COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL PROTECTION
BUREAU OF POINT AND NON-POINT SOURCE MANAGEMENT

RATIONALE FOR THE DEVELOPMENT OF AMBIENT WATER QUALITY CRITERIA FOR

DISSOLVED OXYGEN

PROTECTION OF AQUATIC LIFE USE

Revised 02/01/13

Statement of Issue

Aquatic life in Pennsylvania freshwater waterbodies are currently being protected from adverse impacts associated with low dissolved oxygen by four categories of dissolved oxygen criteria (DO), which is found in PA Code Chapter 93.7 Table 3. Only slight revisions have been made to the numerical component of the dissolved oxygen aquatic life criteria since the Department of Health Sanitary Water Board adopted their Rules and Regulations in 1967. Since then, many new resources of new scientific literature and information have been made available, including EPA's review of literature that resulted in a dissolved oxygen criteria recommendation in the "Quality Criteria for Water 1986" (also known as the "Gold Book"). Based on the availability of updated scientific studies and recent concerns about the appropriateness of the current dissolved criteria, a review of the current information regarding dissolved oxygen requirements of aquatic life was undertaken.

Background

Dissolved oxygen refers to the oxygen gas that is dissolved in the water and made available to aquatic life. Oxygen gets into the water by diffusion from the surrounding air, by aeration from moving water or as a product of photosynthesis. The solubility of oxygen in water is highly dependent on the temperature of the water, but is also affected by atmospheric pressure and salinity. Dissolved oxygen fluctuates diurnally in a freshwater ecosystem due to photosynthesis and respiration. Additionally, DO fluctuates seasonally mostly due to change in water temperatures.

DO requirements for aquatic organisms were highly studied until the 1980's. As such, there are many peer-reviewed studies on the topic. The abundance of literature relating to lethal and sub-lethal effects is helpful to understanding the deleterious effects of low dissolved oxygen concentrations. Many lab experiments studying DO requirements of fish focused on determining minimum DO concentrations necessary to avoid mortality in both adult and larval stages of fishes. Other field and lab studies that examined sub-lethal effects of varying DO conditions have shown stress responses in the form of avoidance, decreased swimming performance, reduction in metabolic rate, reduced growth, and changes in behavior that may increase risk of predation. Additionally, low DO concentrations have been shown to prevent spawning, and

reduce fecundity of female fish in lab experiments. Stress due to low DO has also been shown to increase fish susceptibility to disease and increase the toxicity of certain chemicals and pollutants. The consensus of many DO studies is that early life stages of fish, such as embryonic and larval stages, are generally more sensitive to low DO concentrations than adult life stages. Salmonids generally require higher concentrations of DO than fish that inhabit warmwater ecosystems, however, some warm and cool species of fish such as shad, herring, pike, sculpins and smallmouth bass, are known to be more sensitive than other warm water species.

The determination of appropriate minima, means, frequency and duration for DO criteria is difficult since the lab experiments typically exposed organisms to a constant DO concentration. The DO concentration used in the experiments represents both the minima and the average. EPA states in the 1986 Recommended Criteria document, "biological effects of low dissolved oxygen concentrations depend upon means, minima, the duration and frequency of the minima and the period of averaging." There is a lack of information on the duration and frequency components of DO criteria; therefore most criteria consist of minima and means.

The Department recognizes and respects both the value and the limitations that this data provides. Developing criteria from existing scientific literature is challenging for numerous reasons. The application of study data for criteria development (a controlled environment vs. a multi-variable environment) must be carefully examined. In reality, an inter-relationship exists among parameters within an aquatic ecosystem; a relationship that cannot be adequately captured within the scope of a scientific study. Thus, the application of study data must take into consideration the natural dynamic of the ecosystem to which it is being applied. For example, some of the literature that exists on DO requirements involves studies based on laboratory experiments where the conditions are artificial in several important aspects. With this understanding, the Department has examined the available data and carefully applied it to the selection of the proposed DO criteria.

Pennsylvania Dissolved Oxygen Criteria

Pennsylvania's first dissolved oxygen criteria were found in the Sanitary Water Board Rules and Regulations and were adopted as follows:

b- *Dissolved Oxygen*

b_1 - *Minimum daily average 6.0 mg/l; No value less than 5.0 mg/l*

b_2 - *Minimum daily average 5.0 mg/l; No value less than 4.0 mg/l*

b_3 - *Minimum daily average not less than 5.0 mg/l, except during the period of 4/1 - 6/15 and 9/16 – 12/31, not less than 6.5 mg/l*

b_4 - *Minimum daily average not less than 3.5 mg/l, except during the period of 4/1 - 6/15 and 9/16 – 12/31, not less than 6.5 mg/l*

The following dissolved oxygen criteria were added December 20, 1967:

b_5 – *For the period 3/15 to 6/30 of any year; no value less than 5.0 mg/l. for the remainder of the year,; no value less than 4.0 mg/l*

b_6 – *No value less than 7.0 mg/l*

b_7 – *For lakes, ponds and impoundments only; no value less than 4.0 mg/l in the epilimnion*

b_8 – *For lakes, ponds and impoundments only; no value less than 5.0 mg/l*

Dissolved oxygen criteria b_1 and b_2 corresponded to cold water fishes (CWF) use and warm water (WWF) fishes use, respectively. DRBC dissolved oxygen criteria for the Delaware River and Estuary were incorporated as b_3 and b_4. The b_5 criterion corresponded to the trout stocking use and b_6 corresponded to conservation areas (conservation areas became high quality waters in the 1978-79 rulemakings; both the trout stocking use and conservation area use were added in 1967). The b_7 criterion corresponded to warm water lakes, ponds and impoundments, while the b_8 criterion corresponded to and cold water lakes, ponds and impoundments.

The Sanitary Water Board's dissolved oxygen criteria were similar to, but in some cases, less stringent than, the Federal Water Pollution Control Administration's recommendations in the 1968 "Report of the Committee on Water Quality Criteria" (The "Green Book"). The Green Book recommended that dissolved oxygen criteria in a warm water fishery should be "above 5.0 mg/l assuming normal seasonal and daily variations are above this concentration. Under extreme conditions, however, they may range between 5 and 4 mg/l for short periods during any 24-hour period, provided that the water quality is favorable in all other aspects." For cold water species, the Green book stated that "it is desirable that DO concentrations be at or near saturation. This is especially important in spawning areas where DO levels must not be below 7 mg/l at any time. For good growth and general well being of trout, salmon and their associated biota, DO concentrations should not be below 6 mg/l. Under extreme conditions, they may range between 6 and 5 mg/l provided the water quality is favorable in all other respects and daily and seasonal fluctuations occur."

DER adopted a few changes to the DO criteria in 1973 and 1974. The changes were as follows (underlined):

b_3 - *Minimum daily average not less than 5.0 mg/l, except during the period of 4/1 - 6/15 and 9/16 – 12/31, not less than 6.5 mg/l* <u>as a seasonal average</u>

b_4 - *Minimum daily average not less than 3.5 mg/l, except during the period of 4/1 - 6/15 and 9/16 – 12/31, not less than 6.5 mg/l* <u>as a seasonal average</u>

b_5 – *For the period* <u>2/15 – 7/31</u> *of any year* <u>minimum daily average of 6.0 mg/l</u>*., no value less than 5.0 mg/l. For the remainder of the year* <u>minimum daily average 5.0 mg/l</u>*., no value less than 4.0 mg/l.*

*Added:

<u>b_9 - Minimum daily average 7.0 mg/l, No value less than 6.0 mg/l</u>

In the 1976 Quality Criteria for Water, also known as the "Red Book," EPA recommended "a minimum concentration of dissolved oxygen to maintain good fish populations is 5.0 mg/liter. The criterion for Salmonid spawning is a minimum of 5.0 mg/liter in the interstitial water of the gravel." DER Chapter 93 criteria remained as a minimum daily average of 5.0 mg/l and minimum of 4.0 mg/l for warm water fishes, and 6.0 mg/l minimum daily average and 5.0 minimum for cold water fishes.

In 1979 DER adopted additional changes in Table 3; these changes include: the deletions of $b_{7,}$ b_8 and $b_{9.}$ Language from the lakes, ponds and impoundment criteria ($b_{7,}$ b_8) was combined with b_1 and $b_{2.}$ Additionally, the symbol "b" was replaced with "DO".

In 1986, EPA revised the national water quality criteria recommendations in "Quality for Water 1986," also known as the "Gold Book." EPA reviewed a large body of literature in order to make these recommendations relating to warm water fishes and cold water fishes (including salmonids).

DER made minor reformatting revisions to the DO criteria in Chapter 93.7 Table 3 in 1988, but did not incorporate the 1986 Recommendations for unknown reasons.

DRBC criteria were deleted from Chapter 93.7 Table 3 during the 2000 Triennial Review and referenced in the appropriate segments in 93.9. Consequently, criteria b_3 and b_4 were deleted and the remaining D.O. criteria were renumbered in Table 3.

In 2005, the DO_1 criterion was revised to clarify the criterion that applies to lakes, ponds and impoundments to incorporate reference to the natural stratification that may occur in those waterbodies.

The current dissolved oxygen criteria, as outlined in Chapter 93.7 Table 3 are as follows:

DO_1	For flowing waters, minimum daily average 6.0 mg/l; minimum 5.0 mg/l. For lakes, ponds and impoundments, minimum 5.0 mg/l.	CWF HQ-WWF HQ- TSF
DO_2	Minimum daily average 5.0 mg/l; minimum 4.0 mg/l.	WWF
DO_3	For the period February 15 to July 31 of any year, minimum daily average 6.0 mg/l; minimum 5.0 mg/l. For the remainder of the year, minimum daily average 5.0 mg/l; minimum 4.0 mg/l.	TSF
DO_4	Minimum 7.0 mg/l.	HQ-CWF

Review of "Ambient Water Quality Criteria for Dissolved Oxygen" (1986)

EPA reviewed and considered a large number of studies on dissolved oxygen for the development of the recommended criteria for freshwater aquatic life. Although there are typically two main ways to express a dissolved oxygen criterion: concentration (mg/L) or percent saturation, EPA determined that it is more direct and easier to express the dissolved oxygen criteria as a minimum concentration.

Much of the DO research has focused on acute responses such as mortality or loss of equilibrium. However, there is extreme variability in test conditions even among those studies that focus on a common endpoint (i.e. mortality), such as: constant or declining exposure to low DO conditions, duration of exposure

EPA recommended two separate sets of aquatic life criteria for dissolved oxygen: coldwater criteria for the protection of salmonids and other coldwater species and warmwater criteria for the protection of species indigenous to warm water habitats. The national criteria also differentiate the protection needed for adult fishes and that needed for the early life stages of those same fishes. Early life stages include spawning, incubation of embryos and larvae up to 30 days after hatch.

EPA's rationale for the 1986 criteria included a discussion of the different life stages and thresholds of salmonids and non-salmonids affected by dissolved oxygen, including metabolic and physiological effects, growth, reproduction, behavioral responses, swimming and acute lethal responses. DO requirements for aquatic macroinvertebrates were evaluated as well as other additive responses such as stress from chemicals, temperature and disease.

Salmonids
Of particular interest are the DO concentrations necessary for early life stages of salmonids. Since most species of salmonids have embryonic and larval stages that develop while buried in the gravel of streams or lakes, protection of DO concentrations in the gravel is required. The area where a female salmonid lays her eggs in the gravel is called a "redd." It's complicated to determine what concentration of DO in the surface water in required in order to protect the redds since there are so many variables that affect the DO in the redds. EPA determined that intergravel DO was generally 3 mg/L lower than that of the overlaying surface water by reviewing several studies on DO and redds.

Nonsalmonids (warmwater fish)
The EPA rationale explained that developing criteria for warmwater fish was more difficult than deriving criteria for salmonids because there is less literature available and much more diversity of fishes in a warmwater ecosystem.

Based on literature review, EPA determined that, except for larval stages, non-salmonid species were less sensitive to low dissolved oxygen concentrations than salmonids. However, literature shows that many species of non-salmonids have early life stages that are much more sensitive to low dissolved oxygen concentrations than adult life stages.

The EPA literature review yielded a few generalizations, such as: adults and juveniles of all species studied survive for at least a few hours at DO concentrations as low 3 mg/L, but there is little knowledge about chronic exposure to low DO concentrations. Reduced concentrations of DO also caused reduced growth in studies. For example, Stewart et al. (1967) observed reduced growth in largemouth bass juveniles below 5.8 mg/L.

Macroinvertebrates
EPA stated that there is much less information available on the DO requirements of macroinvertebrates compared to information available on fish. However, even with limited amount of macroinvertebrate studies, EPA stated that the DO requirements for the survival of aquatic macroinvertebrates are "almost certainly greater than those of most fish species." Chronic effects of low DO on macroinvertebrates are not well known, but EPA suggested that "concentrations adequate to avoid impairment of fish production probably will provide reasonable protection for invertebrates as long as lethal concentrations are avoided."

Temperature Stress
EPA examined studies to evaluate the synergistic effect of temperature and DO on fishes. EPA concluded that "high temperatures almost certainly increase the adverse effects of low dissolved oxygen concentrations." Since most of the laboratory experiments on fish DO requirements are performed using temperatures near the mid-range of the fishes' temperature tolerances, criteria based on these lab studies alone may be under protective at high temperatures that are stressful to fish.

Chemical Stress
EPA discussed several laboratory studies that evaluated the effect of low DO concentrations on the toxicity of various chemicals, such as lead, zinc, copper, monohydric phenols, ammonia, hydrogen sulfide, napthenic acid and potassium cyanide. Some of these chemicals are commonly found in oxygen-demanding wastes. Overall, the studies showed that low DO concentrations increased the toxicity of these chemicals in the fish species studies.

Disease Stress
EPA reviewed the results of several studies that suggest that fish become more susceptible to disease when stressed by low DO concentrations. These studies suggest that many fish pathogens are continuously present in many waterbodies, but fish are only susceptible to infection when their defenses are compromised by stress.

Discussion of DO Literature
EPA summarized a large body of literature in its revisions of recommended DO criteria. This review resulted in a risk level assessment to protect aquatic life from impacts due to low DO concentrations. The qualitative levels of risk include: no production impairment, slight production impairment, moderate production impairment, severe production impairment and limit to avoid acute mortality. Production impairment refers to production impairments in a fishery. EPA summarized the DO concentrations judged to achieve protection at the qualitative levels of risk in a table in the recommended criteria. The recommended criteria were then derived from the DO concentrations in this table.

The DO concentrations that correspond to each risk level were derived from growth data for "other life stages" and are approximately equivalent to 10%, 20% and 40% growth impairment for slight production impairment, moderate production impairment and severe production impairment, respectively. EPA states that, "growth impairment of 50% or greater is often accompanied by mortality, and conditions allowing a combination of severe growth impairment and mortality are considered as no protection."

DO concentrations corresponding to risk levels for early life stages are based on subjective judgments and generalizations of the response curve shape between what would result in no production and impairment and the acute mortality limit. EPA's recommended criteria is based on the DO concentrations judged to be equivalent to the level of risk that was determined to be appropriate for a national criterion.

Proposed Dissolved Oxygen Criteria

The Department proposes to incorporate the DO concentrations from EPA's risk level assessment in its DO criteria. Instead of incorporating values associated with severe production impairment and protection of only acute mortality, the Department proposes to incorporate the slight production impairment as 7-day averages and the moderate production values as minima for early life stages and other life stages to protect aquatic life. It is important to note that the proposed criteria apply to flowing freshwater streams, the epilimnion of a naturally stratified lake and throughout the waterbody of non-stratified lakes.

CWF Criteria

In Pennsylvania, three species of salmonids are commonly found, due to natural reproduction or stocking: brook trout, brown trout and rainbow trout. Steelhead trout are found in the tributaries of Lake Erie and in Lake Erie; Steelhead are a subspecies of rainbow trout.

The Department proposes adopting criteria for coldwater embryonic and larval stages for the appropriate season, depending on whether the species historically spawns in the fall or in the spring. These time periods are based on discussions with Pennsylvania Fish and Boat Commission and can be found in §93.7 (b). The criteria will apply to water column concentrations and therefore will need to achieve intergravel concentrations that will be protective of embryonic and larval stages up to 30 days after hatch. The Department proposes 9.0 mg/l on a 7-day average and 8.0 mg/l as a minimum as the criteria protective of early life stages developing in redds. For the remainder of the year, or year-round in surface waters where natural Salmonid reproduction does not occur: a 7-day average of 6.0 mg/l and minimum of 5.0 mg/l were calculated from the slight production impairment and the moderate impairment value, respectively.

§93.7(b) is added to describe the times of the year the criteria for early life stages apply. Protected early life stages include those embryonic and larval life stages resulting from natural reproduction and is not intended to protect stocked trout fingerlings. The spring spawning Salmonids include Steelhead trout in the Lake Erie basin and the few populations of naturally reproducing rainbow trout [other than Steelhead] around the state. The fall spawning salmonids include brown trout and brook trout.

§93.7(b) also includes language that allows discretion to be applied where it can be demonstrated that natural reproduction of salmonids does not occur and is documented that reproduction has not occurred historically. The criteria for determining whether or not natural salmonid reproduction occurs are based on criteria used by Pennsylvania Fish and Boat Commission to document trout reproduction.

WWF Criteria

The Department proposes to adopt the criteria for warmwater early life stages as the criteria for warm water fishes (WWF). Proposed criteria for WWF are 5.5 mg/l as a 7-day average and 5.0 mg/l as a minimum. Based on discussions with Pennsylvania Fish and Boat Commission, these values are appropriate since PA warm water fisheries are so diverse and include fish species that spawn from early spring to late summer. For example, smallmouth bass typically spawn in the months of May and June in Pennsylvania and therefore early life stages are present during the summer. Late summer spawners (ex: green sunfish and bluegill) lead to the presence of early life stages during the fall and winter. Furthermore, the seasonal change in water temperature is what prompts many warm water species to spawn, and the exact calendar date which these water temperature changes will occur cannot be predicted from year to year. As a result of such variation, it is difficult to discern the specific times of year that require protection of early life stages; therefore, it is appropriate to offer protection of early life stages year-round. An extensive literature search also indicates that the proposed criteria are protective for growth of warm water species in the warm summer months, migration of diadromous fish species and survival of macroinvertebrates.

Laboratory studies on early life stages of warm water fishes show that larval life stages are more sensitive to DO than are embryonic and adult life stages. Many studies show that Centrarchid (bass family) juveniles may be the most sensitive of all warm water fishes to low DO concentrations. In Whitmore's (1960) laboratory experiment, largemouth bass juveniles avoided DO levels equal to or less than 4.5mg/L, and no avoidance occurred at 6 mg/L DO. In experiments by Spoor, larval smallmouth bass were shown to be highly sensitive to low DO from day two through day ten after hatching and hatched at a larger size, but grew slower than largemouth bass (Spoor 1977;1984). At or below dissolved oxygen concentrations of 4.5 mg/L, smallmouth bass hatching and larvae survival was observed to be significantly reduced (Siefert et al., 1974; Spoor, 1984). Lethal and sublethal effects of reduced D.O. (less than 5 mg/L) witnessed in laboratory experiments were, in general, directly related to exposure times which ranged from hours to days (Mount, 1964; Doudoroff & Shumway, 1970; Siefert et al., 1974; Spoor, 1984).

In addition, Spoor (1984) notes that that raising the temperature from 20°C (68°F) to 25°C (77°F) increased the smallmouth bass larvae's sensitivity to oxygen deficiency. It is also important to note that smallmouth bass typically spawn in May and June in Pennsylvania and therefore early life stages are present in the summer. Ambient stream temperatures may reach in excess of 30°C (86°F) in the summer. Chapter 93 Temperature Criteria for June is 84°F and 87°F in July and August.

"Doudoroff and Shumway (1970) were tasked with developing recommendations for DO criteria for freshwater fishes and suggested using various curves to calculate seasonal DO criteria corresponding to the natural DO of a water body and various protection levels. Other indices have been developed that relate fishery performance/suitability to DO concentrations given a particular species. The Habitat Suitability index developed by the USFWS for Smallmouth bass provides a wealth of species information including a model for DO (Edwards et al., 1983). In this model, 5 mg/L DO is associated with a Suitability Index value of approximately 70%. Similarly in Doudoroff and Shumway (1970), the multi-species, multi-life stage averaged trend

line in Figure 2 (Relative Performance Index vs. DO, p. 270) generally agrees with Edwards et al. (1983), scoring slightly higher at approximately 83% Relative Performance Index (at 5 mg/L DO). At 5 mg/L, both indices indicate a reduction in environmental conditions potentially resulting in suboptimal population condition (growth rates, swimming speeds, weight at hatching, survival, etc.)" (Fischer 2009).

Several field studies concerning dissolved oxygen have been conducted; these studies support a minimum of 5 mg/l for protection of warm water fish species. After performing an extensive field study of dissolved oxygen conditions, Ellis (1937) stated that 5 mg/l dissolved oxygen is the "lowest value which may be reasonably be expected to maintain in good condition varied fish faunae of warm-water fishes" when the temperature is above 20°C (68°F) and that 5 mg/l is "approximately the lower limit of favorable conditions". Coble (1982) related fish populations from the Wisconsin River to dissolved oxygen concentration and concluded that percent sport fish, percent walleyes and yellow perch, percent Centrarchidae (bass family), number of fish species, and number of species of sport fish were all greater at sites where the average summer DO concentration exceeded 5 mg/L. Coble (1982) stated that the level of 5 mg/L could be identified as a threshold from poor to good fish populations and strongly supported a DO criterion of no less than 5 mg/L.

Since the anadromous American shad use the Susquehanna and Delaware River basins to complete their life stages, and blueback herring and alewife (collectively river herring) utilize the Delaware River basin, criteria in these WWF river basins must also protect for these migratory Clupeid species. Stier and Crance (1985) determined that dissolved oxygen concentrations less than 5 mg/l would create a migratory block for American shad adults and juveniles. DO concentrations of 5 mg/l are required throughout the American Shad's spawning area. A study referenced by Stier and Crance found no shad eggs in water where DO concentrations were less than 5 mg/l. Maes et al (2007) modeled migration of migratory fish species in Europe (including a species of shad) and concluded that a "baseline concentration of 5 mg/l considerably increases the opportunity for diadromous fish species to pass."

Pennsylvania Fish and Boat Commission summarized that "Given the data and observations in the available literature, largemouth and smallmouth bass are sensitive enough to depressed D.O. concentrations that avoidance may initiate at 4.5 mg/L. Sublethal and lethal effects, in general, are inversely correlated with D.O. concentration. Environmental degradation may significantly complicate threshold values of D.O. for fishes. "Activity and the presence of toxic materials probably would raise the critical concentration substantially." (Mount, 1964). Data presented by researchers and conclusions published by literature reviewers all bottle neck toward a common threshold value of approximately 5 mg/L for freshwater fishes. A prudent and responsible approach to choosing a criterion would not be to accept the highest D.O. concentration where harmful effects are witnessed, but to choose a criterion that prevents D.O. levels from reaching those harmful effects (Fischer 2009)." "Additional stressors such as various pollutions and increased water temperatures during low flow periods would increase this D.O. threshold; therefore, 5 mg/L should be viewed as a value providing a minimal margin of protection to a multi-species warm water fishery throughout all life stages. Such an assertion is supported by the relation of a single criterion of 5 mg/L to the models provided by Doudoroff and Shumway

(1970) [and Edwards et al. (1983) specifically for Smallmouth bass] and the conclusions drawn by Coble (1982)". (Fischer 2009).

TSF Criteria

The Department proposes to adopt the Salmonid other life stages slight production impairment value (6.0 mg/l) as a 7-day average and the Salmonid other life stages moderate production impairment value (5.0 mg/l) as a minimum for during the period of February 15 through July 31 to protect for stocked trout; and nonsalmonid early life stages slight production impairment value (5.5 mg/l) as a 7-day average and the nonsalmonid early life stages moderate production impairment value (5.0 mg/l) as a minimum as the criteria for the remainder of the year for Trout Stocking use (TSF). Proposed criteria for TSF are "For the period February 15 to July 31 of any year, 7-day average 6.0 mg/l; minimum 5.0 mg/l. For the remainder of the year, 7-day average 5.5 mg/l; minimum 5.0 mg/l."

HQ designated streams

Revisions to D.O. criteria do not include specific minima for high quality streams. As stated in chapter 93, "the water quality of High Quality Waters shall be maintained and protected, except as provided in §93.4c.(b)(1)(iii)." Since existing quality must be maintained, a D.O. criterion for these streams is unnecessary.

Use of averages and minima

The Department is proposing to adopt all averages as 7-day averages and instantaneous minima to simplify the criteria. EPA's national criteria include 30-day averages and 7-day mean minima. EPA stated that the averaging period for criteria for protection of early life stages should not exceed 7 days to ensure it is adequately protective.

Although it would be ideal to have minima, means, duration and frequency components in the proposed DO criteria, the information is not available to determine the protective duration and frequency. Also, it cannot be assumed a minimum criterion will only occur occasionally and for short periods of time just because it is paired with a protective mean value criterion. Since DO conditions may fluctuate widely diurnally, especially when there is a large amount of algal activity, a mean value could be misleadingly high and obtained even when a minimum is reached every day/night for many hours and oxygen is supersaturated during the other part of the day. Therefore, it is important to have both average and minimum but it is necessary for the minimum to be protective even if it occurs every day, and not use an extreme low value that only protects for acute survival.

Proposed Dissolved Oxygen Criteria

Dissolved Oxygen

The following specific dissolved oxygen criteria recognize the natural process of stratification in lakes, ponds and impoundments. These criteria apply to flowing freshwater and to the epilimnion of a naturally stratified lake, pond or impoundment. The hypolimnion in a naturally stratified lake, pond or impoundment is protected by the narrative water quality criteria in § 93.6 (relating to general water quality criteria). For nonstratified lakes, ponds or impoundments, the dissolved oxygen criteria apply throughout the lake, pond or impoundment to protect the critical uses.

Symbol	*Criteria*	*Critical Use**
DO_1	For flowing waters, 7-day average 6.0 mg/l; mg/l; minimum 5.0 mg/l. For salmonid early life stages, applied in accordance with (b), 7-day average 9.0 mg/l; minimum 8.0 mg/l. For lakes, ponds and impoundments, minimum 5.0 mg/l.	CWF
DO_2	7-day average 5.5 mg/l; minimum 5.0 mg/l.	WWF
DO_3	For the period February 15 to July 31 of any year, 7-day average 6.0 mg/l; minimum 5.0 mg/l. For the remainder of the year, 7-day average 5.5 mg/l; minimum 5.0 mg/l.	TSF

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(b) For naturally reproducing salmonids, protected early life stages include: all embryonic and larval stages and all juvenile forms to 30 days after hatching. The DO_1 standard for naturally reproducing Salmonid early life stages shall apply during October 1 through May 31.

The DO_1 standard for naturally reproducing Salmonid early life stages applies unless it can be demonstrated to the Department's satisfaction, that the following conditions are documented: 1) the absence of young of the year salmonids measuring less than 150 mm in the surface water; and 2) the absence of multiple age classes of salmonids in the surface water. These conditions shall only apply to salmonids resulting from natural reproduction occurring in the surface waters. Additional biological information may be considered by the Department which evaluates the presence or absence of early life stages.

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