Water Quality Standards and Hydropower Release

Executive Summary

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Executive Summary

The Grand River Dam Authority is currently conducting a comprehensive monitoring and remediation effort for dissolved oxygen in the tailraces of the Pensacola Hydroelectric Project (P-1494) and the Markham Ferry Hydroelectric Project (P-2183). Throughout these efforts GRDA has partnered with the Oklahoma Water Resources Board (OWRB) to manage real-time monitoring of the DO above and below the dams. These efforts are in accordance with Articles 403 and 401 respectively for Pensacola and Markham Ferry requiring GRDA to implement a low dissolved oxygen mitigation plan for each project. Because the observed improvement in annual results for DO in the tailrace for both projects were appearing to stabilize by 2015 (with Pensacola by en large meeting Oklahoma Water Quality Standards (WQS) and Markham Ferry improving substantially although not meeting WQS), GRDA proactively began efforts to explore new options for mitigation. GRDA and OWRB continued their partnership on this issue and entered into an Interagency Agreement on September 09, 2015 to complete a report on Water Quality Standards and Hydropower Release. In this report OWRB had an objective to "Explore potential options for water quality standards implementation and compliance below hydropower facilities, namely the tailrace" with the specific project tasks to 1) Review EPA guidance and pertinent scientific literature, 2) Review how other state/federal entities implement water quality standards compliance below hydropower facilities, 3) Propose a list of various options that could be employed, including the pros and cons of each approach.

Oklahoma Water Quality Standards for the Grand River including Grand Lake O' the Cherokees (Pensacola) and Lake Hudson (Markham Ferry); Oklahoma Administrative Code (OAC), Title 785, Chapter 45

- Waterbodies' beneficial uses
    - Public and Private Water Supply (PPWS)
    - Fish and Wildlife Propagation, Warm Water Aquatic Community (WWAC)
    - Aesthetics (AES)
    - Primary body Contact Recreation (PBCR)
    - Irrigation Agriculture (AG)

- Low DO is impairing the WWAC and is the result of complex interactions between watershed influences, productivity, reservoir management, and management of reservoir releases.

Overview of Oklahoma Dissolved Oxygen Criteria

- In 1988, the Environmental Protection Agency (EPA) compiled all DO criteria that were adopted into state WQS at that time (EPA 1988) and as part of this review the 1988 criteria were compared to current criteria for surrounding states and a few other relevant states.
- There is a substantial amount of scientific literature that supports a > 5mg/L DO as protective WWAC criteria as the majority of species will exhibit slowed growth and reduced survival in early life stages below this concentration
- The instantaneous minimum of 2mg/L DO in Oklahoma’s WQS is scientifically sound and less stringent than most other states. Defensible scientific evidence would be needed to prove that any other DO concentration was protective in order to change these criteria.

Regulatory options under Oklahoma Dissolved Oxygen Criteria

Criteria Modification

- Site-specific criteria for DO are typically associated with naturally occurring conditions, which are related to the physics and chemistry of a particular waterbody versus an entire class of waterbodies (e.g., waterbodies below hydropower dams) and are derived through a scientifically sound process that determined the criteria are sufficient to protect the organisms that are adapted to live in a particular habitat (e.g., ecoregional values for Louisiana).
- Site-specific criteria modification sufficient to protect organisms below dams has been done at other hydroelectric facilities; including Alabama, and Idaho that are less stringent than their state values, but these values are still more stringent than Oklahoma’s instantaneous minimum DO criteria of 2mg/L.
- A water quality standard variance is a beneficial use and associated time limited criterion that reflects the highest attainable condition for the waterbody during the term of the variance that would allow states and responsible party’s time to

implement specific actions over a prescribed amount of time; serving as a stepping stone until criteria could be met.

- Under current Oklahoma WQS, DO is not eligible for variance.

Beneficial Use Change

- If a state believes a designated use of a waterbody is not the appropriate use, it may follow procedures outlined by the CWA and OWQS to change the use.
- The tailraces below Pensacola and Markham Ferry dams are considered human modifications and would not be eligible for beneficial use change from WWAC for habitat limited aquatic community.
- Biological collections from below Pensacola Dam and Markham Ferry indicate higher species richness than area reference sites and has attained WWAC status since 1975.
- Engineering and Mitigation and operational strategies were briefly highlighted as potential avenues to consider, however OWRB concluded that watershed management to reduce nutrient loading is a critical area of focus for continued work.

Watershed Management

- The Grand River stream segments below Pensacola (WBID 121600020170) and Markham Ferry (WBID 121600010280) are identified on the 303(d) list as impaired due to low dissolved oxygen conditions.
- Based on the 2008 Grand Lake Watershed Plan and the water quality assessments for the 303(d) listings, the underlying cause of the low DO conditions is eutrophication.
- Improved water quality conditions with respect to nutrients and algal biomass in both the reservoirs and streams will improve dissolved oxygen conditions.
- Effective tools for addressing poor water quality conditions include Total Maximum Daily Loads (TMDL) and watershed planning, modeling, and implementation efforts (see conclusions).

Engineering/Mitigation

- A range of mitigation and engineering approaches exist for increasing DO in tailraces races and the viability of those options at a given project depends on the severity of the DO problem, facility design, source water quality and quantity, stream morphology, and project cost.
- A few of these options have been explored and successfully implemented at the two GRDA projects.
- Several comprehensive reviews have been completed by various government entities and private researchers that compare the effectiveness of these approaches including FERC, EPA, Electric Power Research Institute, and the Tennessee Valley Authority (TVA).
- The engineering approaches and technology used to develop these structures are continuing to advance and may provide new possibilities for consideration

Conclusions

Although there is flexibility within the Oklahoma WQS the applicability of the various standards options to the waterbodies below Pensacola and Markham Ferry hydropower facilities is unfeasible. Typically low DO in tailraces is achieved through structural and operational changes, which GRDA has and continues to actively pursue. However, the critical area of focus for long-term sustained improvement is watershed management to reduce nutrient loads. Toward that end there has been and continues to be extensive work through the efforts of GRDA, OWRB and others to improve water quality in the Grand River Watershed.

However achieving reductions of nutrient loads is highly complex due in part to vast size of the Grand Lake Watershed and the natural and anthropogenic processes affecting nutrient loading to Grand Lake (Pensacola) and Lake Hudson (Markham Ferry). Between 2011 and 2013, EPA Region 7 completed extensive modeling of the Grand Lake watershed hoping to establish DO Total Maximum Daily Loads (TMDL) for portions of the lake and a select group of lake tributaries. The outcome recommended a greater than 90% reduction in nutrient loading throughout the Grand Lake watershed. Most of this loading comes from outside of the project boundary. Thus the establishment of DO TMDLs was ultimately unsuccessful resulting in the conclusion that the EPA modeling exercise necessitates a different approach to evaluate adaptive management strategies to improve water quality downstream.

In 2013 EPA released a new policy document A Long-Term Vision for Assessment, Restoration, and Protection under the Clean Water Act Section 303(d) Program. This vision acknowledges other approaches that can be used to address complex 303(d) listed waterbodies. Using this guidance, beginning in August of 2014 GRDA and the Oklahoma Department of Environmental Quality co-funded an project in cooperation with OWRB, Kansas Department of Environmental Health and the Oklahoma conservation Commission to protect the long-term economic benefits and ecosystem services (i.e., the beneficial uses) provided by Grand and Hudson Lakes that are largely dependent on water quality. Through this project they plan update/develop a water quality model in lieu of a TMDL to estimate nutrient loading to Grand Lake and evaluate potential management practice scenarios. It is expected that this updated water quality model will support the development of an updated Watershed Plan that can provide GRDA and stakeholders better tools and information to evaluate options to improve water quality. This includes guidance for adaptive management through a cost/benefit analysis of both point and nonpoint source management practices.

Water Quality Standards and Hydropower Release

Final Report
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Prepared for Grand River Dam Authority

In satisfaction of Interagency Agreement approved on August 5, 2015

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Introduction

Managing low dissolved oxygen in the tailwaters of hydroelectric dams is a common challenge across the country. Monitoring and/or mitigating for low dissolved oxygen in tailraces is a requirement of an estimated 40% of Federal Energy Regulatory Commission (FERC) licenses (EPRI 2002). A myriad of options ranging from dam structural/operational modifications to regulatory approaches and watershed management have been employed to deal with the challenge of low dissolved oxygen conditions. The applicability of these options varies depending on the situation and the state and federal laws which govern how the hydroelectric facility is regulated. The two hydropower facilities operated by Grand River Dam Authority (GRDA) located on the Grand River in northeastern Oklahoma are required by FERC to monitor and implement mitigation measures to improve dissolved oxygen concentrations in their tailraces (FERC 1992; FERC 2006). GRDA contracted the Oklahoma Water Resources Board (OWRB) to explore and summarize regulatory approaches potentially applicable to tailraces below hydropower facilities. This report provides an overview of current conditions associated with the Pensacola and Markham Ferry (Kerr Dam) facilities and explores options to address low dissolved oxygen concentrations in tailraces of hydroelectric facilities.

Grand River Watershed

Site Description

The Grand (Neosho) River originates in Morris County, Kansas and meets the Arkansas River approximately 470 miles southeast in Muskogee County, Oklahoma. The entire Grand River Watershed (HUC 110702) covers approximately 12,400 mi^2 and drains portions of Kansas, Missouri, Arkansas and Oklahoma as shown in Figure 1. The Grand River has several impoundments along its length; Council Grove Lake and John Redmond Reservoir in Kansas, and Grand, Hudson and Fort Gibson Lakes in Oklahoma. Several other lakes or reservoirs in the area are located in the watershed but are not impoundments on the Grand River including Spavinaw, Eucha, and W.R. Holway in Oklahoma. The majority of the Lower Grand Watershed (HUC 11070209) is located in Northeast Oklahoma spanning portions of Ottawa, Craig, Rogers, Mayes, Delaware, Wagoner, Cherokee and Muskogee counties (USGS). The level III ecoregions in this area of Oklahoma include the Central Irregular Plains in the west, the Ozark Highlands in the east and a small area in the Boston Mountains in the south (Omernik 1987). The annual mean temperature in the area ranges from 70-72°F maximum to 47-49°F minimum and annual mean precipitation ranges from 44 inches in the north to 46 inches in the south (OCS, 2017). Land use is a mix of cropland, pastureland, rangeland, and deciduous oak-hickory forest supported by Mollisols, Inceptisols and Ultisols (USDA 2017). The Boston Mountains, Claremore Cuesta Plains, Grand Lowland, and Ozark Plateau geomorphic provinces in this area are dominated by Mississippian and Pennsylvanian sandstones, limestones, shale and chert (Johnson 1998).

History

The Grand River Dam Authority was created in 1935 with the passing of Senate Bill 395 to serve as, "a conservation and reclamation district for the waters of the Grand River" with the mission of developing hydroelectric power and providing flood control in the area (GRDA 2017). GRDA is responsible for the management of Grand and Hudson Lakes and operation of the hydropower facilities at Pensacola and Markham Ferry Dam. In high flow and flood conditions, when the surface elevation of Grand Lake reaches 745 ft, the U.S. Army Corps of Engineers (USACE) are responsible for releases from these reservoirs. Ft Gibson Lake, the final impoundment of the Grand River before its confluence with the Arkansas River, was designed, built and is currently managed by USACE.

Pensacola Dam, the first hydroelectric facility in Oklahoma and longest multiple arch dam in the United States, was completed in March 1940 (Holway 1968). Grand Lake has 460 miles of shoreline, 41,749 acres of surface area, 1,515,414 acre-feet capacity, with an average depth of 36.3 feet and a maximum depth of 133 feet (OWRB 2015). The six units at Pensacola Dam have a combined generation capacity of approximately 120 megawatts. The dam has 21 floodgates on the main spillway and 21 on the east spillways (GRDA 2017). Lake Hudson was created upon GRDA's completion of the second hydroelectric facility on the Grand River, Robert S. Kerr Dam, also referred to as the Markham Ferry Project in April 1964. Lake Hudson has a normal surface elevation of 619 feet, 11,029 acres of surface area, 143.3 miles of shoreline, 200,185 acre-feet in capacity and an average depth of 18.2 feet and a maximum depth of 65 feet (OWRB 2015). The Markham Ferry Dam's powerhouse contains four, 28.5-megawatt generators that combine to produce 114 total megawatts of electricity and 17 floodgates and a total discharge potential of 599,000 cubic feet per second (GRDA 2017).

Dissolved Oxygen Challenges

Dissolved oxygen (DO) is required to sustain all aerobic aquatic life and is influenced by the watershed and in-lake processes. As such, dam operation can also influence e dissolved oxygen concentrations. The concentration of DO is dynamic and may fluctuate daily and/or seasonally depending on the physical, chemical or biological processes originating in the watershed and those that occur in the waterbody. Oxygen enters the water from the atmosphere or biological processes. Dissolved oxygen saturation, (the maximum amount of oxygen water can hold) is influenced by temperature and pressure; as temperature and pressure decrease oxygen holding potential increases. Due to physical entrainment, fast moving water tends to contain more oxygen than slow moving or stagnant water. Photosynthesis and respiration greatly impact DO concentrations, especially during warm weather when biological productivity can be high. Productivity is heavily influenced by nutrient concentrations and availability, which originate in runoff from the watershed and is stored and recycled in the lake. Runoff with high levels of nutrients often increases algal productivity and is a notable driver of cultural eutrophication. Productivity can heighten diurnal DO fluctuations (Wetzel 2001). Summer thermal stratification of lakes results in a warm oxygenated upper layer (i.e., the epilimnion) and a colder bottom layer containing less oxygen (i.e., the hypolimnion). Dissolved oxygen becomes depleted in the hypolimnion through biological oxidation processes and the hypolimnion will remain depleted throughout the stratification period. Because of complex feedbacks with watershed nutrient inputs, nutrient cycling in-lake, and typical dam operation, low DO in the tailwaters of hydroelectric facilities is common especially when reservoirs are stratified because generators are often pulling in hypolimnetic water with an existing oxygen deficit (Wetzel 2001).

The Environmental Assessment (EA) completed by the Federal Energy Regulatory Commission (FERC) in 1991 on the Grand River and its tributaries recommended measures for monitoring and enhancing DO in the tailrace below Pensacola Dam (FERC 1991). Subsequently, Article 403 of the Pensacola project license (FERC No. 1494) issued April 24, 1992 requires GRDA to perform DO monitoring and mitigation and Article 401 of the Markham Ferry project license

(FERC No. 2183) issued August 9, 2006 requires DO improvement measures to be taken downstream in the Grand River. Under contract to GRDA, the OWRB Monitoring and Assessment Section has developed, tested, and implemented dissolved oxygen mitigation plans. Compliance has increased over time in the respective downstream areas (see Monitoring and Mitigation below). However, the Grand River below Markham Ferry although improved is not consistently supporting the Fish and Wildlife Propagation beneficial use and the OWRB Monitoring and Assessment Section ultimately recommends alternative mitigation approaches be implemented by GRDA to achieve OWQS compliance at this location (OWRB 2016h). Although compliance has improved for both projects, the solution that has been so successful on Pensacola is not feasible for Markham-Ferry. This is due to differences in the way the projects are engineered, primarily including differences in the sizes of respective projects' tailraces, differences in width of tailraces, and especially the difference in the types of turbines used in each facility (Francis turbines at Pensacola vs. Kaplan turbines at Markam-Ferry).

Monitoring and Mitigation

To comply with the 401 certifications and FERC licenses for Pensacola (FERC No. 1494, Article 403) and Markham Ferry (FERC No. 2183, Article 401) projects, GRDA partnered with the OWRB to improve DO below the dams in the summer of 2006. Currently, GRDA continues to partner with OWRB to manage real-time DO monitoring operations on-going above and below Pensacola and Markham Ferry Dams (Figure 2 and 3). Monitoring was the initial step in efforts to increase DO in the tailraces, followed by structural modifications and mitigation measures. In 2008 GRDA partnered with the Tennessee Valley Authority to develop a plan for improving downstream DO that ultimately led to the modification and installation of vacuum breaker bypass valves on all 6 Francis type turbines associated with the Pensacola project. These efforts have been very successful at Pensacola in reducing the frequency and duration of low dissolved oxygen occurrence in the tailrace (OWRB 2016d). In 2006 35% of measurements were below the criteria, but after the first couple years of efforts marked improvements were observed. With the exception of 2013, approximately 90% or more of measurements each year from 2009-2016, were above the criteria and supporting the beneficial use. At Markham Ferry, there was also improvement in DO compliance over time and in 2016 88% of measurements were above the criteria. Since 2006, when efforts began at Markham Ferry, the DO criteria have only been attained for the entire year in 2008 and 2012 when DO concentrations less than 2mg/L were not recorded (OWRB 2016e).

To further investigate options available to increase DO in the tailraces, GRDA contracted the OWRB to plan and conduct mitigation tests at both facilities, as well as completion of an extensive DO mapping project at Markham Ferry to better understand the dynamics of the releases on the downstream area (OWRB 2012). The results of the testing and mapping informed mitigation efforts suited to each project's unique characteristics. Although the facility and dynamics of the two systems differ, the goal of mitigation testing was the same: to conduct continuous spill release mitigation testing and obtain the greatest increase in DO for the longest amount of time and in the largest area possible. Details of these mitigation testing methods are discussed in the annual compliance reports completed by the OWRB for GRDA (OWRB 2016d). Based on the mitigation testing results from the 2009-2011 critical seasons, GRDA and OWRB recommended further testing of pulsing/spilling scenarios to determine effects on down river DO concentrations (OWRB 2016). This process resulted in the formation of Adaptive Mitigation Plans (AMP) which detail how and when mitigation actions will take place, a final adaptive mitigation plan was approved by FERC for Pensacola in 2015, but the Markham Ferry plan has not been finalized.

Through this process, the mitigation measures implemented at Pensacola in addition to structural modifications largely resolved the DO issue and allows the Grand River below the dam to meet Oklahoma Water Quality Standards (OWQS) as long as the AMP is operated appropriately. The following AMP for Pensacola (OWRB 2016e) was recommended for implementation beginning in 2015 and is recommended to be continued along with DO monitoring. The AMP states:

> *"The action limit will be set at the Oklahoma Water Quality Standards (OWQS) criterion of 6 mg/L from 10/16 through 6/15 and at 5 mg/L from 6/16 through 10/15. Once the action limit is reached, according to any one of the Langley Bridge DO probes, one turbine will begin running at 20% wicket gate (~320 cfs) with full aeration. Once a release is started, it will continue until the average DO value exceeds the criterion, but, depending on lake level conditions in Grand Lake and Lake Hudson, will continue for three to eight hours. A second action limit will*

be set at 4.0 mg/L. If the second action limit is reached, the first turbine will be upped to 25% wicket gate (~ 430 cfs) and will continue for a minimum of 2 hours. This operational plan will run year round."

Through the mitigation testing process, the Adaptive Mitigation Plan for Markham Ferry was developed during 2011 testing and was implemented during the 2012 testing period and continued through 2016 with no current plans for change (OWRB 2016f). The AMP states:

"A one chain link release from the spillway will be used to mitigate acute and nuisance DO conditions. When either median daily DO values fall below 5ppm for a 48 hr time period or when greater than 4 15-minute samples fall below 3ppm in any 24 hr period, the mitigation release shall be used continuously until 90% of samples are above 5ppm and no values are below 2ppm over a consecutive 7-day period, or until Hudson Lake falls below the regulatory rule curve. If any single value is less than 1ppm, the mitigation scenario will be implemented and continue until the afore-mentioned conditions are met. The Compliance stations will be used jointly to provide data for use in managing implementation (Figure 68). Testing will continue to document variance in DO concentrations during the continuous release periods. The 24 and 48 hr time periods run from 0600 to 0600 hours over two consecutive days."

In 2013, a modification was made to the adaptive mitigation plan that allowed for the use of sluice logs to increase the elevation of intake, which provides potentially higher dissolved oxygen concentrations from the source water, while reducing damage to the gate's seal from leaving it partially open. Continued monitoring of downstream and forebay DO and following of the AMP was recommended for 2017 along with exploring alternate options to meeting OWQS.

Oklahoma Water Quality Standards

Consistent with Clean Water Act section 303 and Title 82 O.S., §1085.30, the OWRB is the state agency responsible for promulgating water quality standards to ensure water quality protection across the state. Water quality standards define the goals for a waterbody and work to safeguard human health and aquatic life by establishing provisions to limit pollution to waterbodies.

Standards are comprised of three components 1) a waterbody's beneficial uses, 2) water quality criteria to protect those uses and determine if they are being attained, and 3) antidegradation policies to protect high quality waters. Oklahoma's water quality standards are located in the Oklahoma Administrative Code (OAC), Title 785, Chapter 45. Grand River, including Grand Lake and Lake Hudson are identified in the OWQS and are designated with the beneficial uses listed below (785:45, Appendix A).

- Public and Private Water Supply (PPWS)
- Fish and Wildlife Propagation, Warm Water Aquatic Community (WWAC)
- Aesthetics (AES)
- Primary Body Contact Recreation (PBCR)
- Irrigation Agriculture (AG)

As presented in the monitoring section above, the low DO conditions is impairing the WWAC beneficial use and the stream segments have frequently been on Oklahoma's 303(d) list of impaired waters since 1998 (ODEQ 2014). However, as mentioned previously, the causes of these impairments are complex interactions between watershed influences, productivity, reservoir management, and management of reservoir releases.

Overview of Oklahoma Dissolved Oxygen Criteria

Aquatic life criteria must consider the adverse effects from both short-term (acute) and long-term (chronic) exposure, to protect from lethal and sub-lethal outcomes. All aquatic life criteria have three components, the magnitude of a concentration, the duration or averaging period, and the frequency of exposure (EPA 1994). The DO criteria adopted in Oklahoma and recommended by the EPA (EPA 1985) were developed based on studies of low DO effects on aquatic life. This research, which informed the development of and serves as the foundation for the nationally recommended and state DO criteria, was primarily conducted in the 1980's and review of any new scientific knowledge since has not changed these conclusions. In 1988, the Environmental Protection Agency (EPA) compiled all DO criteria that were adopted into state WQS at that time (EPA 1988) and as part of this review the 1988 criteria were compared to current criteria for surrounding states and a few other relevant states. In 1988, most of the state subset's WWAC DO criteria were either 5 mg/L or greater at all times (KS, ID, MO) or 5mg/L with an allowable 1mg/L excursion (AL, AR). Texas and Oklahoma WQS both had WWAC subcategories with

DO criteria ranging from 6 to 3mg/L depending on applicable subcategory and life stage. Today, the DO criteria in these states are identical or very similar to the criteria in place in 1988.

As previously discussed, the concentration of DO required for fish to survive varies across species and reproductive stages. Fish may survive with DO above acutely toxic concentrations, but could be sustaining chronic effects with negative impacts on health, growth and reproduction. DO concentrations have also been found to directly impact species richness in a community (Shields and Knight 2012) in similar systems. Therefore, DO criteria must protect a variety of species in a community during all life stages to ensure that the beneficial use will be maintained and protected. There is a substantial amount of scientific literature that supports a > 5mg/L DO as protective WWAC criteria as the majority of species comprising a typical WWAC will exhibit slowed growth and reduced survival in early life stages below this concentration (McMahon et al. 1984; Stuber et al. 1982a; Stuber et al. 1982b; Welch et al. 2011). DO concentrations become acutely toxic for adult WWAC fish around 3 mg/L and below depending on species (Bain and Bain 1982; Douglas and Jahn 1987; Stuber et al. 1982a; Stuber et al. 1982b). The instantaneous minimum of 2mg/L DO in Oklahoma's WQS is one of the least stringent minimum of any state in the country. As a whole, these DO criteria are long standing, scientifically sound and are not outside the values found nationwide and in many cases are actually less stringent than other states. Defensible scientific evidence would be needed to prove that any other DO concentration was protective in order to change these criteria.

There are regulatory tools available through water quality standards which provide regulatory flexibility while still ensuring beneficial use protection; however often these tools have limited applicability to a particular waterbody or water segment and may only be used under very specific circumstances. Each waterbody and situation is unique and need to be evaluated individually; however, some approaches that have been used in other states to address low dissolved oxygen in tailraces include modifying criteria, variance, removal or revision of the beneficial use, and improved watershed management. The following section describes various regulatory and management approaches that may be considered to address the low DO conditions and restore the WWAC beneficial use.

Regulatory Options

Criteria Modification

Typically, the modification of statewide criteria are developed and implemented under particular conditions such as a specific site or time frame. For example, the ambient water chemistry in a given location may reduce the toxicity of a metal to aquatic life and allow for the criteria to be less stringent while still fully protecting the beneficial use. All criteria including site-specific must be developed in a scientifically defensible manner and protect the beneficial uses of the waterbody as previously discussed above. The process for developing site-specific water quality criteria in Oklahoma can be found in their entirety in OAC 785:45-5-4(g) and 785:45, Appendix E. Site-specific criteria have typically been developed for metals or minerals, but may be developed for other parameters and could include seasonal, spatial or other limitations as well as specific numeric limitations. Development of site-specific criteria for other parameters that lack specific guidance documents will require extensive coordination from OWRB.

Site-specific criteria for DO are typically associated with naturally occurring conditions, which are related to the physics and chemistry of a particular waterbody opposed to those that are meant to be protective of an entire class of waterbodies (e.g. lakes). Site-specific DO criteria, which are less stringent than national or state values, are derived through a scientifically sound process that determined the criteria are sufficient to protect the organisms that are adapted to live in a particular habitat. For example, the local ecology in parts of Louisiana exhibits naturally low DO concentrations because of low flow and high organic inputs and they are in the process of revising their WQS standards to incorporate recently developed ecoregion based values (LDEQ 2014). Ecoregional values were deemed appropriate for Louisiana following a number of Use Attainability Analyses (UAA) conducted across the state to determine if the natural physical conditions of some waterbodies in Louisiana may preclude them from achieving the state-wide criteria of 5mg/L. The revised DO criteria for the applicable regions is 2.3 mg/L for the months of March through November; for the months of December through February the DO criteria for inland streams will remain as 5.0 mg/L (LDEQ 2013).

In some cases, site-specific criteria have been developed to protect waterbodies from manmade influences, such as hydropower facilities. Alabama and Idaho have site-specific criteria that only apply to waterbodies below hydropower dams. In these instances, a site is referring to any waterbody reach below a hydropower facility and not one particular location. In Idaho, the DO criteria for the protection of warm water aquatic species is 5 mg/L and cold is 6 mg/L but the DO criteria specifically for waters discharged from dams, reservoirs, and hydroelectric facilities is listed in the Idaho Water Quality Standards (IDAPA 58.01.02.276). In these waterbodies, the minimum 30 day mean is 6.0 mg/L, while the minimum 7 day mean is 4.7 mg/ L with an instantaneous minimum of 3.5 mg/L from June 15-October 15. In Alabama, existing hydropower releases must maintain DO of at least 4.0 mg/L and new facilities must be designed to meet 5.5 mg/L. In both of these situations, the DO criteria are less than the statewide criteria, but still protective of the aquatic community. In comparison, the minimum of 4mg/L in Alabama waters receiving hydropower releases is still more stringent than Oklahoma's instantaneous minimum DO criteria of 2mg/L.

Another path to modifying criteria is a water quality standard variance, which is a beneficial use and associated time limited criterion that reflects the highest attainable condition for the waterbody during the term of the variance. A variance works to provide states and/or responsible parties' time to implement specific actions to improve water quality over a prescribed time period. It can be helpful to think of a variance as a temporary water quality standard. A variance can be a useful regulatory tool used for a defined timeframe and serve as a stepping stone to ensure that the ambient water quality is not being lowered as specific planned progress is made to full beneficial use attainment (EPA 2014). Oklahoma's water quality standards include a variance provision (785:45-5-4(e)). However, Oklahoma has long had a very limited application of the variance provision with it only applicable to toxics numeric criteria in Appendix G, Table 2. Under Oklahoma's existing provision, dissolved oxygen criteria are not eligible for a variance.

Beneficial use change

If a state believes a designated use of a waterbody is not the appropriate use, it may follow procedures outlined by the CWA and OWQS to change the use. States must consider section 101(a)(2) of the CWA, which states, as a goal, that water quality should provide for the protection and propagation of fish, shellfish and recreation in and on the water, wherever attainable. This is commonly referred to as the "fishable/swimmable" goal (40 CFR 131.2). If the WWAC beneficial use was removed and replaced with the Habitat Limited Aquatic Community (HLAC) beneficial use, DO criteria would still apply to the waterbody, but the criteria would be less stringent. As shown in Table 1, when compared to WWAC the DO criteria for HLAC during early life stages decreases from 6.0 to 4.0 mg/L and from 5.0 to 3.0 mg/L during other life stages compared to WWAC concentrations. However, 2.0 mg/L minimum DO concentration, not to exceed more than twice per year would still apply.

Because removing the fish and wildlife propagation beneficial use or lowering the use from warm water aquatic community subcategory to a habitat limited community subcategory is removing the 101(a) uses from a waterbody, a use attainability analysis (UAA) is required. Use attainability analyses are structured scientific assessments of the factors affecting the attainment of a use which may include physical, chemical, biological, and economic factors (40 CFR 131.3). Assessments should provide enough information to conclude which beneficial use(s) are currently or potentially could be attained in the waterbody given the physical, chemical, and biological characteristics of the waterbody and any sources of impairment. Water quality standards regulations establish a "rebuttable presumption" that 101(a) uses can be attained unless proven otherwise, Therefore, to remove a use, the UAA must conclude that one of the conditions described in OAC 785:45-5-2 (b) are true and attaining the use is not feasible. These conditions are:

1. the use, despite being designated, is not a use which is or has been actually attained in the water body on or after November 28, 1975; and
2. for the use of Fish and Wildlife Propagation, Primary Body Contact Recreation or Secondary Body Contact Recreation, or any subcategory of such use or uses, it is demonstrated to the satisfaction of the Board and the U.S. E.P.A. that attaining the designated use is not feasible because:

A. naturally occurring pollutant concentrations prevent the attainment of the use, or
B. natural, ephemeral, intermittent or low flow conditions or water levels prevent the attainment of the use, unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating state water conservation requirements to enable uses to be met, or
C. human caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place, or

D. dams, diversions or other types of hydrologic modifications preclude the attainment of the use, and it is not feasible to restore the waterbody to its original condition or to operate such modification in a way that would result in the attainment of the use, or
E. physical conditions related to the natural features of the water body, such as the lack of a proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality, preclude attainment of aquatic life protection uses, or
F. controls more stringent than those required by sections 301(b) and 306 of the federal Clean Water Act as amended would result in substantial and widespread economic and social impact; and

3. such downgrade, removal, or establishment of a subcategory will maintain or improve the quality of water affected.

When considering the tailraces below Pensacola and Markham Ferry dams, there are several reasons that the conditions listed above would not be met. The installation of dams, hydropower or otherwise are human modifications of the waterbody and would not be considered naturally occurring conditions. Also, there is evidence to conclude the WWAC designation of these waterbodies has been attained since 1975, which means that the WWAC designation is an existing use and cannot be removed. The biological data collected by the OWRB in these areas are not unlike others in this region. The macroinvertebrate species richness in the Grand River near Chouteau during 2009-2013 ranged from 5-16 and 8-19 near Langley during 2010-2014. Fish collections near Chouteau in 2010 and 2013 produced 25-26 total species with 8-10 species in the Centrarchid family. Similarly, collections from 2010-2014 at Langley produced 22-24 total species with 8-10 Centrarchid species. In comparison, collections from regional reference streams in the area range from 18-22 total species and 3-6 Centrarchid species (OWRB Bioassessments 2009-2015). Additionally, the modifications of the operations at Pensacola were more successful than those at Markham Ferry as mentioned. It is not apparent that the conditions in 2.D. above have been successfully met. To date, three structural modifications have been attempted, and it is not possible to conclude without a detailed reevaluation of new and alternate technologies that other technologies might satisfy DO requirements. More importantly, management of significant nutrient loads in the watershed, which are just now beginning will work to mitigate low DO concentrations in both lakes and tailraces.

Watershed Management

As noted above the Grand River stream segments below Pensacola (WBID 121600020170) and Markham Ferry (WBID 121600010280) are identified on the 303(d) list as impaired due to low dissolved oxygen conditions. In addition to these stream segments the upstream reservoir of Grand Lake is also impaired due to low dissolved oxygen conditions and monitoring data at Lake Hudson reports that the dissolved oxygen concentration was less than 2 mg/L in 58% of the water column in August 2016 (OWRB 2016c). Based on the 2008 Grand Lake Watershed Plan and the water quality assessments for the 303(d) listings, the underlying cause of the low DO conditions is eutrophication. Eutrophication is defined by the increased nutrient (nitrogen and phosphorus) loading to a waterbody and the resulting increased growth of phytoplankton and other aquatic plants. Excessive algal growth directly relates to low dissolved conditions and impairment of the WWAC beneficial use through algal respiration and decay which depletes oxygen from the water column. Improved water quality conditions with respect to nutrients and algal biomass in both the reservoirs and streams will improve dissolved oxygen conditions. Effective tools for addressing poor water quality conditions include Total Maximum Daily Loads (TMDL) and watershed planning, modelling, and implementation efforts.

Over the years numerous stakeholder partners have worked together to improve water quality in the Grand River Watershed. The 2008 Grand Lake Watershed Plan and the 2011-2013 water quality modeling work supported by EPA Region 7 provided important planning and technical information to support current and future work in the watershed (GLWAF 2008). Currently, with support provided by the GRDA and the Oklahoma Department of Environmental Quality, a multistate interagency workgroup is cooperating to update/develop a water quality model to estimate nutrient loading to Grand Lake and evaluate potential management practice scenarios. The work to update/develop a water quality model is supported by monitoring and watershed implementation activities conducted from 2009 - 2017. It is expected that this updated water quality model will support the development of an updated Watershed Plan that includes both point and nonpoint source management practices, and will serve to guide watershed wide activities focused on achieving measurable improvements in water quality.

Engineering /Mitigation

Although not water quality standards regulatory options, there are a range of mitigation and engineering approaches that have been effective at increasing dissolved oxygen concentration in tailraces around the country. A few of these options have been explored and successfully implemented at the two GRDA projects. The severity of the DO problem, design of the facility, source water quality and quantity, stream morphology, and cost of the project will determine if a structural upgrade or replacement will be a viable option. Several comprehensive reviews have been completed by various government entities and private researchers that compare the effectiveness of these approaches including FERC, EPA, Electric Power Research Institute, and the Tennessee Valley Authority (TVA).

The TVA completed a large-scale reservoir release upgrade in the 1990's that improved the quality of releases from 20 major dams (Higgins et al. 1999). They implemented operational procedures including appropriate daily scheduling, turbine pulsing, small hydro units and reregulation weirs. Aeration technologies including turbine venting, turbine air injection, oxygen injection, aerating weir, and surface water pumps were installed at some locations and a combination of these approaches was used at multiple dams. The DO deficit in tailwaters was reduced in all 20 locations by at least 52% and 15 out of 20 dams reduced the DO deficit by 90% (Higgins et al 1999). The effectiveness of similar approaches used in other locations were reviewed by Bevelhimer et al., with the Oakridge National Laboratory in 2006 and found to increase the dissolved oxygen concentration by 0.5 to 7 mg/L (Table 2). As mentioned above some of these TVA approaches have been employed at the Pensacola project (see Monitoring and Mitigation above). The engineering approaches and technology used to develop these structures are continuing to advance and may provide new possibilities for consideration.

Conclusion

Water Quality Standards do provide for some regulatory flexibility and there are examples from other states where relaxed DO criteria have been applied to waterbodies influenced by hydropower operations, while still protecting beneficial uses. However, the applicability of various standards options to the waterbodies below Pensacola and Markham Ferry hydropower facilities is unfeasible. Oklahoma's dissolved oxygen criteria are already similar to or less stringent than those with similar climates and ecology and DO criteria nationwide. Watershed management approaches and structural/operational changes to the hydropower dam and/or the impacted waterbodies are overwhelmingly the most commonly used and successful methods to address low dissolved oxygen in tailraces. GRDA has actively pursued an AMP that uses both structural and operational changes and these processes have improved water quality in both tailraces. To continue to improve DO concentrations and fully support beneficial uses, watershed management to reduce nutrient loading is a critical area of focus for continued work. The efforts currently underway should continue and be expanded to include Lake Hudson. Stakeholders working together on both technical analysis and implementation actions is critical for successful measured water quality improvements.

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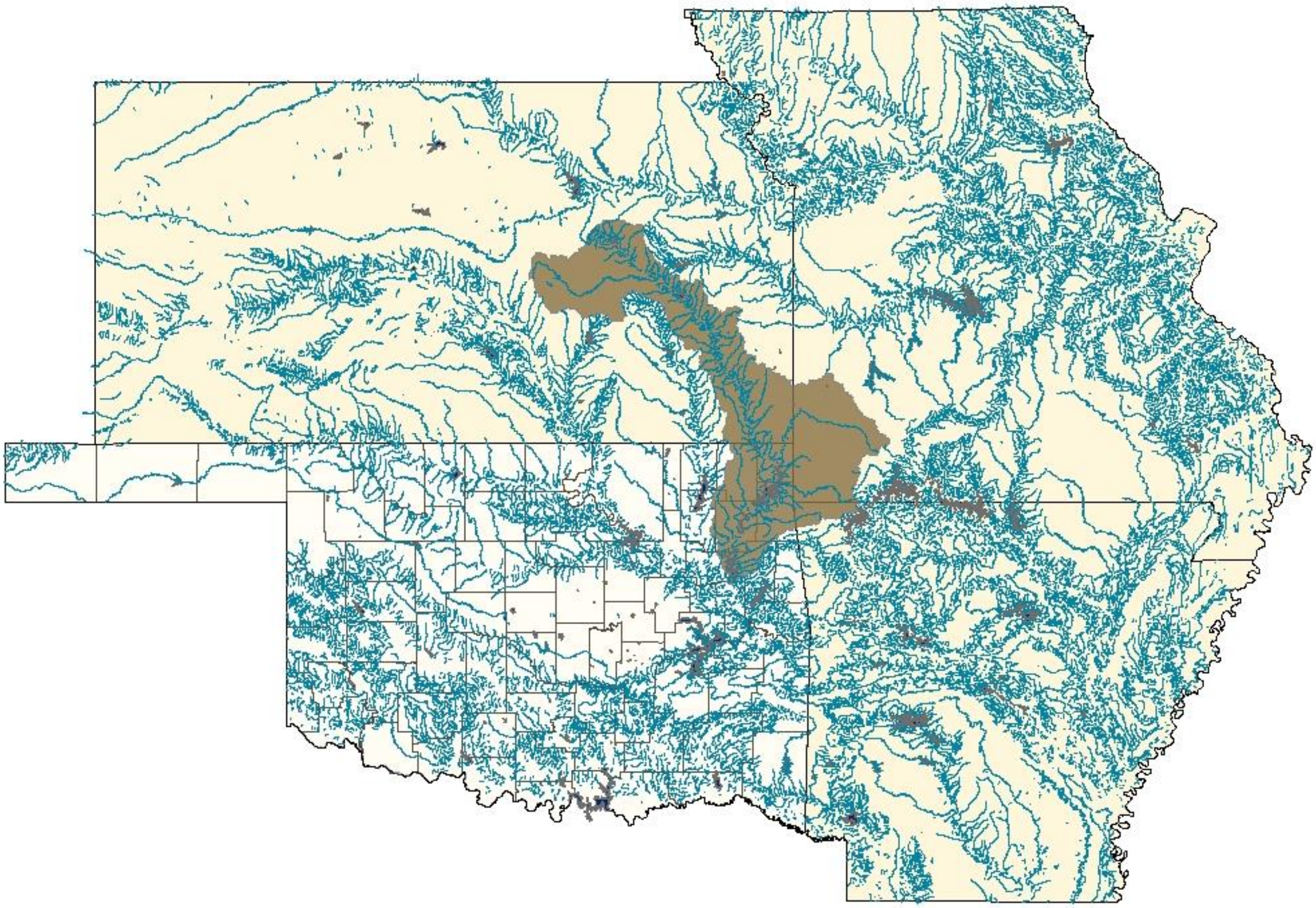

Figure 1. The Grand River watershed (shaded brown) and other major waterbodies in Arkansas, Kansas, Missouri and Oklahoma. In Oklahoma, the Grand River watershed covers the majority of Ottawa, Craig, Mayes, Delaware, and smaller portions of Rogers, Wagoner, Cherokee and Muskogee counties.

Figure 2. Beneficial use monitoring and assessment locations on the Grand River below Pensacola Dam (Grand Lake) Langley, Oklahoma.

Figure 3. Beneficial use monitoring and assessment locations on the Grand River below Markham Ferry Dam (Hudson Lake) near Locust Grove, Oklahoma.

Table 1. Dissolved Oxygen Criteria to Protect Fish and Wildlife Propagation and All Subcategories Thereof (OAC 785:45, Appendix G, Table 1)

Subcategory of Fish and Wildlife Propagation	Dates Applicable	D.O.[4] (mg/L)	Seasonal Temp (°C)
Habitat Limited Aquatic Community			
Early Life Stages	4/1 - 6/15	4.0	25[3]
Other Life Stages			
Summer Conditions	6/16 - 10/15	3.0	32
Winter Conditions	10/16 - 3/31	3.0	18
Warm Water Aquatic Community[5]			
Early Life Stages	4/1 - 6/15	6.0[2]	25[3]
Other Life Stages			
Summer Conditions	6/16 - 10/15	5.0[2]	32
Winter Conditions	10/16 - 3/31	5.0	18
Cool Water Aquatic Community & Trout			
Early Life Stages	3/1 - 5/31	7.0[2]	22
Other Life Stages			
Summer Conditions	6/1 - 10/15	6.0[2]	29
Winter Conditions	10/16 - 2/28	6.0[2]	18

[1] For use in calculation of the allowable load.

[2] Because of natural diurnal dissolved oxygen fluctuation, a 1.0 mg/l dissolved oxygen concentration deficit shall be allowed for not more than 8 hours during any 24 hour period.

[3] Discharge limits necessary to meet summer conditions will apply from June 1 of each year. However, where discharge limits based on Early Life Stage (spring) conditions are more restrictive, those limits may be extended to July 1.

[4] DO shall not exhibit concentrations less than the criteria magnitudes expressed above in greater than 10% of the samples as assessed across all life stages and seasons.

[5] For lakes, the warm water aquatic community dissolved oxygen criteria expressed above are applicable to the surface waters.

Table 2. Dissolved oxygen concentration improvements resulting from the installation or implementation of various techniques at projects across the United States (Bevelhimer et al. 2006, adapted from EPRI 2002)

Technique	DO Improvement (mg/L)			Case Study	
	Total	From	To	Dam	Citation
Forebay Mitigation					
Hypolimnion aeration	4 to 5	1	6	Richard B. Russell Dam, Savannah R., GA/SC (Corps of Engineers)	Lemons et al. 1998
Surface water pump	2.3	1.3	3.6	Bagnell Dam, Lake of the Ozarks, MO (Union Electric Co.)	Garton and Miller 1982
	1.3	2.7	4.0	J. Percy Priest Dam, Stones R., TN (Corps of Engineers)	Price 1988
	2.0	0.1	1.2	Douglas Dam, Holston R., TN (TVA)	Mobly et al. 1995
Turbine Vicinity Mitigation					
Penstock air injection	Up to 5	1	4-6	Tim's Ford Dam, Elk R., TN (TVA)	Harshbarger et al. 1995
Draft tube venting	0.5 to >3	4	6	Logan Martin Dam, Coosa R., AL (Alabama Power Co.)	EPRI 2002
Turbine venting (vacuum breaker)	Up to 3.5			Deer Cr. Power Plant, Provo R., UT (Bureau of Reclamation)	Wahl et al. 1994
Turbine venting (baffles)	2 to 3 (single unit); 1-2 (8 units)			Bulls Shoals Dam, White R., AR (Southwestern Power Admin.)	Harshbarger et al. 1998
	2 to 3			Table Rock Dam, White R., AR (Southwestern Power Admin.)	Harshbarger et al. 1998
	2.5 to 3 (one unit); 0.5 (2 units)			Norfolk Dam, White R., AR (Southwestern Power Admin.)	Harshbarger et al. 1998
Turbine venting	0.5 to 3			Wylie Dam, Catawba R., SC (Duke Power Co.)	Gaffney et al. 1999
	4.5	0.5	5	Osage Project/Bagnell Dam, Lake of the Ozarks, MO (Ameren UE)	Jarvis et al. 1998
Turbine venting (aerating runners)	7	<0.5	5.5 to 7	Norris Dam, Clinch R., TN (TVA)	Hopping et al. 1997
	Up to 5.5			Wateree Dam, Wateree R., NC (Duke Power Co.)	Sigmon et al. 2000
Tailwater Mitigation					
Infuser weir	6.6	1.0	7.6	Chatuge Dam, Hiawassee R., NC (TVA)	Hauser and Morris 1995; EPRI 1996
Labyrinth weir	2.4	3.0	5.4	Lloyd Shoals Project, Okmulgee R., GA (Georgia Power Co.)	Hendricks 1998
	4.2	3.0	7.2	South Holston Dam, South Fork Holston R., TN (TVA)	Hauser and Brock 1993; EPRI 1996
	3.0	3.5	6.5	Canyon Dam, Guadelupe R., TX (Guadelupe-Blanco River Authority)	Hauser and Morris 1995; EPRI 1996