Review of Total Maximum Daily Load Methods to Address Dissolved Oxygen Impairments Final Report

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Texas Water Resources Institute
make every drop count

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Abbreviations

Acronym	**Meaning**
ATTAINS	Assessment TMDL Tracking and Implementation System
AU	Assessment Unit
BASINS	Better Assessment Science Integrating Point and Non-point Sources
BOD	Biological Oxygen Demand
CBOD	Carbonaceous Biochemical Oxygen Demand
CEAM	Center for Exposure Assessment Modeling
DO	Dissolved Oxygen
E. coli	*Escherichia coli*
EPA	Environmental Protection Agency
MOS	Margin of safety
MS	Microsoft
MS4	Municipal Separate Storm Sewer System
TCEQ	Texas Commission on Environmental Quality
TMDL	Total Maximum Daily Load
TSSWCB	Texas State Soil and Water Conservation Board
WLA	Wasteload Allocation

Summary

Among non-legacy contaminants, depressed dissolved oxygen (DO) is the second most frequent cause of water quality impairments in Texas. While much of the current focus of water quality efforts has been to address fecal indicator bacteria, substantial opportunity exists for addressing DO impairments. This report provides a review of methods and approaches used for developing DO Total Maximum Daily Loads (TMDLs) in the US Environmental Protection Agency (EPA) Regions 4 and 6. While many different approaches and models are available, TMDL development appears to have coalesced around only a few mechanistic models. In general, the use of linked watershed and receiving water body models is most common, with the choice of receiving water body model varying among the QUAL2E, WASP, and EFDC models. The development of frameworks for choosing modelling approaches using expertise available among agencies, universities and other stakeholders will help build consensus in decision-making prior to TMDL development. Due to the data requirements and model complexity in some of the identified approaches, additional discussion is needed to identify preliminary data needs for DO TMDL development. With anticipation of future DO TMDL (and other water quality planning efforts) development, this study suggests following a model similar to the previously convened Bacteria TMDL Task Force for providing expert guidance and building high level consensus of approaches and data requirements for developing DO TMDLs within Texas.

1 Introduction

Under Section 303(d) of the Clean Water Act and 40 Code of Federal Regulations Part 130, states are required to identify and list water bodies that do not meet designated water quality uses and to develop Total Maximum Daily Loads (TMDLs) for pollutants causing the impairment. The TMDL designates the allowable pollutant load that can be discharged into the waterbody and continue to meet water quality standards. TMDLs are required to include wasteload allocations (point source pollutants), load allocations (non-point source), future growth allocations, and a margin of safety. A TMDL Implementation Plan, which outlines the strategies and practices that will be used to achieve the TMDL, is developed along with the TMDL.

In 2006, the Texas Commission on Environmental Quality (TCEQ) and Texas State Soil and Water Conservation Board (TSSWCB) created and convened a Bacteria TMDL Task Force along with a 50-person Expert Advisory Group (Jones et al. 2009). The group was tasked with developing and recommending approaches for developing and implementing bacteria TMDLs which are responsible for the overwhelming portion of water quality impairments across the state. Although progress is still needed on developing and implementing bacteria TMDLs, it is clear the approach developed by the Bacteria TMDL Task Force facilitated the rapid expansion of TMDL planning efforts in Texas (Schramm et al. 2022). To date, over 200 TMDLs have been developing with the vast majority focused on indicator bacteria impairments, typically Enterococcus or *Escherichia coli* (*E. coli*) (**Figure 1**).

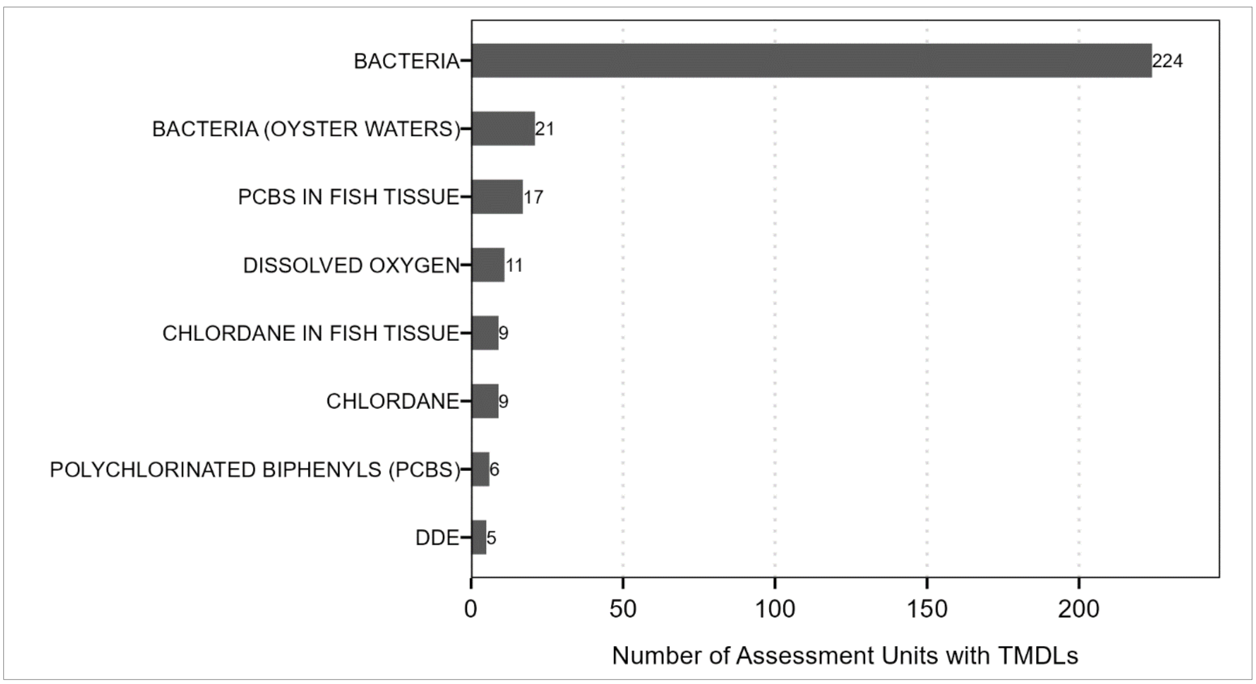

Figure 1. Number of assessment units (AUs) with TMDLs developed in Texas between January 2001 and August 2022 by pollutant.
Figure data obtained from the U.S. Environmental Protection Agency (EPA) Assessment Total Maximum Daily Load (TMDL) Tracking and Implementation System (ATTAINS) and the rATTAINS software package (EPA 2023; Schramm 2023a).

Among non-legacy contaminant sources, dissolved oxygen (DO) is the second most frequent cause of impairment listings in Texas (**Figure 2**). To date, eleven assessment units (AUs) have DO TMDLs in Texas (**Figure 1**). In the 2022 Texas Integrated Report, freshwater streams had the greatest number of impaired AUs attributed to nutrient enrichment/oxygen depletion (n=122; **Figure 3**). However, tidal streams had the highest proportion of assessment units not meeting designated uses due to nutrient enrichment/oxygen depletion (30%; **Figure 3**). Because the number of assessment units impaired due to DO has been relatively stable since 2016 there is an opportunity to substantially reduce the number of Category 5 listed assessment units by developing DO TMDLs. Unlike bacteria TMDLs, a general approach for developing and implementing DO TMDLs has not been identified. Given the hydrogeologic, land use/land cover, and climatic diversity across Texas, a wide variety of drivers of DO impairments and subsequent TMDL assessment methods are possible. Identification of suitable methods and models and subsequent selection of model for development of DO TMDLs in Texas is needed given the potentially wide variety of approaches available. The objective of this report is to provide a review of methodologies used in accepted DO TMDLs relevant to Texas by:

1. Identifying DO TMDLs developed in EPA Regions 4 and 6.
2. Assessing the methodological approaches used for TMDL development.
3. Discuss what methods are suitable for DO TMDL development in Texas.
4. Summarize methodological specific concerns such as data, time, and expertise requirements.

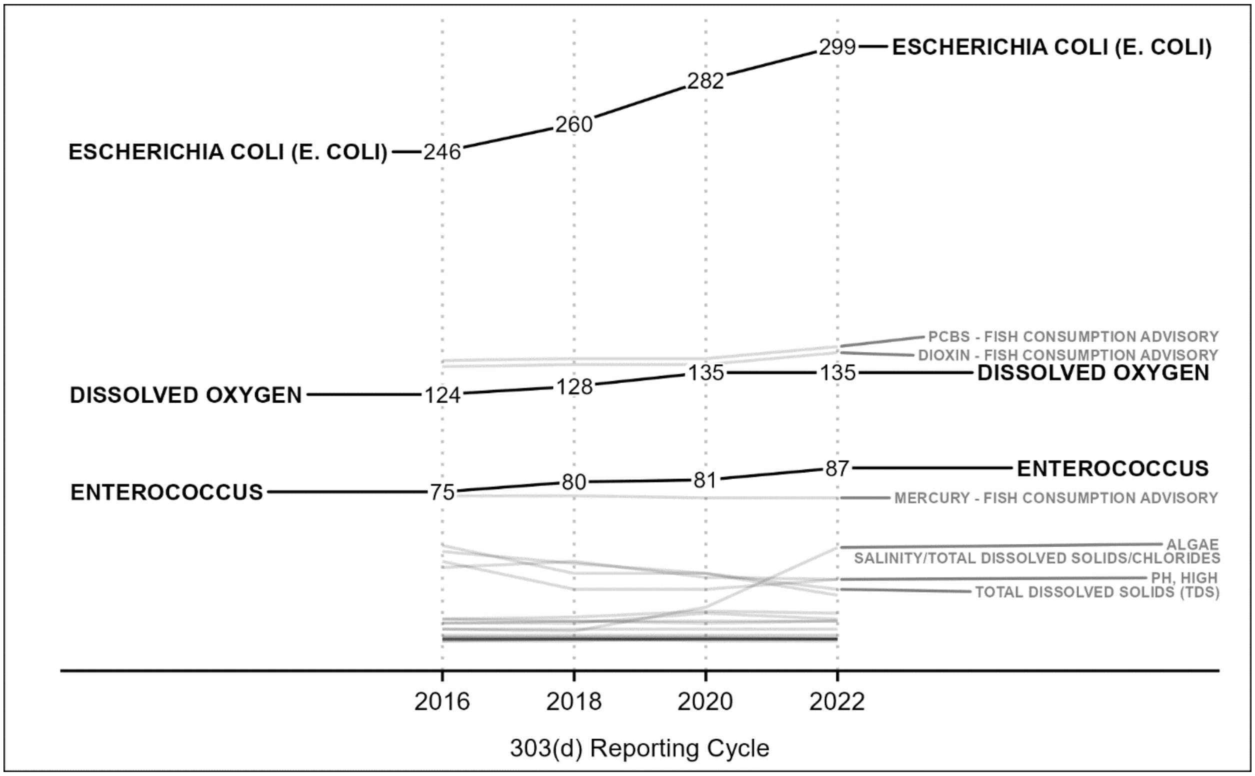

Figure 2. The total number of impaired assessment units (summarized by parameter) listed under Category 5 in the 2016 through 2022 versions of the Texas Integrated Report.
Figure data obtained from the U.S. Environmental Protection Agency (EPA) Assessment Total Maximum Daily Load (TMDL) Tracking and Implementation System (ATTAINS) and the rATTAINS software package (EPA 2023; Schramm 2023a).

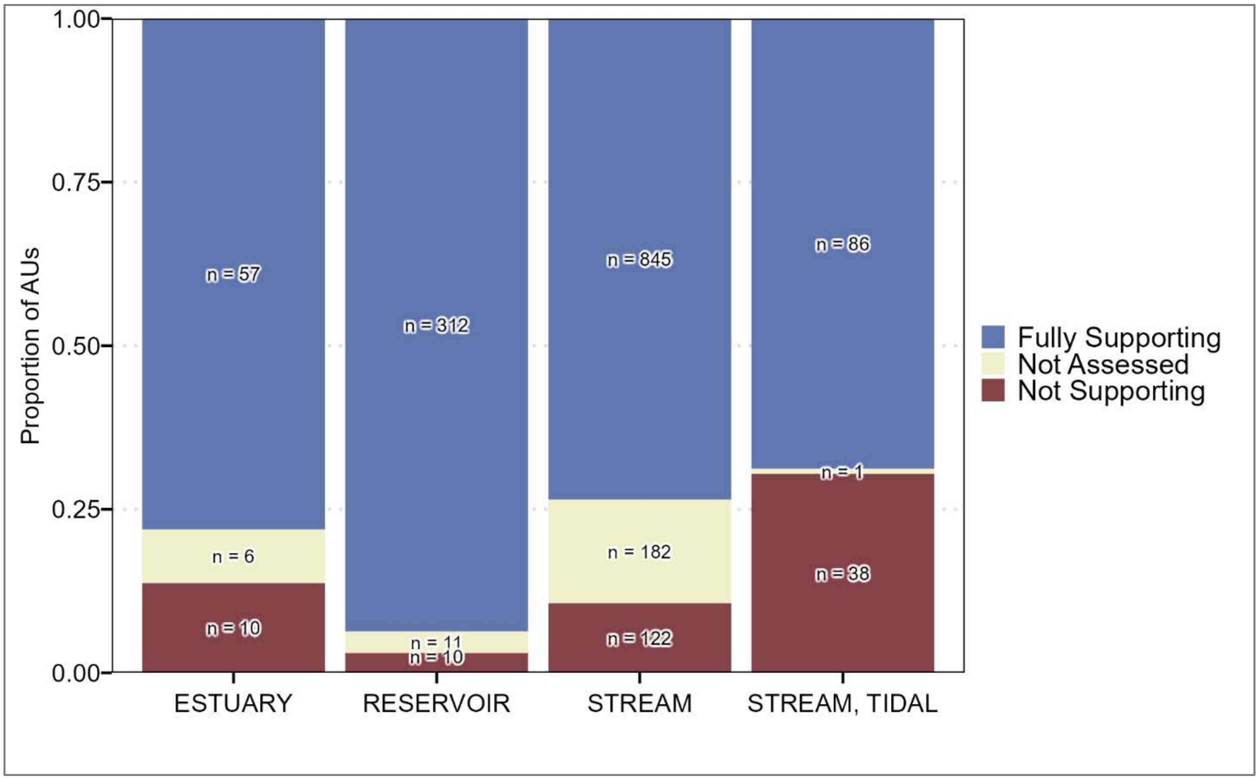

Figure 3. The proportion and number of AUs summarized by water body type not meeting designated uses due to organic enrichment/oxygen depletion in the 2022 Texas Integrated Report.
Figure data obtained from the U.S. Environmental Protection Agency (EPA) Assessment Total Maximum Daily Load (TMDL) Tracking and Implementation System (ATTAINS) and the rATTAINS software package (EPA 2023; Schramm 2023a).

1.1 Drivers of Depressed DO

DO concentration is a function of the interactions between dissolved nutrient constituents, biological oxygen demand (BOD), phytoplankton, periphyton, aquatic plants, aeration and reaeration, physical processes such as water temperature and salinity that impact oxygen solubility, and oxygen flux rates among other potential constituents and processes (EPA 1995a). Anthropogenically altered nitrogen and phosphorus supply rates are typically attributed with increasing primary productivity leading to eutrophication and depressed dissolved oxygen in receiving waterbodies globally (Smith 2003; Smith et al. 2006). Texas coastal waters have been shown to be nitrogen limited, although primary production is also influenced by other physical factors such as light limitations and freshwater inflow (Gardner et al. 2006; Hou et al. 2012; Dorado et al. 2015; Wetz et al. 2017; Paudel et al. 2019). While phosphorus loading is commonly attributed as the cause of eutrophication and depressed DO in freshwater bodies (Smith et al. 2006), there is increasing evidence, for lakes and reservoirs in particular, that management of both nitrogen and phosphorus loads is important due to internal cycling of legacy phosphorus loadings (Paerl et al. 2016; Scott et al. 2019). Common anthropogenic sources of both inorganic and organic sources of nitrogen and phosphorus include wastewater discharges, septic systems, fertilizers, and pet waste among others. Point and nonpoint sources of particulate or dissolved organic matter serves as another driver of dissolved oxygen (EPA 1995a; Mallin et al. 2006; McCabe et al. 2021). Organic matter is often measured as BOD and is essentially a measurement of the organic nitrogenous and carbonaceous content in a sample of water. BOD as a measurement unit is the amount of DO consumed by microbiological activity in a given sample of water and is most typically included as a parameter in wastewater discharge permits although can be quantified for both point and nonpoint sources.

1.2 TMDLs

EPA defines TMDLs as:

$$TMDL = \sum WLA + \sum LA + MOS$$

where WLA is the wasteload allocation for each point source discharging to the waterbody (including diffuse point sources such as municipal separate stormwater permits); LA is the load allocation of unregulated non-point sources; MOS is the margin of safety that accounts for measurement and modeling uncertainty. Within the load allocations a Future Growth component is designated to account for changes in population, land use, and other future changes that might impact pollutant loading and or waterbody capacity. Although water quality standards are often established as concentrations units, the TMDL itself is commonly expressed as load in units of mass per day. EPA requires that all TMDLs and associated LAs and WLAs be expressed as a uniformly applicable 24-hour load (EPA 2006b).

TMDL documents must identify:

1. The desired endpoint or water quality target to achieve the designated water body use.
2. Seasonal variation in watershed condition and loadings and
3. The linkage between the water body impairment and pollutant loadings and sources.

The desired endpoints are typically identified by the water quality standard applicable to the given water body use. Seasonal variations can be accounted for by specifying allowable daily pollutant loads as a function of flow or water quality volume on a given day (EPA 2006b; Sridharan et al. 2021). The cause-and-effect relationship between pollutant loads and the water body impairment as well as subsequent load allocation determination can be established by a wide variety of models and methods (Sridharan et al. 2021) and is the focus of this report.

1.3 Review of TMDL Methods and Models

Choosing a method and model for TMDL development is not a simple task and there is relatively little guidance for deciding. In an unconstrained scenario, models would be selected based on parsimony and defensibility (Sridharan et al. 2021). Practical resources constraints, available technical capacity and skill with given models, and other logistical issues are possible tradeoffs when selecting appropriate methods and models (Sridharan et al. 2021). DePinto et al. (2004), Shoemaker et al. (2005), R. Muñoz-Carpena et al. (2006), and Sridharan et al. (2021) outline some key steps for selecting TMDL models and approaches.

For indicator bacteria impairments, the primary pollutant of concern is fecal indicator bacteria, and it is well established that streamflow is the primary driver of pollutant loads and levels. This simplifies the model selection process and allows the generalized application of relatively easy to apply empirical methods linking impairments, loads, and streamflow across many projects. DO impairments on the other hand might be driven by processes within a waterbody (stratification and temperature), by watershed sources of nutrients and organic materials, or some mix of the two. Therefore, it can become a more complicated task of linking and modeling the sources and fate of multiple pollutants with DO driven impairments.

EPA recognizes the challenges of predictive modeling for nonpoint source pollutants (EPA 1991). For waterbodies where reductions in point sources alone will not reach the desired endpoint, a phased approach for developing TMDLs is appropriate. The phased approach requires that the TMDL provide reasonable assurances that reductions will be achieved to meet the desired endpoint, but additional monitoring and updates to the TMDL will be made with new information (EPA 1991; 2006a). By implementing this approach, the state and stakeholders can move forward with implementation and assessment without getting bogged down in the development of a perfectly uncertain model. This iterative approach to TMDL development and implementation can also be considered an adaptive management approach in which models are updated as new information is provided (DePinto et al. 2004).

Shoemaker et al. (2005), Muñoz-Carpena (2006), Martin et al. (2015), Borah et al. (2019), and Camacho et al. (2019) reviewed methods and models useful for TMDL development. Most broadly, these approaches can be summarized as *empirical methods* (regression-based statistical models, exceedance curves, and probabilistic models), *analytic models* (dilution and mass-balance approaches, Streeter-Phelps and associated modified transport equations), and *numeric* or *mechanistic models*. Models can also be subdivided by the number of dimensions represented by the model (Cox 2003). Zero dimensional models assume a complete and instant mixing of pollutants within the volume of water. One dimensional models represent flow and downstream dispersion of pollutants but assume the pollutants are completely mixed across the width and depth of the water body. Two-dimensional models also simulate the dispersion either across the width or the depth of the water body. Three-dimensional models simulate pollutant dispersion in all directions in a water body.

1.3.1 Empirical Methods

Empirical methods relate impairments to observed or estimated loads based on parametric, semi-parametric or non-parametric regression, or based on flow and load exceedance probabilities (EPA 1991; Sridharan et al. 2021). These approaches are typically easy to implement, but often require larger monitoring datasets because relationships are based on some statistical assumptions (as opposed to established numeric relationships) that may not extrapolate accurately beyond observed data. Sridharan et al. (2021) note that these approaches are most useful for novel pollutants or if specific transport process are not well known.

The flow and load duration curve (or exceedance probability) approach was recommended by the Bacteria TMDL Task Force as an appropriate approach for most bacteria TMDLs due to simplicity and ability to generally discern between point and non-point sources of bacteria loading (EPA 2007; Jones et al. 2009). In cases where stakeholder consensus cannot be developed based on the approach, more extensive monitoring and/or detailed modelling approaches can be pursued.

1.3.2 Analytic Models

Analytic models are simplified equations or systems of equations calculating the mass balance between pollutant loads entering the water body and pollutant loads within the stream, typically compared to allowable water body loads. For DO, one of the first approaches mass-balance approaches developed by Streeter and Phelps (1925), estimates the amount of oxygen removed along the stretch of a river based on a steady state flow and biological oxygen demand (BOD) input and reaeration. Over the years the Streeter-Phelps model (often called the DO Sag equation) has been modified to include other DO sources and sinks within a given stream reach.

1.3.3 Mechanistic Models

Mechanistic models mathematically describe and simulate some or all the hydrology, pollutant fate and transport, hydraulics, and other water quality processes in a given system. Model applications can include many adjustable parameters. Models are parameterized using a calibration set of observed data then validated using an independent set of data. While model documentation may include recommended ranges of individual parameters, determining suitable ranges and application of appropriate calibration/validation strategies requires a skilled and knowledgeable modeler (Moriasi et al. 2015).

Mechanistic models require both temporal and spatial data. Typical data requirements include land use/land cover, topography, soil, and precipitation/weather although individual models and watersheds will require different and additional data to reliably replicate the system. Hydrology and water quality data requirements vary based on the spatial and temporal extent of the modeled data and required certainty. The use of improper temporal data scales in model calibration and validation can lead to incorrect conclusions and/or inadequate model performance (Baffaut et al. 2015). Ambient water quality data used in assessment decisions are adequate for modeling baseflow conditions but are typically inadequate for long term models that must capture loading variation during high flow conditions in which the majority of loading occurs in most streams and rivers (Baffaut et al. 2015; Sridharan et al. 2021; Schramm 2023b).

Mechanistic models used in TMDL development can be categorized as watershed or receiving water models (Martin et al. 2015; Sridharan et al. 2021). Watershed models represent landscape hydrology and the transport and fate of pollutants between sources and receiving waterbodies. These are especially useful for simulating the effect of BMPs on runoff water quality (Borah et al. 2019). Receiving water quality models describe the hydraulics and water quality processes within a waterbody and simulate responses to various pollutant loads (Camacho et al. 2019). Non-point sources pollutant loads are often determined by a watershed model which serve as an input to receiving water quality models. Mechanistic models can be further broken down into steady-state and dynamic models. Steady state models are time invariant, meaning input variables might be spatially distributed but the model inputs and parameters will not vary with time (Cox 2003). In comparison, spatial and temporal variability are simulated by dynamic models resulting in both model inputs, parameters, and outputs being time-dependent (Cox 2003). Quasi-steady state models are time invariant but might simulate diel patterns, streamflow variability, load variability or some other single time variable (EPA 1995b).

1.4 Prior Work on TMDL Methodology

There is substantial literature listing and describing available water quality models (EPA 1995b; Shoemaker et al. 2005; Martin et al. 2015; TMDL Analysis and Modeling Task Committee 2017; Borah et al. 2019; Camacho et al. 2019; Zhang and Quinn 2019; Yuan et al. 2020; Sridharan et al. 2021). Literature describing or recommending TMDL methodology selection is slightly more limited (EPA 1995b; DePinto et al. 2004; Sridharan et al. 2021). Reviews of practices employed in TMDL development are scarce. Martin et al. (2015) conducted a model survey of 545 different TMDLs to examine the most commonly used models across pollutant types. Sridharan et al. (2021) reviewed models and model selection practices in TMDLs developed between 2015 and 2020 across pollutant and water body types. Governor et al. (2017) reviewed pollutants associated with invertebrate-based impairments for streams with TMDLs. Nunoo et al. (2020) reviewed MOS selection practices found in TMDLs developed between 2002 and 2016.

1.5 TMDL Review

The purpose of this report is to review and describe methodologies implemented in EPA accepted DO TMDLs relevant to Texas. We queried the EPA Assessment TMDL Tracking and Implementation System (ATTAINS) database (EPA 2023) in December of 2023 using the rATTAINS package (Schramm 2023a) in R for all DO TMDLs accepted in EPA Region 4 and 6. Distinct TMDLs were downloaded and manually reviewed to identify key characteristics including: state, water body type, methodology and model used, load allocation pollutant parameters, data requirements, and relevant information used to develop linkages between pollutant parameters and the impairment. A review of EPA produced technical guidance and academic literature discussing TMDL appropriate models was also conducted to identify key features that are useful for identifying appropriate approaches when developing DO TMDLs.

2 Summary of TMDLs

A total of 203 TMDLs addressing DO impairments were identified in EPA regions 4 and 6. The earliest DO TMDL was accepted in 1999 for the Waccamaw River and Atlantic Intracoastal Waterway in South Carolina. Accepted TMDLs peaked in 2008 and 2013 with 39 and 37 TMDLs accepted in each respective year (**Figure 4**). Since 2014, no more than one DO TMDL has been accepted between the two EPA regions. The state of Florida (n=104), Louisiana (n=60), and Georgia (n=21) have produced the most DO TMDL documents (**Figure 5**).

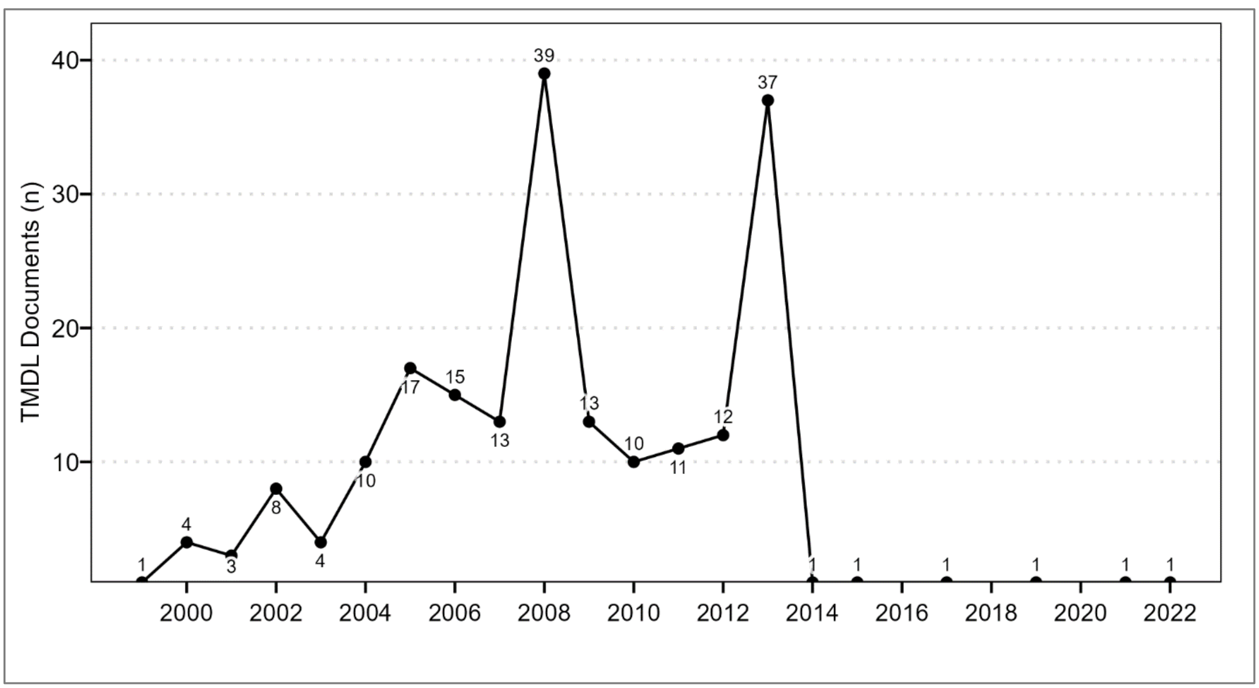

Figure 4. Number of DO TMDL documents in EPA Regions 4 and 6 finalized per year.

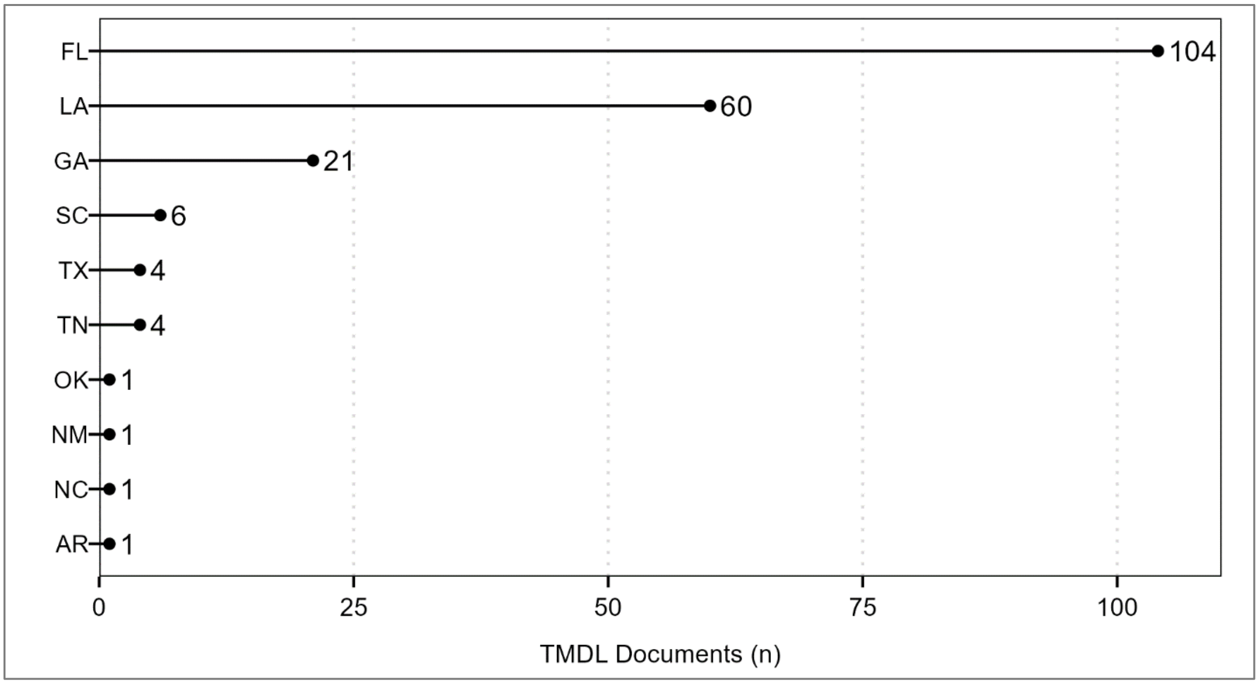

Figure 5. Total number of DO TMDL documents by state.

The DO TMDLs were associated with 26 different types of water bodies. Because each state has different designations for waterbodies, designations were renamed to one of: Freshwater Stream, Lake/Reservoir, Tidal Stream, or Bay/Estuary in order to align with those used in Texas. The majority of TMDLs applied to freshwater streams (n=127), followed by tidal streams (n=31), bay/estuary (n=14), and lake/reservoir (n=9, **Figure 6**). The remaining TMDLs were composed of some combination of water body types (for example, a freshwater stream and lake/reservoir). Within Texas, there are currently two TMDL documents addressing freshwater streams (Salado Creek and Upper Oyster Creek), one TMDL document for a lake/reservoir (Lake O' the Pines), and one TMDL document that addresses both freshwater and tidal streams (Adams and Cow Bayou). DO TMDL efforts in Florida, Georgia, and Louisiana have focused heavily on freshwater and tidal streams (**Figure 7**). Development of DO TMDLs for bays and estuaries has generally only occurred in Florida and South Carolina.

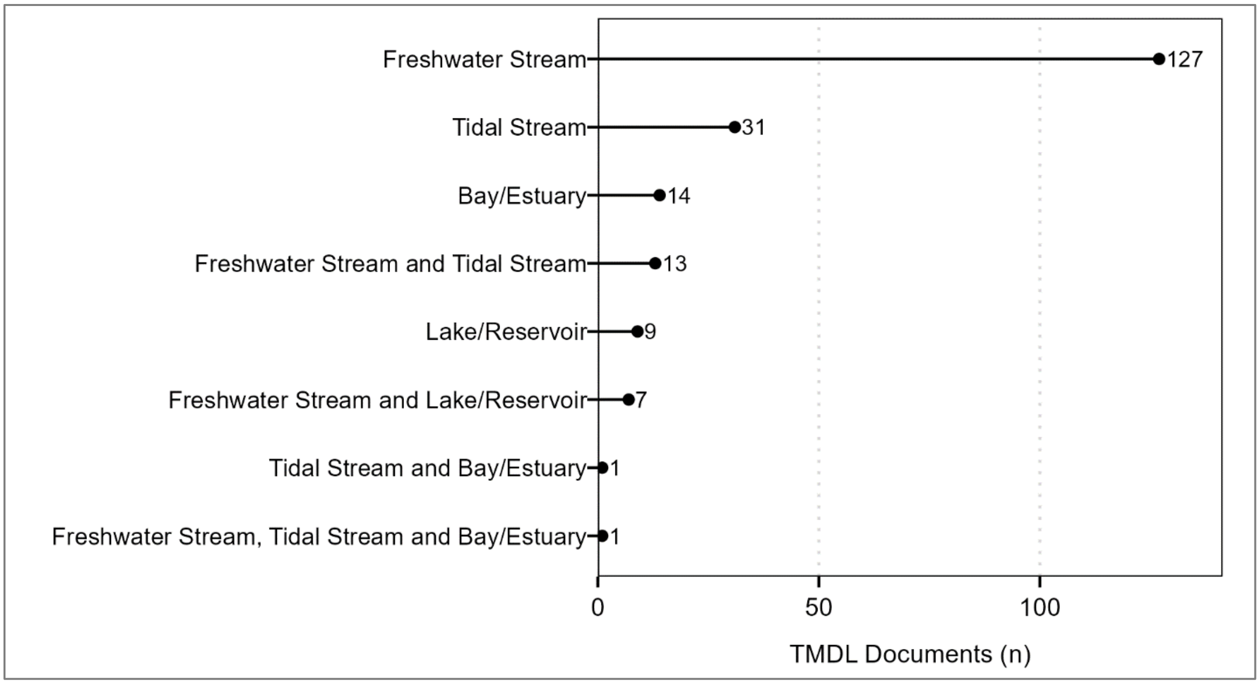

Figure 6. Total number of DO TMDLs in EPA Regions 4 and 6 by water body type.

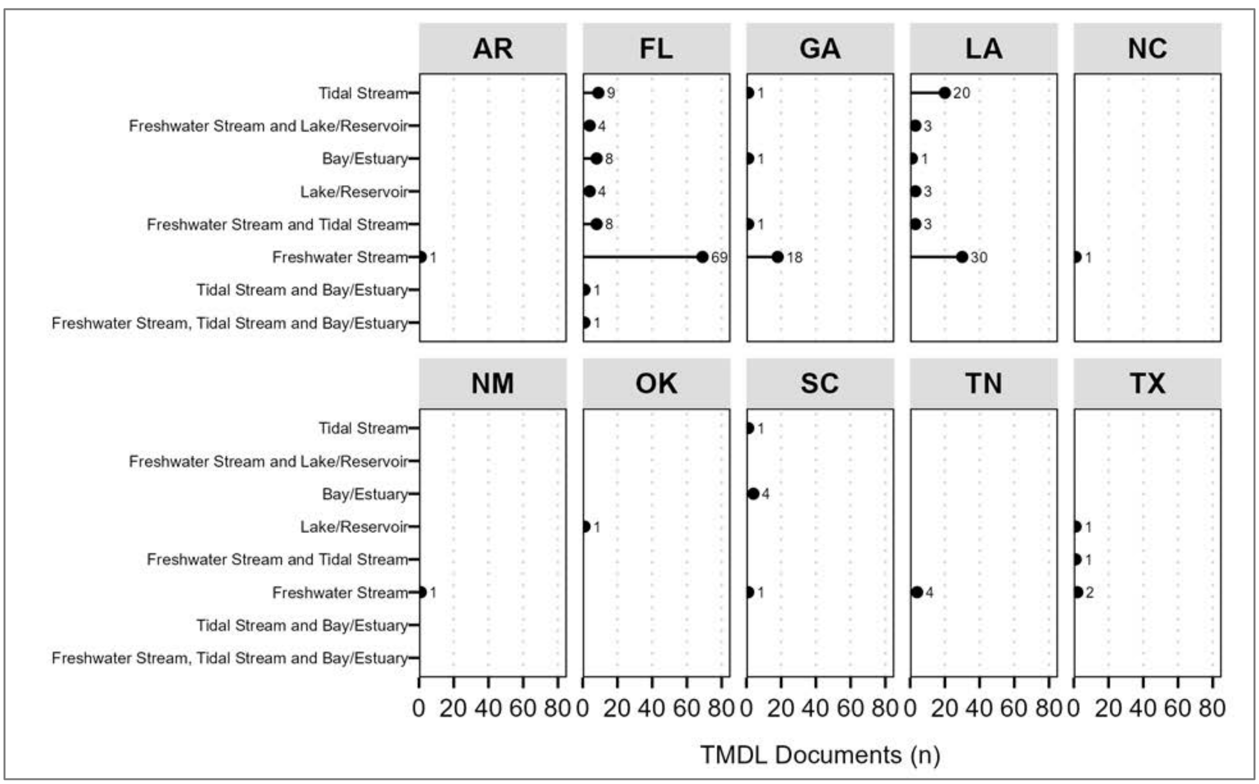

Figure 7. Total number of DO TMDLs in EPA regions 4 and 6 by water body type and state.

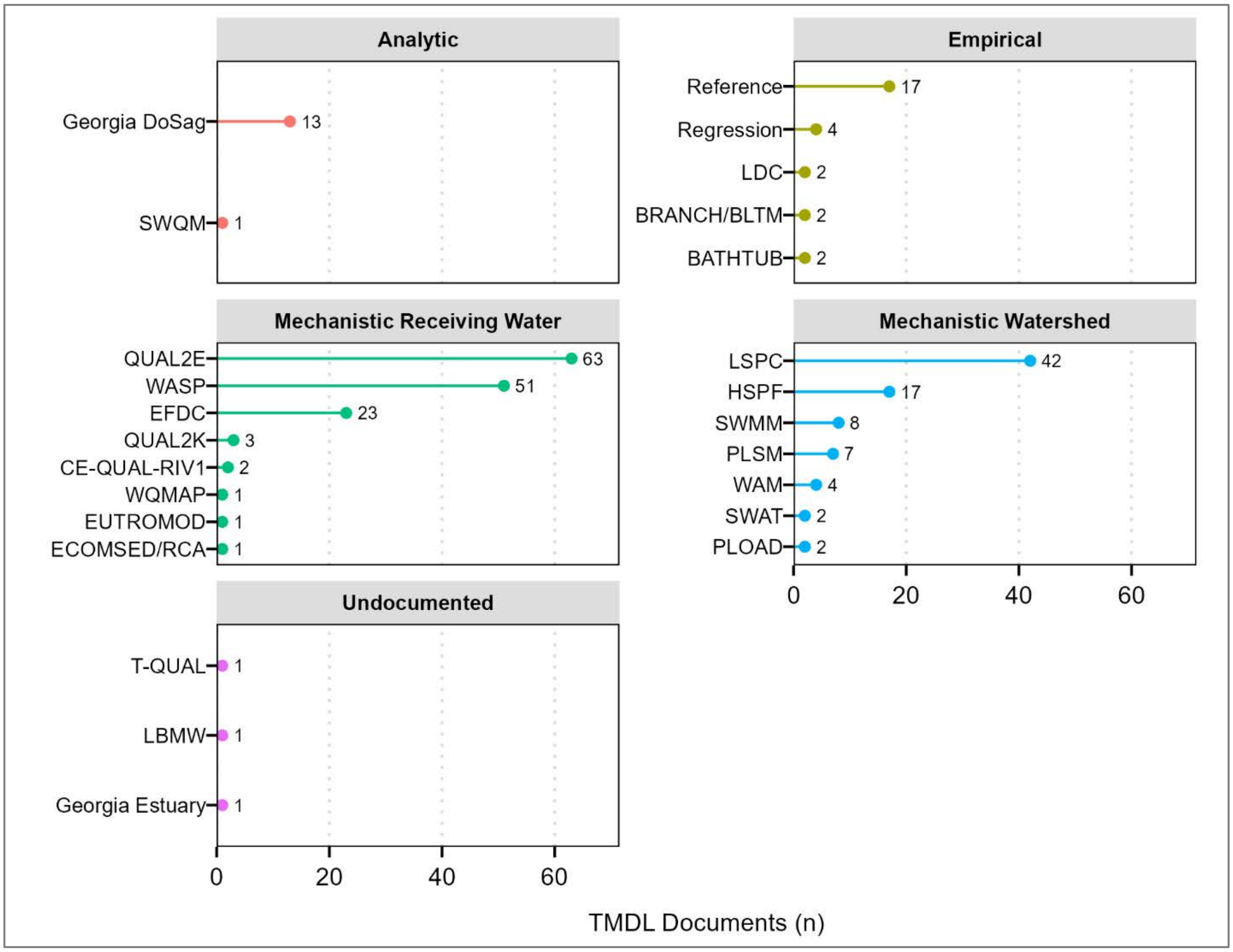

Figure 8. Frequency of occurrence for methods and models used to identify watershed loads or allowable loads in DO TMDLs in EPA Regions 4 and 6.
Note: For summary purposes, LA-QUAL and QUALTX are classified as QUAL2E and EPD RIV-1 is classified as CE-QUAL-RIV1.

3 Summary of TMDL Methods and Models

3.1 Models used in Dissolved Oxygen TMDLs

The overwhelming majority of methodological approaches used in DO TMDLs are mechanistic receiving water and mechanistic watershed models (**Figure 8**). Among receiving water models, QUAL2E (including related models such as LA-QUAL and QUALTX; n=63), WASP (n=51), and EFDC (n=23) are the most employed models. LSPC (n=42) and HSPF (n=17) are the most used watershed models. The state of Georgia uses the proprietary Georgia DO Sag model extensively and is the primary analytic approach found in the region. Among empirical models, the reference approach (n=17) was used frequently in Florida to determine nutrient endpoints and subsequent load allocations. We also identified 3 TMDLs that used models that we could not obtain documentation to assess how they work or are utilized in sufficient detail (T-QUAL, LBMW, and Georgia Estuary).

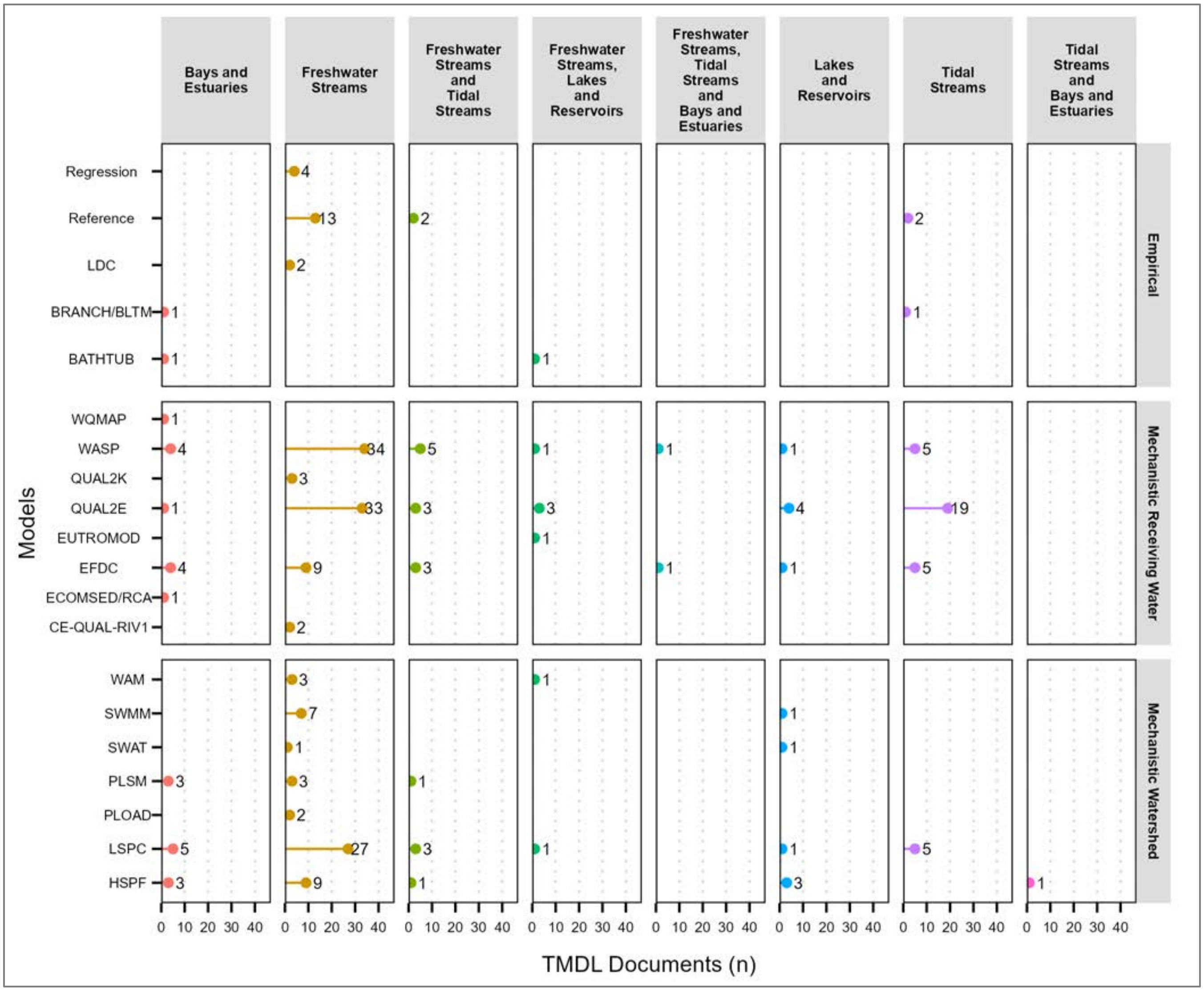

Figure 9. Method or model used in TMDLs by waterbody type(s) addressed in the TMDL document.

There are a wide variety of freshwater stream conditions in the reviewed TMDLs, and this is reflected in the approaches identified in our review (**Figure 9**). The simplest cases employed setting load allocations based on nutrient concentrations identified in reference streams. However, for most freshwater streams a watershed model was used either alone or combined with a water quality model. LSPC and HSPF for the most common watershed models and WASP and QUAL2E were the most common receiving water models.

WASP, EFDC, and LSPC were the most common models used in bay/estuary TMDLs (**Figure 9**). Specific methodologies varied substantially between bay/estuary TMDLs. However, the general approach was to model input loads using a watershed model (typically LSPC or HSPF). Water quality responses were modeled using a combination of a hydrodynamic model (EFDC) and water quality model (WASP) or just a water quality model depending on the specific characteristics of the water body. Tidal streams generally followed the same approach as bays/estuaries, except that

QUAL2E (or related QUAL-TX and LA-QUAL models) was the most common water quality model. When required, EFDC was used to model hydrodynamics and LSPC was used to model watershed loadings. There were very few lakes/reservoirs identified in the TMDL search. HSPF in conjunction with QUAL2E was the most common approach identified in the development of lake/reservoir DO TMDLs.

3.2 Description and Application of Selected Models used in DO TMDLs

Several of the most identified empirical and mechanistic approaches are described below. For conciseness, not all of the identified models are described here. Readers are referred to Shoemaker et al. (2005) for description of models not discussed below.

3.2.1 Mechanistic Watershed Models

3.2.1.1 Loading Simulation Program C++

The Loading Simulation Program C++ (LSPC) is a watershed modeling system based on the Hydrologic Simulation Program – Fortran (HSPF) model, ported to the C++ programming language to improve efficiency and flexibility. The model adopts HSPF algorithms for simulating hydrology, sediment, and general water quality constituents. LSPC is supported and maintained by the EPA, is free and available to the public. The LSPC model is the most used mechanistic watershed model in DO TMDLs in EPA 4 and 6 regions. The LSPC model can be run as a plugin in the Better Assessment Science Integrating Point and Non-point Sources (BASINS) environmental assessment system publicly available at the EPA Center for Exposure Assessment Modeling (CEAM) - BASINS website[1].

Data requirements and simulated outputs are like those for HSPF. However, LSPC uses a simplistic data preprocessing and storage system based on Microsoft (MS) Excel and Access programs. The model uses an MS Access database to manage model configuration and parameterization data, and editable weather text files to drive the simulation. The setup Excel spreadsheet provided with the model helps to populate the LSPC MS Access database.

The model includes a land-based water quality module that simulates water quality constituents derived from the land surface via surface, interflow and groundwater flow paths and a reach water quality module that allows for simulation of instream kinetics. LSPC uses the same algorithms used in HSPF for simulating DO.

3.2.1.2 Hydrological Simulation Program - FORTRAN

HSPF is a continuous simulation watershed model that simulates nonpoint-source runoff and pollutant loadings for a watershed and performs flow and water quality routing in stream reaches and well-mixed lakes and impoundments. HSPF can be used to estimate nonpoint-source loads from various land uses as well as fate and transport processes in streams and lakes. HSPF is jointly supported and maintained by the EPA and USGS. The HSPF model is the second most used mechanistic watershed model in DO TMDLs in EPA regions 4 and 6. The model can be downloaded from EPA CEAM webpage[2] for HSPF.

The model can simulate streamflow and a wide range of water quality constituents including; water temperature, sediment, dissolved oxygen, biochemical oxygen demand, nutrients (nitrogen and phosphorous), and plankton (phytoplankton and benthic algae). Data needs for HSPF can be extensive. As a watershed loading model, data inputs for HSPF include information that influences

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[1] https://www.epa.gov/ceam/better-assessment-science-integrating-point-and-non-point-sources-basins

[2] https://www.epa.gov/ceam/hydrological-simulation-program-fortran-hspf

the transport of runoff and groundwater filtration. At a minimum, continuous rainfall records are required to drive the runoff model, and additional records of evapotranspiration, temperature, and solar intensity are desirable (Vellidis et al. 2006). Input data requirements for DO modeling include terrain, land use, meteorological, soil data. Hydrological and water quality data is required for model calibration.

For simulation with HSPF, the watershed has to be represented in terms of land segments and reaches/reservoirs. A segment of land that has the capacity to allow enough infiltration to influence the water budget is considered pervious. Otherwise, it is considered impervious (Bicknell et al. 1997). Water quantity and quality is calculated for each land segment. Water and water quality constituents are then added to the downslope segment or to a reach/reservoir.

The model consists of three groups of subroutines; PERLND (Pervious Land Segment) and IMPLND (Impervious Land Segment) for simulating water quantity and quality processes on land, and RCHRES (free-flowing reach or mixed reservoirs) for simulating instream environments. The water temperature and gas subroutine simulate DO levels in overland flow, interflow, and groundwater for pervious surfaces, and only in runoff for impervious segments. The instream oxygen reaction subroutine is used to account for temporal variations in oxygen balance, and the DO and BOD state variables in the reach.

HSPF affords the ability of simulating the complex DO processes both on land and in the stream. However, the model requires significant amounts of input data and users must have strong modeling skills and adequate training.

3.2.1.3 Storm Water Management Model

The storm water management model (SWMM) is a dynamic rainfall-runoff and water quality simulation model, primarily used but not exclusively for urban areas, for single-event or long-term (continuous) simulation. Both single-event and continuous simulation can be performed on catchments, for prediction of flows, stages, and pollutant concentrations. The model has capabilities to simulate impacts of BMPs including rain barrels, permeable pavers, vegetative swales, bioretention cells, infiltration trenches, detention basins, infiltration practices, wetlands, ponds on water quality and quantity. SWMM is an open-source Windows-based desktop program maintained by the EPA. The model can be downloaded from the EPA's SWMM webpage[3].

The runoff component of SWMM operates on a collection of subcatchments areas that receive precipitation and generate runoff and pollutant loads. Spatial variability in on land processes is achieved by dividing a study area into a collection of smaller, homogeneous subcatchments areas, each containing its own fraction of previous and impervious sub-areas. Overland flow can be routed between sub-areas, between subcatchments, or between entry points of a drainage system. The routing portion of SWMM transports this runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators. SWMM tracks the quantity and quality of runoff generated within each subcatchments, and the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period comprised of multiple time steps.

[3] https://www.epa.gov/water-research/storm-water-management-model-swmm

3.2.2 Mechanistic receiving water models

3.2.2.1 Enhanced Stream Water Quality Model and

The Enhanced Stream Water Quality Model (QUAL2E) is a DOS-based precursor water quality model to QUAL2K. The updated QUAL2K is a Microsoft Windows based one-dimensional river and stream water quality model with steady state hydraulics, non-uniform steady flow, and diel heat budget/water-quality kinetics. QUAL2K can simulate a number of water quality parameters, including temperature, pH, carbonaceous biochemical oxygen demand, sediment oxygen demand (SOD), dissolved oxygen (DO), fate of nitrogen and phosphorous, phytoplankton and bottom algae. The model does not simulate watershed processes. QUAL2E/QUAL2K is often liked with other watershed/ hydrologic models. QUAL2K is an open-source Windows-based desktop program whose development and maintenance is supported by the EPA. The model and tutorials are available for download at the model developers' website[4].

Data input to the QUAL2K model includes geometric data of the river system, hydraulic data, parameters, and data of the surroundings. The model uses a finite difference solution of the advective-dispersive mass transport and reaction equations. The program simulates changes in flow conditions along the stream by computing a series of steady-state water surface profiles. The calculated stream-flow rate, velocity, cross-sectional area, and water depth serve as a basis for determining the heat and mass fluxes into and out of each computational element due to flow. Mass balance determines the concentrations of state variables e.g., coliform bacteria, DO at each computational element/ reach.

3.2.2.2 Water Quality Analysis Simulation Program

The Water Quality Analysis Simulation Program (WASP) can be used to simulate conventional pollution (involving dissolved oxygen, biochemical oxygen demand, nutrients, and eutrophication) and toxic pollution (involving organic chemicals, metals, and sediment). The model has a suite of options that allow the user to tailor the degree of complexity, and to investigate 1, 2, and 3 dimensional systems, and a variety of pollutant types. The model can be downloaded from the EPA Center for Exposure Assessment Modeling (CEAM) - WASP download page[5].

The WASP system consists of two stand-alone computer programs, DYNHYD and WASP, which can be run in conjunction or separately. The hydrodynamics program, DYNHYD, simulates the movement of water while the water quality program, WASP, simulates the movement and interaction of pollutants within the water. The DYNHYD model does not simulate watershed processes. Therefore, in absence of measured streamflow, and stormwater loads, WASP is often liked with other watershed/ hydrologic models.

As an example, in the Final Peace River Basin DO, nutrient, turbidity and TSS TMDL[6], the Watershed Assessment Model (WAM) in conjunction with the WASP model. WAM was used to estimate the non-point source loads from the watershed and the flow for streams. The WASP model was then used for estimating the effects of non-point source and point source loads on dissolved oxygen.

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[4] https://qual2k.com/index.html

[5] https://www.epa.gov/ceam/wasp8-download

[6] https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/22666/107805

3.2.3 Empirical methods

3.2.3.1 Regression Equations

Regression is a statistical method that attempts to determine the strength and character of the relationship between one dependent response (predicted) variable and a series of other predictor independent variables. Linear regression, the most basic form of regression establishes the linear relationship between the response variable and predictor based on a line of best fit. The line can then be used to examine how the response variable changes as the predictor variable changes, and to predict the value of a response variable for any predictor variable. Theoretically, there is no limit to the number of predictor variables. When more predictor variables are involved, multiple regression equations can be used to examine the effects of multiple predictors on the value of the response variable.

In several DO TMDLs, an argument is made that since DO is not a pollutant, but rather a water quality condition needing improvement, the TMDL shouldn't be developed for DO loads but rather for related pollutants/ parameters causing poor DO conditions. Regression analysis is conducted to determine equations that relate controllable water quality/quantity parameters to DO conditions. The load reductions for the DO TMDL can then be determined from water quality targets that are based on the regression equations. Generally, variation in DO in TMDLs was determined to be explained by variables such as temperature, BOD, chlorophyll, nutrients, total organic carbon, and flow.

A common practice is to carry out quantile regression (estimation of a family of equations for the quantiles (e.g., 5%, 10%, 25%, and so on) of a data set. For a set of (or individual) parameters, quantile regression can be performed in relation to DO for several quantiles, along with the quantile for the DO criteria of interest (e.g., cool-water criteria – e.g., 6.5 mg of DO/ml). Only water quality parameters are statistically significant i.e., with a p-value less than the α-level selected for the QR analysis, can be screened further, or used to determine DO.

Screening, which involves further reducing the number of water quality parameters, can consider several factors e.g., controllability and whether the regression relationship between the water quality parameter-DO make physical sense. An example of non-controllability is decreasing DO concentrations with respect to increasing air temperatures. The amount of DO water can hold is strongly related to water temperature, which in turn is related to air temperature. However, the air temperature is not very controllable. Another example of a non-controllable relationship is the need for extreme changes in a water quality parameter to improve DO conditions. It may not be possible to change the level of a water quality levels to improve DO conditions, say if nitrate levels of zero are required. Lastly, an example of a regression relationships not making physical sense would be if the regression results indicate that as water temperature increases DO conditions improve. This is the opposite to what is commonly understood about the physical relationship between DO and temperature.

3.2.3.2 Region-Based Reference Approaches

For waterbodies with nutrients and DO impairments, it is assumed in several TMDLs that controlling nutrients should result in improved DO conditions. Like regression equations, region-based reference approaches use potential causative agents/parameters for DO impairment as surrogates for developing DO TMDLs. The approach involves establishing nutrient targets (e.g., total nitrogen and/or total phosphorus). The target concentrations are derived by using data from waters not impaired for DO and nutrients in the region of interest, that are similar to DO and nutrient impaired waterbodies, in terms of hydrologic conditions and drainage area size. Sets of DO and nutrient target and impaired values are compared, and reductions in nutrients loads of impaired waterbodies, required to reach target nutrient loads (thus target DO levels) are determined.

3.3 Parameter Allocations

While modelling approaches are used to establish the relationship between loading inputs and resulting water quality, additional steps are required to allocate loads and develop the TMDL. The specific methods for establishing loading allocations will vary based on the exact methodology chosen, but EPA provides general guidance for performing load allocations in DO TMDLs (EPA 1995b). Overall, these steps include: (1) identification of DO endpoint, (2) determination of upstream and background BOD and DO conditions, (3) identification of alternative loading scenarios, and (4) iterative model application until endpoint is achieved.

Under most scenarios, DO endpoints were set to corresponding state water quality standards. Some exceptions occurred in Georgia and Florida which have provisions for streams that are naturally low in DO and do not meet statewide DO criterion. When it was determined that streams would not meet the DO criterion under background condition the targets were 90% of the background DO concentration. Background DO and BOD conditions were generally determined using (1) reference watersheds if available or (2), more commonly, changing developed land uses into pre-developed land uses in calibrated watershed models. For models that required boundary DO and/or BOD boundary conditions TMDLs in Louisiana used regionally specific values, Georgia TMDLs relied on historic field data, while other states rarely included the documentation within the TMDLs. Statistical and empirical based approaches typically do not require alternative scenarios or iterative modelling to allocate parameters. For mechanistic models, iterative modelling procedures and alternative scenarios other than current and natural background conditions were rarely documented.

3.4 Critical Conditions and Seasonal Variation

EPA requires that TMDLs consider critical conditions and seasonal variation when developing loading allocations. Consideration of critical conditions and seasonal variation differed between states and methodological approaches. Many of the DO TMDLs in Louisiana were developed under steady state conditions using critical seasonal temperature and flow conditions. Conversely in Florida, critical conditions were incorporated in different fashions. For example, when using dynamic long-term models, critical conditions and seasonality were implicitly incorporated by using long term simulations that included a range of expected conditions. However, other modeling approaches, such as regression-based approaches, required statistical tests of seasonality and critical conditions. The state of Georgia, which typically used the DO Sag approach for TMDL developed applied models under critical flow (summer 7Q10 low flows) conditions. It was evident that the remaining states used a variety of approaches for addressing critical conditions based on the modelling approach used in the TMDL. For steady-state models and empirical approaches, loadings are allocated under a well-defined critical condition. The use of time and flow variable models allowed an implicit consideration of both season and flow critical conditions.

3.5 Margin of Safety

TMDLs must incorporate a MOS to account for uncertainty in models. An implicit method of incorporating MOS into TMDL allowable loads is accomplished by utilizing conservative assumptions during the calculation of the allowable load. Conversely, the explicit method reserves an unallocated portion of the load allocations. Based on our review, MOS designation varied from state to state, consistent with previous reviews on MOS (Nunoo et al. 2020). For example, many (but not all) of the TMDLs in Florida, Georgia and South Carolina incorporated implicit MOSs by setting nutrient targets using natural background conditions or using conservative assumptions in the modelling process. TMDLs in Louisiana generally set explicit MOS values ranging from 10% to 20%. TMDLs in Tennessee generally included an explicit MOS but also included details on how implicit MOS was incorporated through conservative modelling assumptions.

4 Case study TMDLs

Several case studies are provided to outline approaches used under a range of typical land use and hydrologic conditions.

4.1 Urban Bay/Estuary: Boggy Bayou

Boggy Bayou belongs to the much larger Choctawhatchee Bay system in western Florida near Destin Pass. Specifically, Boggy Bay is in the western quadrant of the larger Choctawhatchee Bay where small tributaries feed a highly urbanized watershed. Land use within the watershed during the project period was primarily urban (67%), but also had some transportation and upland forest land use. This bayou is designated as a class III waterbody, which means used for recreation and propagation and maintenance of a healthy, well-balanced population of fish and wildlife.

The Boggy Bayou was first listed on Florida's 303(d) list as impaired for dissolved oxygen in 1998. Dissolved oxygen fell below the water quality criterion of 5 mg/L for a class III waterbody. It also has high chlorophyll-a levels, indicating nutrient concerns within the bayou as well.

4.1.1 Source Analysis

Pollution within the Boggy Bayou watershed is mainly from nonpoint source urban runoff, but there are also point source urban stormwater flows. The cities Niceville, Eglin AFB, Valpar, and all of Okaloosa County are contributors to stormwater discharge and urban stormwater flows are currently managed through municipal separate storm sewer system (MS4) stormwater permits.

Table 1. Potential sources identified in the Boggy Creek TMDL.

Waste Load Allocation	Load Allocation
• MS4 stormwater for Niceville, Eglin AFB, Valpar, and Okaloosa County	• Failing septic systems • Urban runoff from residential, industrial, and commercial areas • Agricultural runoff • Transportation (airports, roads, railroads) • Illicit discharge of sanitary waste • Domestic pets

4.1.2 Endpoint Identification

The State of Florida has narrative criteria for nutrients requiring in no case shall nutrient concentrations of a body of water be altered to cause an imbalance in natural populations of aquatic flora or fauna. Under these criteria DO endpoints are established to either the numeric standard associated with the designated use *or* to the DO concentrations expected under natural conditions (assuming the standard would not be achieved under natural conditions). A combined watershed/receiving water body model was calibrated to current conditions to predicted loadings and estuary concentrations for total nitrogen, total phosphorus, BOD, DO, and chlorophyll-*a*. The models were then run with anthropogenic land uses replaced with pre-developed land cover to predict predevelopment DO concentrations. For this TMDL, it was determined that predevelopment DO concentrations would not achieve the standard and were used as the DO endpoint. The receiving water body model was then used to establish nutrient and BOD loading scenarios required to meet the DO endpoint.

4.1.3 Models

Three models were used in this project: the watershed model LSPC, hydrodynamic model EFDC, and the receiving water model WASP. LSPC was used to simulate runoff, streamflow and resulting pollutant loadings for total nitrogen, total phosphorus, and BOD. The resulting output was used in the EFDC model to simulate flow and transport of pollutants for the entire Choctawhatchee Bay, which is linked to the WASP model. LSPC output was also used in WASP to predict resulting water quality for different modeling scenarios within Boggy Bay.

Model Inputs

- LSPC: Continuous meteorological data, land use and soils data, water quality data.
- EFDC: Stream flow and pollutant loading (from LSPC), surface water elevation, meteorological data, Land use data (for event mean concentrations), water quality data.
- WASP: Stream flow and pollutant loading (from LSPC), width and depth of the waterbody, water quality data.

The LSPC watershed model was set up first and the Boggy Bayou watershed was delineated into 226 sub-watersheds so that the effect of precipitation on runoff and pollutant loadings over time could be simulated for each sub-watershed. The simulation time period was from 2002 to 2009, which covered a variety of critical conditions and seasonal variations. This model was run for two modeling scenarios, current conditions and natural conditions. To run the model for natural conditions all anthropogenic land use was converted to upland forests. The time-series output generated from these modeling scenarios was used in the subsequent models.

For the hydrodynamic EFDC model, a grid of the entire Choctawhatchee Bay was created to study transport of pollutants within the system. The time-series from the LSPC watershed model was entered into the model and the grid was calibrated to existing water quality data. This model generated the total pollutant loads for total nitrogen, total phosphorus, and BOD of the watershed that a TMDL is calculated from.

Next, the same grid with all the hydrodynamic data was reduced to a smaller grid focused on only the Boggy Bayou. The time-series from the LSPC watershed model was entered into the model and the grid was calibrated to existing water quality data. This model simulated water quality response to a reduction in pollutant loading.

4.2 Urban Freshwater Stream: Cedar River

Cedar River is an urban freshwater stream in northeast Florida near the city of Jacksonville. The river is part of the larger drainage area of the Lower St. Johns River Basin. Cedar River flows for about 3.6 miles southeast and then drains into the Ortega River; it is the largest tributary for the Ortega River. Land use within the watershed during the project included mostly urban (56%), wetlands (19%), and upland forests (11%). This river is designated as a class III waterbody, which means used for recreation and propagation and maintenance of a healthy, well-balanced population of fish and wildlife.

Cedar Creek was first listed on Florida's 303(d) list as impaired for both bacteria and dissolved oxygen in 2004. It also shows concern for nutrients although it was not officially impaired for nutrients due to a lack of data at the time. Dissolved oxygen fell below the water quality criterion of 5 mg/L for a class III waterbody. This TMDL calculation did not address the bacteria impairment at all, as there was a separate document to address bacteria impairments.

4.2.1 Source Analysis

Pollution for Cedar River within the larger Ortega River watershed comes from point source urban stormwater flows and nonpoint surface runoff. The City of Jacksonville is the largest contributor to stormwater discharge and urban stormwater flows are currently managed through MS4 Stormwater Program. Additionally, industrial stormwater discharges are also managed under stormwater permits.

Table 2. Potential sources identified in the Cedar River TMDL.

Waste Load Allocation	Load Allocation (LA)
• MS4 stormwater from City of Jacksonville • Industrial stormwater discharges	• Failing septic systems • Agricultural run off • Urban runoff from residential, industrial, and commercial areas • Domestic pets

4.2.2 Endpoint Identification

The DO endpoint was established as the applicable numeric standard for the water body's designated use (5mg/L). A causative relationship between BOD and DO was established with graphical correlations of monthly and seasonally averaged BOD with DO. Similar graphical correlations were established with total phosphorus. In consistency with the narrative nutrient criteria used by Florida, the BOD and total phosphorus targets were established as the modeled background loads as predicted under predevelopment conditions.

4.2.3 Models

The models used for this project were the watershed loading SWAT baseflow program and the watershed runoff model SWMM. SWAT was used to determine baseflow and then that output was fed into SWMM to produce total stream flow. With total stream flow quantified, the model can calculate loads for BOD and total phosphorus. Both SWAT and SWMM are supported by the EPA and have been used broadly for surface runoff and stormwater transport through sewers in urban watersheds.

Model Inputs

- SWAT: USGS flow data, long-term watershed quality data, Land use/cover data, soil data, topography, and meteorological data.
- SWMM: Land use/cover data, infiltration and percent imperviousness area of each land use category, geometry of the watershed, stormwater system geometry, and continuous meteorological data.

SWAT was used to determine and correlate baseflow at the two different USGS gages within the study area. SWAT helped quantify a mathematical relationship between the two gages, then the equation was fed to SWMM. To perform the SWMM simulation, the Cedar River watershed was divided into six sub-watersheds. Next, all other data inputs such as soil, land use, and meteorological etc., were fed into the model. The model was calibrated by changing the percent impervious area from the lowest flow values to incrementally higher flow values. Once calibrated, the model was used to determine BOD and total phosphorus loads through an entire year. This allowed authors to determine reductions necessary to obtain satisfactory water quality standards.

4.3 Rural Freshwater Stream: Crabgrass and Jane Green Creek

Jane Green Creek and Crabgrass Creek are freshwater streams in the east panhandle of Florida. They are located within the Jane Green Creek Planning Unit. Land use within the watershed is primarily agricultural (55%), with wetlands (25%), upland forests (8%), and rangeland (9%). Both rivers are designated as a class III waterbody, therefore they are used for recreation and propagation and maintenance of a healthy, well-balanced population of fish and wildlife. Both Crabgrass and Jane Green Creek were first listed as impaired waterbodies on Florida's 303(d) list for dissolved oxygen and nutrients in 1988. Dissolved oxygen fell below the water quality criterion of 5 mg/L half the time for Crabgrass Creek and for almost 90% of the time for Jane Green Creek. Both waterbodies displayed elevated chlorophyll-*a* and nutrients.

4.3.1 Source Analysis

For both creeks it is suspected that agricultural non-point sources pollution is the dominant form of watershed loading. Over half of the land use within the study area is agriculture and the watershed is bordered by high agricultural land use as well. There are no stated point sources of pollution for this watershed, all pollutant loading is assumed to be from non-point sources.

Table 3. Potential sources identified in the Crabgrass and Jane Green Creek TMDLs.

Waste Load Allocation	Load Allocation (LA)
• None	• Agriculture • Leaking septic tanks • Urban, residential and commercial developments • Rangeland

4.3.2 Endpoint Identification

Similar to other DO TMDLs in Florida, the DO endpoints are established to either the numeric standard associated with the designated use or to the DO concentrations expected under natural conditions (assuming the standard would not be achieved under natural conditions). In this case a combined watershed and receiving water body model were calibrated to current conditions. A natural condition scenario was developed with anthropogenic land uses converted to predevelopment conditions to establish expected DO conditions. For this TMDL, it was determined that predevelopment DO concentrations would not achieve the standard and were used as the DO endpoint. The receiving water body model was then used to establish nutrient and BOD loading scenarios required to meet the DO endpoint.

4.3.3 Models

The LSPC watershed model and WASP receiving water body model were used for this TMDL. LSPC simulated surface runoff for the two creeks and the output was used in the WASP model. WASP calculated load reductions to obtain water quality standards. These models were used to predict total phosphorus, total nitrogen, BOD, DO, and chlorophyll-*a*.

Model Inputs

- LSPC: Continuous meteorological data, land use and soils data, water quality data.
- WASP: point and nonpoint sources, flow, water quality data.

First, LSPC was calibrated to current conditions during simulation time period from 1997 to 2010. Then LSPC simulated a runoff time series for flow, and all parameters of interest in natural conditions. The simulation was repeated for current conditions. These time series were both fed into the WASP model to calibrate it and determine the effect of load reductions on the watershed.

4.4 Lake/Reservoir: Lake Thunderbird

One of the few lakes or reservoirs with a TMDL focused on DO, Lake Thunderbird is located within EPA region 6 east of Norman, Oklahoma. The reservoir lies within the drainage area of the upper Little River watershed and has a surface area of about 6,070-acres and an average depth of 19.7 ft. Land use within the watershed included mostly grassland/herbaceous (38%) and deciduous forest (35%) with some urban developments (~16%). This lake provides recreation, wildlife habitat, flood control and municipal water supply for cities of Norman, Del City, and Midwest City.

Lake Thunderbird was listed on Oklahoma's 303(d) list as a category 5a lake: impaired for some of its designated beneficial uses. Specifically, Lake Thunderbird's high chlorophyll-a levels did not meet water quality standards for its designated beneficial use as a public water supply. Additionally, water quality standards were surpassed due to high turbidity and low dissolved oxygen for its warm water aquatic community under the designated beneficial use for fish and wildlife propagation. Like many other reservoirs, Lake Thunderbird has seasonal issues with thermal stratification and anoxia. Final TMDLs were approved by the EPA in November 2013 for total suspended solids, total nitrogen, total phosphorous, and carbonaceous biochemical oxygen demand (CBOD).

4.4.1 Source Analysis

Pollution for Lake Thunderbird within the Little River watershed comes from point source urban stormwater flows and nonpoint source rural runoff. The three largest contributors (Moore, Norman, Oklahoma City) to urban stormwater flows are currently managed through the MS4 Stormwater Program.

Table 4. Potential sources identified in the Lake Thunderbird TMDL.

Waste Load Allocation	Load Allocation (LA)
• MS4 stormwater from City of Jacksonville • Permitted industrial stormwater • Permitted construction stormwater	• Failing septic systems • Sanitary sewer overflows • Agriculture • Urban runoff • Grazing livestock • Domestic pets

4.4.2 Endpoint Identification

Water quality targets were based on criteria set for the designated uses for (a) Fish & Wildlife Propagation for a Warm Water Aquatic Community because of excessive levels of turbidity and low dissolved oxygen; and (b) Public Water Supply because of excessive chlorophyll-a levels. Water quality criteria for DO are defined for: (a) the surface layer (epilimnion) during periods of thermal stratification and (b) the entire water column when the lake is not stratified. A Warm Water Aquatic Community Lake is fully supporting its designated beneficial uses for the epilimnion and the entire water column if 10% or less of DO samples are less than 6 mg/L from April 1 through June 15 and less than 5 mg/L during the remainder of the year (June 16 through March 31). DO criteria for a Warm Water Aquatic Community Lake are also defined based on the anoxic volume of the lake that is less than a target cutoff level of DO. During the period of thermal stratification, the lake is fully supporting if 50% or less of the lake volume is less than the target cutoff of 2 mg/L. A calibrated lake model was used to evaluate load reduction scenarios to establish linkages between reductions in sediment, CBOD, total nitrogen, and total phosphorus with water quality targets for turbidity, chlorophyll-*a* and DO.

4.4.3 Models

This TMDL used the were the mechanistic watershed model, HSPF, and the mechanistic receiving water model, EFDC, within the EPA's watershed modeling platform, BASINS. For calculation of load allocation, the HSPF model was used to generate streamflow and resulting pollutant loads and that output was used within EFDC model to establish a cause-effect relationship between external pollutant loading and the Lake response over time. Historical data was insufficient to calibrate the models, therefore intensive monitoring of the Lake Thunderbird and its tributaries was performed from April 2008 through April 2009 to supplement existing efforts. Rain gauges and programmable automatic samplers were set up at five monitoring stations, in major tributaries within the watershed.

Model Inputs

- HSPF: stream discharge and water quality data for calibration (parameters needed; water temperature, total suspended sediment, total organic carbon, nitrogen, phosphorous, DO) for at least one-year, meteorological data, Land use/cover data.
- EFDC: Bottom elevation of the lake (high resolution bathymetry), stream flow and pollutant loading (from HSPF), water withdrawal for municipalities and release flow at the dam, meteorological data, and wet/dry atmospheric deposition of nutrients over project period.

The HSPF model was set to a time step of one hour and calibrated. Once the HSPF simulation generated an output, the TMDL calculation could proceed to the next step. The EFDC model was set up with a fine mesh grid to physically represent the geometry of the Lake and once all needed inputs were established, the model was calibrated to existing conditions. The simulation was used in a 35% removal scenario for 8 years to demonstrate that recommended pollutant load reductions would bring conditions into compliance with water quality standards within a reasonable time period.

The performance of the linked models was evaluated by comparing simulated output and actual measurements using root mean square error and relative root mean square error. Using these metrics, the model was found to perform well in all criteria except for total organic carbon and total organic nitrogen. These results are adequate to develop TMDLs, however, there are some shortcomings of this strategy. One source of error in the models chosen for this project was that EFDC does not actually simulate turbidity. A substitute, total suspended solids, is used and a relationship between turbidity and total suspended solids needs to be created using paired turbidity and total suspended solids monitoring data.

5 Discussion and Recommendations

Within the queried region, the states of Florida, Louisiana, and Georgia had the most TMDLs. Within Florida, WASP was frequently used as a receiving water body model with LSPC/HSPF typically used as a watershed model. Louisiana almost exclusively relies on QUAL-LA, a variation of the QUAL2E family of models, to model DO during critical conditions. DO TMDLs in Georgia almost exclusively used the Georgia DO Sag model. The heavy use of steady state models and the DO Sag analytic approach in Louisiana and Georgia suggests that impairments were primarily point source driven. However, many of the TMDLs only had nonpoint source load allocations, indicating impairments were driven by flow events and a steady state model may not have been an appropriate approach. These results are consistent with previous research suggesting the selection of TMDL models are largely ad-hoc, perhaps guided by an agency or individual modeler's familiarity and expertise in a given model (TMDL Analysis and Modeling Task Committee 2017; Sridharan et al. 2021).

5.1 Model Selection and Requirements

Clearly, a single method or model will not be appropriate across water body conditions found in Texas. DO TMDLs, especially recently, are dominated by the use of mechanistic watershed and receiving body models. Instances of empirical approaches such as regression and reference watersheds were generally restricted to freshwater streams and to TMDLs developed prior to 2010. TMDLs that utilized regression-based approaches explained relatively small amounts of variation in DO and the incorporation of additional covariates are restricted by the available model degrees of freedom. The robustness of statistical methods for extrapolating beyond the observed combination of covariates will always cause considerable concern (Ehrenberg and Bound 1993; Forbes and Calow 2002). Finally, these relatively simple approaches lack mechanistic linkages between loadings and instream impairments making them difficult to incorporate into implementation planning. For small watersheds with limited available data, region-based reference approaches could be adequate for phased approaches similar to the current approach used for bacteria TMDL development in Texas where LDCs are often first used for load allocations.

Given the observed limitations in statistical approaches and recent recommendations by the American Society of Civil Engineers TMDL Analysis and Modeling Task Committee for the use of models that mechanistically link loads to impairments (TMDL Analysis and Modeling Task Committee 2017) the remaining discussion focuses on mechanistic watershed and receiving water body models. **Table 5** and **Table 6** provide a summary time-scales associated with models and a summary of model requirements identified in our literature review (EPA 1995b; Ward and Benaman 1999; Shoemaker et al. 2005; Vellidis et al. 2006; Borah et al. 2019; Camacho et al. 2019).

Watershed Models

HSPF and LSPC are the predominantly used watershed models and are suited for Texas watersheds. Although we did not identify many uses, SWAT would be appropriate for modeling agriculturally dominated watersheds, due to its ability to model agricultural BMPs for implementation planning. Conversely, in heavily urbanized watersheds, SWMM can simulate surface and subsurface drainage networks with stormwater BMPs. It should be noted that both SWAT and HSPF/LSPC can be used to simulate instream concentrations, including DO. However, in the reviewed applications, watershed models were only used to simulate upstream loadings and streamflow with a linked watershed model simulating water quality responses in the impaired assessment unit. HSPF/LSPC are perhaps the most adaptable watershed models for representing time scales and spatial coverage. HSPC/LSPC can be setup as steady state models, single event simulations, or continuous long-term simulations (Table 5). SWAT is most suited for long-term continuous simulations of daily/monthly/annual timesteps. SWMM is suitable for storm events or long-term continuous timesteps. In comparison to SWAT, HSPF/LSPC will generally have larger data and setup time requirements (Table 7). Although, the incorporation of locally specific data will lessen the discrepancy. SWAT has a number of approachable GUI environments including integration with ArcGIS, QGIS, and BASINS that may facilitate usage for less experienced modelers reducing time and effort required for model development.

Receiving Water Body Models

The QUAL2E/QUAL2K family of models and WASP are the predominate receiving water body models used in DO TMDLs. These models are generally suited for freshwater streams and shallow water lakes. The steady state nature of QUAL2E/2K simulations are likely suited for situations in which impairments primarily occur under critical low flow or point source driven conditions under which a single design flow can be specified. For dynamic issues driven by non-point source runoff, WASP is more suitable since it integrates multiple dimensions. For deep or large reservoirs subject to extensive stratification or strong circulation, the CE-QUAL-W2 (not identified in any of the reviewed TMDLs) appears to be the most appropriate receiving water body model. It is also possible to use WASP, in conjunction with the DYNHYD hydrodynamic module for simulating deep water reservoirs, although it is not immediately clear if it is more appropriate that CE-QUAL-W2 which has not been extensively used in the study area,

QUAL2E/2K is appealing due to its more limited data requirements, wide adoption (many analysts have experience with it), and its limited technical modelling requirements. WASP in comparison has relatively high data requirements, requires experienced modelers, and substantial time. Both models are publicly available, but WASP is integrated into EPA's BASINS modeling environment, facilitating integration with widely used data sets and a few different watershed models. For tidal streams and riverine estuaries, EFDC and WASP appear suitable for simulating time-varying impairments. The state of Louisiana extensively uses LA-QUAL (similar to QUAL2E/2K) in tidal stream TMDLs with the presumption that impairments primarily occur under critical low-flow conditions. The EFDC and ECOMSED models are well suited for open water bays and estuaries. Both EFDC and ECOMSED have high technical and data requirements, requiring substantial effort to model tidal systems.

5.2 Recommendations

This report identified numerous approaches used in the two EPA regions. However, it is clear that agencies in the regions have coalesced around a handful of watersheds and receiving water quality models to develop DO TMDLs. This suggests acceptance of approaches by EPA regional offices but does not signify that the most appropriate approaches were routinely used for a given water body type. Development of a framework for choosing among accepted approaches based on local stakeholder needs, water body and watershed characteristics, available data, and required complexity would provide baseline criteria and expectations for agencies, contractors, and stakeholders. The Bacteria TMDL Taskforce provides a good model for developing consensus among experts identified best practices and recommendations for DO TMDL development.

In addition to modelling approaches, attention needs to be made to data availability and applicability for DO TMDL development and Use Attainability Assessments. Although the use of 24-hour DO monitoring is increasing, it is plausible that many impairments are based on field measurement taken during routine sampling visits. Development of the technical and staff capacity to confirm impairments through robust monitoring may be required for TCEQ's many monitoring program partners. While nutrient parameters are now included in most routine monitoring plans across the state, relevant parameters such as BOD and CBOD are generally not evaluated in the state's surface water quality monitoring programs. Identification of priority water quality parameters required for adequate DO source assessments and modeling of different water body types might ensure local monitoring partners and labs have the capability to begin collecting and building water quality data required for TMDL development.

Table 5. Summarization of domain and time scales associated with models most commonly found in the review.
Adapted from Ward and Benaman (1999), Shoemaker at al. (2005), Borah et al. (2019), and Camacho et al. (2019).

	Time Scale		
Domain	**Steady State**	**Quasi-Dynamic**	**Fully-Dynamic**
Watershed	HSPF	HSPF, LSPC, SWAT, SWMM, WAM	HSPF, LSPC, SWMM, WAM
Freshwater Stream	QUAL2E/2K	EFDC, WASP, CE-QUAL-RIV1	WASP, CE-QUAL-RIV1
Tidal Stream	EFDC, QUAL2E/2K, WASP	EFDC, WASP	WASP
Lake/Reservoir	EFDC, QUAL2E/2K, WASP	EFDC, WASP	WASP
Bay/Estuary	ECOMSED, EFDC, WASP	ECOMSED, EFDC, WASP	ECOMSED, WASP

Table 6. Summarization of model requirements.
Adapted from EPA (1995b), Shoemaker et al. (2005), and Vellidis et al. (2006)

	Requirements				
Model	**Experience**	**Time**	**Data**	**Software Cost**	**Support Available**
Watershed Models					
HSPF	Substantial	> 6 months	High	Public Domain	High
LSPC	Substantial	> 3 months	High	Public Domain	High
SWAT	Moderate	> 1 month	Moderate	Public Domain	High
SWMM	Substantial	> 3 months	High	Public Domain	Moderate
WAM	Unknown	> 3 months	Moderate	Limited Distribution	Unknown
Receiving Models					
CE-QUAL-RIV1	Substantial	> 3 months	Moderate	Limited Distribution	Low
ECOMSED	Substantial	> 6 months	High	Public Domain	Low
EFDC	Substantial	> 6 months	High	Public Domain	High
QUAL2E/2K	Limited	> 1 month	Moderate	Public Domain	Moderate
WASP	Substantial	> 6 months	High	Public Domain	Low

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Appendix A: Total Maximum Daily Loads in the Study

Table 7. DO TMDLs identified in EPA Regions 4 and 6 and developed between 2000 and 2022.

Report Title	Region	State	Year Published	Link to Document
TMDL Evaluation for Beaverdam Creek	4	GA	2000	https://attains.epa.gov/attains-public/api/documents/actions/21GAEPD/97/105987
TMDL Evaluation for Bear Creek	4	GA	2000	https://attains.epa.gov/attains-public/api/documents/actions/21GAEPD/74/105836
TOTAL MAXIMUM DAILY LOAD (TMDL) DEVELOPMENT For Dissolved Oxygen In the Ogeechee River	4	GA	2000	https://attains.epa.gov/attains-public/api/documents/actions/21GAEPD/888/106087
TOTAL MAXIMUM DAILY LOAD (TMDL) DEVELOPMENT For DISSOLVED OXYGEN in the TAYLORS CREEK In the Ogeechee River Basin	4	GA	2000	https://attains.epa.gov/attains-public/api/documents/actions/21GAEPD/1186/105891
One Total Maximum Daily Load for Dissolved Oxygen in Salado Creek (Segment 1910)	6	TX	2001	https://attains.epa.gov/attains-public/api/documents/actions/TCEQMAIN/9687/107477
Ochlockonee River Basin Dissolved Oxygen TMDLs	4	GA	2001	https://attains.epa.gov/attains-public/api/documents/actions/21GAEPD/2393/105791
TOTAL MAXIMUM DAILY LOAD (TMDL) DEVELOPMENT For Oxygen Demanding Material/Dissolved Oxygen In the BRUNSWICK HARBOR SYSTEM	4	GA	2001	https://attains.epa.gov/attains-public/api/documents/actions/21GAEPD/1444/105909
Total Maximum Daily Load Cooper River, Wando River, Charleston Harbor System South Carolina	4	SC	2002	https://attains.epa.gov/attains-public/api/documents/actions/21SC60WQ/3809/104725
Seventeen Mile River Dissolved Oxygen TMDLs Satilla River Basin (HUC 03070201)	4	GA	2002	https://attains.epa.gov/attains-public/api/documents/actions/21GAEPD/22963/105948
Turkey Branch Dissolved Oxygen TMDL Alapaha River Basin (HUC 03110202) in the Suwannee River Basin	4	GA	2002	https://attains.epa.gov/attains-public/api/documents/actions/21GAEPD/22964/105810
BLACK RIVER TMDLS FOR DISSOLVED OXYGEN AND NUTRIENTS (080302)	6	LA	2002	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/2569/100736

Report Title	Region	State	Year Published	Link to Document
Oconee River Basin Dissolved Oxygen TMDLs	4	GA	2002	https://attains.epa.gov/attains-public/api/documents/actions/21GAEPD/2422/105734
Ocmulgee River Basin Dissolved Oxygen TMDLs	4	GA	2002	https://attains.epa.gov/attains-public/api/documents/actions/21GAEPD/2394/105731
Big Creek Dissolved Oxygen TMDL	4	GA	2002	https://attains.epa.gov/attains-public/api/documents/actions/21GAEPD/2399/105950
BAYOU CHENE TMDL FOR DISSOLVED OXYGEN	6	LA	2002	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/2031/100674
TOTAL MAXIMUM DAILY LOAD (TMDL) for Ammonia Toxicity & Organic Enrichment/Dissolved Oxygen in Eagle Creek Located in the Tennessee Western Valley (Beech) Watershed (HUC 06040001) Benton & Decatur County, Tennessee	4	TN	2003	https://attains.epa.gov/attains-public/api/documents/actions/TDECWR/10049/101815
Total Maximum Daily Load (TMDL) Ashley River, South Carolina	4	SC	2003	https://attains.epa.gov/attains-public/api/documents/actions/21SC60WQ/31682/104674
Total Maximum Daily Load (TMDL) for the Palatlakaha River to Address Dissolved Oxygen Impairment	4	FL	2003	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/10779/108021
Chattahoochee River Basin Dissolved Oxygen TMDLs	4	GA	2003	https://attains.epa.gov/attains-public/api/documents/actions/21GAEPD/9982/105998
Nutrient and Dissolved Oxygen TMDL for Thirty Mile Creek (WBID 1639)	4	FL	2004	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/22537/108012
FINAL ORGANIC ENRICHMENT/LOW DISSOLVED OXYGEN TOTAL MAXIMUM DAILY LOAD (TMDL) FOR WATERS IN THE HARPETH RIVER WATERSHED (HUC 05130204)	4	TN	2004	https://attains.epa.gov/attains-public/api/documents/actions/TDECWR/10821/102027
BAYOU VERRET, BAYOU CHEVREUIL, BAYOU CITAMON, AND GRAND BAYOU TMDL FOR BIOCHEMICAL OXYGEN-DEMANDING SUBSTANCES (Subsegment 020101)	6	LA	2004	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/10729/100917

Report Title	Region	State	Year Published	Link to Document
BAYOU DES ALLEMANDS WATERSHED TMDL FOR BIOCHEMICAL OXYGEN-DEMANDING SUBSTANCES	6	LA	2004	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/10727/100918
ST. CHARLES PARISH CANALS AND BAYOUS IN SEGMENT 0205 TMDL FOR BIOCHEMICAL OXYGEN-DEMANDING SUBSTANCES	6	LA	2004	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/10726/100878
BAYOU SEGNETTE TMDL FOR BIOCHEMICAL OXYGEN-DEMANDING SUBSTANCES (020701)	6	LA	2004	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/10699/100978
BAYOU BOEUF, HALPIN CANAL, AND THERIOT CANAL AND LAKE BOEUF TMDLS FOR BIOCHEMICAL OXYGEN-DEMANDING SUBSTANCES	6	LA	2004	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/10715/101062
Total Maximum Daily Load Development For the Middle and Lower St. Johns River, Florida Nutrients, DO, and BOD	4	FL	2004	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/10916/107795
Total Maximum Daily Load Evaluation for the Coosa River in the Coosa River Basin for Dissolved Oxygen	4	GA	2004	https://attains.epa.gov/attains-public/api/documents/actions/21GAEPD/9848/106017
Total Maximum Daily Load Evaluation for McFarland Branch in Tennessee River Basin for Dissolved Oxygen	4	GA	2004	https://attains.epa.gov/attains-public/api/documents/actions/21GAEPD/9844/106039
TMDL Report Dissolved Oxygen TMDL for Long Branch, WBID 3030	4	FL	2005	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/31815/107974
TMDL Report Dissolved Oxygen TMDL for Crane Strand Drain (WBID 3014)	4	FL	2005	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/22769/107997
BAYOU POINTE AU CHIEN WATERSHED TMDL FOR BIOCHEMICAL OXYGEN-DEMANDING SUBSTANCES AND NUTRIENTS	6	LA	2005	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/31648/100865
BAYOU GRAND CAILLOU WATERSHED TMDL FOR BIOCHEMICAL OXYGEN-DEMANDING SUBSTANCES AND NUTRIENTS (120501)	6	LA	2005	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/22882/100937

Report Title	Region	State	Year Published	Link to Document
BAYOU MARINGOUIN WATERSHED TMDLS FOR BIOCHEMICAL OXYGENDEMANDING SUBSTANCES AND NUTRIENTS	6	LA	2005	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/22729/100616
BAYOU PETIT CAILLOU WATERSHED TMDL FOR BIOCHEMICAL OXYGEN-DEMANDING SUBSTANCES AND NUTRIENTS (120503)	6	LA	2005	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/22728/100640
TMDL for the San Juan River Watershed (Part Two)	6	NM	2005	https://attains.epa.gov/attains-public/api/documents/actions/21NMEX/22615/101568
Upper Hillsborough River Basin, Florida Total Maximum Daily Load for Dissolved Oxygen and BOD in Blackwater Creek (WBID 1482), Itchepackesassa Creek (WBID 1495B), and New River (WBID 1442)	4	FL	2005	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/22541/107716
TOTAL MAXIMUM DAILY LOAD (TMDL) for Low Dissolved Oxygen & Nutrients in the Upper Duck River Watershed (HUC 06040002) Bedford, Coffee, Marshall, & Maury Counties, Tennessee	4	TN	2005	https://attains.epa.gov/attains-public/api/documents/actions/TDECWR/11676/101854
LAKE CATAOUATCHE TMDLS FOR DISSOLVED OXYGEN AND NUTRIENTS	6	LA	2005	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/11577/100693
BAYOU DES ALLEMANDS TMDLS FOR DISSOLVED OXYGEN AND NUTRIENTS	6	LA	2005	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/11576/101008
TOTAL MAXIMUM DAILY LOAD (TMDL) For Nutrients and Dissolved Oxygen In Muddy Branch WBID 175	4	FL	2005	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/11341/107835
TMDLs for Nutrient, DO, and BOD for Delaney Creek (WBID 1605)	4	FL	2005	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/11342/108011
TMDL Development for Dissolved Oxygen and Nutrients for Bayou Lafourche Subsegment (020401) in the Barataria Basin, Louisiana	6	LA	2005	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/11321/100757
Total Maximum Daily Load Evaluation for Three Stream Segments in the Savannah River Basin for Dissolved Oxygen	4	GA	2005	https://attains.epa.gov/attains-public/api/documents/actions/21GAEPD/11214/105968

Report Title	Region	State	Year Published	Link to Document
Total Maximum Daily Load Evaluation for Twenty-Three Stream Segments in the Ogeechee River Basin for Dissolved Oxygen	4	GA	2005	https://attains.epa.gov/attains-public/api/documents/actions/21GAEPD/10586/105965
TMDLs for Lochloosa Lake (Nutrients) and Cross Creek (Nutrients, DO, and BOD) Alachua County, Florida	4	FL	2005	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/11240/107781
BAYOU PIERRE WATERSHED TMDL FOR BIOCHEMICAL OXYGEN-DEMANDING SUBSTANCES AND NUTRIENTS	6	LA	2006	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/31648/101071
Nutrient and DO TMDLs for the St. Johns River above Lake Poinsett, Lake Hell n' Blazes, and St. Johns River above Sawgrass Lake	4	FL	2006	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/31818/107975
TOTAL MAXIMUM DAILY LOAD (TMDL) For Dissolved Oxygen and Nutrients In Butcher Pen Creek (2322) Lower St. Johns River Basin, Florida	4	FL	2006	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/31810/107973
TOTAL MAXIMUM DAILY LOAD (TMDL) For Dissolved Oxygen In Gottfried Creek in Sarasota Bay (WBID 2049)	4	FL	2006	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/22989/107882
One Total Maximum Daily Load for Dissolved Oxygen in Lake O' the Pines (Segment 0403)	6	TX	2006	https://attains.epa.gov/attains-public/api/documents/actions/TCEQMAIN/23011/107421
IATT CREEK WATERSHED TMDL FOR BIOCHEMICAL OXYGEN-DEMANDING SUBSTANCES (Subsegment 101303)	6	LA	2006	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/22943/100869
TOTAL MAXIMUM DAILY LOADS FOR DISSOLVED OXYGEN FOR Beaufort River in the Salkehatchie River Basin, South Carolina	4	SC	2006	https://attains.epa.gov/attains-public/api/documents/actions/21SC60WQ/22962/104706
TOTAL MAXIMUM DAILY LOAD (TMDL) For Dissolved Oxygen In Hogan Creek (WBID 2252) Lower St. Johns River Basin, Florida	4	FL	2006	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/22771/107928
TOTAL MAXIMUM DAILY LOAD (TMDL) For Nutrients and Dissolved Oxygen In Cedar River (WBID 2262)	4	FL	2006	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/22765/107650
TOTAL MAXIMUM DAILY LOAD (TMDL) For Dissolved Oxygen In Williamson Creek (WBID 2316)	4	FL	2006	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/22753/107976

Report Title	Region	State	Year Published	Link to Document
DO and Nutrient TMDLs for Lake Hancock and Lower Saddle Creek	4	FL	2006	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/22737/107806
TMDL for Nutrients, BOD, and DO in the Caloosahatchee River Basin	4	FL	2006	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/22731/107753
Total Maximum Daily Load Evaluation for the St. Marys River in the St. Marys River Basin for Dissolved Oxygen	4	GA	2006	https://attains.epa.gov/attains-public/api/documents/actions/21GAEPD/11666/106034
Final Peace River Basin, Florida Dissolved Oxygen, Nutrient, Turbidity and TSS Total Maximum Daily Loads	4	FL	2006	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/22666/107805
TOTAL MAXIMUM DAILY LOAD (TMDL) For Dissolved Oxygen and Biochemical Oxygen Demand In St. Johns River above Sawgrass Lake(WBID 2893X)	4	FL	2006	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/22763/107881
Seventeen Total Maximum Daily Loads for Bacteria, Dissolved Oxygen, and pH in Adams Bayou, Cow Bayou, and Their Tributaries	6	TX	2007	https://attains.epa.gov/attains-public/api/documents/actions/TCEQMAIN/33048/107426
WEST ANACOCO CREEK WATERSHED TMDL FOR BIOCHEMICAL OXYGEN-DEMANDING SUBSTANCES AND NUTRIENTS	6	LA	2007	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/33886/100877
Total Maximum Daily Load Evaluation for Three Stream Segments in the Savannah River Basin for Dissolved Oxygen	4	GA	2007	https://attains.epa.gov/attains-public/api/documents/actions/21GAEPD/GAR4_07_01_03/195279
Total Maximum Daily Load Evaluation for Twenty-Three Stream Segments in the Ogeechee River Basin for Dissolved Oxygen	4	GA	2007	https://attains.epa.gov/attains-public/api/documents/actions/21GAEPD/GAR4_07_02_02/195276
BAYOU DU LARGE WATERSHED TMDL FOR BIOCHEMICAL OXYGEN-DEMANDING SUBSTANCES AND NUTRIENTS	6	LA	2007	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/32773/101070
BAYOU CHAUVIN WATERSHED TMDL FOR BIOCHEMICAL OXYGEN-DEMANDING SUBSTANCES AND NUTRIENTS	6	LA	2007	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/32772/100879

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BAYOU GROSSE TETE WATERSHED TMDL FOR BIOCHEMICAL OXYGEN-DEMANDING SUBSTANCES AND NUTRIENTS, INCLUDING BAYOU PORTAGE AND BAYOU FORDOCHE	6	LA	2007	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/32460/100880
TOTAL MAXIMUM DAILY LOAD (TMDL) For Dissolved Oxygen, Nutrients, and BOD In Peace River above Bowlegs Creek, FL (WBID 1623J)	4	FL	2007	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/32351/107763
Total Maximum Daily Load Evaluation for Seven Stream Segments in the Ocmulgee River Basin for Dissolved Oxygen	4	GA	2007	https://attains.epa.gov/attains-public/api/documents/actions/21GAEPD/33696/106021
Total Maximum Daily Load Evaluation for Five Stream Segments in the Altamaha River Basin for Dissolved Oxygen	4	GA	2007	https://attains.epa.gov/attains-public/api/documents/actions/21GAEPD/GAR4_07_06_01/194747
Total Maximum Daily Loads for the Northern and Central Indian River Lagoon and Banana River Lagoon, Florida Nutrients and Dissolved Oxygen	4	FL	2007	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/32101/107762
TOTAL MAXIMUM DAILY LOAD (TMDL) For Nutrients and Dissolved Oxygen In Wagner Creek (WBID 3288A)	4	FL	2007	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/32065/107839
TMDL for Nutrients, BOD, and DO in the Dade City Canal (WBID 1399)	4	FL	2007	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/32035/107895
Nutrient and Dissolved Oxygen TMDL for the Little Wekiva Canal, WBID 3004	4	FL	2008	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/35991/107698
Nutrient and Dissolved Oxygen TMDL for the St. Lucie Basin	4	FL	2008	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/35988/107877
Nutrient and DO TMDLs For Alligator Lake (WBID 3516A)	4	FL	2008	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/35806/107828
TMDLs for Dissolved Oxygen in Selected Subsegments in the Pearl River Basin, Louisiana (090105, 090204, 090207)	6	LA	2008	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/35655/100603

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Nutrient and Dissolved Oxygen TMDL for the Suwannee River, Santa Fe River, Manatee Springs (3422R), Fanning Springs (3422S), Branford Spring (3422J), Ruth Spring (3422L), Troy Spring (3422T), Royal Spring (3422U), and Falmouth Spring (3422Z)	4	FL	2008	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/35235/107977
TMDLs for Dissolved Oxygen and Nutrients in Selected Subsegments in the Upper Terrebonne Basin, Louisiana	6	LA	2008	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/35234/100824
TMDLs for Dissolved Oxygen and Nutrients in Selected Subsegments in the Middle Terrebonne Basin, Louisiana	6	LA	2008	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/35265/100747
TMDLs for Dissolved Oxygen and Nutrients in Selected Subsegments in the Lower Terrebonne Basin, Louisiana	6	LA	2008	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/35233/100688
Fecal Coliform TMDL for New River (WBID 3506) and Dissolved Oxygen TMDL for New River (WBID 3506B, 3506A and 3506)	4	FL	2008	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/35232/107966
Dissolved Oxygen TMDLs for Hendry Creek (WBIDs 3258B and 3258B1)	4	FL	2008	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/35222/107965
DO and Nutrient TMDL for Spruce Creek, WBID 2674A	4	FL	2008	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/35219/107964
Dissolved Oxygen TMDL for the Gordon River Extension, WBID 3278K (formerly 3259C)	4	FL	2008	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/35214/107963
Dissolved Oxygen TMDL for Imperial River, WBID 3258E	4	FL	2008	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/35210/108007
Nutrient, Un-ionized Ammonia, and DO TMDLs for Lake Trafford (WBID 3259W)	4	FL	2008	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/35211/107962
Biochemical Oxygen Demand, Dissolved Oxygen, and Nutrients In the Lake Okeechobee Tributaries	4	FL	2008	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/34673/108010
TOTAL MAXIMUM DAILY LOAD (TMDL) for Low Dissolved Oxygen & Nutrients in the Stones River Watershed (HUC 05130203)	4	TN	2008	https://attains.epa.gov/attains-public/api/documents/actions/TDECWR/34347/102009

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GRAND BAYOU WATERSHED TMDL FOR BIOCHEMICAL OXYGEN-DEMANDING SUBSTANCES	6	LA	2008	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/34154/100982
PETIT CAILLOU WATERSHED TMDL FOR BIOCHEMICAL OXYGEN-DEMANDING SUBSTANCES AND NUTRIENTS	6	LA	2008	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/34155/101073
BAYOU FOLSE WATERSHED TMDL FOR BIOCHEMICAL OXYGEN-DEMANDING SUBSTANCES AND NUTRIENTS	6	LA	2008	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/34157/101058
BAYOU TERREBONNE WATERSHED TMDL FOR BIOCHEMICAL OXYGEN-DEMANDING SUBSTANCES AND NUTRIENTS	6	LA	2008	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/34270/100860
TOTAL MAXIMUM DAILY LOAD (TMDL) I For Nutrients, Dissolved Oxygen and Biochemical Oxyge Demand Springs Coast Basin (WBIDs 1668A, 1668B, 1508)	4	FL	2008	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/34131/107901
TOTAL MAXIMUM DAILY LOAD (TMDL) For Nutrients and Dissolved Oxygen In South Branch (WBID 1456)	4	FL	2008	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/34128/107715
Total Maximum Daily Load for Dissolved Oxygen in the South Prong of the Sebastian River (WBID 3129B)	4	FL	2008	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/34127/107900
TMDL FOR DISSOLVED OXYGEN FOR BAYOU TORO, LOUISIANA (SUBSEGMENT 110401)	6	LA	2008	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/34511/100774
TMDLS FOR DISSOLVED OXYGEN FOR BLACK LAKE BAYOU (100702), BLACK LAKE AND CLEAR LAKE (100703), AND SALINE BAYOU (100803)	6	LA	2008	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/34493/101014
BAYOU PIERRE TMDLS FOR DISSOLVED OXYGEN AND NUTRIENTS SUBSEGMENT 100601	6	LA	2008	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/34233/101024
TMDLS FOR DISSOLVED OXYGEN FOR BLACK LAKE BAYOU (100702), BLACK LAKE AND CLEAR LAKE (100703), AND SALINE BAYOU (100803)	6	LA	2008	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/34493/101014

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TMDLS FOR DISSOLVED OXYGEN AND NUTRIENTS FOR LOST LAKE AND FOUR LEAGUE BAY, LOUISIANA (SUBSEGMENT 120708)	6	LA	2008	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/34231/100665
TMDLS FOR DISSOLVED OXYGEN FOR CYPRESS BAYOU RESERVOIR AND BLACK BAYOU RESERVOIR, LOUISIANA (SUBSEGMENTS 100404 AND 100405)	6	LA	2008	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/34393/100703
TMDLS FOR DISSOLVED OXYGEN AND NUTRIENTS FOR BAYOU PETIT CAILLOU (SUBSEGMENT 120709)	6	LA	2008	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/34205/100833
TMDL FOR DISSOLVED OXYGEN FOR LAKE CONCORDIA, LOUISIANA (SUBSEGMENT 101604)	6	LA	2008	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/34200/100941
BAYOU DORCHEAT TMDL FOR DISSOLVED OXYGEN (SUBSEGMENT 100501)	6	LA	2008	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/34480/100595
BAYOU RIGOLETTE AND IATT LAKE TMDL FOR DISSOLVED OXYGEN	6	LA	2008	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/34481/100705
TMDL FOR DISSOLVED OXYGEN AND NUTRIENTS FOR FLAT RIVER SUBSEGMENT 100406	6	LA	2008	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/34483/101026
TMDLS FOR DISSOLVED OXYGEN AND NUTRIENTS FOR BOGGY BAYOU, LA	6	LA	2008	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/34479/100893
BAYOU RIGOLETTE AND IATT LAKE TMDL FOR DISSOLVED OXYGEN	6	LA	2008	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/34199/100892
TMDLS FOR DISSOLVED OXYGEN FOR CYPRESS BAYOU RESERVOIR AND BLACK BAYOU RESERVOIR, LOUISIANA (SUBSEGMENTS 100404 AND 100405)	6	LA	2008	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/34191/100839
TMDLs for Dissolved Oxygen and Nutrients (Nitrate/Nitrite, and Total Phosphorus) in Bayou Blue (Subsegment 120606) within the Terrebonne Basin, Louisiana	6	LA	2008	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/34148/100946
TMDLS FOR DISSOLVED OXYGEN FOR BLACK LAKE BAYOU (100702), BLACK LAKE AND CLEAR LAKE (100703), AND SALINE BAYOU (100803)	6	LA	2008	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/34493/101014

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Dissolved Oxygen and Nutrient TMDLs for Trout River (WBID 2203)	4	FL	2009	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/52291/107673
DO and Nutrient TMDLs for Swimming Pen Creek and Nutrient TMDL for Doctors Lake	4	FL	2009	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/50522/107746
DO TMDL for Sixteen Mile Creek	4	FL	2009	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/50521/107732
DO and Nutrient TMDL for Dog Branch	4	FL	2009	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/50520/107745
Nutrient and DO TMDLs for the Indian River Lagoon and Banana River Lagoon	4	FL	2009	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/38207/107944
Nutrient and DO TMDLs for the Middle St. Johns River Segments between the Inlet of Lake Harney (2964A) and the St. Johns River above the Wekiva River (2893C)	4	FL	2009	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/37738/107922
Dissolved Oxygen TMDL for The Smith Canal (WBID 2962)	4	FL	2009	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/37736/107921
Dissolved Oxygen and Nutrient TMDLs for Rattlesnake Slough, WBID 1923	4	FL	2009	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/37463/108003
Dissolved Oxygen TMDL for Nonsense Creek, WBID 1913	4	FL	2009	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/37560/107910
Dissolved Oxygen for Coral Creek – East Branch (WBID 2078B)	4	FL	2009	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/37542/107907
Dissolved Oxygen and Nutrient TMDLs for Little Gully Creek (WBID 1039)	4	FL	2009	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/37520/107905
Dissolved Oxygen and Nutrient TMDL for Mustang Ranch Creek (WBID 1592C)	4	FL	2009	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/37513/107903
TMDL Report Dissolved Oxygen and Nutrient TMDL for the Alafia River Above Hillsborough Bay-Tidal Segment (WBID 1621G)	4	FL	2009	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/37512/107902
Bayou Manchac Watershed TMDL for Biochemical Oxygen-Demanding Substances - Phase I (Subsegment 040201)	6	LA	2010	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/40258/100922

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DO and Nutrient TMDLs for Mill Creek (WBID 2460)	4	FL	2010	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/39778/107936
Grays Creek Watershed TMDL for Biochemical Oxygen-Demanding Substances (Subsegment 040304)	6	LA	2010	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/39699/100923
TMDL Gills Creek Watershed DO	4	SC	2010	https://attains.epa.gov/attains-public/api/documents/actions/21SC60WQ/39444/104691
DO TMDL for Sikes Creek, WBID 142	4	FL	2010	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/39305/107948
DO TMDL for Minnow Creek (WBID 130)	4	FL	2010	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/39311/107949
Two TMDLs for DO in Upper Oyster Creek (Segment 1245)	6	TX	2010	https://attains.epa.gov/attains-public/api/documents/actions/TCEQMAIN/39139/107422
TMDL for DO, BOD, and Nutrients/Unionized Ammonia in the Elevenmile Creek (WBID 489)	4	FL	2010	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/39138/107947
TMDL for DO in the West Atchafalaya Basin Floodway - Simmesport to Butte La Rose Bay and Henderson Lake, Louisiana (Subsegment 010301)	6	LA	2010	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/38350/100870
TMDLs for St. Andrews Bay, Florida Nutrients and DO (WBIDs 1088, 1123, 1128, 1131, 1141, 1144, and 1172)	4	FL	2010	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/39026/107923
Bayou Liberty and Bayou Bonfouca Watershed TMDL for Biochemical Oxygen-Demanding Substances - Phase I (Subsegments 040905, 040906, 040907, and 040908)	6	LA	2011	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/41427/101067
DO TMDL for the Brown Creek Watershed, Anson County, North Carolina (WBID 13-20b)	4	NC	2011	https://attains.epa.gov/attains-public/api/documents/actions/21NC01WQ/40789/101325
Selsers Creek Watershed TMDL for Biochemical Oxygen-Demanding Substances (Subsegment 040603)	6	LA	2011	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/40501/100814
Colyell Creek Watershed TMDL for Biochemical Oxygen-Demanding Substances - Phase I (Subsegment 040305)	6	LA	2011	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/40502/100624

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TMDL for DO and Nutrients in Phillippi Creek	4	FL	2011	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/40418/107857
Bayou Cane Watershed TMDL for Biochemical Oxygen-Demanding Substances - Phase I (Subsegments 040903 and 040904)	6	LA	2011	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/40315/100921
Lower Amite River Watershed TMDL for Biochemical Oxygen-Demanding Substances - Phase I (Subsegment 040303)	6	LA	2011	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/40302/100680
TMDL for the Boggy Bayou Nutrients and DO (WBID 692)	4	FL	2011	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/40237/107846
TMDL for the Alligator Creek Nutrients, DO, and BOD (WBID 123)	4	FL	2011	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/40262/107854
TMDL for the Caloosahatchee River above S-78 Nutrients, DO, and BOD (WBID 3237A)	4	FL	2011	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/40261/107852
TMDL for the Manual Branch Nutrients and DO (WBID 3240I)	4	FL	2011	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/40264/107856
TMDL for DO in Long Branch Creek (WBID 1627)	4	FL	2012	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/42743/107749
TMDL for Chloride, Copper, DO, Lead, pH, Sulfate, TDS, and Turbidity in the Bodcau Creek and Dorcheat Bayou Watersheds, Arkansas	6	AR	2012	https://attains.epa.gov/attains-public/api/documents/actions/ARDEQH2O/42670/107544
TMDL for DO for Violet Canal (Subsegment 041805) in the Lake Pontchartrain Basin, Louisiana	6	LA	2012	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/41599/100588
TMDL for DO for Ponchatoula Creek and Ponchatoula River in the Lake Pontchartrain Basin, Louisiana	6	LA	2012	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/41682/101009
TMDL for DO for Bayou Labranche (Subsegment 041201) in the Lake Ponchartrain Basin, Louisiana	6	LA	2012	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/41667/100887
TMDL for DO for New Orleans East Leveed Waterbodies in Lake Ponchartrain Basin, Louisiana	6	LA	2012	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/41664/101010

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Lower Tchefuncte River Watershed TMDL for Biochemical Oxygen-Demanding Substances - Phase I, Subsegments 040802 and 040803	6	LA	2012	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/41523/100751
Bayou Lacombe Watershed TMDL for Biochemical Oxygen-Demanding Substances - Phase I (Subsegments 040901 and 040902)	6	LA	2012	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/41503/100987
TMDL for BOD, DO, and Nutrients in Kitching Creek (WBID 3224B)	4	FL	2012	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/41744/107819
TMDL for DO in Big Gant Canal (WBID 1378)	4	FL	2012	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/41506/107869
TMDL for DO and Nutrient in Tampa Bypass Canal Tributary (WBID 1536C)	4	FL	2012	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/41521/107871
TMDL for DO in Cross Canal-North Tidal (WBID 1625) and DO and Nutrient Tidal in Allen Creek Tidal (WBID 1604)	4	FL	2012	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/41522/107872
Final TMDL for DO and Nutrients in Crabgrass Creek	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/53661/107734
Lake Thunderbird Report for Nutrient, Turbidity, and Dissolved Oxygen TMDLs	6	OK	2013	https://attains.epa.gov/attains-public/api/documents/actions/OKDEQ/55040/106764
Dissolved Oxygen and Nutrient TMDLs for Eight Tributary Segments of the Indian River Lagoon	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/FL68632/205948
TMDLs for Munson Slough, Lake Munson, and Munson Slough below Lake Munson	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/57640/107696
Dissolved Oxygen and Nutrient TMDL for Channelized Stream (WBID 1483)	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/54423/107641
Final TMDL for Dissolved Oxygen & Nutrients in Cockroach Bay	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/53843/107678
FInal TMDLs for DO in Hollin Creek and DO and Nutrients in Anclote River Bayou Complex (Spring Bayou) and BOD, DO, and Nutrients in Anclote River	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/53700/107702

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Final TMDLs for DO and Nutrients in Ortega River and Cedar River	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/53850/107679
Final TMDL for DO and Nutrients in McKay Creek	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/53846/107665
Final TMDLs for DO in Pace Mill Creek	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/53847/107677
Final TMDLs for DO and Nutrients in Minnow Creek (Direct Runoff to Gulf) and Cedar Creek (Tidal)	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/53741/107724
Final TMDL for DO and Nutrients in Pinellas Park Ditch No. 1	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/53745/107736
TMDL revision for Charleston Harbor, Cooper, Ashley, and Wando Rivers	4	SC	2013	https://attains.epa.gov/attains-public/api/documents/actions/21SC60WQ/50760/104737
Final TMDL for DO and Nutrients in 34th Street Basin, Clam Bayou Drain, Clam Bayou (East Drainage), Clam Bayou Drain (Tidal)	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/53761/107735
Final TMDLs for DO and Nutrients in Brushy Creek, Rocky Creek, Double Branch, Sweetwater Creek	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/53777/107725
Final TMDLs for DO in Jones Creek	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/53775/107661
Final TMDL for DO and Nutrients in Bullfrog Creek	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/53789/107662
TMDL for DO and Nutrients in Smacks Bayou	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/53523/107668
TMDL for DO and Nutrients in Wall Spring	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/53520/107654
TMDL for DO and Nutrients in Bellows Lake Outlet (East Lake Outfall)	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/53521/107701
TMDL for Nutrients and DO in Fort Drum Creek	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/53660/107676

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TMDL for DO and Nutrients in Crabgrass Creek and Jane Green Creek	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/53661/107734
TMDL for Nutrients and DO in Sawgrass Lake WBID 28931	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/53663/107733
TMDL for DO and Nutrients in Wolf Creek WBID 3075	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/53662/107726
Total Maximum Daily Loads for Dissolved Oxygen, BOD and Nutrients in St. Johns River Above Puzzle Lake – WBID 2893I and for Dissolved Oxygen in Lake Poinsett – WBID 2893K	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/53664/107727
TMDL for Nutrients and DO in Julington and Big Davis Creek	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/53665/107728
TMDL for Nutrients and DO in Sixmile Creek (WBID 2411)	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/53666/107643
TMDL for Nutrients, DO, and BOD in Six Mile Creek/Tampa Bypass Canal (WBIDs 1536F and 1536B)	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/53547/107723
TMDL for DO in Horse Creek (WBID 3081)	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/53680/107671
TMDL for the Camp Branch (WBID 251) Nutrients and DO	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/51324/107718
TMDL for DO in Pithlachascotee River (WBID 1409)	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/51319/107683
TMDL for DO, Nutrients, and BOD in Myrtle Slough (WBID 2054)	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/51469/107731
TMDL for DO and Nutrients in Mud Lake Slough	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/51205/107666
TMDL for DO in Jacks Branch (WBID 291)	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/53507/107640
TMDL for DO and Nutrients in McKay Bay (WBID 1584B), Palm River (1536E), and Ybor City Drain (1584A)	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/51140/107721

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TMDL for the Cedar Creek (WBID 1926) DO and Nutrients	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/51280/107681
TMDL for DO and Nutrients in Owen Creek (WBID 1933) and Myakka River (WBID1981B)	4	FL	2013	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/51185/107682
Lower Grand/Belle River Watershed Revised TMDL for Biochemical Oxygen-Demanding Substances and Nutrients	6	LA	2014	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/23058/101005
Revised Final TMDL Report Nutrient and Dissolved Oxygen TMDLs for Lake Jackson (WBID 3183G)	4	FL	2015	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/66446/107672
Final TMDL Report Nutrient TMDLs for Sanibel Slough (WBIDs 2029F1 and 2029F2) and Documentation in Support of Site-Specific Numeric Interpretations of the Narrative Nutrient Criterion	4	FL	2017	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/68442/203158
Revised Total Maximum Daily Load Evaluation for Brunswick Harbor in the Satilla River Basin for Dissolved Oxygen	4	FL	2019	https://attains.epa.gov/attains-public/api/documents/actions/21GAEPD/GAR4_19_07_03/137764
Upper Terrebonne Basin Revised Total Maximum Daily Loads for Biochemical Oxygen Demanding Substances	6	LA	2021	https://attains.epa.gov/attains-public/api/documents/actions/LADEQWPD/LA_2021_Upper_Terrebonne_TMDL_Rev/201156
Dissolved Oxygen TMDL for Haw Creek above Crescent Lake (WBID 2322A)	4	FL	2022	https://attains.epa.gov/attains-public/api/documents/actions/21FL303D/FL68629/205916
Total Maximum Daily Load Determination for the Waccamaw River and the Atlantic Intracoastal Water Way Near Myrtle Beach, SC	4	SC	1999	https://attains.epa.gov/attains-public/api/documents/actions/21SC60WQ/560/104734