Review of Dissolved Oxygen Wasteload Allocation Procedures for Selected States

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INTRODUCTION

MEC Water Resources, Inc., (MEC), on behalf of the Environmental Resources Coalition (ERC), is supporting efforts by the Missouri Department of Natural Resources (MDNR) to develop dissolved oxygen wasteload allocation procedures. Wasteload allocation procedures are intended to serve as a technical methodology to support consistent, transparent, and defensible development of water quality-based wasteload allocations. Development of these procedures will be guided in part by a review of wasteload allocation guidance from other states. This report serves as this summary.

State procedures selected for summary include Alabama, Illinois, Iowa, Louisiana, Oklahoma, and Texas. Although the original intent was to summarize wasteload allocation procedures for all states bordering Missouri, significant guidance for Kansas, Arkansas, Tennessee, Kentucky, and Nebraska was not readily available. Therefore, MEC expanded its search to any state with readily available wasteload allocation procedures. An exhaustive review of all 50 states procedures was not performed.

Guidance summarized in this report was limited to a few key policy and technical areas regarding the development of dissolved oxygen wasteload allocations. Developing an appropriate dissolved oxygen wasteload allocation is a complex and technically rigorous process. Therefore, many states develop procedures to ensure an appropriate and consistent application of the process. This report summarizes the most critical technical and policy aspects found in other state procedures to assist Missouri with its development of an objective methodology. The subject areas covered in this report include the following:

- Effort Level (i.e., what is required in terms of data collection, model complexity, and level of calibration);
- Recommended Models and Processes (i.e., what water quality models are used and which processes are simulated); and
- Recommended Model Inputs (i.e., how hydraulic and kinetic parameters are determined and what default values are used).

SECTION 2

EFFORT LEVEL

SECTION 2
EFFORT LEVEL

Effort level in developing dissolved oxygen wasteload allocations can range from applying default limits (i.e., no water quality modeling) to a fully calibrated and verified water quality model requiring extensive field work. Not all situations warrant the same level of effort. In general, states recommend a greater modeling effort for larger facilities or where preliminary modeling efforts indicate advanced treatment is necessary. However, state guidance on this matter is fairly subjective, generally leaving such decisions to best professional judgment. A discussion of state guidance on effort level is provided below and is summarized in Table 1.

TABLE 1. State Comparison of Wasteload Allocation Effort Levels

State	Level	Description
Alabama	No explicit guidance	No guidance on level of analysis or calibration.
Illinois	Minimum limits	30 mg/L CBOD5/30 mg/L suspended solids (>5:1 dilution ratio) or 10 mg/L CBOD5/12 mg/L suspended solids (<5:1 dilution ratio)
	Modeling	Applicable to third-stage treatment lagoons. No explicit guidance on level of analysis or calibration.
Iowa	Assimilative capacity formula	Effluent limited streams. See Equation 1.
	Modified Iowa Model	Minimal modeling effort. Used to evaluate adequacy of secondary treatment.
	Vermont QUAL-II	Large modeling effort. Applicable where advanced treatment is required.
Louisiana	Statewide Sanitary Effluent Limitations Policy	Applicable for design flows less than 0.5 MGD. Policy generally assigns defaults limits. See Appendix A.
	Level 1: Dilution	Assimilative capacity formula. Secondary treatment only. See Equation 2.
	Level 2: Uncalibrated	Depends on treatment level and design flow.
	Level 3: Calibrated	Depends on treatment level and design flow.
	Level 4: Calibrated and Verified	Case-by-case basis considering model accuracy and applicability, manpower and field equipment availability, and laboratory availability.
Oklahoma	Simple Model	Less than 1 MGD discharge
	Complex Model	Greater than or equal to 1 MGD discharge
	Method 1: Uncalibrated Model	Used initially in all modeling analyses. Results may be used to determine if further data collection or analysis is necessary.
	Method 2: Calibrated Model	Depends on level of uncertainty in previous level.
	Method 3: Confirmed	Depends on level of uncertainty in previous level.
	Method 4: Post Audit Model	Depends on level of uncertainty in previous level.
Texas	Uncalibrated screening level model	Applicable for flows less than or equal to 0.2 MGD.
	Calibrated model	Applicable to flows greater than 0.2 MGD. Level of analysis can depend on impairment issues, availability of data, type of waterbody, location of discharge point, and availability of previously developed models.

Notes: CBOD5 = 5 day carbonaceous biochemical oxygen demand (mg/L). MGD = million gallons per day.

2.1 Alabama Effort Level

No explicit guidance on effort level could be identified for Alabama. Guidance documents from Alabama were generally limited to descriptions of their water quality model. Alabama provides no model calibration guidance.

2.2 Illinois Effort Level

Limited guidance is available from Illinois on assigning permit limits and applying water quality models. Section 304.120 of Title 35 of the Illinois Administrative Code (35 Ill. Adm. Code 304.120) prescribes limits for 5 day biochemical oxygen demand (BOD_5) and suspended solids of 30 mg/L where there is a dilution ratio no less than five to one. The BOD_5 and suspended solids limits decrease to 10 mg/L and 12 mg/L, respectively, where the dilution ratio is less than five to one. However, at any dilution ratio these limits may be exceeded for three stage lagoon treatment systems provided the limits are water quality-based. Modeling guidance written explicitly for three stage lagoon treatment systems is provided for in 35 Ill. Adm. Code 373, but no model calibration guidance is provided.

2.3 Iowa Effort Level

Iowa uses a three stage screening approach for deriving wasteload allocations (IDNR, 2004). Each stage is progressively more complex, time consuming, and is only used if the previous stage proves insufficient. The three stages include: 1) assimilative capacity formula; 2) the Modified Iowa model; and 3) the Vermont QUAL-II model.

The hand calculation approach is intended to be a quick method for determining whether a carbonaceous biochemical oxygen (CBOD) discharge of standard secondary or BPT/BAT[1] is protective of water quality standards (IDNR, 2004). This approach assumes a stream can assimilate up to 20 pounds per day per cubic feet per second (lbs/day/cfs) of 5 day CBOD ($CBOD_5$). The stream capacity is calculated by multiplying the dry weather discharge flow (Q_d) plus the critical stream flow (Q_u) by 20 lbs/day/cfs as shown in Equation (1).

Eq. (1) $$\text{Stream Capacity of } CBOD_5 = (Q_u + Q_d) \cdot 20 \text{ lbs/day/cfs}$$

If the treatment facility loading does not exceed this value then the stream is termed effluent limited for CBOD and no additional modeling is required. The $CBOD_5$ effluent limit will be set for standard secondary or the technology level.

The Modified Iowa model is intended to be a quick modeling exercise with minimal staff time (IDNR, 2004). It is based on a modified version of the Streeter-Phelps equation and uses calibrated rate constants, if available, and literature values. If the modeling shows that advanced treatment is required, then the Vermont QUAL-II program is used to determine the final wasteload allocation. Detailed calibrations will be carried out only for the QUAL-II model.

1 BPT = Best Practical Treatment are EPA derived minimum treatment levels that are required for both municipal and industrial wastewater treatment facilities. BAT = Best Available Treatment are EPA derived levels for industry.

The Vermont QUAL-II model requires more effort to set up and run than the modified model (IDNR, 2004). The Iowa Department of Natural Resources (IDNR) prefers that calibrated rate constants be used whenever possible at this level of analysis. Calibrated values can come from data obtained from intensive stream surveys, from calibration data on similar streams, or from literature values.

2.4 Louisiana Effort Level

Louisiana Department of Environmental Quality (LDEQ) has published guidance outlining the use of default limits and different levels of calibration. Sanitary wastewater treatment facility flows less than 0.5 MGD are assigned effluent limitations according to the Statewide Sanitary Effluent Limitations Policy (SSELP). The SSELP can be found in the Louisiana Water Quality Management Plan (Appendix A). It should be noted, however, that effluent limits assigned according to the SSELP are minimum limits. The LDEQ reserves the right to assign an effluent limitation based upon an individual discharge analysis.

Effluent limitations for sanitary wastewater treatment facilities greater than 0.5 MGD, or for facilities selected for individual analysis, are modeled. The four modeling levels recognized by LDEQ include: 1) dilution models; 2) uncalibrated models; 3) calibrated models; and 4) calibrated and verified models. Selection of the appropriate model level is determined by a matrix of factors such as facility flow, dilution, and treatment level (Table 3). Further discussion is provided below.

TABLE 3. Louisiana Guide to Level of Water Quality Model Analysis

Oxygen Demanding Treatment Level	Facility Flow in MGD			
	<2.0	2.0 – 5.0	5.0 – 10.0	>10.0
Secondary	Dilution or Min Hydro & Uncalibrated WQ	Dilution or Min Hydro & Uncalibrated WQ	Dilution or Min Hydro & Uncalibrated WQ	Dilution or Min Hydro & Uncalibrated WQ
Facility Flow < 10% of the critical stream flow	Min Hydro & Uncalibrated WQ	Min Hydro & Uncalibrated WQ	Min Hydro & Uncalibrated WQ	Min Hydro & Uncalibrated WQ
20 $CBOD_5$/10 NH_3-N	Min Hydro & Uncalibrated WQ	Min Hydro & Uncalibrated WQ	Min Hydro & Uncalibrated WQ	Full Hydro & Uncalibrated WQ
10 $CBOD_5$/10 NH_3-N	Min Hydro & Uncalibrated WQ	Min Hydro & Uncalibrated WQ	Full Hydro & Uncalibrated WQ	Calibrated Hydro & WQ
10 $CBOD_5$/5 NH_3-N	Min Hydro & Uncalibrated WQ	Min Hydro & Uncalibrated WQ	Full Hydro & Uncalibrated WQ	Calibrated Hydro & WQ
10 $CBOD_5$/2 NH_3-N	Min Hydro & Uncalibrated WQ	Full Hydro & Uncalibrated WQ	Calibrated Hydro & WQ	Calibrated Hydro & WQ
5 $CBOD_5$/2 NH_3-N	Min Hydro & Uncalibrated WQ	Full Hydro & Uncalibrated WQ	Calibrated Hydro & WQ	Calibrated Hydro & WQ

Notes: Adapted from Louisiana Total Maximum Daily Load Technical Procedures. CBOD5 = 5 day carbonaceous biochemical oxygen demand (mg/L); NH3-N = Ammonia as Nitrogen (mg/L); Min Hydro = minimum hydrologic data; Full Hydro = full hydraulic data; WQ = water quality. Uncalibrated models are calibrated to hydraulics but not to water chemistry.

The LDEQ level 1 dilution model applies a simple mass balance of ultimate biochemical oxygen demand (UBOD). The only parameters required for the model include the upstream critical flow, critical dissolved oxygen content, and the discharge design flow. The model conservatively assumes that all discharged oxygen demand is instantaneously consumed. If minimum dissolved oxygen standards are still met under secondary treatment then no further analysis is required. For purposes of LDEQ Level 1 analysis UBOD is calculated as follows in Equation (2):

Eq. (2) $UBOD = 1.5 \cdot CBOD_5 + 4.3 \cdot NH_3\text{-}N$

The LDEQ level 2 uncalibrated models are calibrated to hydraulics but not to water chemistry. Depending on the treatment level and design flow LDEQ requires different levels of hydraulic analyses (Table 3). "Minimum data" uncalibrated models are based on hydrologic data from one or more short reaches representative of the stream length that is impacted by the discharger. "Full data" uncalibrated models are based on hydrologic data for most of the length of the stream that is impacted by the discharger. Time-of-travel studies may be required in either case.

LDEQ level 3 calibrated models require one intensive hydraulic and water quality stream survey. The minimal water quality data collection requirements include BOD series, nitrogen series, total suspended solids, chlorides or conductivity, dissolved oxygen, pH and temperature. Other water quality parameter requirements may be determined on a case-by-case basis. The hydraulic portion requires time of travel measurements. LDEQ level 4 calibrated/verified models require two intensive stream surveys. The need for a level 4 model is determined on a case-by-case basis considering model accuracy and applicability, manpower and field equipment availability, and laboratory availability.

2.5 Oklahoma Effort Level

Modeling guidance found in the Oklahoma Administrative Code (OAC) at 252:690-3-62 applies a 1 MGD discharge threshold between simple and complex models. OAC 252:690-3-62 describes simple models as requiring little or no field data and complex models as requiring calibration and/or verification with observed conditions. Further guidance concerning effort level can be found in Oklahoma's 2002 Continuing Planning Process (CPP) but is generally more subjective.

Oklahoma's CPP outlines four levels of model analysis for developing wasteload allocations: 1) uncalibrated model; 2) calibrated model; 3) confirmed model; and 4) post audit model (ODEQ, 2002). The level 1 uncalibrated model relies on existing literature or other data for estimating water quality data and kinetics. A single intensive stream survey is required for determining hydraulic parameters, water quality conditions, and biochemical kinetic rates in a level 2 calibrated model. A level 3 confirmed model requires and second intensive stream survey. An additional intensive stream survey may be necessary for a level 4 post audit model if the uncertainty is still too high. With each successive level, model complexity, data requirements, and cost of application increases. However, as model complexity and use of actual data increases, the recommended margin of safety decreases (Table 2).

TABLE 2. Modeling Effort and the Corresponding Margin of Safety Recommended in the Oklahoma Continuing Planning Process

Model	System Complexity	Margin of Safety
Uncalibrated	Multiple Source/Complex Waste	25%
	Single Source/Uniform Waste	20%
Calibrated	Multiple Source/Complex Waste	15%
	Single Source/Uniform Waste	10%
Verified	-	5%

Notes: Adapted from Oklahoma's Continuing Planning Process

Guidance on selecting the appropriate model level in the Oklahoma CPP is relatively subjective. The CPP states that "The model used will be selected on a case-by-case basis and based on available resources, the identified pollutant source(s) and the availability of historical data" (p.158). The CPP also states that an uncalibrated model should be used initially in all modeling analyses and that the "results from this analysis may then be used to determine if further data collection or analysis is needed" (p. 161). If the results from this analysis indicate limits more stringent than technology based, then a calibrated or verified model may be required.

2.6 Texas Effort Level

The State of Texas has a Memorandum of Agreement with the EPA Region 6 regarding the use of an uncalibrated water quality model for facilities with discharge flows less than or equal to 0.2 million gallons per day (MGD). A wasteload allocation developed for any such facility using an uncalibrated QUAL-TX model with default reaction rates is considered technically acceptable without EPA Region 6 review (TCEQ, 2003).

Texas modeling guidance for facilities larger than 0.2 MGD is more subjective than for its smaller facilities. The "Procedures to Implement the Texas Surface Water Quality Standards" (TCEQ, 2003) place a preference on models calibrated to site-specific information if available. However, little explicit guidance is provided as to when a calibrated model is necessary. Guidance includes such suggestions as the following (TCEQ, 2003):

- "Model selection depends on factors such as:
    - the type of water body to be analyzed
    - the type and quantity of available site-specific information
    - the location of the discharge point
    - the availability of previously developed models."

- "Additional scrutiny is given to applications for discharges that enter water bodies with impaired dissolved oxygen levels"; and

- In the absence of site-specific information, "simplified screening level methods are used".

SECTION 3

RECOMMENDED MODELS AND PROCESSES

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RECOMMENDED MODELS AND PROCESSES

Dissolved oxygen models can range from simple dilution or spreadsheet-based formulae to the very complex. The appropriate level of model complexity varies depending on the situation. For this reason, none of the evaluated states limit the development of wasteload allocations to a particular model or set of modeled processes. However, most states do recommend the use of certain water quality models (Table 4).

TABLE 4. State Recommended Water Quality Models

State	Recommended Model(s)	Model Processes†
Alabama	Spreadsheet Water Quality Model (SWQM)	CBOD decay, reaeration, nitrification, TON hydrolysis, SOD, CBOD settling‡, TON settling‡
Illinois	Modified Streeter-Phelps	CBOD decay, reaeration, nitrification
Iowa	Modified Iowa Model	CBOD decay, reaeration, nitrification, P&R
	Vermont QUAL-II	CBOD decay, reaeration, nitrification, SOD, P&R
Louisiana	LIMNOSS/XLIMNOSS	varies
	LACOULEE	varies
	QUAL-TX, QUAL2E, LA-QUAL	varies
	Branch, LTM, And BLTM	varies
Oklahoma	Multi-discharger Desktop Model (MULTID)	CBOD decay, CBOD settling, nitrification, reaeration, SOD
Texas	QUAL-TX	CBOD decay, reaeration, nitrification, SOD

Notes: CBOD = carbonaceous biochemical oxygen demand, TON = total organic nitrogen, SOD = sediment oxygen demand.
† - Processes identified from model and/or state guidance (i.e., not necessarily limited to processes identified here).
‡ - Optional model process

3.1 Alabama Recommended Models and Processes

In 2001, the Alabama Department of Environmental Management (ADEM) developed guidance for their Spreadsheet Water Quality Model (SWQM). Alabama uses this model for developing wasteload allocations and total maximum daily loads for oxygen demanding wastes. ADEM derived the SWQM model from an earlier steady-state dissolved oxygen model written in the BASIC computer language and variously referred to as DOMOD2 and W2EL.

The SWQM model is a version of the Streeter-Phelps dissolved oxygen deficit equation modified to account for nitrification and sediment oxygen demand (SOD). The model relates dissolved oxygen to CBOD, nitrogenous biochemical oxygen demand (NBOD), SOD, and reaeration through the equation shown below in Equation (3).

Eq. (3)

$$D = \frac{K_1 L_0}{K_2 - K_1}(e^{-K_1 t} - e^{-K_2 t}) + \frac{K_3 N_0}{K_2 - K_3}(e^{-K_3 t} - e^{-K_2 t}) + \frac{SOD}{K_2 / H}(1 - e^{-K_2 t}) + D_0 e^{-K_2 t}$$

where: D = dissolved oxygen deficit at time t, mg/L
L_o = initial CBOD, mg/L

N_o = initial NBOD, mg/L
D_o = initial dissolved oxygen deficit, mg/L
K_1 = CBOD decay rate, day^{-1} (at simulated temperature)
K_2 = reaeration rate, day^{-1} (at simulated temperature)
K_3 = nitrification rate, day^{-1} (at simulated temperature)
SOD = sediment oxygen demand, g O_2/m^2/day (at simulated temperature)
H = average stream depth, ft
t = time, days

Some of the features of the ADEM SWQM model include the ability to simulate branched systems and the application of optional processes. Up to 24 stream segments can be modeled and oxygen demanding loading sources can be partitioned among different land uses (nonpoint sources) and wastewater treatment facilities (point sources). The SWQM model also allows for simulation of the following optional processes: SOD, CBOD settling rate, total organic nitrogen (TON), and TON settling rate.

3.2 Illinois Recommended Models and Processes

Illinois provides dissolved oxygen water quality modeling guidance for third stage treatment lagoons at 35 Ill. Adm. Code 373. The Illinois Administrative Code provides no modeling guidance for non-treatment lagoons. The Illinois model relates dissolved oxygen to carbonaceous biochemical oxygen demand (CBOD), nitrogenous biochemical oxygen demand (NBOD), and reaeration through Equation (4) shown below.

Eq. (4) $$D = \frac{K_1 L_0}{K_2 - K_1}(e^{-K_1 t} - e^{-K_2 t}) + \frac{K_3 L_0}{K_2 - K_3}(e^{-K_3 (t-t_0)} - e^{-K_2 (t-t_0)}) + D_0 e^{-K_2 t}$$

where: t_o = nitrogenous lag time, days
(Note: remainder of model notation same as used in Equation (3))

3.3 Iowa Recommended Models and Processes

The Iowa Department of Natural Resources (IDNR) uses two dissolved oxygen water quality models: 1) Modified Iowa model, and 2) Vermont version of QUAL-II (IDNR, 2004). The Modified Iowa model is recommended for use as a quick screening tool to eliminate the advanced wastewater treatment requirements for permitted discharges on potentially water quality limited stream segments. The Vermont QUAL-II Model is used for developing final wasteload allocations on water quality-based stream reaches.

The Modified Iowa model is a modification of the Streeter-Phelps equation relating dissolved oxygen deficit to CBOD, NBOD, reaeration, and photosynthesis and respiration. It is based on Equation (5) shown below:

Eq. (5)

$$D = \frac{K_1 L_0}{K_2 - K_1}(e^{-K_1 t} - e^{-K_2 t}) + \frac{K_3 N_0}{K_2 - K_3}(e^{-K_3 t} - e^{-K_2 t}) + \frac{(R-P)}{K_2}(1 - e^{-K_2 t}) + D_0 e^{-K_2 t}$$

where: R = Algal respiration oxygen utilization, mg/L/day
P = Photosynthetic oxygen production, mg/L/day
(Note: remainder of model notation same as used in Equation (3))

Although not explicitly included in the above equation, the Modified Iowa model also simulates algal uptake of ammonia. Phytoplankton consumption reduces instream concentrations of inorganic nutrients including ammonia (NH_3-N) and nitrate nitrogen (NO_3-N). Therefore, it is critical to know the fraction of consumed nitrogen which is NH_3-N. The IDNR calculates the amount of NH_3-N removed by algae in a reach with the MS-ECOL model (Shindala *et al.*, 1981) shown below as Equation (6).

Eq. (6) $$UP = \frac{(GP)(ANP)(NF)(CHLA)(e^{(GP-DP)(t)} - e^{-(K_3)(t)})}{GP - DP + K_3}$$

where: UP = amount of NH_3-N removed in a reach, mg/L
ANP = mg N/ug chlorophyll-a
CHLA = chlorophyll-a concentration, ug/L
NF = fraction of NH3-N preferred for algal uptake (0-0.9)
GP = algal growth rate, day^{-1}
DP = algal death rate, day^{-1}
(Note: remainder of model notation same as used in Equation (3))

The Vermont QUAL-II water quality model is more complex than the Modified Iowa model. It can handle multiple waste discharges, withdrawals, tributary flows, incremental inflow, flow augmentation, and dam reaeration. The model is structured to simulate the major interactions of the nutrient cycles, algal production, benthic oxygen demand, carbonaceaous oxygen uptake, atmospheric reaeration, and the effect these processes have on receiving water concentrations of dissolved oxygen (IDNR, 2004).

3.4 Louisiana Recommended Models and Processes

Louisiana utilizes any of several different water quality models for performing wasteload allocations depending on the situation. In general Louisiana recommends that the least sophisticated model capable of addressing relevant stream characteristics be selected (LDEQ, 2008). Recommended water quality models include:

- LIMNOSS/XLIMNOSS;
- LACOULEE;
- QUAL-TX, QUAL3E, LA-QUAL; and
- Branch, LTM, and BLTM

The Standard Operating Procedures for Louisiana Total Maximum Daily Loads does not specifically address what processes are simulated by these particular models.

Guidance, however, is provided for determining model inputs for the following processes: reaeration, CBOD decay, CBOD settling, nitrification, SOD, and algal photosynthesis and respiration (LDEQ, 2008).

LIMNOSS/XLIMNOSS

LIMNOSS is a modified version of the USEPA AUTOQUAL model that is available on the LDEQ mainframe computer. XLIMNOSS is the personal computer version of LIMNOSS developed by the State of Louisiana to allow use of reaeration equations applicable to Louisiana conditions. Neither model is capable of simulating tributaries other than as point sources.

LACOULEE

LACOULEE is a windows executable version of the USEPA AUTOQUAL model. It allows for the use of Louisiana reaeration equations and does not simulate tributaries other than as point sources.

QUAL-TX, QUAL2E, LA-QUAL

The QUAL-TX. QUAL2E, and LA-QUAL models are all modified versions of the USEPA QUAL-II model. QUAL-TX was developed by the State of Texas and is capable of simulating tidally averaged flows. QUAL2E is supported by the USEPA Center for Exposure Assessment Modeling. Both QUAL-TX and QUAL2E are steady state one-dimensional models that allow for complex branching. Louisiana developed LA-QUAL to allow for the use of reaeration equations applicable to conditions found in the state.

Branch, LTM, and BLTM

Branch, the Lagrangian Transport Model (LTM), and the Branched LTM (BLTM) are water quality models developed by the USGS. These models are considered particularly appropriate for Louisiana's slow and frequently bi-directional streams where dye study data are available.

3.5 Oklahoma Recommended Models and Processes

Oklahoma does not require any particular model or set of model processes be used for establishing a wasteload allocation. In general, more complicated models that simulate a greater number of processes may be required for complex systems, but ultimately professional judgment is required for model selection. OAC 252:690-3-62 does, however, identify typical water quality models as including the various versions of QUAL2, RIVERMOD, HSPF, and the BASINS system.

Although specific water quality models and processes are not explicitly required by Oklahoma, their CPP identifies the Multi-Discharge Desktop Dissolved Oxygen Model (MULTID) as applicable for all initial model analyses. MULTID is a modified version of Streeter-Phelps used for performing dissolved oxygen related wasteload allocations for single and multiple dischargers. Model processes included in MULTID include reaeration, CBOD decay, nitrification, CBOD settling, and SOD.

3.5 Texas Recommended Models and Processes

The Texas Natural Resources Conservation Commission (TNRCC) bases their selection of a model on the amount of available data and the complexity of the water quality problem (TCEQ, 1999). However, QUAL-TX is used for most situations. QUAL-TX is a modified version of the QUAL-II model capable of simulating many different processes. TNRCC considers the most important model inputs for dissolved oxygen analysis to be hydraulic characterization, chemical kinetic rates (i.e., CBOD decay, nitrification, and SOD), reaeration rates, critical conditions (i.e., ambient flow, wastewater flow, and ambient water temperature), and background water quality (TCEQ, 2003).

SECTION 4

RECOMMENDED MODEL INPUTS

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RECOMMENDED MODEL INPUTS

Most surveyed states describe dissolved oxygen mass transfer according to the following kinetic processes: reaeration, CBOD decay, nitrogenous biochemical oxygen demand (NBOD) decay, and SOD. Stream hydraulic features influence these processes. State guidance on selecting appropriate hydraulics and kinetic rates is summarized below.

4.1 Hydraulics

Required hydraulic parameters can vary depending on the model and model options. The most simple water quality models only require a fixed velocity value, whereas more robust models utilize relationships for calculating depth and velocity. Therefore, state guidance on model hydraulics covers a range of methods including empirically derived formulas, Manning's equation, and use of power equations developed by Leopold and Maddock (1953).

The States of Alabama and Texas recommend using empirically derived formula's, unique to their conditions, in the absence of site-specific hydraulic information. Alabama uses the following empirical relationship shown as Equation (7) developed by EPA for streams in the southeast (ADEM, 2001):

$$V = 0.44 \cdot Q^{0.4}(\text{Slope})^{0.2} - 0.2 \quad (7)$$

where: V = velocity, feet/second
Q = stream flow, cubic feet/second
Slope = stream slope, feet/mile

The TNRCC has generalized hydraulic equations developed by the TNRCC using data collected during studies performed throughout the state (TCEQ, 2003).

Manning's equation is an option in many water quality models. Iowa suggests using Manning's equation where there is little historical flow and velocity information. However, Manning's equation requires some field survey work to determine channel hydrogeometry, slope, and roughness. Iowa recommends using a roughness coefficient "n" value of 0.035 for their streams, but also suggests calibrating the "n" value if possible. Oklahoma also recommends calibrating "n" to a dye study, but suggests a range of 0.06 to 0.25 if no data is available (based on notes found in their spreadsheet water quality model).

The Leopold-Maddock equations are included in the more robust water quality models for estimating velocity and stream depth. Iowa guidance suggests that the Leopold-Maddock equations provide more reliable flow velocity relationships than Manning's equation. Determining appropriate coefficient values for the Leopold-Maddock equations generally requires extensive data. Therefore, states typically recommend dye studies for estimating coefficient values.

4.2 Reaeration

Numerous empirical equations exist for estimating stream reaeration. States typically prefer certain reaeration equations, but they do allow most literature based formula to be used if justified. Louisiana recommends selecting reaeration formulas based on field measurements using gas tracers. When field measurements are not available, Louisiana recommends basing the selection on modeling experience from similar streams and calibration of dissolved oxygen values. Similarly, most other states provide flexibility in which reaeration formula is selected provided it is applicable for the hydraulic characteristics of the stream. A list of preferred or recommended reaeration formulas by state is provided below in Table 5.

TABLE 5. State Recommended Reaeration Equations for Uncalibrated Models

State	Author(s)	Equation K_2 =	Applicability
Alabama	Tsivoglou	$C(V)(S)$	C = 1.8 when stream flow < 10 cfs C = 1.3 when stream flow > 10 cfs and < 25 cfs C = 0.88 when stream flow > 25 cfs
	O'Connor-Dobbins	$\frac{12.9V^{0.5}}{H^{1.5}}$	Streams with a depth > 5 feet and a slope less than 2 feet/mile
	In the absence of measured values a minimum of 0.15/day is recommended.		
Illinois	Unspecified	$(110.5H + 0.5832V^2)\frac{(SV)^{0.375}}{H^2}$	Any uncalibrated model
Iowa	Modified Tsivoglou and Wallace	$\frac{c\Delta h(ICE)}{t}$	c = 0.115 for 0 ≤Q≤15 cfs c = 0.054 for 15 ≤Q≤3000 cfs
Louisiana	Many	See Appendix B	Varies
	Maximum = 25/day and Minimum = 2.3/H		
Oklahoma	Tsivoglou	$C(V)(S)$	No guidance
	Turney-Harris	$\frac{1.33S^{0.32}}{n^{0.64}}$	No guidance
	Long ("Texas Equation")	$\frac{4.022V^{0.273}}{H^{0.894}}$	No guidance
	Owens	$\frac{21.7V^{0.67}}{H^{1.85}}$	No guidance
Texas	Long ("Texas" Equation)	$\frac{4.022V^{0.273}}{H^{0.894}}$	Streams with depths between 0.2 and 1.0 meters coupled with velocities between 0.01 and 0.30 m/s
	Maximum = 10/day and Minimum = 0.6/day		

Notes: K2 = Reaeration (units are day^{-1}, at 20 degrees Celsius, base e); C = Tsivoglou coefficient; c = Gas escape coefficient (1/foot); ICE = Factor reflecting effect of ice cover on reaeration rate (unitless); V = Average reach velocity (feet/second); H = Average reach depth (feet); n = Manning's roughness coefficient (unitless); S = slope (feet/mile for Alabama and Oklahoma and feet/feet for Illinois).

4.3 Carbonaceous Biochemical Oxygen Demand Decay

In the absence of site-specific CBOD decay rates, states recommend the following rates for uncalibrated models shown below in Table 6.

TABLE 6. State Recommended CBOD Decay Rates for Uncalibrated Models

State	CBOD Decay Rate (day^{-1})	Applicability
Alabama	0.3	Treatment level: CBOD5 <= 7.0 mg/L
	0.6	Treatment level: CBOD5 > 15 mg/L
	0.4	Treatment level: CBOD5 > 7.0 and <= 15.0 mg/L
Illinois	0.1	Treatment level: CBOD5 <= 10 mg/L
	0.3	Treatment level: CBOD5 > 10 and < 30 mg/L
Iowa	0.23	Ranges from 0.1 day^{-1} to 0.5 day^{-1} for most streams
Louisiana	0.5	Reach average depth < 1 foot
	0.4	Reach average depth >= 1 foot and < 2 feet
	0.3	Reach average depth >= 2 feet
Oklahoma	0.4	Any uncalibrated model
Texas	0.1	Any uncalibrated model

CBOD5 = 5 day carbonaceous biochemical oxygen demand (mg/L) at 20 degrees Celsius, base e

4.4 Nitrogenous Biochemical Oxygen Demand Decay

In the absence of site-specific NBOD decay rates, states recommend the following rates for uncalibrated models shown below in Table 7.

TABLE 7. State Recommended NBOD Decay Rates for Uncalibrated Models

State	NBOD Decay Rate (day^{-1})	Applicability
Alabama	0.3	Stream slope less than 20 feet/mile
	0.5	Stream slope equal or greater than 20 feet/mile
Illinois	0.29	Typical range is 0.25 to 0.37/day. 0.29/day is an average.
Iowa	0.3	Any uncalibrated model
Louisiana	0.4	Reach average depth < 1 foot
	0.2	Reach average depth >= 1 foot and < 2 feet
	0.1	Reach average depth >= 2 feet
Oklahoma	0.3	Any uncalibrated model
Texas	0.3	Any uncalibrated model

NBOD = Nitrogenous biochemical oxygen demand (mg/L) at 20 degrees Celsius, base e

4.5 Sediment Oxygen Demand

In the absence of site-specific SOD rates, states recommend the following rates for uncalibrated models shown below in Table 8.

TABLE 8. State Recommended Sediment Oxygen Demand Rates for Uncalibrated Models

State	SOD ($gO_2/m^2/day$)	Applicability
Alabama	No guidance	Optional model input
Illinois	No guidance	Not simulated in the recommended Illinois model
Iowa	No guidance	Not simulated in the Modified Iowa model
Louisiana	2	Secondary-oxidation ponds or high TSS
	1.5	Secondary-otherwise
	1.0	Treatment level: CBOD5 = 20 mg/L
	0.5	Treatment level: CBOD5 = 10 mg/L
Oklahoma	1.6	Treatment level: CBOD5 > 18 mg/L
	1.1	Treatment level: CBOD5 > 10 mg/L and <= 18 mg/L
	0.8	Treatment level: CBOD5 <= 10 mg/L
Texas	0.35	Any uncalibrated model

SOD = sediment oxygen demand at 20 degrees Celsius, base e; $gO_2/m^2/day$ = grams of oxygen per square meter per day

SECTION 5

SUMMARY

SECTION 5
SUMMARY

A review of state procedures for developing dissolved oxygen wasteload allocations suggests there is no "one-size-fits-all" approach towards developing permit limits. The level or effort that goes into developing a wasteload allocation can range from applying default limits to extensive field work and model calibration. Furthermore, water quality models vary in complexity from a simple mass balance equation to complex computer models. The appropriate level of effort and model depends on the situation. Ultimately, all the reviewed states leave it to best professional judgment as to what is most appropriate, but some guidance is provided.

State guidance on recommended effort level (i.e., model complexity and calibration level) can hinge on multiple factors, but commonly depends on the required level of treatment. Iowa, Louisiana, and Oklahoma all generally call for greater model complexity and calibration where initial analysis suggests advanced treatment may be necessary. Greater efforts are also called for with increasing design flow in Texas, Oklahoma, and Louisiana. Similarly, only minimal efforts are needed where there is a large amount of dilution, such as in Louisiana. Other factors states consider in determining appropriate effort level include model uncertainty, the number of discharges on a segment, the type and quantity of available site-specific information, and whether or not a waterbody is impaired.

States use several different water quality models for developing dissolved oxygen wasteload allocations. Iowa and Louisiana employ simple screener formulas before applying true water quality models. With the exception of these simple screener formulas, all dissolved oxygen models used by the different states are based on the Streeter-Phelps equation. The basic differences are which stream processes are simulated and how stream hydraulics are handled. Ultimately, the actual model used (e.g., QUAL-TX, QUAL2E, or Modified Iowa) makes less difference than the selection of which stream processes are simulated. Simulated stream processes that are found in common to all the state Streeter-Phelps based water quality models include CBOD decay, nitrogenous decay, and reaeration. SOD is also routinely simulated but is sometimes considered optional depending on the model and state. Other model processes such as photosynthesis and reaeration are generally only simulated where greater model complexity is called for.

States typically provide some guidance on model input values for the most basic functions. Alabama and Texas employ the use of empirically derived hydraulic formulas based on conditions unique to their regions, but all states allow for the use of site specific hydraulic studies. For reaeration rates, states generally rely on literature formulas, but in some instances apply boundaries to these equations. Texas and Louisiana limit reaeration rates to between 0.6 and 10 per day, and 2.3/depth(meters) and 25 per day, respectively. State recommended CBOD decay rates range from 0.1 to 0.6 per day, whereas recommended nitrogenous decay rates range from 0.1 to 0.5 per day. Guidance on SOD values is generally dependant on the effluent CBOD value, but ranges from 0.5 to 2 $gO_2/m^2/day$.

SECTION 6

REFERENCES

SECTION 6
REFERENCES

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APPENDIX A

LOUISIANA STATEWIDE SANITARY EFFLUENT LIMITATIONS POLICY

LOUISIANA STATEWIDE SANITARY EFFLUENT LIMITATIONS POLICY
(LDEQ, 2008)

7/20/2007

STATEWIDE SANITARY EFFLUENT LIMITATIONS POLICY

1. Dischargers given specific limits in a final TMDL shall be assigned those limits.

2. The Atchafalaya, Red, and Mississippi Rivers are river systems which because of flow or dispersion would not be significantly impacted by a secondary discharge of the largest size to be reasonably expected from these areas. Sanitary wastewater treatment facilities discharging into these systems will be assigned *SECONDARY TREATMENT*.

3. Areawide policies adopted by the Department for establishment of effluent limits in specified area of the State, will supersede limits assigned in the original 1980 Basin Plans.

4. Remaining sanitary dischargers will be assigned effluent limits according to the following schedule:

FLOW	TREATMENT LEVEL MG/L
<25,000 GPD	30 BOD_5/30 OR 90 TSS Secondary*
25,000 – 50,000 GPD	20 BOD_5/20 TSS Advanced Secondary
>50,000 GPD	10 BOD_5/15 TSS Advanced

5. Individual dischargers may request alternate permit limits by performing an individual analysis which is supervised and approved by the Department.

NOTE: The LDEQ reserves the right to assign an effluent limitation based upon an individual discharge analysis, regardless of any previously established effluent limitation.

+ Whenever NH_3 limits are assigned to a facility, $CBOD_5$ will be required rather than BOD_5.
* Louisiana Administrative Code: Volume 14, 33:IX.711D
    - Mechanical Treatment Systems = 30 TSS
    - Oxidation Ponds = 90 TSS

APPENDIX B

LOUISIANA RECOMMENDED REAERATION EQUATIONS

LOUISIANA RECOMMENDED REAERATION EQUATIONS (LDEQ, 2008)

Author(s)	Equation K2 =	Units	Applicability
Bennett & Rathbun (1972) **	$20.2\ U^{0.607} / H^{1.689}$	English	Based on a reanalysis of historical data.
Churchill et. al. (1962) **	$11.6\ U^{0.969} / H^{1.673}$	English	Based on observed reaeration rates below dams from which oxygen deficient water was released. 2'<H<11'; 1.8fps<U<5 fps
Isaacs & Gaudy (1968) **	$8.62\ U / H^{1.5}$	English	Developed using regression analyses from data collected using a recirculating cylindrical tank. 0.6fps<U<1.6fps; 0.5'<H<1.5'
Langbein & Durum (1967) **	$7.60\ U / H^{1.33}$	English	Based on synthesis of data from O'Connor-Dobbins (1958), Churchill et al. (1962), Kernkel and Orlob (1963), and Streeter et al. (1936).
Long (1984) **	$1.923\ U^{0.273} / H^{0.894}$	Metric	Known as the "Texas" Equation. Based on data collected on streams in Texas.
Negulescu & Rojanski (1969) **	$10.9\ (U / H)^{.85}$	English	Developed from a recirculating flume with depths less than 0.5 feet.
O'Connor & Dobbins (1958) **	$12.9\ U^{0.5} / H^{1.5}$	English	Moderately deep to deep channels; 1'<H<30', 0.5fps<U<1.6fps; 0.05<K2<12.2/day.
Owens et. al. (1964) **	$23.3\ U^{0.73} / H^{1.75}$	English	This is a second formula developed by Owens et al., and applies for 0.1fps<U<1.8fps; 0.4'<H<11'
Padden & Gloyna (1971) **	$6.9\ U^{0.703} / H^{1.054}$	English	Regression analysis performed on data where 9.8<K2<28.8/day.
Tsivoglou & Neal (1976)**	0.11 (Îh / t)	English	Based on data collected on 24 different streams using radioactive tracer method. Applies for 1cfs<Q<10 cfs
Tsivoglou & Neal (1976)**	0.054 (Îh / t)	English	Based on data collected on 24 different streams using radioactive tracer method. Applies for 25cfs<Q<3000 cfs
Tsivoglou & Neal (1976) (Derivation)	3600 * 24 * 0.11 US	English	Based on data collected on 24 different streams using radioactive tracer method. Applies for 1cfs<Q<10 cfs
Tsivoglou & Neal (1976) (Derivation)	3600 * 24 * 0.054 US	English	Based on data collected on 24 different streams using radioactive tracer method. Applies for 25cfs<Q<3000 cfs
Louisiana (1996) ***	2.18[(1+6.56U)/H]	English	Based on empirical data collected by the LA DEQ. 0.3'<H<3.0', .02fps<U<0.8fps
Maximum K2	25	English	EPA Policy in the absence of a measured value
Minimum K2	2.3/H	English	Louisiana Policy

U = The average velocity for the sampled reach, fps or mps; H = The average depth for the sampled reach, feet or meters; Metric Conversion = fps or feet multiplied by .3048 to convert to mps and meters;
K2 units are day -1, at 20 degrees Celsius, base e; Îh / t = drop in water surface elevation, feet / time of travel, days

** Rates, Constants, and Kinetics Formulations in Surface Water Quality Modeling (Second Edition), June 1985, EPA/600/3-85/040. Table 3-6 on pages 103-106.

*** Reaeration in Shallow, Low-Flow Louisiana Stream Reaches - Verification of the Louisiana Equation, Michael G. Waldon, March 27, 1996. Equation 2, Page 1.