REVISED

GLEAS Procedure #80

GUIDANCE ON WATER QUALITY-BASED EFFLUENT LIMIT RECOMMENDATIONS FOR OXYGEN DEMANDING SUBSTANCES

Approved:_____

Date

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I. Introduction

The following guidance is provided for calculating water quality-based effluent limit recommendations (WQBELs) for oxygen demanding substances. Considerable judgment must be exercised by the analyst to produce a recommendation that is scientifically defensible, based on meeting Water Quality Standards. However, this guidance is meant to encourage consistency and to give each analyst easy access to data summaries that are useful in choosing input values for water quality models.

WQBELs are generally developed in response to a request from Permits Section and the guidance provided below should help the analyst to develop WQBELs, document the basis for the WQBELs, and transmit the WQBEL recommendations clearly.

Throughout the WQBEL development process, the analyst should briefly document the rationale used. The Streeter-Phelps Dissolved Oxygen Model Worksheet (Attachment A) can provide a good summary of the model input values used and the basis for the selection of each input value. For sensitive model parameters, thorough documentation of calculations should be developed. Model output used as a basis for recommendations should be clearly labeled. Model output and the rationale for the selection of model input values should be kept in the Effluent Limit File.

Once WQBELs have been developed, a memo for transmittal of WQBEL recommendations to Permits Section should be drafted. The draft memo, along with the Effluent Limit File, including important correspondence and WQBEL development rationale, should be presented to the supervisor for review and approval.

The WQBEL transmittal memo needs to provide the specific information noted below and may also include additional information as needed for special cases. With regards to the facility requesting the permit, the WQBEL transmittal memo needs to identify the facility by name and permit number, state the location of the outfall, state the outfall design flow, and state the type of wastewater discharged. The receiving stream needs to be identified, the stream's designated uses need to be listed and the stream flows need to be provided.

WQBEL recommendations are usually provided in a table attached to the memo. The table should include recommendations both as concentration and mass limits and should include a brief rationale for the limit. The memo should state the basis for the recommendations (water quality standards and/or criteria) and should identify water quality models used to develop the recommendations. The memo should also state any important assumptions made and should note when site specific information is used. If combinations of effluent quality other than those recommended will also meet water quality standards, the memo should state so.

II. Development of Design Flows

A. Introduction

The monthly 95 percentile exceedance flows are generally used for the receiving stream design flow in the development of seasonal WQBELs for discharges of oxygen demanding substances.

However, the analyst may need to consider other factors, as described below, when developing design flows. The 95 percentile exceedance flows are provided by hydrologists in the Land and Water Management Division upon request of the GLEAS analysts developing WQBELs.

It is very important that the facility's permit application clearly identifies the facility's effluent flow rate to be used in WQBEL development. For municipal WWTPs, the effluent flow rate is the 20 year annual average flow rate. For industrial facilities, the effluent flow rate is the maximum flow rate. For situations where WQBELs will be based on effluent flow rates other than that described above, the analyst should clearly document the basis for the effluent flow rate prior to developing WQBELs.

B. Requesting Exceedance Flows

As part of the permit development process, the analyst is given a facility's permit application along with a Tracking Checklist. Within one week of receiving these (three days for expedited permits), the analyst must review the application and determine where exceedance flows will be needed for use in WQBEL development. Exceedance flows should be requested for new use facilities and for existing facilities with new outfall locations. The analyst should also request updated exceedance flows for existing facilities where previous flows were developed more than four years ago.

The analyst should request updated flows if he or she is aware of changes to the stream system that may affect flow calculations. These changes may include such things as changes in dam operation, changes in gage locations, or completion of consumptive use studies. For stream systems that are extremely stable, such as the connecting channels of the Great Lakes, existing flows developed more than four years ago may be adequate for WQBEL development.

When requesting flows, the analyst must provide the geographic location information requested in Section C of the Tracking Checklist and Low Flow Request Form (Attachment B) for each stream location where flows are needed. The analyst should then give the Tracking Checklist and any additional Low Flow Request Forms with geographic location information to the unit secretary for transmittal to the Land and Water Management Division.

C. Selection of Locations Where Exceedance Flows are Needed

It is important that the facility's permit application clearly identifies each discharge location. Exceedance flows are almost always needed for the receiving stream just upstream of the discharge location. Flows at this location are used to develop WQBELs for discharges of metals, toxic substances and oxygen demanding substances. For analyses of oxygen demanding substances or other substances that consider downstream dilution or chemical kinetics, flows may be needed at additional locations downstream of the discharge.

Selection of additional locations for flow requests is typically based on the location of relatively large tributaries. The analyst will need to use judgment to estimate which size tributaries will significantly affect model results and how far downstream the model will extend.

When in doubt as to whether a tributary will have significant flow or whether the tributary will be located within a critical reach of the model, it is recommended that the analyst include the questionable locations in the initial flow request. Including these locations in the initial flow request can avoid delays that would be associated with subsequent flow requests.

When flows are needed at additional locations downstream of a discharge, it is recommended that the analyst request flows in the mainstream, just downstream of the confluence with the tributary. Flow at this location will include flow from the tributary and any incremental inflows upstream of the tributary.

D. Additional Design Flow Considerations

When determining the design flow, the analyst should take into account all factors that affect the stream flow. For example, if a facility has a water intake or withdraws water from the receiving stream near the discharge, the flow removed by the facility may need to be subtracted from the exceedance flow to determine the appropriate design flow. For any significant discharges or withdrawals, the analyst needs to know if the discharges or withdrawals were accounted for by the hydrologist that developed the exceedance flows. For example, if the gage used for estimating flows is located downstream of a discharge being modeled, the flow from the discharge may cause the exceedance flow calculation to be higher than the natural exceedance flow. For this situation, it may be appropriate to subtract the discharge flow from the exceedance flow to arrive at the correct design flow for the receiving stream. In summary, the analyst should use judgment to account for any circumstances that may affect the design flow.

The appropriate design flow for use in a lake model or other unique model would depend on the specific physical aspects of the system being modeled. For example, when using a lake model that simulates equilibrium conditions that would occur at some time several years in the future, a design flow based on annual average flows may be appropriate.

III. Calculation of Water Quality-Based Effluent Limits

A. Choice of Model and Level of Effort

1. Introduction

We have two in-house models available to calculate WQBELs for oxygen demanding substances, Streeter-Phelps and O'Connor-DiToro. A commonly held rule of thumb for modeling is to use the simplest model available that can adequately answer your question.

Streeter-Phelps is a steady state single reach model that includes separate decay of CBOD and ammonia, built in velocity by Boning (1974), reaeration by Tsivoglou and Neal (1968) and sensitivity analysis. Model output is provided at 20 locations within the reach. In addition to calculating dissolved oxygen (DO) using the Streeter-Phelps equation, this model can also be used to calculate unionized ammonia concentrations at all reach locations and the total dissolved solids concentration in the initial mix.

O'Connor-DiToro (1970) is a multi-reach model that is time variable with respect to photosynthetic oxygen production and otherwise steady state. It has decay of CBOD and ammonia, velocity as a function of flow using user defined coefficients, a choice of reaeration options, plant photosynthesis and respiration and separate removal and decay of CBOD.

For discharges to receiving waters other than free flowing streams, the Streeter-Phelps and O'Connor-DiToro models will have only limited applicability. For these situations, the use of other models should be considered. The analyst may consider developing a site-specific model (Thomann and Mueller, 1987) or using an appropriate EPA model.

For all situations, the model configuration used should depend on the level of effort desired, the problem complexity, the data that are available or that can be obtained, and the consequences of the results. Ideally, the complexity of the model should be based on what is necessary to answer the question at hand.

2. Streeter-Phelps Model

In keeping with the principal of using the simplest model that your data can support, the Streeter-Phelps model is the more commonly used model. Consider the use of this model if the stream has one discharger (or multiple dischargers all at approximately the same stream location) and the stream characteristics such as velocity, slope and flow do not change significantly throughout the reach. The analyst may have some field data to characterize background water quality, velocity, or even decay coefficients. The analyst might even have some diurnal intensive chemistry data to calibrate the model. If so, then the analyst would only use this model if the diurnal variation in DO was fairly small (say less than 1 mg/l). If the diurnal variation was greater than 1 mg/l and the analyst has data with which to calibrate the model, then the analyst should probably use the O'Connor-DiToro model.

The Streeter-Phelps model can only simulate daily average DO and the daily minimum is simulated by subtracting a constant from the daily average (see Section I).

3. O'Connor-DiToro Model

Consider the use of this model if one or more of the following are true:

1. There are multiple dischargers to the reach.

2. There is a tributary inflow within the sag area downstream of the discharge that is large enough to affect DO.

3. Physical characteristics of the stream (such as slope, velocity or depth) vary spatially.

4. Diurnal DO variation is greater than 1 mg/l and you have data with which to calibrate the photosynthesis and plant respiration parameters.

Certain features of the O'Connor-DiToro model can be ignored. For example, the photosynthesis and respiration coefficients can be left at zero and the model can be used to simulate daily average DO as in the Streeter-Phelps model. Do not make the model unnecessarily complex just because the variables are there to use.

One of the features of this model is that the location of the nodes is user defined. Nodes should be located at least at every major tributary and at each discharger. This makes it easier to keep track of inputs since there will be a node for each flow input. Nodes can also be added to account for significant changes in stream slope, and nodes can be added at sampling locations to facilitate model calibration. Be sure to have enough downstream nodes so that the shape of the DO curve can be well defined. Frequently the model is truncated at a downstream impoundment, major tributary or one of the Great Lakes.

4. Modeling Strategy

The model chosen should be used to determine what concentration and load of pollutant can be discharged at design flow to just meet the DO standard. All model input parameters, except temperature and wastewater inputs, should be chosen to represent the average expected value at design flow. For some parameters there may be sufficient site-specific information to define how the parameter varies with flow in the stream. For an example of this for BOD see the 1986 Huron River report (Suppnick, 1986). Usually the mean or median expected value is used. For municipal WWTPs, the effluent flow rate is the 20 year annual average flow rate. For industrial facilities, the effluent flow rate is the maximum flow rate. The effluent BOD and ammonia values should be interpreted as the daily composite maximum for WQBEL recommendations. See Temperature section below for how to choose temperature values.

Sometimes it is not possible to determine an effluent quality that will meet the standard because even in the absence of all discharges the standard would not be met due to nonpoint sources. In this case, the model should be used to illustrate the sensitivity of the stream DO, at design stream flow, to various levels of point source loads. The model could also be used to show the relative importance of all factors that deplete DO in the stream. For examples see the Huron River report (Suppnick, 1986).

5. Model Calibration and Verification

Ideally, prior to using a model to predict results at design conditions, a model should be calibrated to a data set, and then verified with an independent data set. Calibrating the model means to adjust model inputs (within the range of possible values) so that the model accurately predicts values that were actually observed in the stream. Verifying the model means to test the model accuracy by simulating a second scenario, with data other than the calibration data, and comparing the simulated results with actual measurements (see EPA, 1986; Suppnick, 1986).

When calibrating a model, it is important that the analyst use the available data to calibrate model process independently and in the proper sequence. The analyst must first select a type of model that is appropriate for the physical system being modeled. The model needs to include all significant inputs to the system and the model needs to simulate all the significant processes that occur within

the system. Model reaches should be identified based on the location of outfalls and tributaries, changes in stream slope or physical characteristics, or the location of sampling stations.

Stream flow and velocity (and dispersion if necessary) should be defined first. Loadings and inflows should be verified with a conservative substance. CBOD decay should be verified with measured ultimate BOD loads. Oxygen demand due to nitrification should then be added. Reaeration (and sediment oxygen demand if necessary) should then be added and the model daily average DO should be verified with measured DO. Then photosynthesis and respiration (if necessary) should be added and verified with the measured diurnal DO variation. After a model is calibrated and verified with field data, input parameters can be modified to represent design conditions, and model output will represent the expected impact at design conditions.

B. Development of Model Parameters

Once the analyst has selected a model to represent the stream system, whether it is an in-house model, an EPA model, a model developed by the analyst, or a model provided by an outside agency, the analyst will then need to select appropriate model input values to accurately represent the physical and biochemical processes that occur in the stream system. Important processes and model inputs are briefly described below. Along with the descriptions, recommendations are provided to help the analyst calculate and select appropriate model input values.

1. Velocity

Stream velocity is an important model consideration with respect to the time available for biochemical reactions to occur and the location of DO sags. Additionally, the velocity is often used in development of the reaeration rate.

a. Determining Velocity

Time of Passage (TOP) studies are typically easy to conduct using a dye tracer and are recommended when feasible if the model is sensitive to velocity (see GLEAS Procedure #70). If possible, TOP studies should be conducted at two different measured flow rates, one of which should be at or near
the design flow. With two measurements, a power function equation, $v = a*Q^b$, where v = velocity and Q = flow, can be solved for the coefficient, a, and the exponent, b. This relationship can be used to find velocity as a function of flow assuming that the function is approximately linear within the measured range.

If only one TOP study is conducted, consider using an appropriate exponent from Boning (1974) and solving for a site-specific velocity coefficient. For model reaches outside of the TOP study, consider using the reach slope with the appropriate Boning slope exponent. The reach slope can then be considered a constant and factored into the velocity coefficient for that reach.

If no TOP studies have been conducted, use the appropriate Boning equation with site-specific stream slope. For many channels at design flow conditions, the Pool and Riffle channel type is appropriate. Note the ranges of flow rates and channel characteristics used by Boning to develop his

TOP equations and note specifically that for Pool and Riffle channels, the minimum flow rate in the data base is 3 cfs. For streams with flow rates less than 3 cfs, consider using the Manning equation.

For streams with flow rates less than 3 cfs, consider using the Manning equation. Past analysis used a Manning roughness coefficient of 0.1 to represent natural streams and a width to depth ratio of 40 based on 677 data points for 10 Michigan rivers. The Manning equation can then be written as $v = 2.937 * Q^{(0.25)} * s^{(0.375)}$, where v is in feet per second, Q is in cubic feet per second, and s = slope in foot per foot. In a comparison of predicted velocity to measured velocity using 407 measurements in 14 rivers, the Manning equation provided a better estimate of velocity than the Boning equation.

Stream slopes can be obtained from USGS quadrangle maps with vertical contours. The horizontal distance between the contour lines can be determined with a digitizer or dividers.

b. Model Velocity Inputs

Reach specific velocity coefficients and exponents can be input into the O'Connor-DiToro model and the model will calculate velocities for each reach as a function of flow in that reach. Reach velocities can also be input directly to the O'Connor-DiToro model if desired.

The Streeter-Phelps model will calculate velocity using Boning's equations as a function of flow, stream slope, and channel type. The Streeter-Phelps model also allows for direct input of velocity. One version of the Streeter-Phelps model uses the Manning equation to calculate velocity as a function of flow and stream slope. The Manning equation in this model uses n = 0.1 for natural streams and a width to depth ratio of 40. This equation is applicable for small streams.

2. Dispersion

Physical dispersion is typically negligible in steady state models of streams with good mixing characteristics and is not included in the O'Connor-DiToro or Streeter-Phelps models. Dispersion can be significant in lakes where the O'Connor-DiToro and Streeter-Phelps models are not appropriate.

Several EPA models (i.e., QUAL2E, WASP and SWMM Transport) include numerical dispersion inherent in the model equations. These models may also allow input of coefficients to represent physical dispersion. When using these models, it is important that the total dispersion in the model, due to numerical dispersion and model inputs for physical dispersion, represents the actual dispersion in the stream. Model dispersion exceeding that in the stream can effectively remove contaminants from the model even though the contaminants exist in the stream.

Dispersion, although typically negligible in streams, can be easily measured in a stream using a conservative substance, such as dye. Measurements in lakes or estuaries where dispersion may be significant is more difficult.

3. Background Water Quality (Temperature, DO, BOD, NH3)

a. Introduction

Both the Streeter-Phelps and the O'Connor-DiToro models require inputs of daily average temperature, DO, CBOD5 and ammonia immediately upstream of the discharge. Temperature and DO are different than BOD and ammonia because they typically vary diurnally in response to air temperature and the photosynthetic oxygen production by plants. Therefore, for temperature and DO, it is best to use site-specific data where all times of day are represented in the database.

b. Temperature

The design background temperature is an important factor in calculating WQBELs. It directly affects the BOD, ammonia-nitrogen, and dissolved oxygen limits. To assure that these limits are developed in a clear and consistent manner, the design background temperature should be chosen using a uniform procedure.

The design background temperature is the highest monthly temperature likely to be exceeded only 10% of the time. In cases where there are site-specific data available, these temperatures can be calculated directly. In cases where there are no data available, the following temperatures are recommended:

	90% Occurrence Temperature , Degrees Celsius		
Discharge Period	Southern Warmwater	Northern Warmwater	All Coldwater
January	2	0.5	2
February	2	0.5	2
March	7	2	5
April	14	11	11
May	22	19	17
June	26	24	22
July	28	27	22
August	27	25	21
September	24	21	17
October	17	15	12
November	10	7	8
December	4	1	4

Southern warmwater streams are those streams south of a line between Bay City, Midland, Alma and North Muskegon which are protected for warmwater fish. Northern warmwater streams are those streams north of this line which are protected for warmwater fish. Coldwater streams are all streams protected for coldwater fish.

These temperatures should only be used as background temperatures for inland streams. Other factors affecting the temperature of the background-effluent mixture such as thermal discharges or impoundments should be considered.

c. Chemical Parameters

Whenever possible, for DO, BOD and ammonia, site-specific data should be used from immediately upstream of the discharge. Samples have been collected for this purpose immediately upstream of many surface water dischargers and these data can be found in STORET. Otherwise the analyst should consider using default or statewide average values which are discussed in more detail below.

One problem the analyst frequently has is whether to use mediocre site-specific data or statewide average data. Data could be considered mediocre if it is not exactly at the background site or if there are only a few observations. The choice between state wide average and mediocre site-specific data should be made after consideration of what pollution sources, tributaries, dams, or other hydrologic features occur between the sampling station and the true background location, and how variable the data are. As a general rule of thumb, if in doubt, use the statewide averages.

A summary of statewide average background water quality was made in 1970 (MDNR, 1970). One hundred twenty-one (121) lower peninsula streams and 33 upper peninsula streams were sampled upstream of any point source dischargers. The average BOD5 was 2.1 mg/l for the upper peninsula and 2.8 mg/l for the lower peninsula streams. The statewide average was 2.6 mg/l.

In 1980 (Hobrla, 1980) a STORET retrieval of background stations from the monthly monitoring program was performed. The data are presented below in Table 1. Although these data are at least 16 years old, they remain the most comprehensive data summary available. In 1994 (Lundgren, 1994), a summary was made for selected water quality parameters at seven reference sites in the state. The average ammonia concentration was 0.027 mg/l which compares favorably with values in Table 1.

A summary was also made of all available diurnal dissolved oxygen data from coldwater streams in Michigan (Suppnick and Stauffer, 1987). The statewide daily average DO expressed as % saturation was 93.7%. The median diurnal difference (daily average minus daily minimum) was 0.65 mg/l. See section 3.I. for more on diurnal variation of DO.

4. CBOD Decay and Ultimate to 5 Day Ratio

The rate coefficient for the decay of CBOD, Kd, is used in the Streeter-Phelps and the O'Connor-DiToro models. An additional rate coefficient for the removal of CBOD, Kr, is used in the O'Connor-DiToro model. In general, site-specific information is used whenever possible to determine these coefficients. Methods used to determine these coefficients, with or without site-specific information, are described below.

a. CBOD Removal Rate Coefficient, Kr

The CBOD removal rate coefficient, Kr, in units of 1/day (base e) is the coefficient for the rate of removal of CBOD from the water column, including removal by decay, settling and extraction. Site-specific information needed to calculate this coefficient includes in-stream CBOD loading for at least two locations and time of travel between the locations. Kr is determined from the slope of the best fit line through a plot of the natural logarithm of the ultimate CBOD load versus the cumulative time of passage.

Table 1. A Summary of STORET Water Quality Data at Background Stations for Selected Parameters

	DO % saturation		BOD5 (mg/l)		Ammonia (mg/l)	
Month	cold	warm	cold	warm	cold	warm
Jan	82.4	74.1	1.94	2.12	0.05	0.13
Feb	82.8	72.7	2.08	2.26	0.06	0.16
Mar	84.5	81.4	2.00	2.60	0.04	0.12
April	90.7	88.0	1.82	2.10	0.04	0.08
May	90.2	87.0	1.61	1.96	0.04	0.08
June	89.6	84.6	1.41	1.85	0.04	0.05
July	90.4	85.1	1.36	1.67	0.03	0.05
Aug.	88.4	92.4	2.07	1.82	0.03	0.03
Sept.	89.0	89.1	1.23	1.47	0.06	0.04
Oct.	87.9	85.9	1.11	1.43	0.02	0.03
Nov.	90.4	89.0	1.42	1.81	0.02	0.04
Dec.	88.0	84.4	1.87	2.40	0.02	0.06
Annual Average	87.9 n=1364	84.6 n=1314	1.65 n=1329	1.95 n=1265	0.036 n=1317	0.07 n=1275

b. CBOD Decay Rate Coefficient, Kd

The CBOD decay rate coefficient, Kd, in units of 1/day (base e) is the coefficient for the rate of oxidation of CBOD in the water column. Under most model applications where wastewater treatment has removed the settleable fraction of the CBOD, the CBOD decay rate coefficient will be set equal to the CBOD removal rate coefficient. In the Streeter-Phelps model, this is always the case. However, the O'Connor-DiToro model allows the flexibility of using unequal CBOD decay and removal rate coefficients.

In the O'Connor-DiToro model, if the CBOD decay rate coefficient is set less than the CBOD removal rate coefficient, some of the CBOD is removed from the model without exerting an oxygen demand. This technique could be used to simulate discharge of primary treated or untreated wastewaters to quiescent water bodies, where some fraction of the CBOD settles out of the water column without exerting an oxygen demand.

If the model CBOD decay rate coefficient is set greater than the CBOD removal rate coefficient, some fraction of the CBOD remains in the model and continues to exert an oxygen demand. In some situations, this technique could be used to simulate oxygen demand from sources other than the water column such as SOD or bacterial slimes.

c. Selection of Model Kr and Kd

Site-specific in-stream measurements are used whenever possible to determine Kr and Kd. In the absence of site-specific in-stream decay rate measurements, the analyst should use in-stream decay measurements of similar wastewaters. In free flowing streams below municipal WWTPs providing secondary treatment, Kr is assumed to be equal to 0.5 per day at 20°C. Based on the judgment of the analyst, model Kr may be reduced for sluggish streams or if the treatment level increases.

Lacking site-specific in-stream decay rates for atypical industrial wastewaters, the bottle decay rate may be considered to represent a lower boundary for the in-stream decay rate. CBOD decay rates in natural waters are typically higher than decay rates in bottles because of the mixing that occurs in natural waters.

d. CBOD Ultimate to 5 Day Ratio

Modeling of CBOD is done in terms of the ultimate CBOD (UBOD). Waste loads are input to the model as UBOD and the assimilative capacity of the receiving stream is determined as UBOD. The assimilative capacity is then converted to a permit recommendation in terms of effluent $CBOD_5$ by using the effluent UBOD to $CBOD_5$ ratio.

The UBOD to $CBOD_5$ ratio should be determined from effluent samples analyzed concurrently for UBOD and $CBOD_5$. In the absence of site-specific information, the ultimate to five-day ratio is assumed to be equal to 1.5 for municipal WWTPs providing secondary treatment. The ultimate to five-day ratio generally increases with increased levels of waste treatment. The ultimate to five-day ratio of industrial wastes can be much different than that of municipal wastes. The ultimate to five-day ratio for effluent containing paper mill waste has been measured as high as 23.

When using the O'Connor-DiToro model, it is readily apparent that UBOD, rather than $CBOD_5$, is being modeled, but it is important that the analyst remember to convert the model UBOD to permit recommendations as effluent $CBOD_5$. When using the Streeter-Phelps model, CBOD is input as $CBOD_5$, but model calculations are performed as UBOD, so the analyst must take care to use appropriate ultimate to five-day ratios in the model.

Note that in water quality models, the decay rate coefficient represents decay of UBOD in the receiving stream, while the ultimate to five-day ratio is based on bottle analyses of effluent UBOD

and $CBOD_5$. Consequently, the model in-stream decay rate coefficient, and the bottle ultimate to five-day ratio of the effluent, are not dependent on each other with respect to the first order decay equation.

5. Nitrification Rate Coefficient, Kn

The nitrification rate coefficient, Kn, in units of 1/day (base e) is the coefficient for the rate of oxidation of ammonia to nitrate plus nitrite. A variety of methods are available to calculate the nitrification rate coefficient. The method used by the analyst should be based on the increase of nitrates plus nitrites. Two acceptable equations are provided below. Site-specific information needed to calculate the nitrification rate coefficient includes in-stream ammonia and nitrate plus nitrite loading for at least two locations and time of travel between the locations.

Method 1: $Kn=(\ln NH3_a-\ln(NH3_a-(NOX_b-NOX_a)))/TOP$

Method 2: $Kn=(\ln((NH3_a+NH3_b)/2)-\ln(((NH3_a+NH3_b)/2)-(NOX_b-NOX_a)))/TOP$

Where:

$NH3_a$ = Upstream ammonia-N loading (kg/d)
$NH3_b$ = Downstream ammonia-N loading (kg/d)
NOX_a = Upstream NO_3 + NO_2 loading (kg/d)
NOX_b = Downstream NO_3 + NO_2 loading (kg/d)
TOP = Time of passage from a to b in days

Nitrification rates can vary widely (see Bowie et al., 1985), and rates have been measured as high as 10 /day in Michigan. Nitrifying bacteria are associated with substrate, so shallow, rocky, swift moving streams generally have higher nitrification rates than deep slow moving streams, although nitrifying bacteria may also be associated with suspended solids in turbid streams.

In the absence of site-specific data, Kn is assumed to be within the range of 0.6 /day to 0.9 /day. However, the analyst may use judgment to adjust Kn based on the physical aspects of the stream.

6. Sediment Oxygen Demand

The analyst is generally not expected to model sediment oxygen demand (SOD) explicitly when modeling free flowing streams. For free flowing streams where SOD may be on the order of 1 gram/(square meter-day), models are not expected to be sensitive to SOD. The Streeter-Phelps and O'Connor-DiToro models do not allow direct inputs for SOD. However, for systems where SOD is significant (see Bowie et al., 1985, and Hatcher et al., 1986), site-specific models may be developed or one of several EPA models could be used to simulate SOD. The O'Connor-DiToro model can be used to simulate the effects of SOD by adjusting inputs for respiration or by setting Kr less than Kd.

Measuring representative SOD is problematic due to the spatial variability of SOD in the stream and the difficulty of matching stream velocity during SOD measurements. Because of these problems,

SOD is more easily determined by accurate measurement of the other processes that affect DO including reaeration and diurnal variation.

The effects of control measures on eliminating SOD are not well quantified, so the analyst is urged to use extreme caution when estimating SOD in future water quality scenarios.

7. Reaeration

The reaeration rate coefficient, Ka, in units of 1/day (base e), is the coefficient for the rate of oxygen transfer of atmospheric oxygen to water. For water quality models that are sensitive to reaeration, and where measurement of Ka is feasible, it is recommended that Ka be measured. GLEAS Procedure #68 describes a method of reaeration measurement using ethylene or propane as the tracer. See also Suppnick (1984).

a. Equations for Predicting Reaeration

Where site-specific Ka information is not available, the analyst should consider the predictive equations described in the literature (see Bowie et al., 1985). Five of these methods are well summarized in the 1983 report by Casey and Synk (1983), and guidance for use of these equations is provided in the report. The guidance from this report is recommended and it is described below.

The Gameson (1973) formulation is recommended for waterfalls, weirs and cascades. The Banks-Herrera (1977) formulation is recommended for lakes, impoundments and estuaries.

For free flowing streams, the Tsivoglou-Neal (1968) method, with the Hobrla (1982) logarithmic equation for the escape coefficient, is recommended. If the Ka predicted with the Tsivoglou-Neal equation is less than 1/day, the analyst should consider using the O'Connor-Dobbins (1956) equation for depths greater than 2 feet, or the Owens-Edwards-Gibbs (1964) equation for depths less than 2 feet.

b. Model Inputs for Reaeration

The O'Connor-DiToro model will calculate reaeration rates based on the Tsivoglou-Neal equation if the analyst enters escape coefficients. It will also calculate reaeration rates based on the O'Connor-Dobbins, or the Owens-Edwards-Gibbs equations, if the analyst enters depths. It also allows for direct input of Ka.

The Streeter-Phelps model will calculate the reaeration rate based on the Tsivoglou-Neal equation and the escape coefficient using the Hobrla logarithmic equation. The analyst can effectively input a specific Ka by editing the escape coefficient to produce the desired Ka.

8. Diurnal Variation of DO Photosynthesis and Respiration

The diurnal DO difference (daily average minus daily minimum) must be subtracted from the predicted daily average to calculate daily minimum if the analyst is using the Streeter-Phelps model or using the O'Connor-DiToro model without the photosynthesis (P) and respiration (R) coefficients.

For coldwater streams, a statewide median of 0.65 mg/l was determined from an analysis of 77 individual days worth of diurnal sampling data representing 66 locations on 33 different streams (Suppnick and Stauffer, 1987). This statewide median number should be used in the absence of site-specific data. No statewide summary has been conducted for warmwater streams in Michigan. Unless site-specific data indicate otherwise, assume 1 mg/l for the expected diurnal difference in warmwater streams.

P and R coefficients should only be used when the O'Connor-DiToro model has been calibrated to field DO data. When P and R are determined through a calibration process the R coefficient includes sediment oxygen demand (SOD).

Since P and R (especially P) vary with the physiological state and density of the plant community it is sometimes difficult to choose the correct P and R values for a design flow condition. One frequently used approach is to choose R based on the value expected at design flow and then choose a value for P that corresponds to no net oxygen production. These rates can be expressed as a ratio and this ratio can be determined from the following formula:

$$P/R = \frac{3.1416}{\{1 - \cos(3.1416\ D/24)\}}$$

Where:

P = photosynthetic rate in mg/l/d
R = respiration rate in mg/l/day
D = Hours of daylight

Remember that this ratio applies only to the portion of R that is attributable to aquatic plant respiration. Hours of daylight can be determined from Figure 1.

9. Effluent Quality

The effluent quality in the model is varied until a combination of BOD, ammonia and DO are found that meets the DO standard in the stream. Sometimes it is useful to generate a trade-off curve that illustrates the idea that many different combinations of effluent BOD and ammonia exist that would still allow the DO standard to be met. There are two special cases that must be dealt with regarding EPA treatment technology requirements and advanced waste treatment.

a. Treatment Technology

Do not recommend WQBELs that are less restrictive than the Federal treatment technology definition. As stated in section III.A.4. above, the model point source inputs should be interpreted as a daily composite maximum value. However, for municipal wastewater treatment plants, secondary treatment is defined by 7 day average and 30 day average BOD5 or CBOD5 values. Since EPA regulations do not define a daily maximum to use in the model, the following approach should be used. For existing secondary treatment plants, the maximum CBOD5 should be determined by reviewing daily composite maximums reported on the most recent discharge monitoring reports for

times when the facility met secondary treatment limits. In no case should a value less than 45 mg/l of CBOD5 be used to represent secondary treatment in the model. When little or no BOD performance data are available for a proposed secondary treatment plant, then 60 mg/l of CBOD5 as a daily composite maximum is a good assumption to represent secondary treatment in the model. For industrial facilities, you should receive from the Permits Section the treatment technology limit, if any, for daily maximum BOD5 and use it in the model initially. If this meets the DO standard, then no further modeling is necessary. Otherwise, you should incrementally reduce the effluent BOD concentration in the model until the standard is met and then recommend that concentration as a daily composite maximum for the permit.

The ammonia value representative of a discharger can also be determined by selecting the maximum value recorded on discharge monitoring reports in recent years. Ammonia limits should not be recommended for a permit if the limit will be obviously met. If a facility has reported a daily maximum or 30 day average value approaching or greater than the WQBEL, then the limit should be recommended for the permit. If there are limited (less than about 100 values) or no ammonia sampling data available, then 30 mg/l is a reasonable assumption for the daily maximum that is not likely to be exceeded and 23 mg/l is a reasonable assumption for the 30 day average that is not likely to be exceeded by a secondary treatment plant.

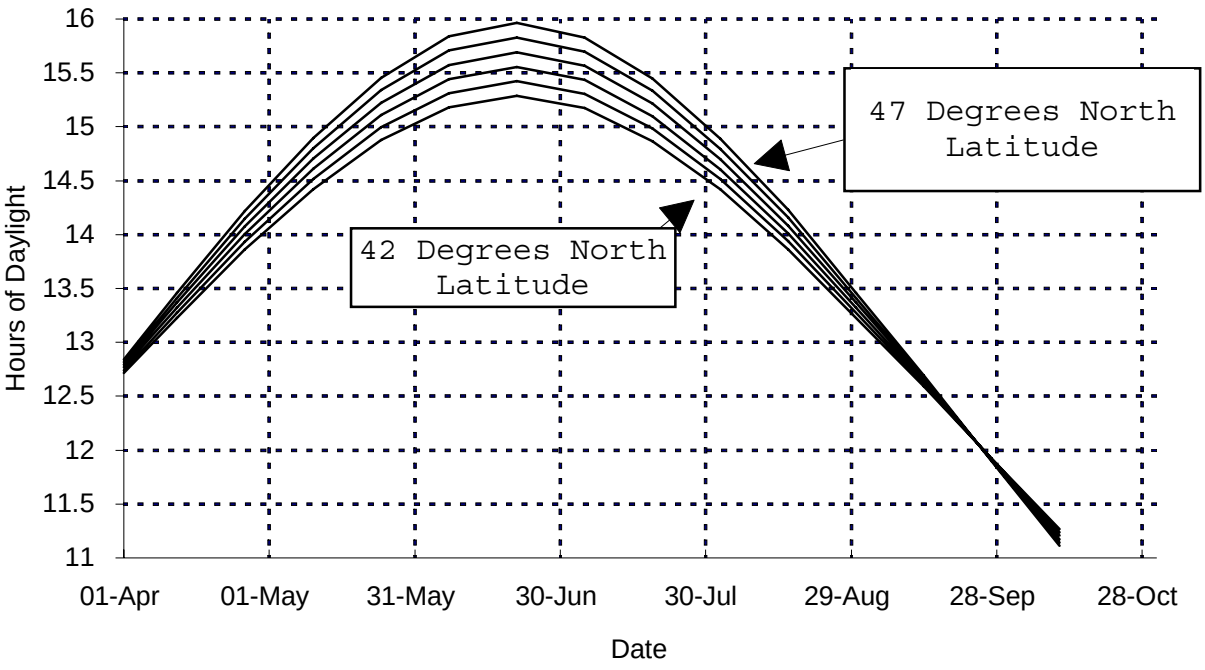
b. Advanced Waste Treatment

The maximum amount of treatment that can usually be achieved by biological treatment processes is commonly referred to as stable effluent or advance wastewater treatment (AWT) and is defined by past practice as:

CBOD5	=	10 mg/l as a daily composite maximum
		4 mg/l as a 30 day average
Ammonia-N	=	2 mg/l as a daily composite maximum
		0.5 mg/l as a 30 day average
Dissolved Oxygen	=	7 mg/l as a minimum 24 hour value

A biological treatment system which meets these criteria can normally be assumed to meet water quality standards under almost any stream flow conditions if these effluent concentrations are achieved from biological treatment. This is because after biological treatment, the BOD remaining is usually not readily oxidizable. It is not normally necessary to calculate WQBELs more restrictive than AWT for treatment systems that incorporate biological treatment. If modeling shows that AWT effluent quality is insufficient to meet the DO standard in the stream, no further modeling should be done unless the Permit Section staff requests it. Occasionally Permits Section staff will request the actual WQBEL, in which case the analyst should calculate and transmit the actual WQBEL. Attachment C is the procedure used by the Permits Section to convert WQBELs for municipal WWTPs into permit limits.

Figure 1. Hours of Daylight
at Various Latitudes in Michigan



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ATTACHMENT A

Analyst _____
Date _____

STREETER-PHELPS DISSOLVED OXYGEN MODEL

Facility Name _____
Watercourse _____ Designation: [ ] warmwater [ ] coldwater
Location _____
Description _____

Parameter	Data				Source
	Winter	Spring	Summer	Fall	
Background flow, cfs					
Wastewater flow, mgd					
Background temperature, C					
Wastewater temperature, C					
Background DO, mg/l or % Sat.					
Wastewater DO, mg/l					
Background CBOD5, mg/l					
Wastewater CBOD5, mg/l					
Background NH3-N and organic-N, mg/l					
Wastewater NH3-N and organic-N, mg/l					
Background BODu/BOD5 ratio					
Wastewater BODu/BOD5 ratio					
CBOD rate constant at 20 C, 1/day					
NOD rate constant at 20 C, 1/day					
Background pH, SU					
Wastewater pH, SU					
Background alkalinity, mg/l					
Wastewater alkalinity, mg/l					
Avg. river slope, feet/mile					
Avg. river velocity, feet/sec					
Channel control (cc) or pool and riffle (pr)					
Escape coefficient, 1/ft					
Minimum dissolved oxygen, mg/l					
Time of passage, days					
River mile point					

SPCVRSHT.XLS

Tracking Number _____ **Permit No.: MI**_____

SECTION C -- LOCATION FOR LOW FLOW DEVELOPMENT (to be completed by GLEAS)

Location _____ of _____ ☐ 90dQ10 Flow ☐ Harmonic Mean Flow

1. Water Course: _____ Location: _____

2. _____ 1/4 of the _____ 1/4 of Section _____, T_____, R_____, of _____ County

3. USGS Topographical Map Name: _____ Quadrangle

4. Should other facilities be reviewed at this time: Yes or No

5. Please list:_____

6. Remarks: _____

_____

_____

SECTION D -- LOW FLOW DATA (to be completed by Hydrology)

1. Water Course is: _____ Perennial _____ Intermittent _____ Ephemeral

2. Drainage Area: _____

3. Monthly Exceedance Flows in CFS:

	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE
50%	_____	_____	_____	_____	_____	_____
95%	_____	_____	_____	_____	_____	_____

	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
50%	_____	_____	_____	_____	_____	_____
95%	_____	_____	_____	_____	_____	_____

4. 90dQ10 Flow in CFS: _____

5. Harmonic Mean Flow in CFS: _____

Remarks: _____

_____

_____ _____ _____

Hydrology Unit Supervisor Date Complete LWMD Record Number

PLEASE RETURN A COPY TO THE PERMITS SECTION UNIT CHIEF AND THE GLEAS UNIT CHIEF INDICATED ON REVERSE SIDE

Attachment C
RELATIONSHIP BETWEEN WATER QUALITY-BASED EFFLUENT LIMITS
AND
NPDES PERMIT LIMITS FOR MUNICIPAL WWTPs

The following is intended to serve as general guidance in translating water quality-based effluent limit (WQBEL) recommendations for NPDES permit use and facility planning purposes. Although this guidance should be applicable in most cases, other factors may be considered in establishing the appropriate NPDES permit limits.

CARBONACEOUS BIOCHEMICAL OXYGEN DEMAND, mg/l			TOTAL SUSPENDED SOLIDS,	
WQBEL	PERMIT LIMITS		PERMIT LIMITS	
Daily Maximum	Daily Maximum	Monthly Average	Monthly Average	7-day Average
40	40	25	30	45
39	39	25	30	45
38	38	25	30	45
37	37	25	30	45
36	36	24	30	45
35	35	23	30	45
34	34	23	30	45
33	33	22	30	45
32	32	21	30	45
31	31	21	30	45
30	30	20	30	45
29	29	19	30	45
28	28	19	30	45
27	27	18	30	45
26	26	17	30	45
25	25	17	30	45
24	24	16	30	45
23	23	15	30	45
22	22	15	30	45
21	21	14	30	45
20	20	13	30	45
19	19	13	30	45
18	18	12	30	45
17	17	11	30	45
16	16	11	30	45
15	15	10	30	45
14	14	9	28	42
13	13	9	26	39
12	12	8	24	36
11	11	7	22	33
10	10	4	20	30

Ammonia Nitrogen as N, mg/l (based on D.O.)		
WQBEL	Permit Limits	
Daily Maximum	Daily Maximum	Monthly Average
>2	same as WQBEL	NA
2	2	0.5

Secondary Treatment - If the WQBEL for CBOD is greater than that allowed for in the federal secondary treatment regulation (40 CFR Part 133), GLEAS will not make a recommendation. The permit limits will be shown as secondary treatment, that is, CBOD limits of 25/40 mg/l (monthly average/7-day average) or total BOD limits of 30/45 mg/l (monthly average/7-day average). EPA amended the secondary treatment regulation in 1984 to allow for the option of using CBOD instead of the standard total BOD. This change was made because many wastewater treatment plants which were built to meet the 30/45 standard at design flow, produce effluents that are partially nitrified. This results in the standard BOD test giving erroneously high values. Accordingly, permits should be drafted using CBOD limits unless the permittee specifically requests total BOD limits. Most wastewater stabilization lagoon operators prefer to use total BOD which is consistent with the general permit for lagoons.

The secondary treatment regulation also provides for the following special considerations: a) alternate percent removal requirements for some combined and separate sewers; b) upward adjustment of BOD and suspended solids limits for POTWs that receive industrial wastes under certain conditions; and c) adjusted suspended solids limits for wastewater stabilization lagoons of 70/100 mg/l (monthly average/7-day average) for the spring discharge, and
40/45 mg/l (monthly average/7-day average) for the fall discharge. The permittee should provide written documentation to support alternate limits under a and b above.

Additionally, the secondary treatment regulation also provides relief for trickling filters that cannot meet 25 /40 mg/l CBOD or 30/45 mg/l BOD limits at design load. These facilities may receive limits as high as 40 /60 mg/l CBOD or 45/65 mg/l BOD. Suspended solids limits may be adjusted as high as 45/65 mg/l and percent removal requirements can be lowered to 65%. The actual permit limits will be based on a judgment of what can be achieved through proper operation and maintenance. Of course, water quality based limits should be used if more restrictive than that allowed for under the secondary treatment regulation.

Load Limits - The loading limits should be calculated using the same flow figure that was used in determining the effluent limitations (annual average design flow or other design flow as appropriate). The loading limit calculated from the maximum concentration should be expressed as a 7-day average, not a daily maximum. The 30-day average concentration should be used to calculate the 30-day average load.

Toxicity Based Ammonia Nitrogen - Where toxicity based ammonia nitrogen limits are more restrictive than those dictated by oxygen demand, the toxicity limit will also be included in the permit as a monthly average. In some cases, it may not be necessary to include the daily maximum ammonia limit if the monthly average ammonia limit is significantly more restrictive.

Stable Effluent Requirements - Stable effluent limits (advanced waste treatment) are defined as 10 mg/l (daily maximum)/4 mg/l (monthly average) for CBOD, and 2 mg/l (daily maximum)/0.5 mg/l (monthly average) for ammonia nitrogen. Unless requested otherwise by Permits Section, GLEAS will not model the actual daily maximum WQBEL below the stable effluent daily maximum values. As an alternative, the permittee may request that the actual WQBEL be used in lieu of stable effluent requirements. In these situations, the permit will include the actual daily maximum WQBEL limits, with negotiated monthly averages. Permits Section will need to request the actual daily maximum WQBEL's from GLEAS to use this alternative approach.