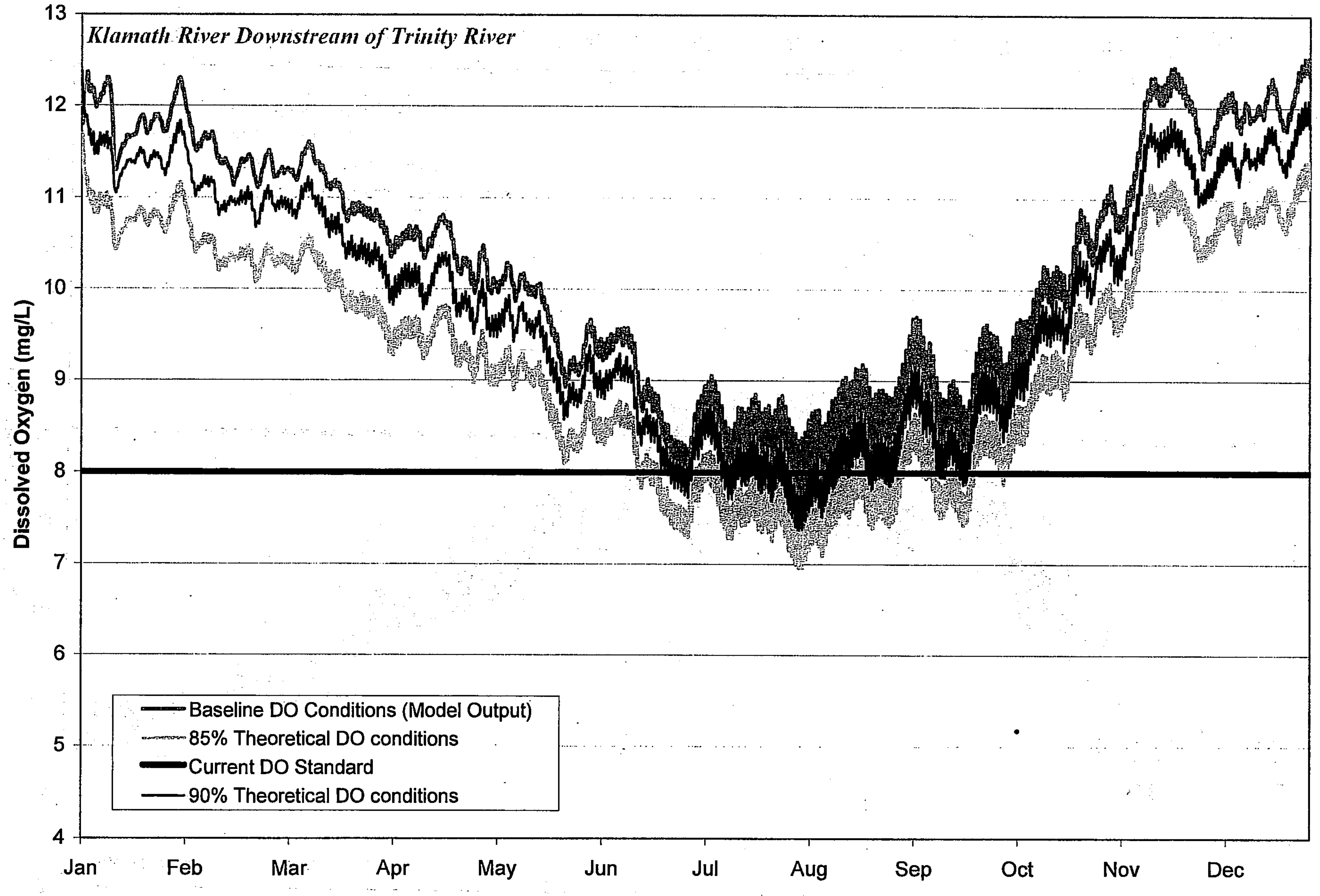
Baseline DO Conditions (Model Output)
85% Theoretical DO conditions
Current DO Standard
90% Theoretical DO conditions


Klamath River Downstream of Trinity River
Dissolved Oxygen (mg/L)
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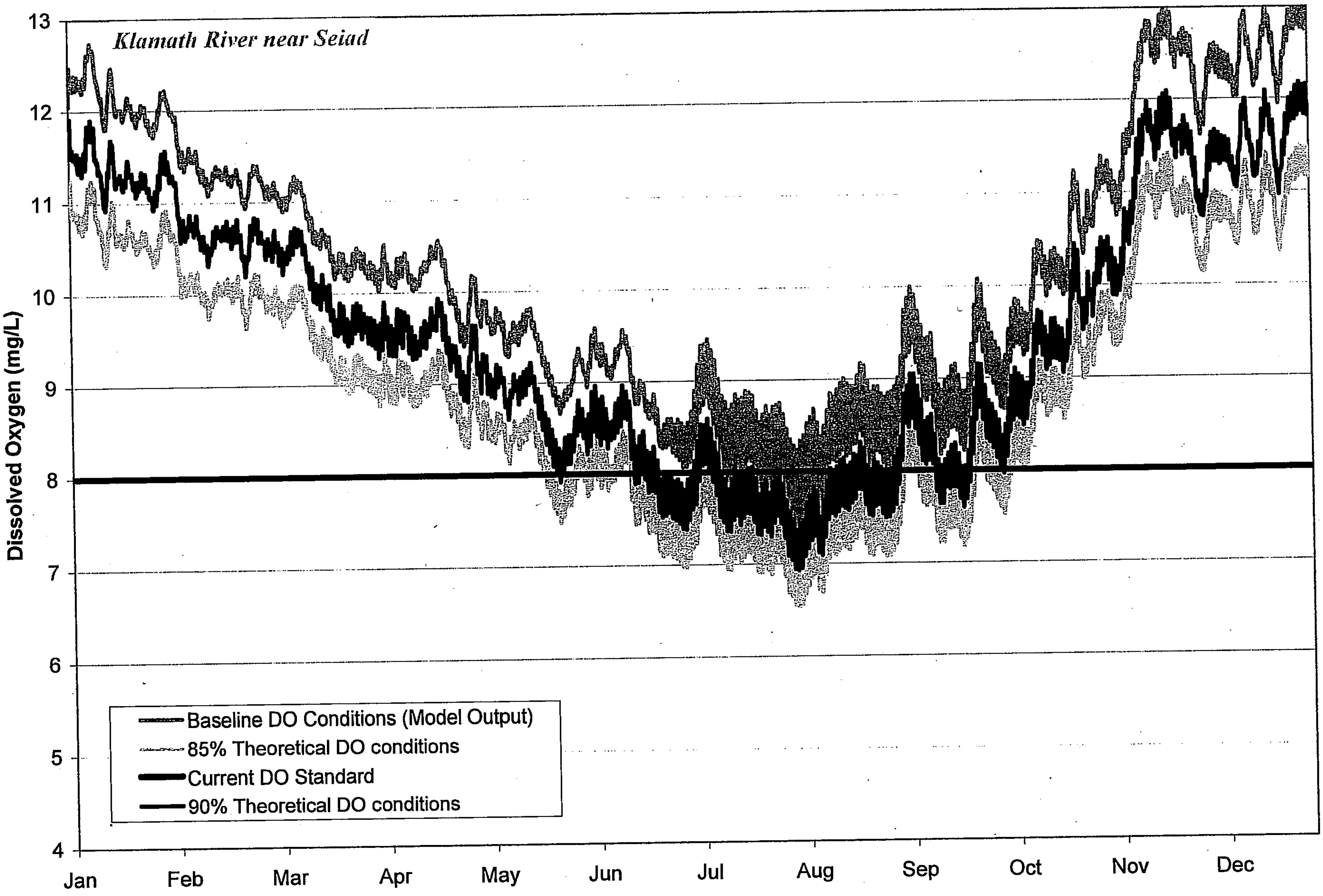
Baseline DO Conditions (Model Output)
85% Theoretical DO conditions
Current DO Standard
90% Theoretical DO conditions


Klamath River near Seiad
Dissolved Oxygen (mg/L)
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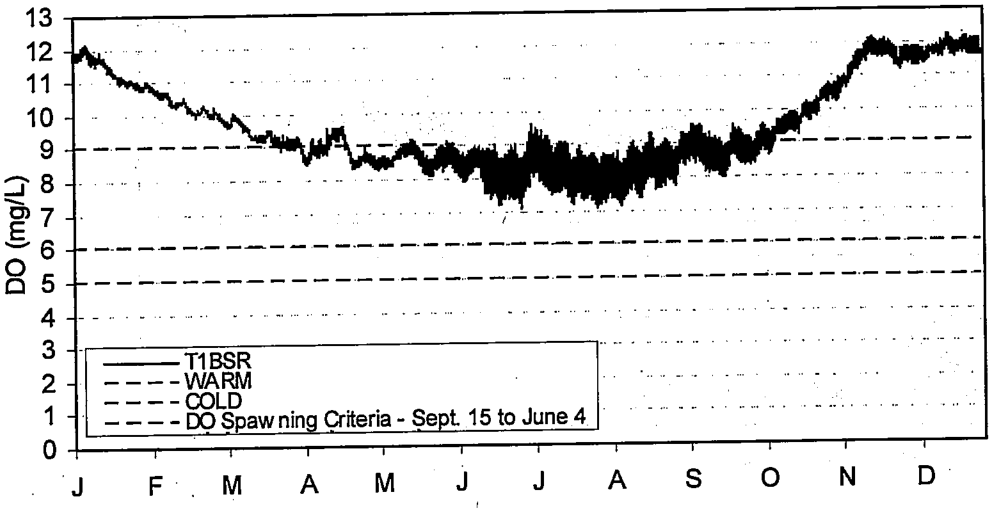
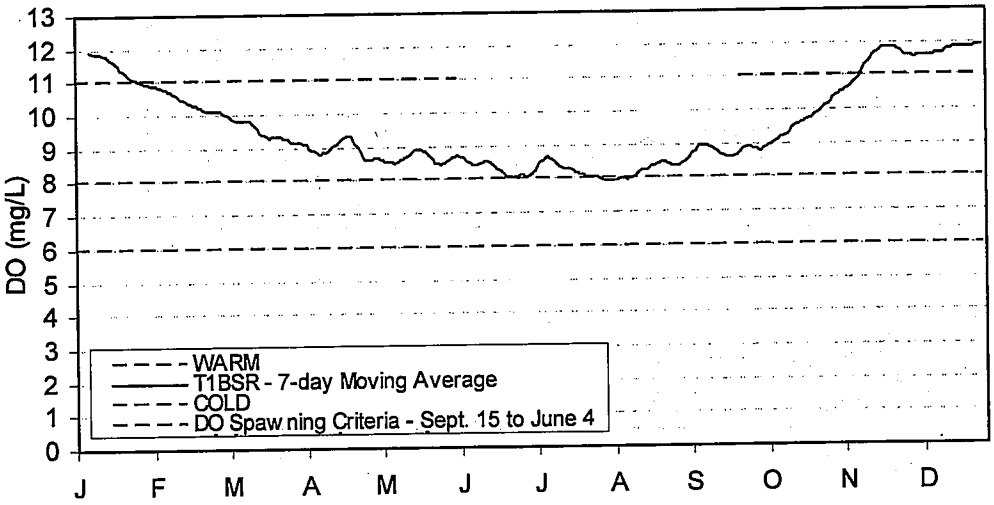
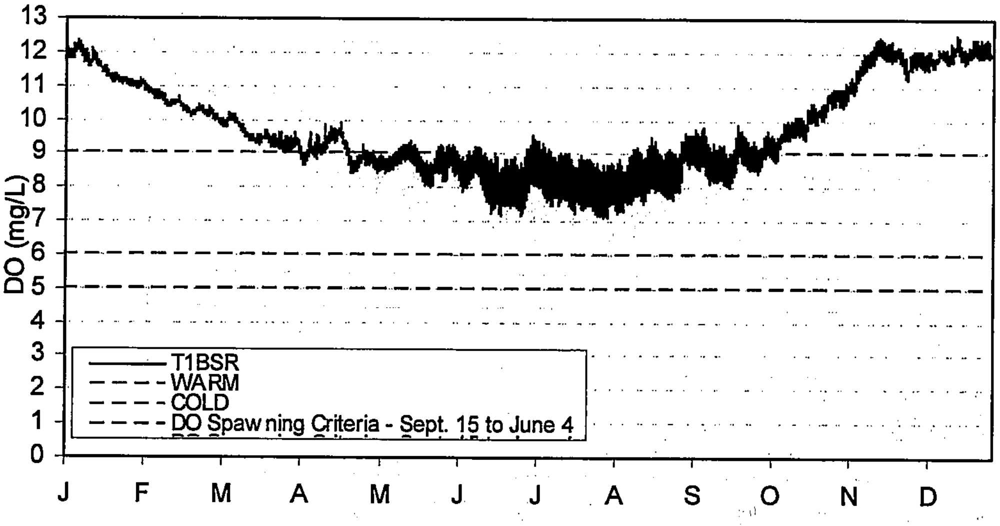
Baseline DO Conditions (Model Output)
85% Theoretical DO conditions
Current DO Standard
90% Theoretical DO conditions

STATELINE – T1BSR





COPCO – T1BSR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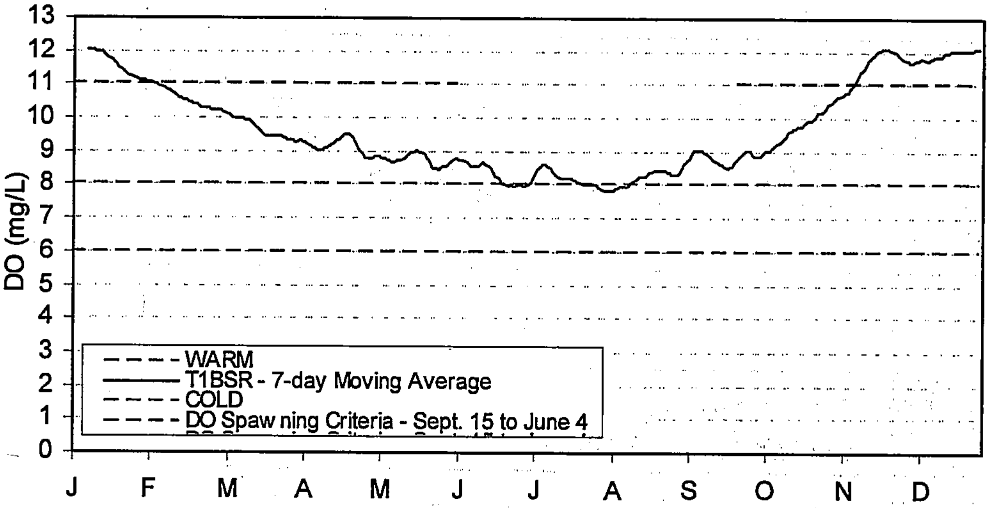
T1BSR
WARM
COLD
DO Spawning Criteria - Sept. 15 to June 4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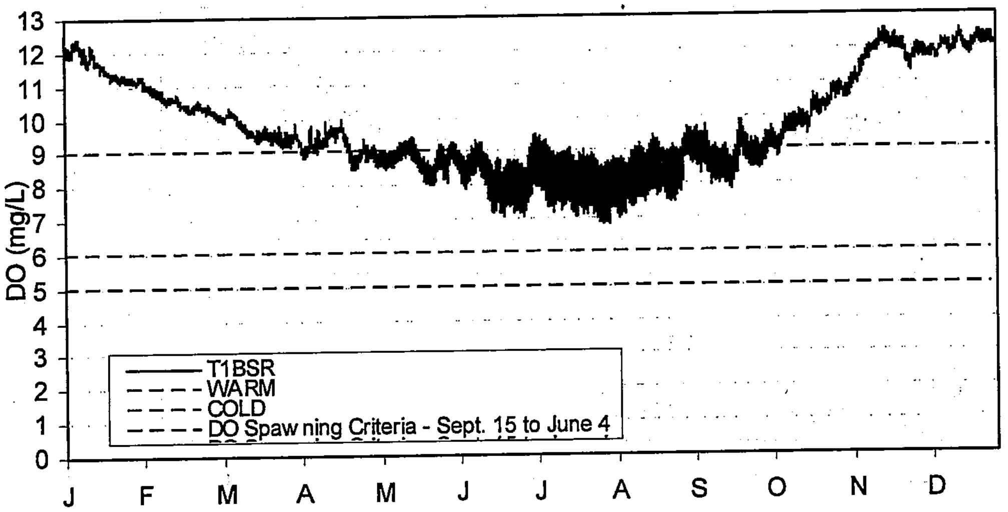
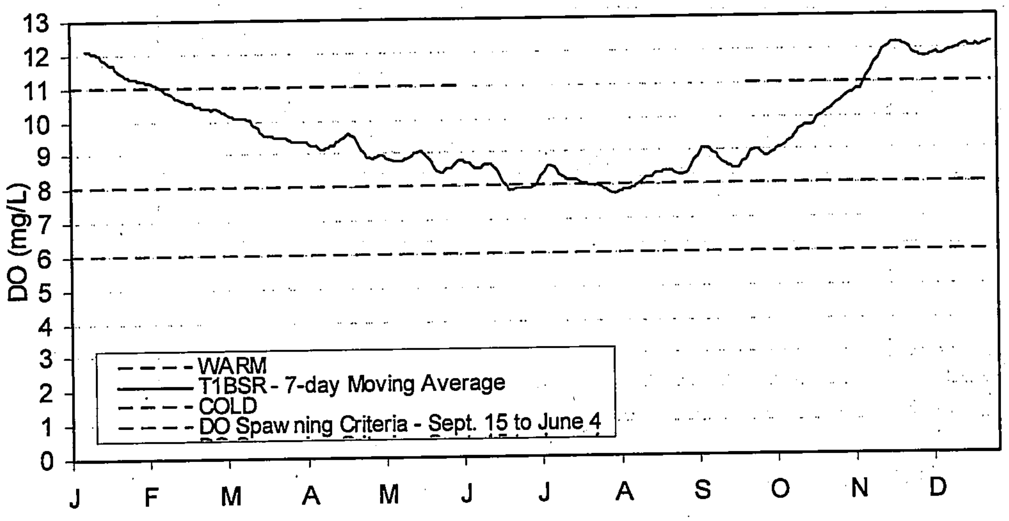
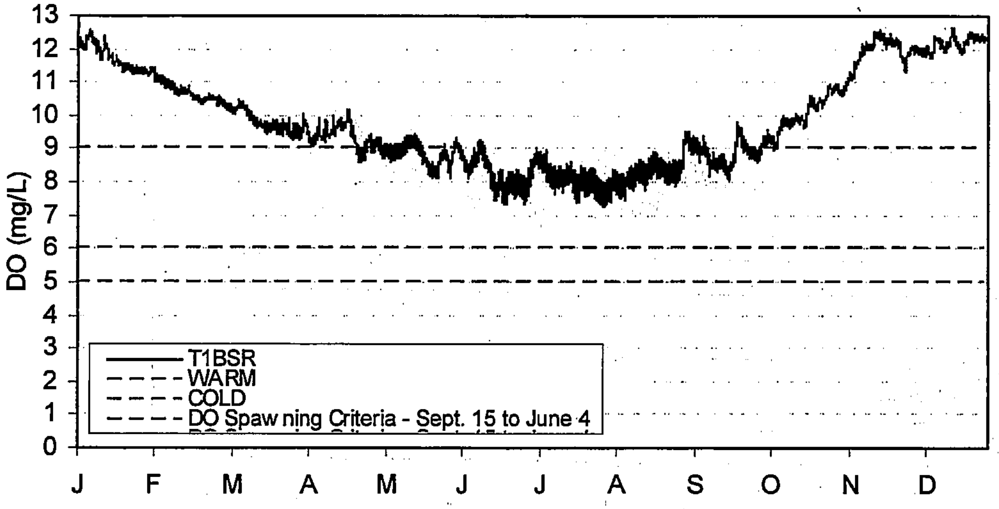
WARM
T1BSR - 7-day Moving Average
COLD
DO Spawning Criteria - Sept. 15 to June 4

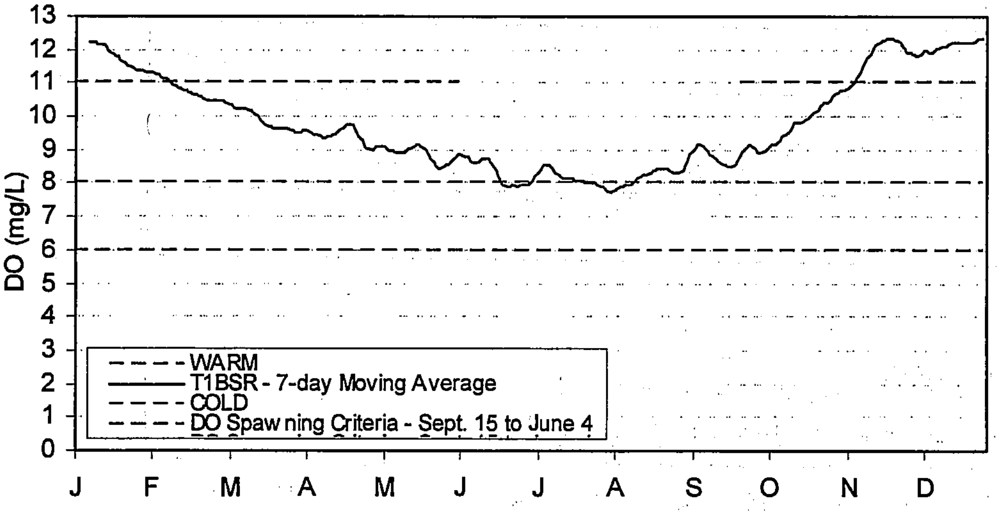
IRON GATE – T1BSR



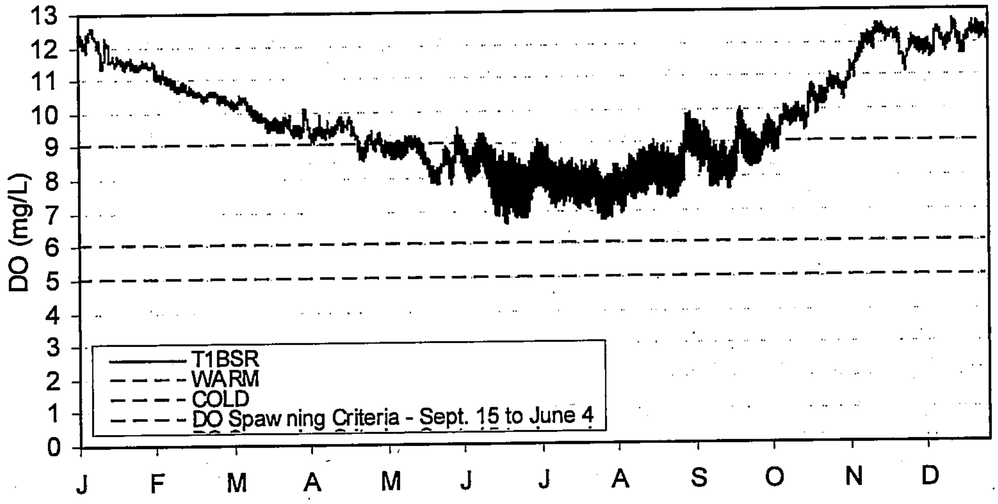


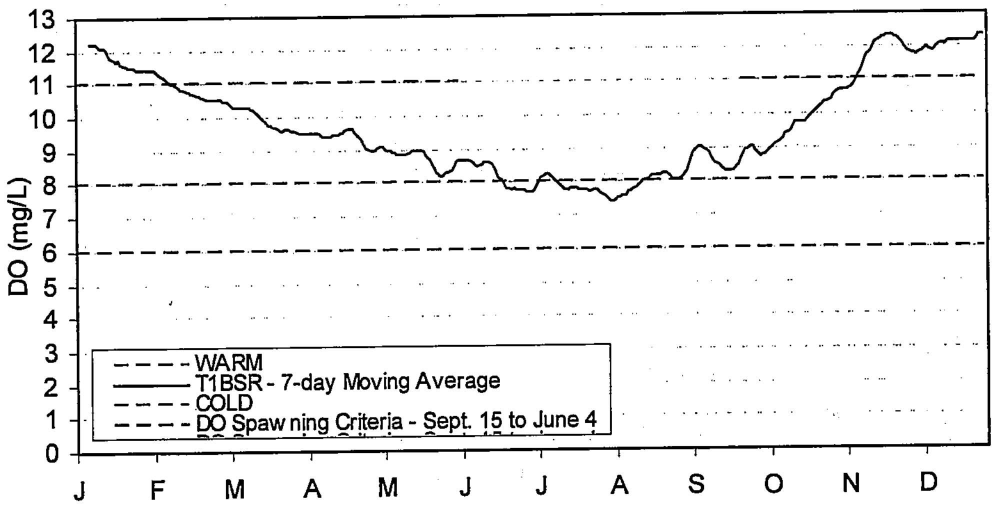
DOWNSTREAM IRON GATE – T1BSR



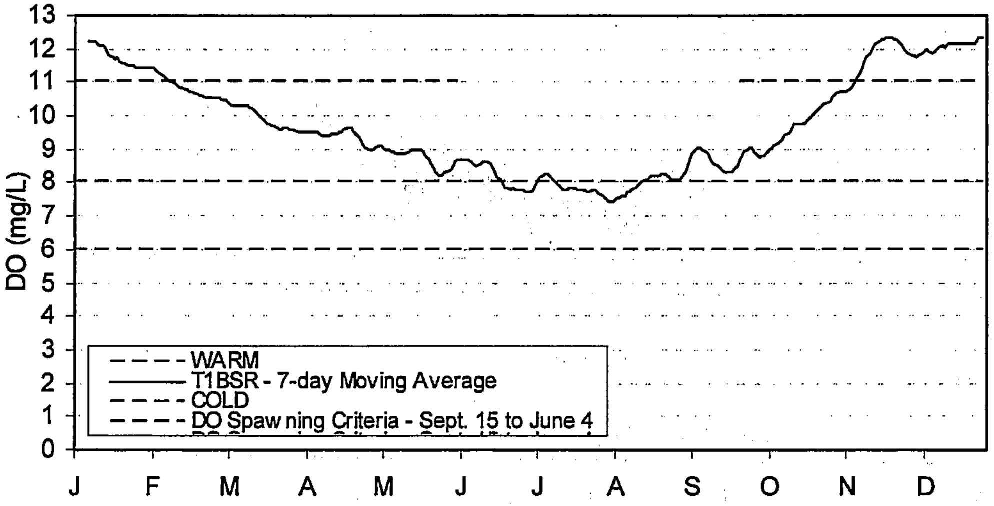


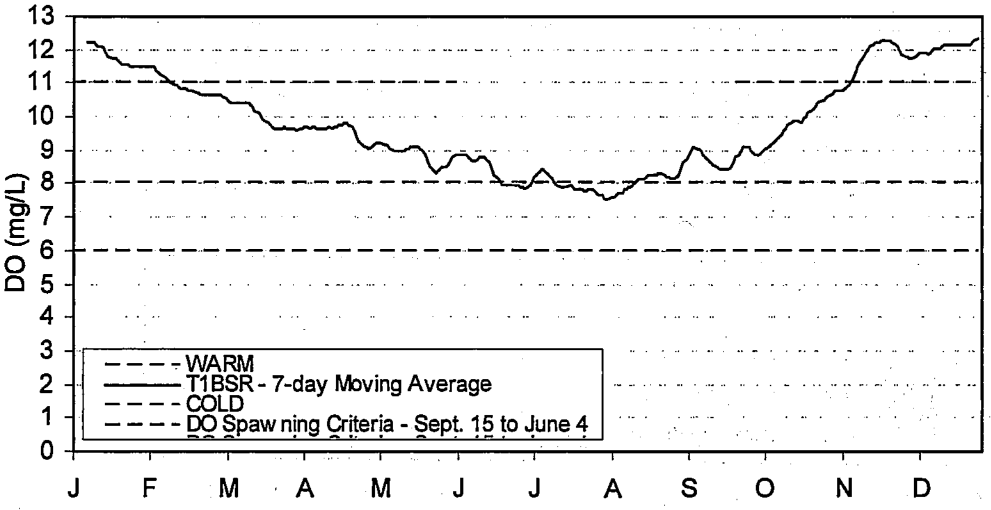
UPSTREAM SHASTA – T1BSR



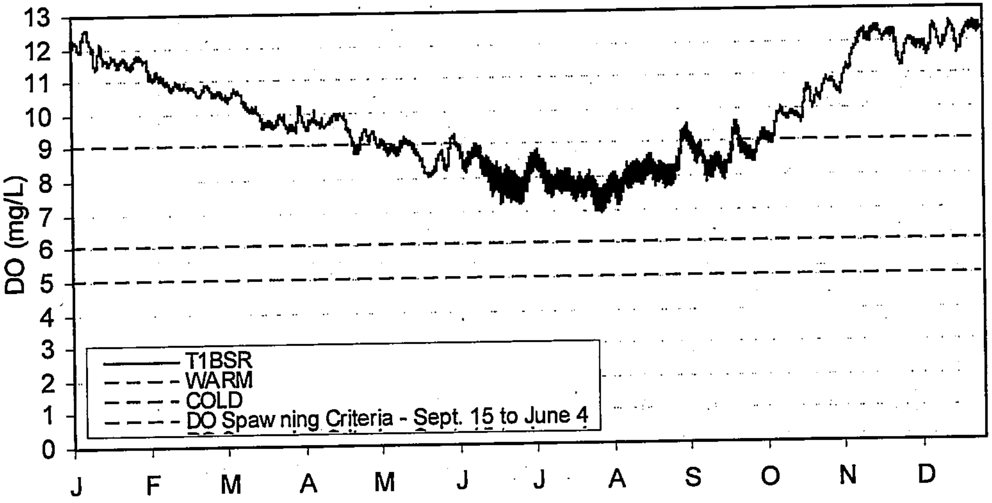


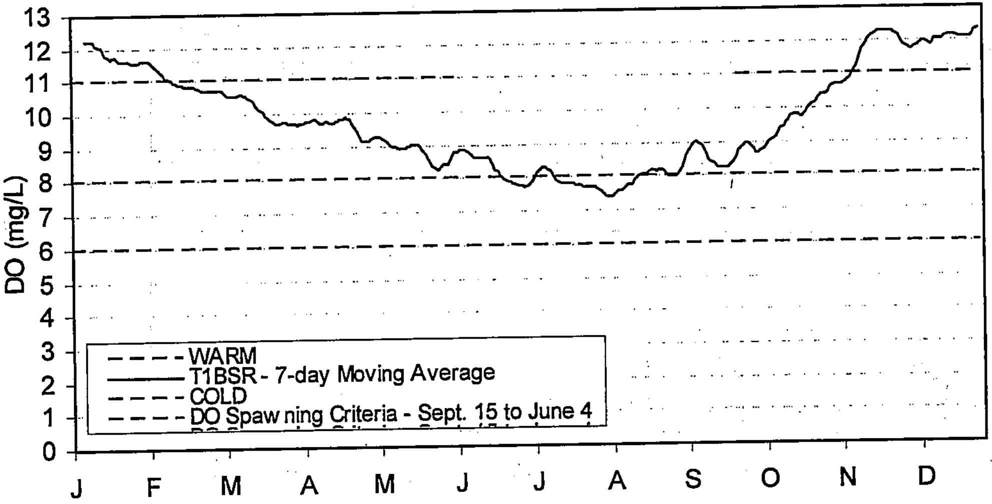
DOWNSTREAM SHASTA – T1BSR



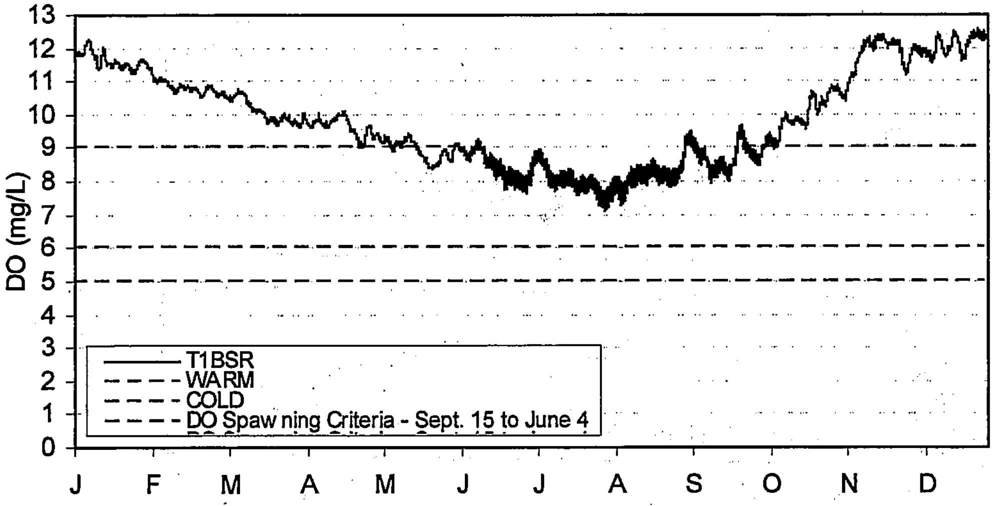


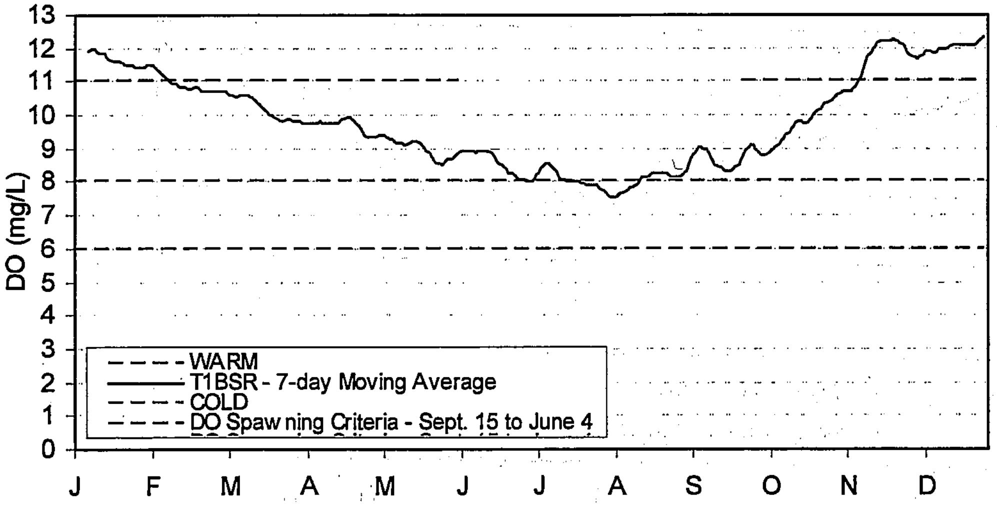
UPSTREAM SCOTT – T1BSR



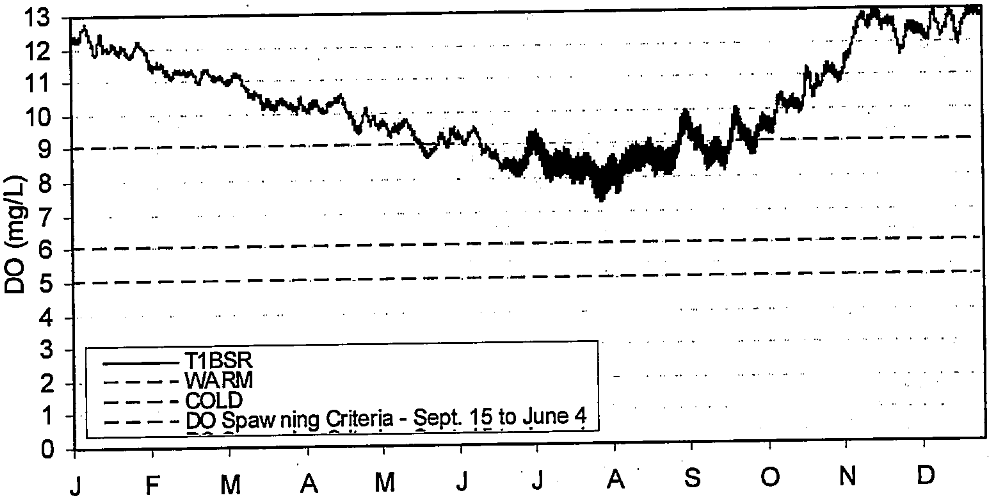


DOWNSTREAM SCOTT – T1BSR





SEIAD – T1BSR


13
12
11
10
9
8
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2
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0
DO (mg/L)
T1BSR
WARM
COLD
DO Spaw ning Criteria - Sept. 15 to June 4
J
F
M
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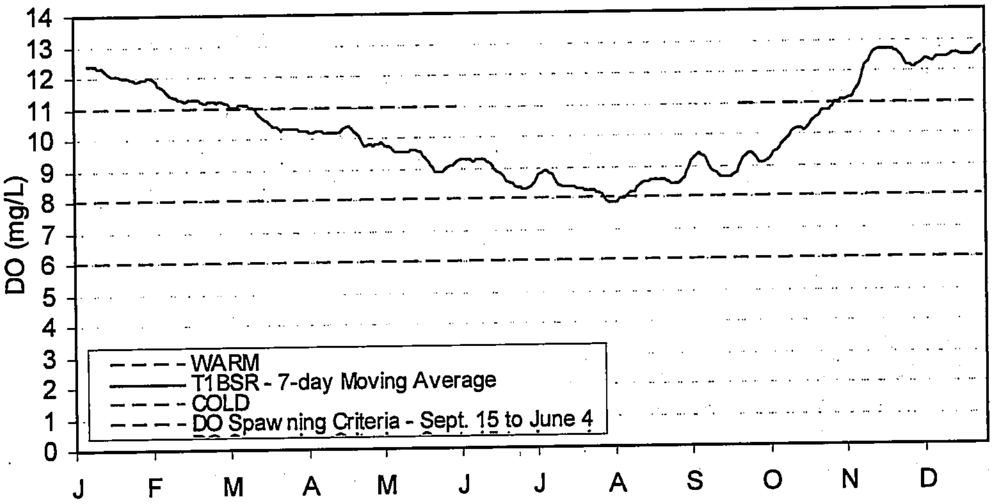
14
13
12
11
10
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8
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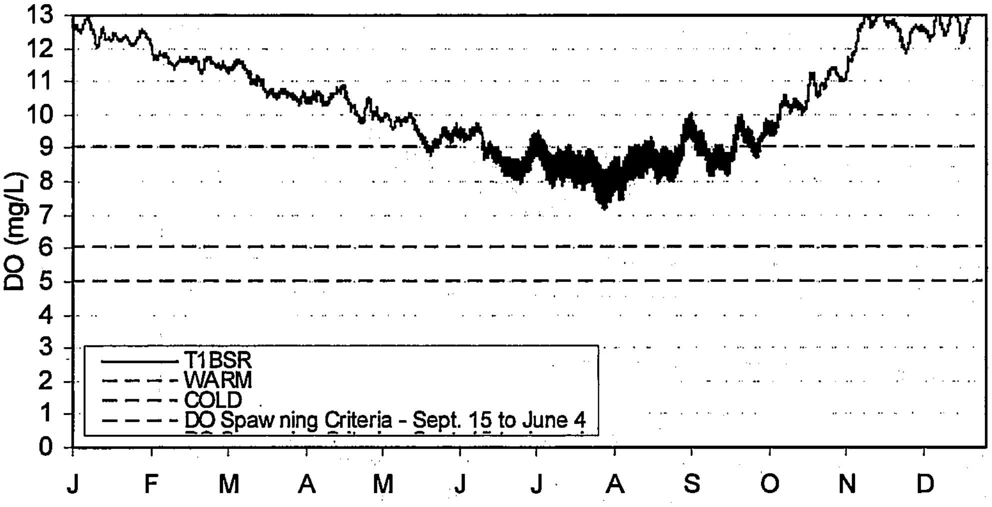
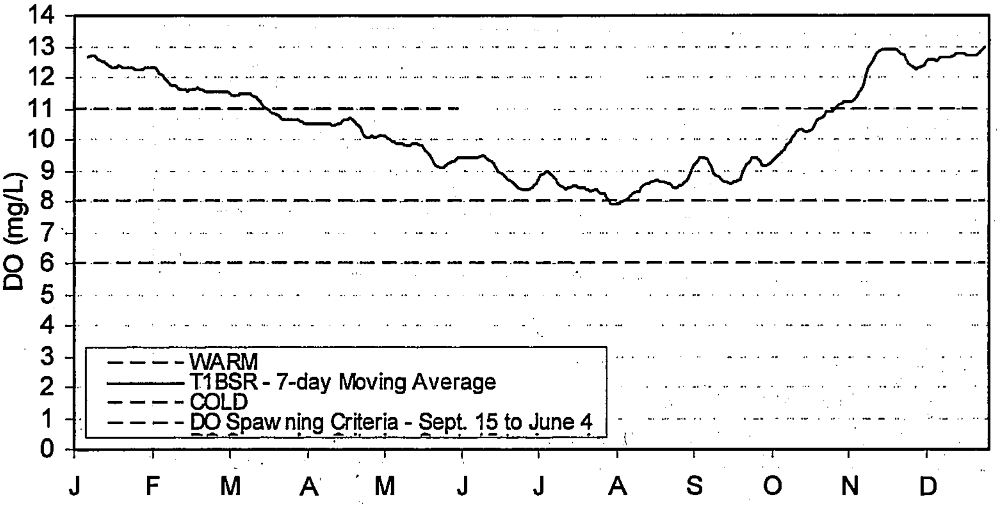
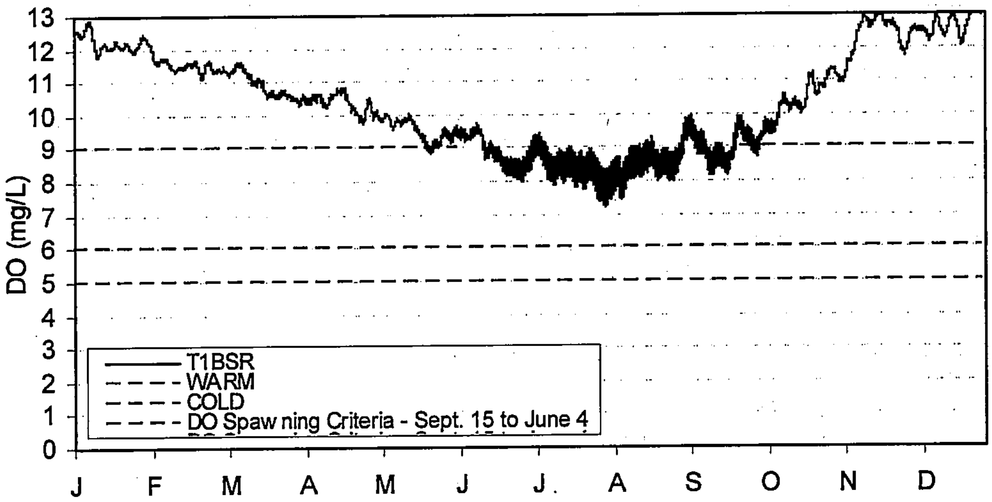
3
2
1
0
DO (mg/L)
WARM
T1BSR - 7-day Moving Average
COLD
DO Spaw ning Criteria - Sept. 15 to June 4
J
F
M
A
M
J
J
A
S
O
N
D

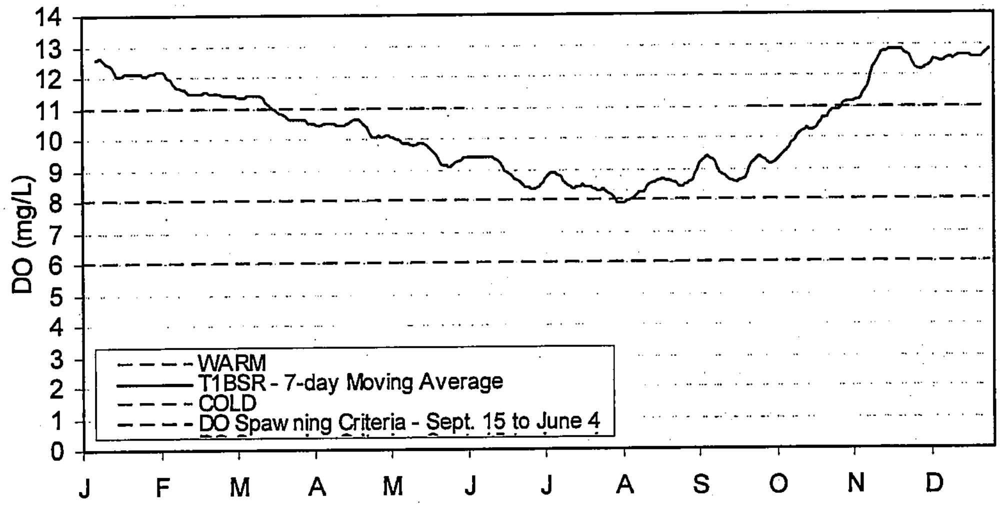
UPSTREAM INDIAN – T1BSR



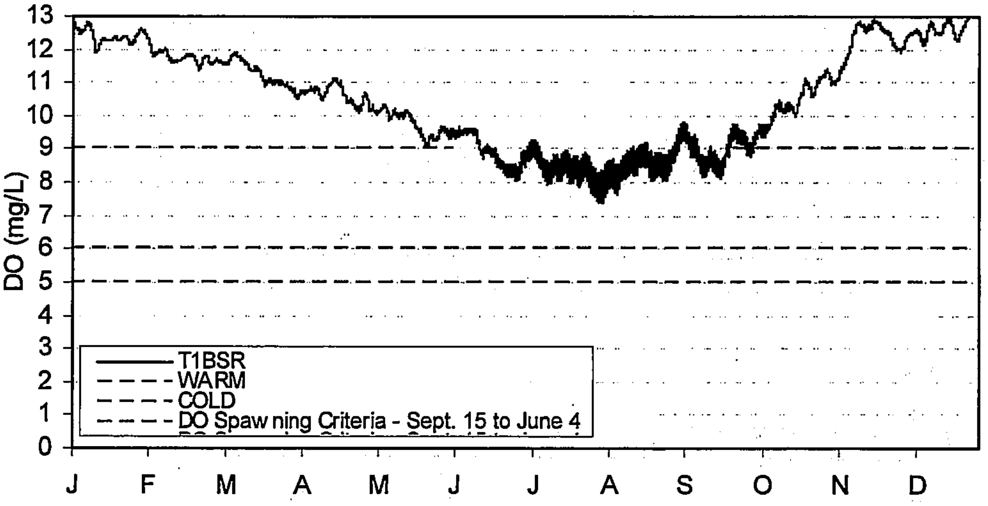


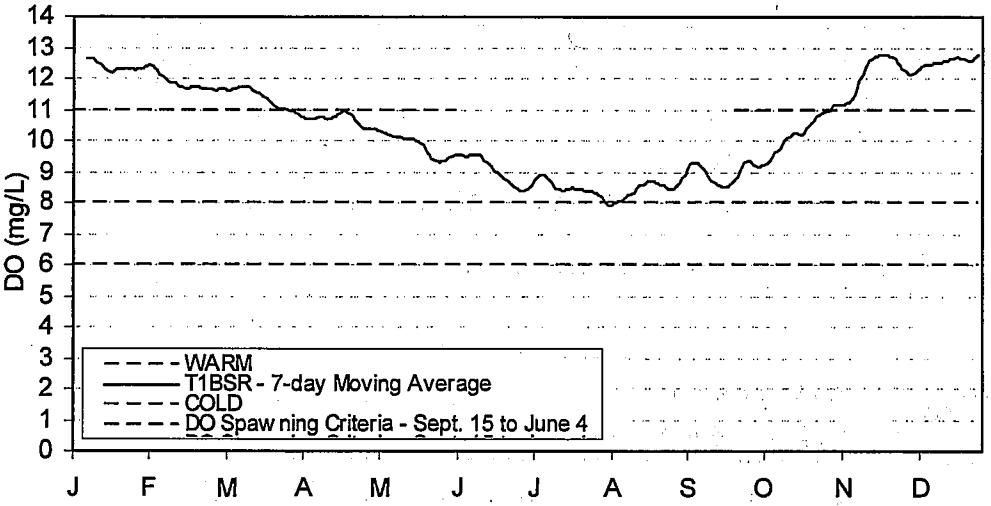
DOWNSTREAM INDIAN – T1BSR



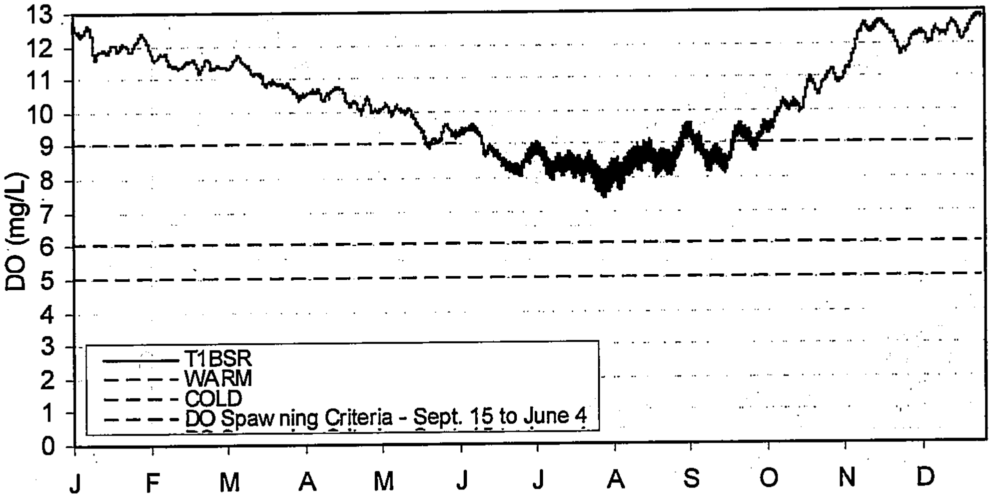


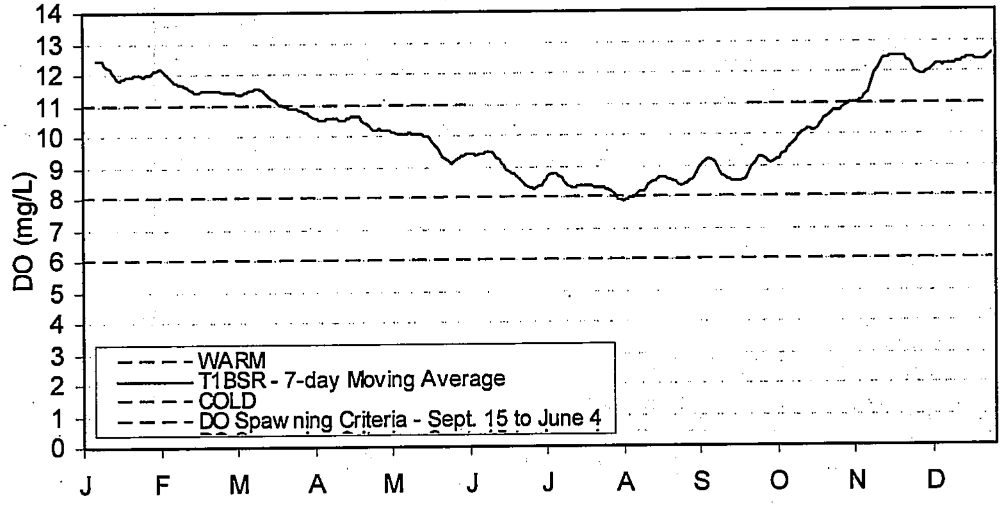
UPSTREAM SALMON – T1BSR



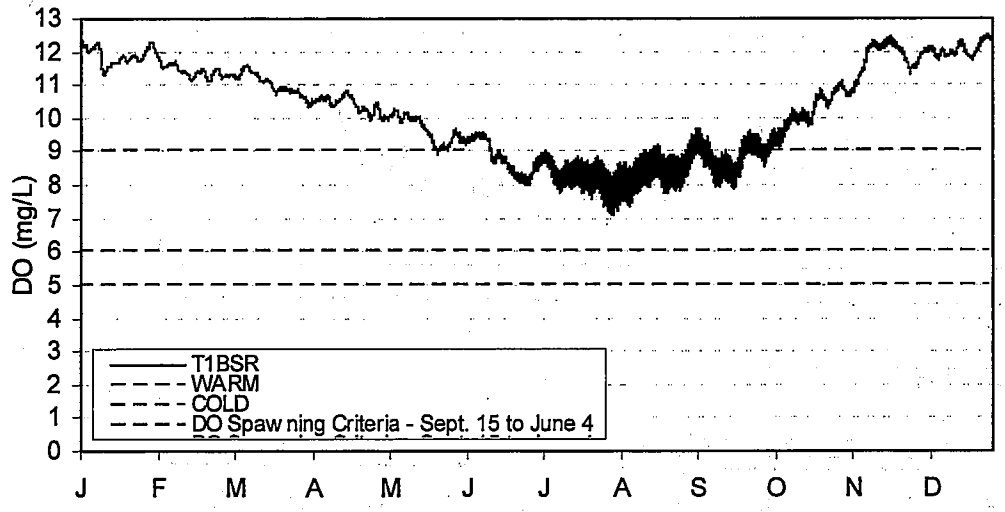


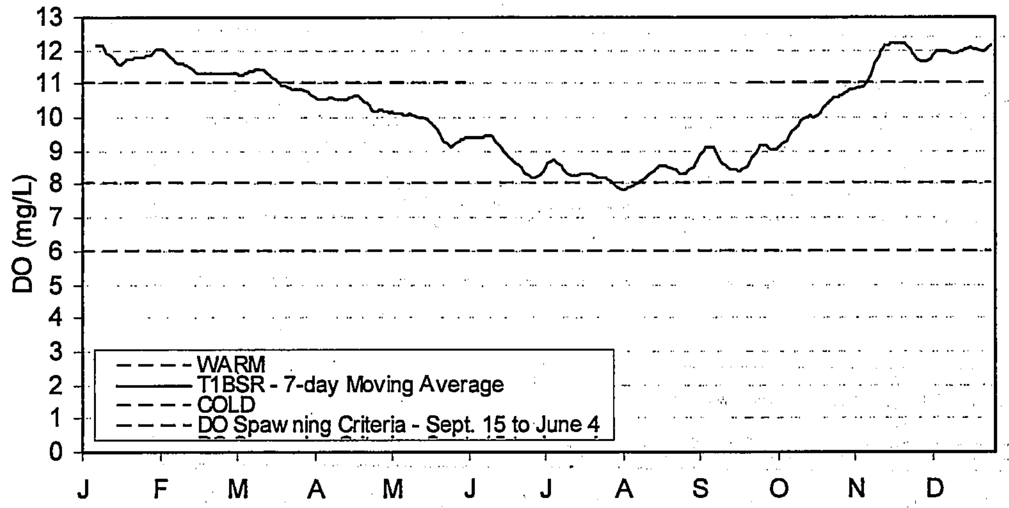
DOWNSTREAM SALMON – T1BSR



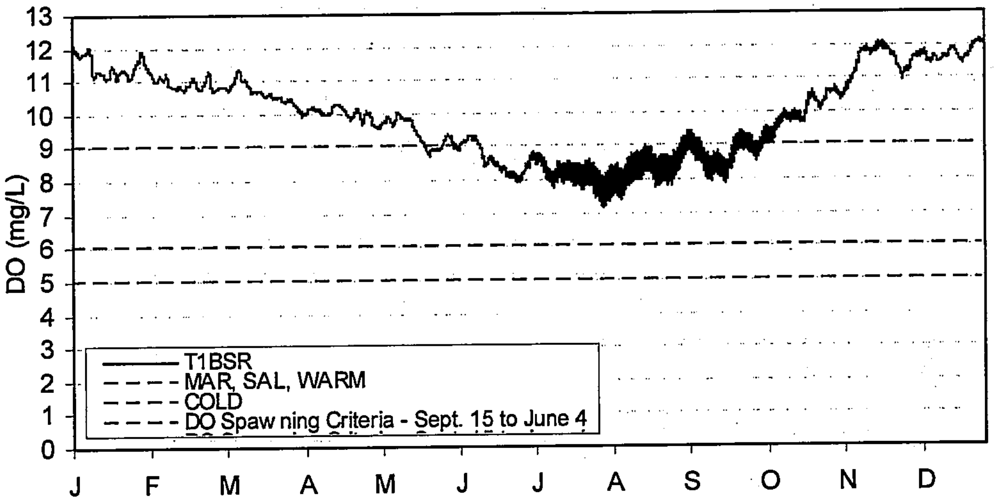


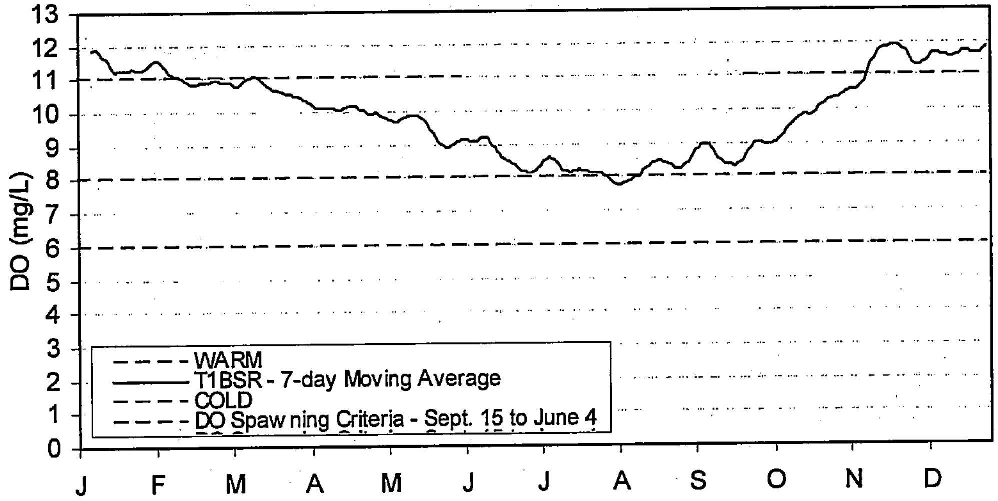
UPSTREAM TRINITY – T1BSR



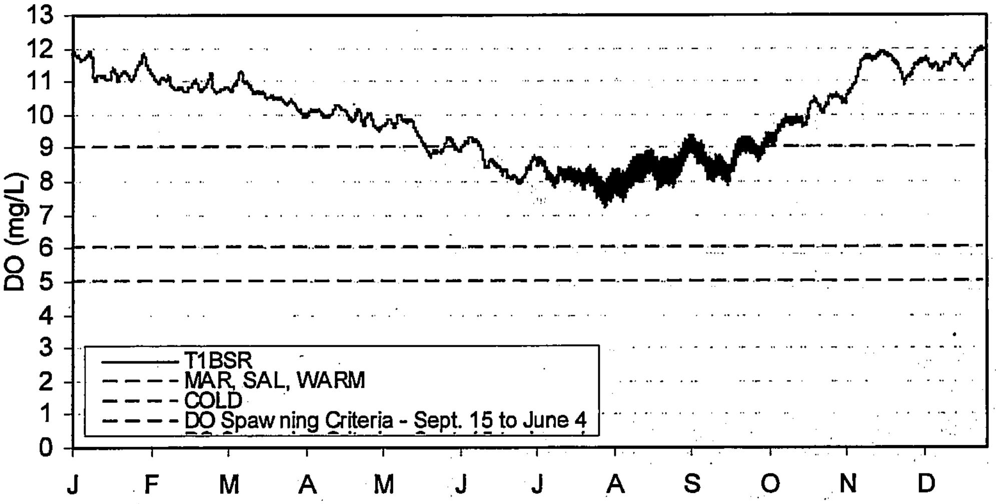


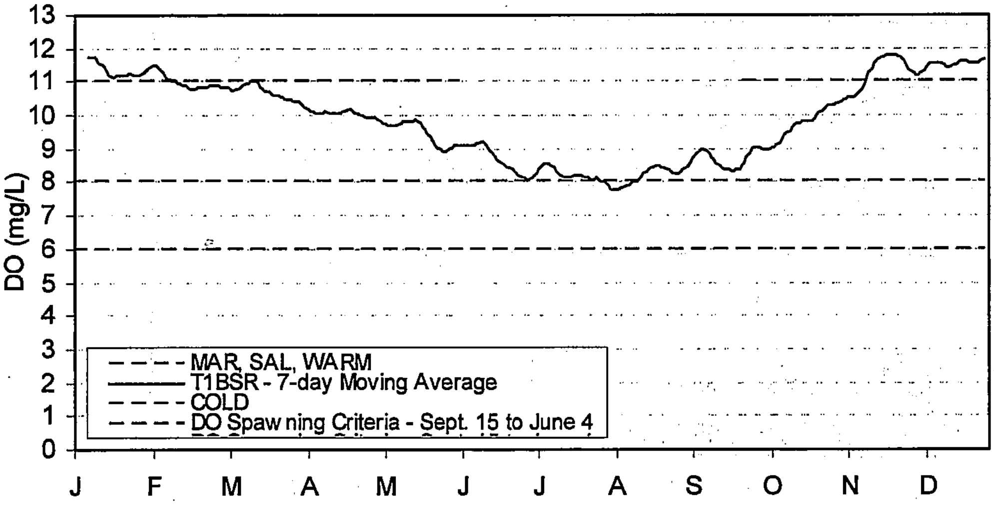
DOWNSTREAM TRINITY – T1BSR



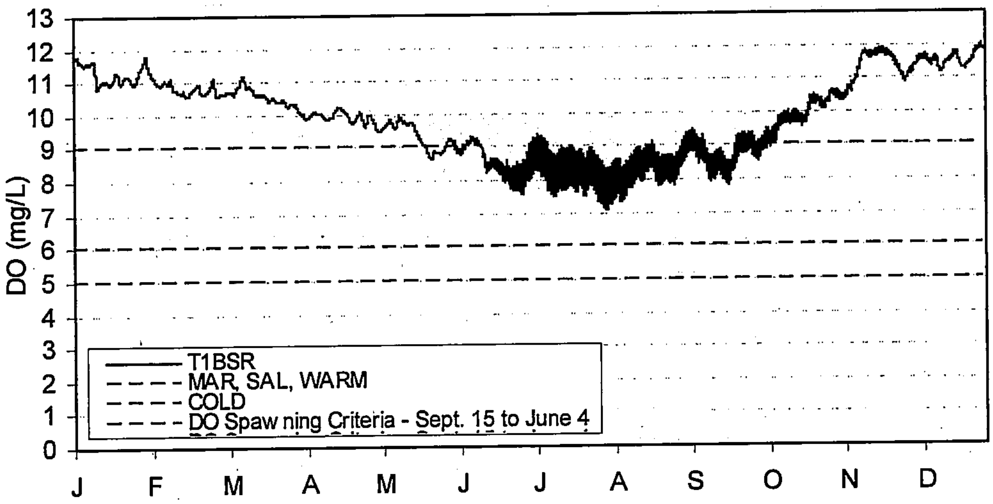


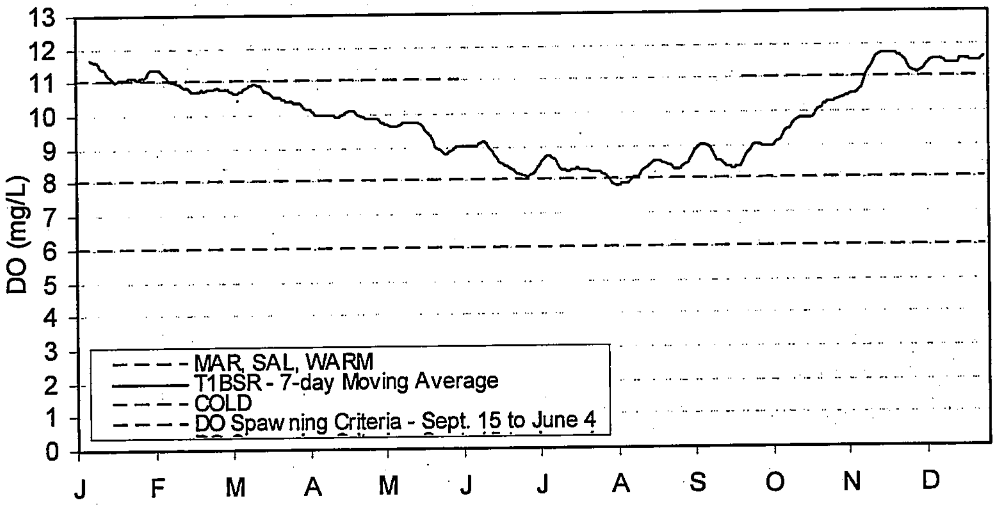
YOUNGSBAR – T1BSR



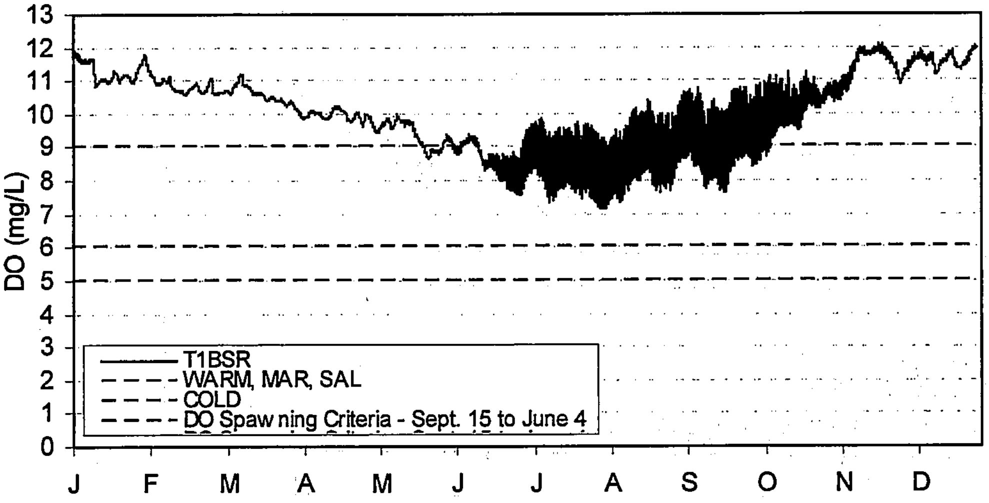


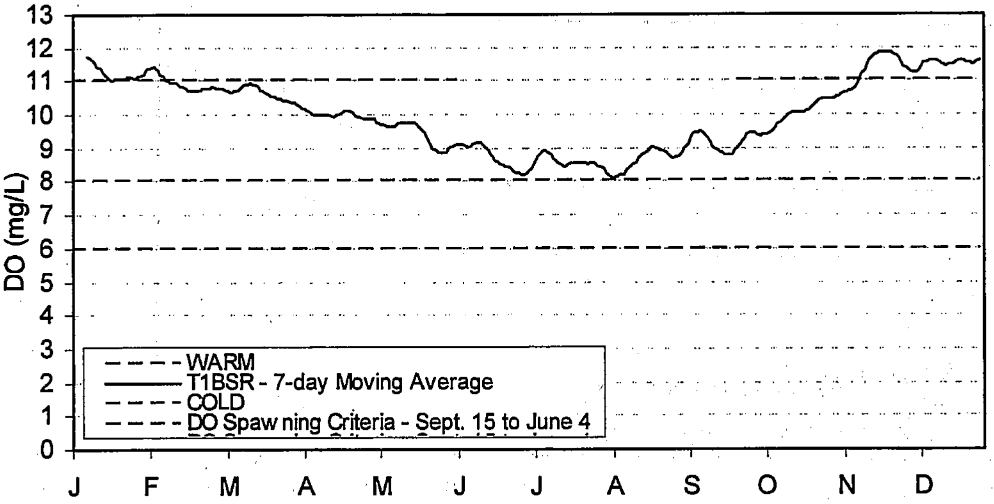
TURWAR – T1BSR



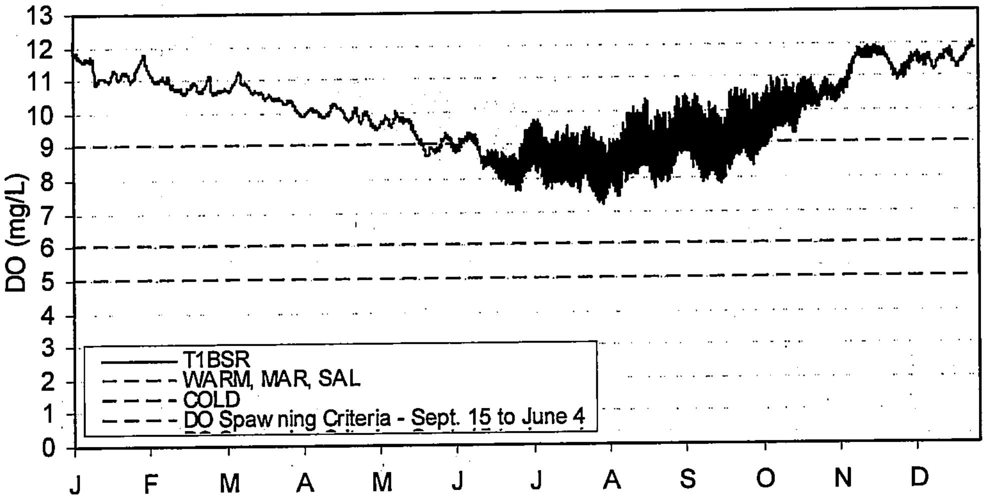


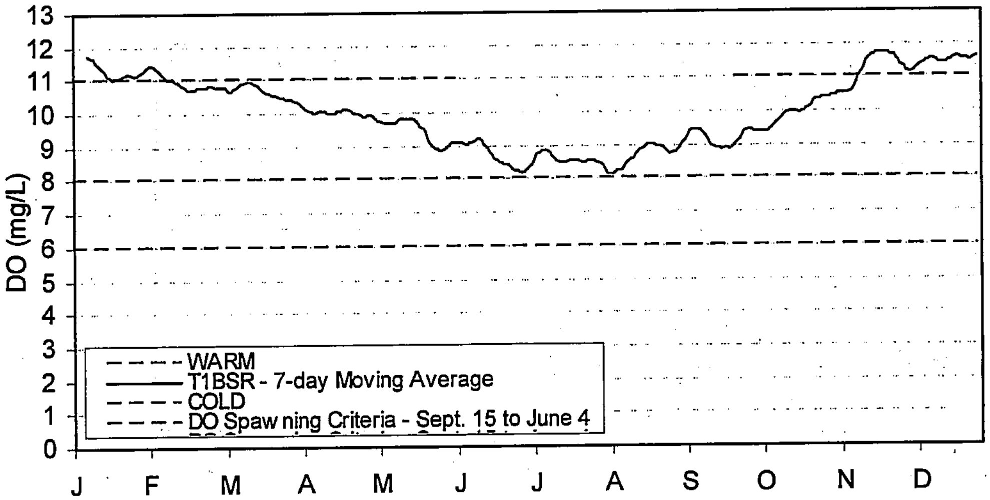
UPPER ESTUARY – T1BSR



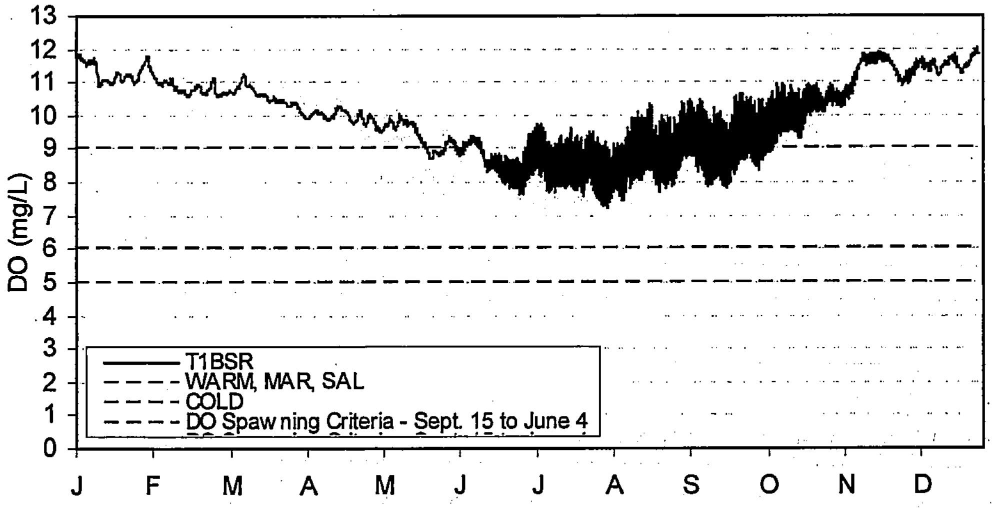


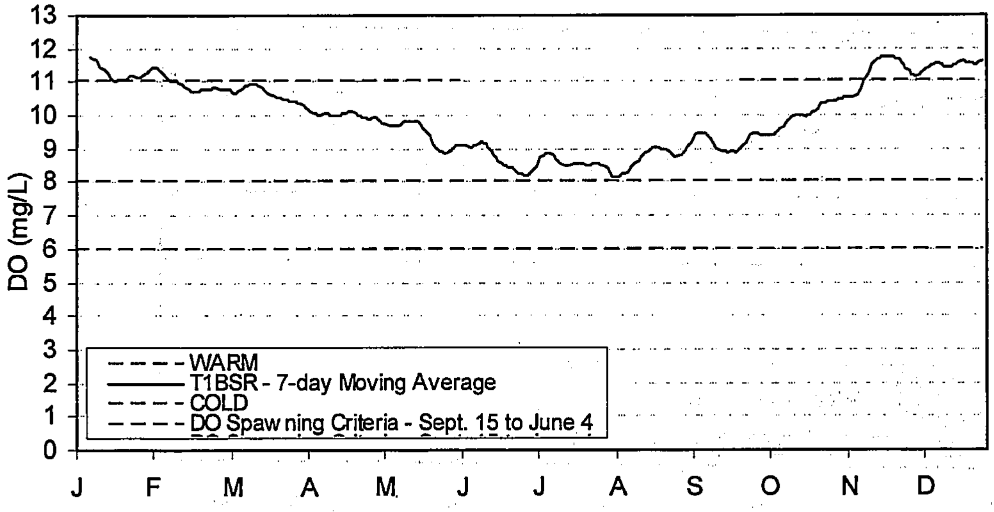
MIDDLE ESTUARY – TOP – T1BSR



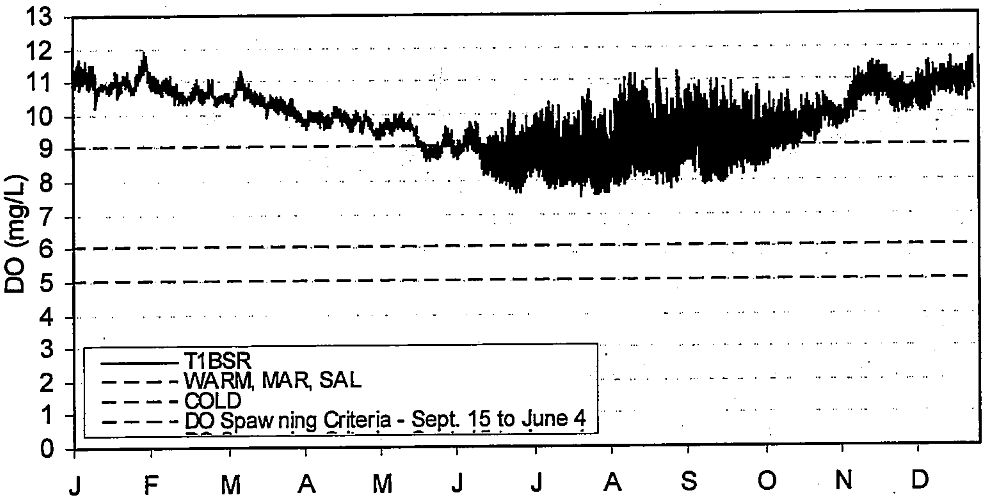


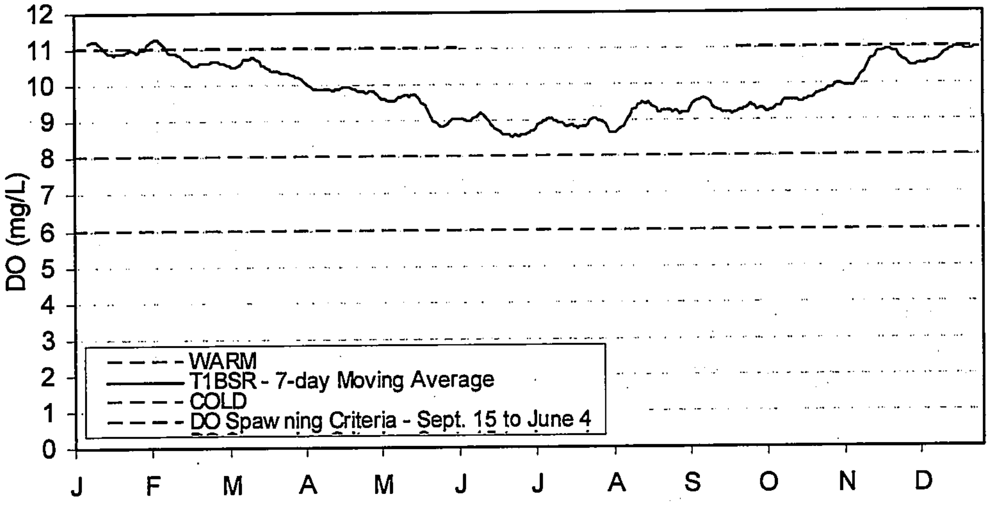
MIDDLE ESTUARY – BOTTOM – T1BSR





LOWER ESTUARY – TOP – T1BSR





LOWER ESTUARY – BOTTOM – T1BSR