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MEMORANDUM

TO: John Hall

CC:

FROM: Ben Kirby

DATE: March 2, 2017

RE: Articles Cited as Support for DO Saturation in New Hampshire WQSs

This memo provides descriptions and assessments of the articles Ted Diers, NHDES, cited as support for DO saturation as a state WQS. The cited articles were:

- Boyd, T.J., Montgomery, M.T., Steele, J.K., Pohlman, J.W., Reatherford, S.R., Spargo, B.J., & Smith, D.C. (2005). Dissolved Oxygen Saturation Controls PAH Biodegradation in Freshwater Estuary Sediments. Microbial Biology, Vol. 49, No. 2, pp. 226-235.
- Breitburg, D. (2002). Effects of Hypoxia, and Balance between Hypoxia and Enrichment on Coastal Fishes and Fisheries. Estuaries, Vol 25, No. 4, Part B, pp. 767-781.
- Karna, D.W. (2003). A Review of Some of the Effects of Reduced Dissolved Oxygen on the Fish and Invertebrate Resources of Ward Cove, Alaska. For the U.S. EPA Region 10 Watershed Restoration Unit.
- Kirkerud, L.A. (1998). Critical Oxygen Levels for Demersal Fishes and Invertebrates. Norwegian Institute for Water Research, Report SNO 3917-98.
- Pollock, M.S., Clarke, L.M.J., & Dube, M.G. (2007). The Effects of Hypoxia on Fishes: from Ecological Relevance to Physiological Effects. Environ. Rev., Vol 15: pp. 1–14 (published on the NRC Research Web site on 2/20/2007).

1. **Boyd et al., 2005**:
   This article focuses on the biodegradation of polycyclic aromatic hydrocarbons (PAHs) and heterotrophic bacterial production in freshwater estuary sediments. DO saturation is discussed in relation to PAHs and PAH mineralization was regressed against DO saturation, for example. However, this article does not address DO saturation effects on aquatic life and provides no recommendation on DO saturation levels required to protect aquatic life.

2. **Breitburg, 2002:**
   This article discusses the effects of varying DO concentrations and DO saturations on coastal fish species. Breitburg notes that adverse impacts on fish depends on the DO concentration, duration of exposure to a certain DO concentration, and temperature. With regard to temperature, Breitburg describes this variable as "an important co-factor determining when lethal conditions are reached, because high temperatures decrease amount of oxygen that can dissolve in water and can increase the metabolic requirements of fish." (at 769). Breitburg asserts that these variables "are therefore very important to consider in setting water quality standards for dissolved oxygen concentrations, highlighting the need to set absolute minima, instead of time-averaged minima, and the need to consider geographic variation in maximum water temperatures." (at 769). However, the article does not recommend any specific DO saturation values to be used in WQSs to protect aquatic life.

3. **Karna, 2003:**
   This review article investigated the likelihood of adverse effects of depressed DO on aquatic life for Ward Cove, Alaska. The article notes that the Alaska WQS for minimum DO in Ward Cove is 5.0 mg/L. With regard to setting DO WQSs to protect aquatic life, Karna concludes that:

   > From the above literature review, two bench mark levels are apparent below which adverse effects occur *if* dissolved oxygen is depressed on a wide scale (i.e., in space and time) in a water body and aquatic resources are present. These levels are 2 and 4 mg/l. As DO falls below 2 mg/l, aquatic species begin to suffer acute mortality and adverse community levels effects occur. At DO levels between 2 and 4 mg/l, chronic effects like reduced growth or increased susceptibility to disease impair fish health, particularly if other stressors are present. (at 9).

   This review article also cites frequently to USEPA's 2000 *Ambient Aquatic Life Water Quality Criteria for Dissolved Oxygen (Saltwater): Cape Cod to Cape Hatteras* (USEPA, 2000) which similarly recommends DO criteria in the form of DO concentration as opposed to DO saturation.

4. **Kirkerud, 1998:**
   This Norwegian article reviews literature on hypoxic responses in benthic marine invertebrates and fishes, seeking "to define safe oxygen conditions for marine bottom communities in the North Sea and adjacent waters." (at 5). Kirkerud notes that DO in terms of percent saturation depends on temperature and salinity and provides equations to account for these variables in calculating DO percent saturation. Ultimately, Kirkerud concludes:

> Critical oxygen concentrations to prevent mortality of microbenthic infauna in seasonally hypoxic environments was found to be about 1 ml/l (measured close to the sediment surface) or about 15% air saturation. (at 7).

and:

> The interval of about 65-50% saturation (sat) is characterised by minor sublethal changes, e.g. reduced resting respiration in some species. In the interval of about 50-35% sat more severe sublethal changes take place, like reduced growth in fishes. From about 35-20% sat lethality may occur in fish fauna in addition to severe sublethal responses in other hyper- and epifauna. Below about 20% sat (1,2 ml/l) lethality also take place in epifauna, and severe sublethal response and finally lethality take place in infauna, depending on duration. Such water may cause fish kills. (at 29).

However, Kirkerud does not recommend specific DO criteria for regulatory application.

5. **Polluck et al., 2007:**
This Canadian article reviews "the effects of low DO on complex fish behaviour, community and fish physiology." (at 1). Polluck et al. present DO concentration and percent saturation values, with associated duration values if available, and the observed fish responses. Ultimately, Polluck et al. note a selection of Canadian Council of Ministers of the Environment (CCME) guidelines for DO concentration, not percent saturation, such as a 9.0 mg/L minimum for state cold waters (at 10). However, the article does not provide numeric recommendations for DO criteria protective of aquatic life.