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Revised March 20, 1990

Modifications to Chapter IV - Basin Plan Support Document

The following is a brief description of the significant changes made in Chapter IV and the reasons for these changes. The changes begin on page 40 to the end of the document. There has not been any changes made to the water quality models or their procedures sections.

I. Modifications to the Wasteload Allocation Procedures.

The 1990 Water Quality Standards revisions have required numerous modifications to the previous wasteload allocation procedures. They include the introduction of the two number criteria, ammonia nitrogen criteria being a function of pH and temperature, more specific physical limitation to the mixing zone, the introduction of a zone of initial dilution, and a permit derivation procedure. These modifications will be discussed below.

A. Two Number Criteria. The new concept of using the two number criteria for toxic pollutants and total residual chlorine represents the instream water quality values necessary to protect aquatic species from both acute and chronic toxicity in designated streams, rivers, lakes, and wetlands. Therefore, the wasteload allocation procedure will now calculate two different values, one for meeting the acute criterion and the other meeting the chronic criterion.

B. Physical Limitations of the Mixing Zone. The standards establish the physical dimensions and flow restrictions of the regulatory mixing zone. The specified length limitations of the mixing zone, the actual low stream flow, and associated width, contained at the boundary of the most restrictive length limitation provides the amount of diluting flow allowed in the wasteload allocation procedures. The chronic criteria contained in the water quality standards will be met at the boundary of the mixing zone through dilution with the available stream flow in the mixing zone.

For toxic parameters (Table 1 of the Water Quality Standards), the mixing zone shall not exceed 25% of the 7Q10 stream flow or protected flow. While for ammonia nitrogen (Table 3 of the Standards) the mixing zone flow is restricted based on the facilities dilution ratio. Dilution ration is the ratio of the 7Q10 stream flow or protected flow to the effluent design flow.

C. Zone of Initial Dilution. This new concept represents a small area within the mixing zone where dilution is allowed such that the acute criteria is met at the defined boundary of this zone of initial dilution. The dimension and stream flow of this zone is limited to 10% of the mixing zone for toxic parameters. For ammonia nitrogen the dimension and stream flow of this zone is limited to 10% of the mixing zone for facilities with a dilution ratio of greater than 2 to 1. For facilities with a dilution ratio equal to or less than 2 to 1, the dimension and stream flow of this zone is limited to 5% of the mixing zone.

D. Ammonia Nitrogen Criteria. The revised ammonia criteria reflects the above mentioned two number criteria approach being pH and temperature dependent. This dependency requires that the wasteload allocation procedures first incorporate the pH and temperature conditions occurring at low stream flow periods in selecting the appropriate acute and chronic criteria. The wasteload allocations procedures then is calculated following the same procedure as for other toxics.

E. Prevention of Toxic Conditions in General Classified Streams. The 1989 water quality standards revisions further clarify the 'free from' statement applicable to all streams. This provisions states that all waters shall be free from substances attributable to wastewater discharges or agricultural practices in concentrations or combinations which are acutely toxic to humans, animal, or plant life. The wasteload allocation procedure to implement this provision will closely follow the existing approach by considering the laboratory toxicity data (96hr.LC_{50}) of the most sensitive aquatic specie present in the receiving stream.

Typically a resident fish (minnow) species is selected.

II. Permit Derivation Procedure.

A new provision of the water quality standards requires that the wasteload allocation value, calculated to protect water quality standards, be mathematically modified prior to being included in NPDES permits as effluent limits. The mathematical modifications, based on EPA guidance documents, reflect the uncertainty of effluent sampling, analytical precision, and effluent monitoring frequency. This procedure, discussed in this Support Document, will only be applied to parameters warranting water quality based permit limits, not to technology based limits, such as secondary treatment or BAT/BPT.

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Chapter IV - Segment Analysis Methodology & Wasteload Allocations

The ability of a stream to maintain an acceptable dissolved oxygen (DO) concentration is an important consideration in determining its capacity to assimilate wastewater discharges. Microbial oxidation of organic and certain inorganic matter present in wastewater uses dissolved oxygen. Oxygen supplied principally by reaeration from the atmosphere will replace any dissolved oxygen lost through oxidation processes. If, however, the rate of oxygen use exceeds the rate of reaeration, the DO concentration may decrease below minimum allowable standards.

To predict the variation in DO, as well as ammonia concentration in streams, several computer-based mathematical models have been used. The two models presently utilized are the Modified Iowa and the more sophisticated QUAL-II program. Each of these are described later in this chapter. Input data for the models were developed from existing technical information and recent field investigations of selected streams. When sufficient data were not available, conservative assumptions have been made that tend to assure a high degree of protection for water quality without necessitating unrealistically stringent effluent limitations. Recent water quality sampling has helped to demonstrate the reliability of particular constants and assumptions used, and improve the validity of the models. It is felt that with available data, a reasonably accurate prediction of the impact of different wastewater loads or treatment arrangements upon the DO and ammonia concentrations may be performed, and that determination of wastewater discharges that will not result in violation of water quality standards is possible.

THEORY AND METHODOLOGY

Modeling Theory

Dissolved oxygen concentrations in streams are controlled by many factors including atmospheric reaeration, biochemical oxygen demands (carbonaceous and nitrogenous), algal photosynthesis and respiration, benthal oxygen demands, temperature, and the physical characteristics of the stream. Many of these factors are difficult, if not impossible, to accurately assess. As a result of this difficulty, limitations on the use of these controlling factors are discussed below.

Photosynthesis can produce large quantities of oxygen during the day if algae are present in the stream. Conversely, at night algal respiration creates an oxygen demand. Research efforts have attempted to fit harmonic functions to this phenomenon, but with limited success. Specific allowance for diurnal fluctuations in oxygen levels is included in the QUAL-II computer model only.

Benthal oxygen demands result from anaerobic decomposition of settled organic material at the bottom of the stream. These reactions release carbonaceous and nitrogenous organic materials which create biochemical oxygen demands. The inclusion of benthal oxygen demands in the QUAL-II model requires extensive field surveys to determine the real extent of sludge deposits within a stream and coefficients that describe the release into the water. Since the impact is minor in most instances and no data are available to accurately describe sludge deposition areas, no special allowance for benthal oxygen demands is included in the Modified Iowa model formulation. However, QUAL-II has provision for benthic activities providing sufficient field data is available to calibrate and verify the rate constants.

A complete mathematical model to describe DO concentrations within the stream would include all significant factors. Natural systems cannot presently be expressed mathematically with absolute certainty, but reasonably accurate predictions can be made through realistic assumptions concerning the reaeration phenomenon and deoxygenation caused by carbonaceous and nitrogenous biochemical oxygen demands (BOD). Specific values obtained in detailed field investigations from other locations, with particular emphasis placed upon data collected in Iowa, provide the only basis for defining ranges of coefficient values being incorporated in the water quality models today. The continued effort towards the collection of water quality data at low flow conditions will aid in defining the above coefficient ranges used in the future.

Nitrogenous BOD is due to the oxidation of ammonia to nitrates by certain species of bacteria. This oxidation process is called nitrification. Nitrification is a two-step process whereby a specific bacterial species oxidizes ammonia to nitrite and a different bacterial species oxidizes the nitrite to nitrate. Theoretically, approximately 4.5 mg/l of oxygen are required to oxidize 1.0 mg/l of ammonia (expressed as nitrogen) to nitrate. This theoretical value may conservatively over estimate the oxygen demand of NH_3 as the nitrifiers obtain oxygen from inorganic carbon sources during combined energy and synthesis reactions. Actual values obtained have varied between 3.8 and 4.5 mg/l of oxygen per mg/l of NH_3-N. The Modified Iowa model uses 4.33 as the ratio of nitrogenous BOD to ammonia nitrogen. Since secondary wastewater treatment plant effluents quite commonly contain ammonia nitrogen levels of 10 mg/l during summer operations and 15 mg/l during winter periods, the equivalent nitrogenous BOD (should all the ammonia be converted to nitrates) is approximately 43 mg/l (summer) and 65.0 mg/l (winter). This is greater than the carbonaceous BOD of most secondary effluents.

Modified Iowa Model

The Modified Iowa model is a minor refinement of computer program historically used by the Department since 1976 to determine wasteload allocations. These refinements were recommended by the consulting firm, JRB Associates, McLean, Virginia, as part of their review of the Department's water quality models. The specific modifications are presented in a Users Manual and described in detail later in this section. The major changes include: replacement of the existing temperature adjustments for nitrification rates, equations to account for alage uptake of ammonia and a photosynthesis minus respiration (P-R) term for improvement of summer dissolved oxygen simulation. A copy of the complete users manual is available from the Department ("User's Manual for Modified Iowa DEQ Model", June, 1983).

1. Dissolved Oxygen Deficit Equation

The Modified Iowa model uses a version of the Streeter-Phelps equation for DO deficit within the stream. This approach recognizes both carbonaceous and nitrogenous BOD, atmospheric reaeration initial DO deficit and photosynthesis. Effects of photosynthesis and benthal oxygen demands are not specifically considered. The modified Streeter-Phelps equation suggested for use by JRB Assiciates is as follows:

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

where:

$D(t)$ = DO deficit at time t (mg/l)
D_0 = Initial DO deficit (mg/l)
L_0 = Initial ultimate carbonaceous BOD (mg/l)
N_0 = Initial ultimate nitrogenous BOD (mg/l)
K_1 = Carbonaceous deoxygenation rate constant, base e (day^{-1})
K_n = Nitrogenous deoxygenation rate constant, base e (day^{-1})
K_2 = Reaeration rate constant, base e (day^{-1})
R = Algal respiration oxygen utilization (mg/l/day)

P = Photosynthetic oxygen production (mg/l/day)
T = Time of travel through reach (day)

In this equation, the rates of oxygen utilization due to carbonaceous and nitrogenous BOD and algal activity are expressed as first order reaction rates. This is an accepted procedure for the carbonaceous demand, but represents a simplification for the nitrogenous demand. The "P-R" term represents the modification to the traditional Streeter-Phelps equations to account for algal influences to the available dissolved oxygen in the stream. The other traditional Streeter-Phelps components (Streeter, 1925) remain unchanged. The "P-R" term was obtained from the MS-ECOL fresh water model (Shindala _et_. _al_., 1981).

Ultimate carbonaceous and nitrogenous BOD concentrations as a function of time (t) are calculated as follows:

$$L(t) = L_o\, e^{-K_1 t}$$

$$N(t) = N_o\, e^{-K_n t}$$

where:

L(t) = Ultimate carbonaceous BOD at time (t) (mg/l)
N(t) = Ultimate nitrogenous BOD at time (t) (mg/l)

Since nitrification is a two-step process, many researchers have proposed that it is a second order reaction. However, most water quality models assume that it is a first order reaction for ease of programming and usage.

Nitrifying bacteria are generally present in relatively small numbers in untreated wastewaters. The growth rate at 20°C is such that the organisms do not exert an appreciable oxygen demand until about eight to ten days have elapsed in laboratory situations. This lag period, however, may be reduced or eliminated in a stream due to a number of reasons including the following: (1) discharge of large amounts of secondary effluent containing seed organisms, (2) nitrifier population buildup on the stream's wetted perimeter. In biological treatment systems, substantial nitrification can take place with a resultant build-up of nitrifying organisms. These nitrifying bacteria can immediately begin to oxidize the ammonia present and exert a significant oxygen demand in a stream below the outfall.

It is known that the biological nitrification process is generally more sensitive to environmental conditions than carbonaceous decomposition. The optimal temperature range for growth and reproduction of nitrifying bacteria is 26° to 30°C. It is generally concluded that the nitrogenous BOD will assume greatest importance in small streams which receive relatively large volumes of secondary wastewater effluents during the low flow, warm weather periods of the year (August and September). These conditions were used for the low flow determination of allowable effluent characteristics during summer periods. During winter low flow periods (January and February), nitrification will probably have limited influence upon the oxygen demand due to the intolerance of nitrifying bacteria to low temperatures. During analysis of winter low flow conditions, limited nitrification was observed to be occurring.

2. Respiration and Photosynthesis Equation

The equations used to calculate P, the photosynethic oxygen production, and R, the algal respiration oxygen utilization, are:

$$P = \frac{(OP)(GP - DP)(CHLA)}{AP}$$

where:

OP = mg oxygen produced by algae/mg algae
AP = ug chlorophyll-a/mg algae
GP = algal growth rate (day^{-1})
DP = algal death rate (day^{-1})
$CHLA$ = chlorophyll-a concentration (ug/l)

and

$$R = 0.025\ CHLA$$

The values of OP, AP and DP are selected from literature values by the modeler. Current literature values are presented in Table IV-1 (Page 19). It is essential that chlorophyll-a measurements be available from the stream sampling data. If not, chlorophyll-a values must be estimated by general field observation or conditions on similar stream and calibration, which detracts from the credibility of the calibration. Since nitrate and inorganic phosphorus are not included in the model, the growth rate (GP) must be calculated outside the model using the equation:

$$GP = \overline{u}\left(\frac{N}{N + K_{MN}}\right)\left(\frac{P}{P + K_{MP}}\right)\left(\frac{LI}{LI + K_{LI}}\right)$$

where:

GP = local algal growth rate at 20°C (day^{-1})

$\overline{u}$ maximum specific algal growth rate at 20°C (day^{-1})
N = sum of observed instream concentrations of NH_3-N and NO_3-N (mg/l)
K_{MN} = Michaelis-Menton half-saturation constant for total inorganic N (mg/l)
P = observed instream concentration of inorganic phosphorus (mg/l)
K_{MP} = Michaelis-Menton half-saturation constant for inorganic P (mg/l)
LI = average incident light intensity (kcal/m^2-sec)
K_{LI} = Michaelis-Menton half-saturation constant for light (kcal/m^2-sec)

Literature values for $\overline{u}$, K_{MN}, K_{MP}, LI, and K_{LI} are found in Table IV-1.

The values of OP and AP are input as constants for the entire stream, while GP, DP and CHLA are specified for each reach. The Michaelis-Menton constants are used to adjust the maximum potential algal growth rate by the amounts of light, nitrogen, and phosphorus that can limit algal growth. Each constant is the concentration at which that particular constituent limits algal growth to half the maximal or "saturated" value.

3. Algal Uptake of Ammonia Equation

Another new feature in the Modified Iowa model is the simulation of algal uptake of NH_3-N. The instream concentrations of inorganic nutrients are reduced by phytoplankton consumption. Phytoplankton requirements for inorganic N may involve both ammonia nitrogen (NH_3-N) and nitrate nitrogen (NO_3-N). The fraction of consumed nitrogen which is NH_3-N must be known if instream concentrations of NH_3-N are to be properly simulated. This fraction is the preferential NH_3 uptake factor.

The amount of NH_3-N removed by algae in a reach is calculated by the following equation taken from the MS-ECOL model (Shindala *et.* *al.*, 1981):

$$UP = \frac{(GP)(ANP)(NF)(CHLA)\left(e^{(GP-DP)(t)} - e^{-(K_N)(t)}\right)}{(GP - DP + K_N)}$$

where:

UP = amount of NH_3-N removed in a reach (mg/l)
ANP = mg N / ug chlorophyll-a
NF = fraction of NH_3 preferred for algal uptake (0 - .9)
t = time of travel through reach (day)

The model calculates t internally. The values for ANP and NF are obtained by calibration or from literature values. Ranges of literature values are found in Table IV-1. The model assumes that algal uptake of ammonia occurs until the instream concentration of NH_3-N is equal to the inorganic N half-saturation constant K_{MN}. If the instream concentration of NH_3 is below the half-saturation constant, the technical literature indicates that algae will switch to NO_3 as the sole source of nitrogen.

4. Rate Constant Determination

a. Deoxygenation Rate Constants

The carbonaceous deoxygenation rate constant (K_1) for most streams will vary from 0.1 to 0.5 per day (base e, 20°C). Early work by Streeter and Phelps (Streeter, 1925) determined an average value for the Ohio River of 0.23/day at 20°C (0.1/day, base 10). This value has been accepted and commonly used for years with reasonable results.

Specific deoxygenation rates for selected Iowa stream segments have been determined from stream surveys performed since 1977. These specific rates showed wide variations within each stream segment and between various streams. Thus, the carbonaceous deoxygenation rate of 0.2/day at 20°C is still used as an initial starting point in calibration/verification efforts. Future stream studies will be used to verify the specific rates applicable for Iowa streams.

Information on nitrogenous deoxygenation rates is extremely limited; however, available information indicates that nitrification rates (when active nitrification does occur) are somewhat greater than carbonaceous oxidation rates. Therefore, a nitrogenous deoxygenation rate (K_N) (of 0.3/day at 20°C was selected) as input data unless calibration/verification efforts provide a more reliable value. Again, future field measurements of typical nitrogenous deoxygenation rates in Iowa streams would greatly enhance the accuracy of the modeling effort.

The modified model alters the value of K_N within each reach as a function of the stream DO concentration. Because nitrifying bacteria are very sensitive to DO levels, K_N is reduced when low DO conditions exist. The following equation, which accounts for the effect of DO concentrations on nitrification rates, is taken from the Wisconsin QUAL III Model (WDNR, 1979):

$$PN = 1-e^{-(.52)(DO)}$$

where:

PN = nitrification reduction factor
DO = dissolved oxygen concentration (mg/l)

The K_N value input to the model is multiplied by the reduction factor PN. The product is the value of K_N which is used in the dissolved oxygen deficit and nitrogenous BOD equations.

b. Reaeration Rate Constant

The particular formulation used on Iowa streams incorporates the recently developed relationship of Tsivoglou and Wallace (Tsivoglou, 1972) adopted for determination of the reaeration rate constant. This formulation is based on the premise that the reaeration capacity of nontidal fresh water streams is directly related to the energy expended by the flowing water, which in turn is directly related to the change in water surface elevation.

The change in water surface elevation divided by the time of flow is the average rate of energy expenditure. The original Tsivoglou and Wallace formulation has been modified to account for the percentage of ice cover. This relationship is expressed by:

$$K_2 = \frac{c\Delta h\ (ICE)\ (at\ 20°C)}{t}$$

where:

K_2 = Reaeration rate constant (1/day), base e
c = Gas escape coefficient (1/ft)
Δh = Change in water surface elevation (ft)
ICE = Factor reflecting effect of ice cover on reaeration rate (unitless) (ICE = 1-% ice cover)
t = Time of travel (days)

Tsivoglou's equation was derived from actual measurement of stream reaeration rates by a new field tracer procedure in which a radioactive form of the noble gas krypton serves as a tracer for oxygen.

The calibration results for sampled Iowa streams have indicated that the following guidelines are appropriate with respect to the gas escape coefficient incorporated in the Tsivoglou expression:

$$c = 0.054\ (@20°C)\ \text{for}\ 15 \leq Q \leq 3000\ \text{cfs}$$

$$c = 0.115\ (@20°C)\ \text{for}\ 0 \leq Q \leq 15\ \text{cfs}$$

Other calibrated/verified values may be used on streams with sufficient water quality data.

In development of Tsivoglou's procedure, other reaeration rate predictive formulas were compared with results obtained from the field tracer technique, but none appeared to predict stream reaeration rates as accurately as the Tsivoglou model.

The ICE factor ranges from 0.05 for complete ice cover to 1.0 for zero cover. The selected input value is based on available field data or estimated by the modeler.

5. Temperature Corrections

Temperature corrections for the carbonaceous and nitrogenous deoxygenation rate constants and also the reaeration rate constants are performed within the computer model. The following equations define the specific temperature corrections used in the program:

$$K_{1(T)} = K_1(20) \times 1.047^{T-20}$$
$$K_{2(T)} = K_2(20) \times 1.0159^{T-20}$$
$$K_n(T) = K_n(20) \times 1.080^{T-20}$$
$$GP_{(T)} = GP_{(20)} \times 1.047^{T-20}$$

where:

T = Water Temperature, °C

This temperature correction for K_1 represents the state-of-the-art, and is a widely accepted formulation. The K_2 and K_N equations represent the more accepted functions used in the Vermont QUAL-II model (Meta Systems, 1979). The growth rate temperature correction is taken from the MS-ECOL model (Shindala _et_. _al_., 1981).

The principal factor affecting the solubility of oxygen is the water temperature. Dissolved oxygen saturation values at various temperatures are calculated as follows:

$$C_s = 24.89 - 0.426T + 0.00373T^2 - 0.0000133T^3$$

where:

T = Water temperature, °F
C_s = Saturation value for oxygen at temperature, t (°F), at standard pressure.

6. Stream Velocity Calculations

Stream velocities are important in determining reaeration rates and the downstream dispersion of pollutants. The computer model used calculates velocity based on either a variation of the Manning Formula for open channel flow and the Leopold-Maddock predictive equation.

a. Manning Formula

The Manning Formula for open channel flow is:

$$v = \frac{1.49R^{2/3}\ S^{1/2}}{n}$$

where:

v = Velocity (fps)
R = Hydraulic radius (ft)
S = Channel Slope (ft/ft)
n = Roughness coefficient

For a river or stream with a width much greater than its depth, the value of R is approximately equal to the mean depth. If both sides of the equation are multiplied by the cross-sectional area (width x mean depth), the following equation results:

$$Q = \frac{1.49}{n}\ wd^{5/3}\ S^{1/2}$$

where:

d = Mean river depth (ft)
Q = Discharge (cfs)
w = Water surface width (ft)
S = Slope (ft/ft)
n = Roughness coefficient

All values except d are input values. Internally, the program solves the above equation for d, then calculates the velocity v by:

$$v = Q/A = Q/wd$$

River slopes were obtained from existing stream profiles when available, but usually were taken from USGS topographic maps. Slopes obtained from USGS maps are rather generalized, and more accurate river profiles would greatly improve the accuracy of velocity determinations.

River widths were estimated from information obtained from field observations and flow and cross-sectional data at each USGS gauging station.

Roughness coefficients are estimated from charts and techniques presented in Chow (Chow, 1965). The value of 0.035 is being used on Iowa streams unless the physical characteristics of the stream are more accurately reproduced by another value.

In developing the particular model run for a stream segment, depth and velocity data from stream gauging stations or from field surveys is used to extrapolate depth and velocity at other points along the segment. The extrapolation is a rough approximation; however, it is reasonably close over the average length of a stream. When available, the use of field investigations to determine actual stream velocities and depths at many selected stream sites in the modeled segment have improved the accuracy of the model.

The Manning equation is used where little historical flow and velocity information exists in the stream segment. If flows and velocities are measured during a calibration sampling event, the roughness coefficient n can be calibrated. However, in most instances, a more reliable flow, velocity relationships can be modeled by using the Leopold-Maddock equation.

b. Leopold-Maddock Equation

The Leopold Maddock (Leopold, 1953) equation predicts stream velocity as a function of discharge according to:

$$V = aQ^b$$

where:

V = Stream velocity (ft/sec)
Q = Discharge (cfs)
a, b = Empirical constants

It is significant to point out that the empirical constants, a and b, apply to a specific stream cross section. The value of b represents the slope of a logarithmic plot of velocity versus discharge and a represents the velocity at a discharge of unit (i.e., the y-axis intercept).

The Leopold-Maddock equation has been used in many studies and has been found to produce reliable results when the empirical constants are properly evaluated. Its use is limited, however, to streams for which considerable historical data are available for determining representative values for the empirical constants. A regression analysis is performed on several sets of velocity-discharge data to determine the empirical constants. The data selected for use in the analysis corresponds to low flow conditions since the use of high flow data may bias the results.

Since stream systems are rarely characterized by reaches of uniform cross section, slope, and roughness parameters, the empirical constants are determined for several representative cross sections of each stream system to be modeled. The same values of the empirical constants usually do not apply to all reaches along a stream segment unless field measured data indicates such is the case. JRB Associates staff indicated the a value for "b" of .25 is commonly used for smaller streams and rivers such as found in Iowa. Thus, where limited field information exists, "a" can be determined if "b" is assumed to equal 0.25 by solving the above equation. The use of this assumption will occur only if insufficient flow or stream cross sectional data exist from various available sources. Data sources for velocity and discharge values are the USGS gauging station data forms 9-207 or from stream surveys obtaining current meter and cross section measurements.

7. Computer Input and Output Data

In order to calculate water quality at various points in the river, the river length to be modeled was divided into reaches. River characteristics such as mean widths, depths, velocities, deoxygenation and reaeration rate constants, and water temperatures were considered for each small reach. The overall stream length modeled was kept to less than 20 miles to insure steady state conditions. The location of the reaches was set by one or more of the following:

a. A tributary.
b. A wastewater discharge.
c. A change in river characteristics, such as river width or slope.
d. A dam.

In order to calculate water quality characteristics at various points within each reach, the reaches were divided into segments called sections.

Actual data input into the computer program are as follows:

1. Initial river conditions such as flow and concentrations of ultimate carbonaceous BOD, ammonia nitrogen, DO.

2. Uniform background flow contributions for each reach and concentrations of ultimate carbonaceous BOD, ammonia nitrogen, and DO in the ground water.

3. The number of reaches.

4. For each reach the following:

    a. Length
    b. Number of sections
    c. Water temperature
    d. Channel Slope
    e. River width
    f. Roughness coefficient

    used in Tsivoglou & Manning equations

    g. Deoxygenation rate constants
    h. Empirical constants - Leopold-Maddock equation
    i. Ice Cover

5. Wastewater or tributary inflows consisting of inflow rates, ultimate carbonaceous BOD ammonia nitrogen, and DO concentrations.

The computer printout of the model run includes a reformat of all input data and key calculated data for each stream reach and segment.

This calculated data includes:

1. Stream Velocity
2. Rate Constants
3. Saturated Dissolved Oxygen Concentration
4. Travel Time
5. BOD_u, NH_3-N and Dissolved oxygen instream concentrations

An example of the output is found in the User's Manual.

TABLE IV-1
TYPICAL VALUES OF INPUT VARIABLES FOR MODIFIED IOWA MODEL

VARIABLE	DESCRIPTION	RANGES OF VALUES	RECOMMENDED WLA VALUE
NF	Preferential NH_3 Uptake Factor	0 - 0.9	Calibrate
ANP	mg Nitrogen/ug Chlorophyll-a	.0007 - .009	Calibrate
K_{MN}	Michaelis-Menton Half-saturation Constant for Nitrogen (mg/l)	.01 - .20	Calibrate
K_{MP}	Michaelis-Menton Half-saturation Constant for Phosphorus (mg/l)	.01 - .05	Calibrate
K_{LI}	Michaelis-Menton Half-saturation Constant for Light (mg/l)	-----	.0035
AP	ug Chlorophyll-a/mg Algae	10 - 100	Calibrate
OP	mg Oxygen Produced by Algae/mg Algae	1.4 - 1.8	1.63
K_1	Carbonaceous Deoxygenation Rate Constant (day^{-1})	.02 - 3.4	Calibrate
K_N	Nitrogenous Deoxygenation Rate Constant (day^{-1})	.3 - 3.0	Calibrate
C	Tsivoglou Escape Coefficient (ft^{-1})	-----	.054, $15 \le Q \le 3000$ cfs .110, $1 \le Q \le 15$ cfs
$\bar{u}$	Maximum Algal Growth Rate (day^{-1})	1 - 3	2
DP	Local Algal Death Rate (day^{-1})	.024, .24	Use higher value if nutrients are scarce or chlorophyll-a concentration exceeds 50 ug/l; otherwise use lower value
ICE	Factor Relating Ice Cover to Reduced Reaeration Capacity	.05 - 1.0	Field observation

Vermont QUAL-II Model

The Vermont QUAL-II water quality model can simulate conservative and nonconservative constituents in branching stream and river systems. The constituents which can be modeled by the revised version of QUAL-II are:

- Dissolved Oxygen (DO)
- Biochemical Oxygen Demand (BOD)
- Temperature
- Algae
- Organic Nitrogen
- Ammonia (NH_3-N)
- Nitrite (NO_2-N)
- Nitrate (NO_3-N)
- Dissolved Phosphorus
- Organic Phosphorus
- Coliform
- Conservative Substances

The model was adapted for Iowa conditions and needs by JRB Associates. A copy of the detailed User's Manual can be obtained from the Department ("User's Manual for Vermont QUAL-II Model", June, 1983). The User's Manual will provide documentation of the theoretical aspects of the model, as well as a description of the model input and data requirements. The following discussion is, in part, key items from the User's Manual. The size and complexity of the document prohibits its reproduction in this chapter of the "Basin Plan Support Document".

1. Background

The QUAL-II model is an extension of the stream model, QUAL-I, developed by F. D. Masch and Associates, and the Texas Water Development Board in 1971. QUAL-I was originally designed to simulate the dynamic behavior of conservative materials, temperature, BOD and DO in streams.

Water Resources Engineers, Inc. (WRE) revised the QUAL-I model to include the steady state simulation of NH_3, NO_2, NO_3, dissolved phosphorus, algae and coliforms as well as DO and BOD. This WRE QUAL-II model has since undergone numerous revisions to incorporate additional parameters and changes in constituent interactions. The version of QUAL-II which is used by the Department is the Vermont version of QUAL-II.

The Vermont QUAL-II is basically a version developed by Meta Systems, Inc. (1979), with later modifications by Walker (1980, 1981) and the Vermont Department of Water Resources and Environmental Engineering (1981). The changes Meta Systems introduced in 1979 to U.S. EPA's version of QUAL-II include the following:

- Incorporation of the simulation of organic nitrogen.
- Provision for algal uptake of ammonia as a nitrogen source.
- Steady state calculation of diurnal oxygen variations due to algal photosynthesis and respiration based on diel curve analysis.
- Changes in the model to delete the dynamic simulation of DO, thus allowing dynamic simulation of temperature only.
- Inclusion of dam reaeration.

- Changes in the methods used to calculate the reaeration coefficient, K_2.

- Deletion of the radionuclide simulation.

To this Meta Systems version of QUAL-II, Vermont has added the simulation of organic phosphorus and has modified the expressions for algal kinetics.

The majority of the information in the User's Manual came from the following four sources:

a. Roesner, L. A., Giguere, P. R. and Evenson, D. E. Feb. 1981. Computer Program Documentation for Stream Quality Modeling (QUAL-II). U.S. EPA Center for Water Quality Modeling, Environmental Research Laboratory, Athens, GA. EPA-600/9-81-014.

b. Roesner, L. A., et al. Feb. 1981. User's Manual for Stream Quality Model (QUAL-II). EPA-600/9-81-015.

c. Meta Systems, Inc. July 1979. Documentation for the Meta Systems Version of the QUAL-II Water Quality Simulation Model.

d. State of Vermont, Agency of Environmental Conservation, Department of Water Resources and Environmental Engineering. Jan. 1982. Lower Winooski River Wasteload Allocation Study, Part B: Mathematical Modeling Report.

2. Stream System Representation

QUAL-II permits any branching, well-mixed stream system to be modeled. It assumes that the major transport mechanisms, advection and dispersion, are significant only along the longitudinal axis of the stream. It can handle multiple waste discharges, withdrawals, tributary flows, incremental inflow, flow augmentation, and dam reaeration. Hydraulically, QUAL-II is limited to the simulation of time periods during which the steam flows in the river basin are essentially constant (Roesner, _et al_., 1981). Thus, the length of river or stream to be modeled is relatively short, less than 20 miles. The length should be long enough to account for the decay of organic pollutants and the recovery to near background conditions. The use of this model is not suitable for one run over the entire stream or river length.

Streams to be simulated by QUAL-II are divided into reaches, and further subdivided into computational elements. River reaches are the basis of most data input. Hydraulic data, reaction rate coefficients, initial conditions, and incremental inflow data are constant for all computational elements within a reach. For the purposes of QUAL-II, the stream is conceptualized as a network of completely mixed reactors -- computational elements -- which are linked sequentially to each other via the mechanisms of transport and dispersion (Roesner, _et al_., 1981).

Although QUAL-II has been developed as a relatively general program, Roesner, _et al_. (1981) cite certain dimensional limitations which have been imposed upon it during program development. These limitations are as follows:

Reaches:	a maximum of 75
Computational elements:	no more than 20 per reach nor 500 in total
Headwater elements:	a maximum of 15
Junction elements:	a maximum of 15

Input and withdrawal elements: a maximum of 90 in total

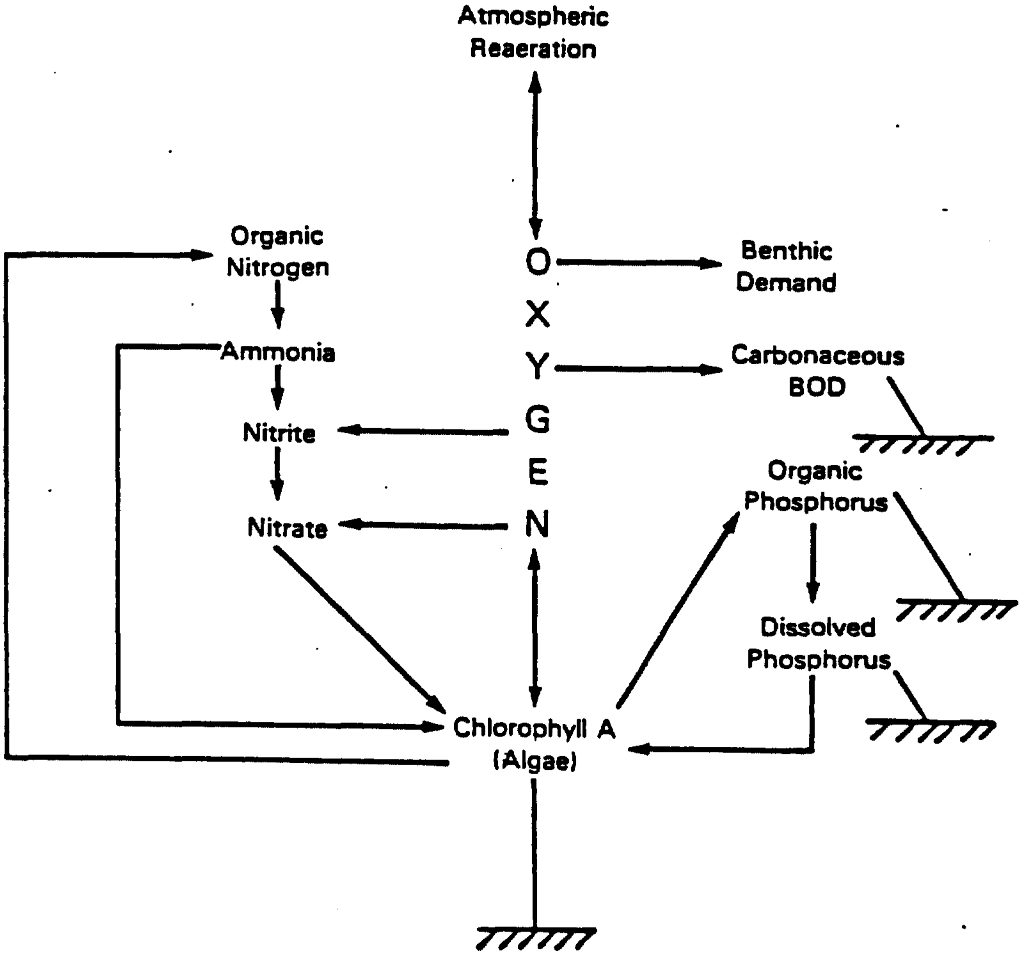
QUAL-II makes certain assumptions about the stream system being simulated, including the following:

- QUAL-II assumes first order kinetics.
- The model utilizes a simplified nutrient-algal cycle with Michaelis-Menton kinetics.
- Only constant inflows and point source discharges are considered in the model.
- Each computational element is assumed to be completely mixed.
- The model does not take into account variations in depth or within stream cross section in each.

3. General Model Relationships

QUAL-II utilizes a mass balance differential equation which describes the behavior of a water quality constituent in one dimension. The model is structured to simulate the major interactions of the nutrient cycles, algal production, benthic oxygen demand, carbonaceous oxygen uptake, atmospheric reaeration, and the effect these processes have on receiving water concentrations of dissolved oxygen. The interactions of all these constituents are illustrated in Figure IV-1. Arrows on Figure IV-1 indicate the direction of normal system progression in a moderately polluted environment; the directions may be reversed in some circumstances for some constituents. Roesner, _et al_. (1981) point out an example of process reversal: under normal conditions, oxygen will be transferred from the atmosphere into the water. Under conditions of oxygen supersaturation, which can occur as a

Figure IV-1
General Model Structure for QUAL-II



Source: Vermont, 1982

result of algal photosynthesis, oxygen might actually be driven from solution, causing the direction of flow to reverse.

Coliforms are modeled as nonconservative decaying constituents, and do not interact with other constituents. The conservative constituents, of course, neither decay nor interact in any way with other constituents.

The detailed mathematical relationships that describe the individual reactions and interactions are presented in the User's Manual. Their inclusion would make this document very lengthy and cumbersome. A brief discussion on the mathematical relationships for phytoplanktonic algae are included as this is one of the significant improvements over the past available model.

The chlorophyll-a concentration in a stream system is assumed to be directly proportional to the concentration of phytoplanktonic algal biomass. In QUAL-II, algal biomass is converted to chlorophyll a by the simple relationship:

$$\text{Chl-}\underline{a} = a_0 A$$

where:

Chl-a = chlorophyll-a concentration (ug/liter)
$\overline{A}$ = algal biomass concentration (mg/l)
a_0 = a conversion factor - chlorophyll a to algae ratio

The growth of algae (chlorophyll-a) is calculated according to the following differential equation:

$$\frac{dA}{dt} = uA - p_0 A - \frac{s}{d} A$$

where:

A = algal biomass concentration (mg/l)
t = time
u = the local specific growth rate of algae which is temperature dependent (1/day)

p_0 = algal death rate (1/day)
s = the local settling rate for algae (ft/day)
d = average depth (ft)

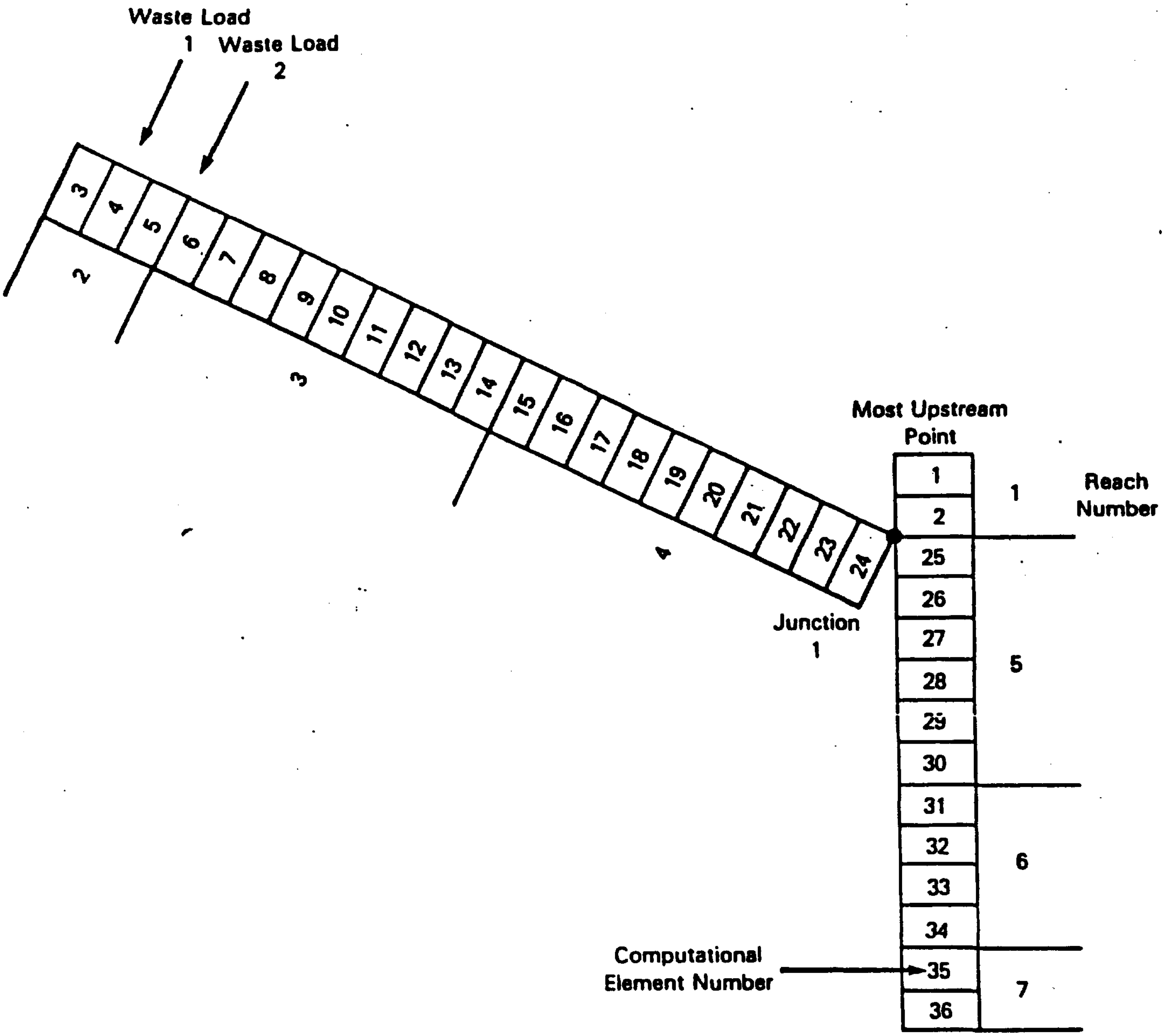
It should be noted that the local algal growth rate is limited by light and either nitrogen or phosphorus, but not both. Thus, nutrient/light effects are multiplicative but nutrient/nutrient effects are alternate (Walker, 1981). The specific expression used to calculate local algal growth rates are listed in the User's Manual. In the QUAL-II model, the "algal respiration rate" controls only the uptake of oxygen by algae, while the "algal death rate" governs both the change in algal biomass due to endogenous respiration and the conversion of algal P to organic P. The "algal N to organic N" term represents the conversion of algal N to organic N. Algae are assumed to use ammonia and/or nitrate as a source of nitrogen. The effective concentration of available nitrogen is the sum of both concentrations. The algal growth rate and death rates are temperature dependent. They are corrected within the model, as are all other temperature dependent system variables, according to the procedure explained in the User's Manual.

4. Input Data

The first step in setting up the input data for QUAL-II is to prepare a graphic representation of the stream system, similar to that shown in Figure IV-2. The best way to begin this is to locate the sampling stations, point source discharges, and stream junctions on USGS topographic maps. Stream miles can then be computed using a map wheel or other measuring device.

As shown in Figure IV-2, the stream must be divided into reaches. Reaches are stretches of stream that exhibit uniform hydraulic characteristics.

Figure IV-2
Sample Reach Network



The reaches are themselves divided into computational elements, which must be the same length throughout the stream system. The length chosen for the computational elements is determined by the degree of resolution needed to approximate the processes taking place in the stream. For example, if the observed dissolved oxygen concentration goes from saturated concentration to critical concentration and back to saturated concentration over an interval of about five river miles, a degree of resolution of less than one mile is appropriate (Roesner, et al., 1981).

A sketch should be made of the stream reach configuration and the elements numbered. Each computational element is numbered sequentially, beginning with the uppermost point of the stream and proceeding downstream. When a junction is reached, the numbering scheme proceeds from the main stream element immediately upstream of the junction, to the uppermost point of the tributary, and continues downstream. Figure IV-2 illustrates this numbering sequence.

Each computational element in the stream reach network is classified into element types. These element types provide the location of discharges, withdrawals, tributaries, etc. The seven element types used in QUAL-II are:

Number	Type
1	Headwater source element
2	Standard element, incremental inflow only
3	Element on main stream immediately upstream of a junction
4	Junction element
5	Most downstream element
6	Input element
7	Withdrawal element

Special attention should be paid to the numbering of elements, particularly at the junctions. The point source loads are numbered downstream in the order of the elements. Any withdrawals are counted as a point source load in the numbering scheme. It is important that this be done correctly, since QUAL-II associates the first wasteload card with the first type 6 or 7 element in the stream configuration. The same is true of the order of the headwaters.

For informational purposes, the following types of input data groups show the complexity and flexibility of the QUAL-II program. These 12 groups each contain different categories of information which the user must supply to the program.

Card Type 0	Titles
Card Type 1	Control Data
Card Type 1A	Model Parameters
Card Type 2	Reach Identification
Card Type 3	Flow Augmentation Data
Card Type 4	Computational Element Flag Fields
Card Type 5	Hydraulic Data
Card Type 6	BOD and DO Reaction Rates
Card Type 6A	Algae, N and P Constants
Card Type 6B	Other Coefficients
Card Type 7	Initial Conditions
Card Type 7A	Initial Conditions (continued)
Card Type 8	Incremental Runoff Conditions
Card Type 8A	Incremental Runoff Conditions (continued)
Card Type 9	Stream Junction Data
Card Type 10	Headwater Sources
Card Type 10A	Headwater Sources (continued)
Card Type 11	Point Source Inputs and Withdrawals
Card Type 11A	Point Source Inputs and Withdrawals (continued)
Card Type 12	Dam Reaeration Data

Specific input sequences and formats are presented in the User's Manual. Detailed procedures for calibrating the rate constants to specific stream conditions are also presented in the User's Manual. While running the program for a specific stream or for calibrating a segment, the suggested ranges for reaction coefficients are presented in Table IV-4. These values serve as a guide for a run of the QUAL-II program.

TABLE IV-4
RECOMMENDED RANGES FOR REACTION COEFFICIENTS FOR QUAL-II

DESCRIPTION	UNITS	RANGE OF VALUES
Ratio of chlorophyll-a to algae biomass	$\frac{ug\ Chl\text{-}a}{Mg\ A}$	10-100
Fraction of algae biomass that is Nitrogen	$\frac{Mg\ N}{Mg\ A}$	0.07-0.09
Fraction of algae biomass that is Phosphorus	$\frac{Mg\ P}{Mg\ A}$	0.01-0.02
O_2 Production per unit of algal growth	$\frac{Mg\ O}{Mg\ A}$	1.4-1.8
O_2 Uptake per unit of algae respired	$\frac{Mg\ O}{Mg\ A}$	1.6-2.3
O_2 Uptake per unit of NH_3 oxidation	$\frac{Mg\ O}{Mg\ N}$	3.0-4.0
O_2 Uptake per unit of NO_2 oxidation	$\frac{Mg\ O}{Mg\ N}$	1.0-1.14
Rate constant for the biological oxidation of NO_2 to NO_3	1/Day	0.10-1.00
Rate constant for the biological oxidation of NO_2 to NO_3	1/Day	0.20-2.0
Rate constant for the hydrolysis of organic-N to ammonia	1/Day	0.02-0.4
Dissolved phosphorus removal rate	1/Day	0.01-0.10
Organic phosphorus settling rate	1/Day	0.001-0.10
Algal settling rate	ft/Day	0.5-6.0
Benthos source rate for phosphorus	$\frac{Mg\ P}{day\text{-}ft}$	Highly Variable
Benthos source rate for NH_3	$\frac{Mg\ N}{day\text{-}ft}$	Highly Variable
Organic P decay rate	1/Day	0.1-0.7
Carbonaceous deoxygeneration rate constant	1/Day	0.02-3.4

TABLE IV-4
RECOMMENDED RANGES FOR REACTION COEFFICIENTS
- Continued -

DESCRIPTION	UNITS	RANGE OF VALUES
Reaeration rate constant	1/Day	0.0-100
Rate of loss of CBOD due to settling	1/Day	-0.36 to 0.36
Benthic oxygen uptake	$\frac{\text{Mg O}}{\text{day-ft}}$	Highly Variable
Coliform die-off rate	1/Day	0.5-4.0
Maximum algal growth rate	1/Day	1.0-3.0
Algal death rate	1/Day	.024-.24
Preferential NH_3 uptake factor	--	0.0-0.9
Algal N to organic N decay rate	1/Day min	.11
Algal respiration rate	1/Day	0.05-0.5
Michaelis-Menton half-saturation constant for light	Langleys	0.02-0.10
Michaelis-Menton half-saturation constant for nitrogen	Mg/l	0.01-0.20
Michaelis-Menton half-saturation constant for phosphorus	Mg/l	0.01-.05
Non-algal light extinction coefficient	1/ft	Variable
Algal light extinction coefficient	$\frac{\text{1/ft}}{\text{ug Chl-a/L}}$	.005-.02

Since the QUAL-II program is written in FORTRAN, it is essential that the input data be in the correct format for the program to run.

MODELING DATA SOURCES

The bulk of the work in stream water quality modeling is the collection and interpretation of all available data describing the stream system to be modeled. This section describes procedures and data sources that may be used in stream modeling for wasteload allocation work.

Wastewater Discharges - Required data for each discharger are effluent flow rates and effluent characteristics such as BOD, NH_3-N and DO concentrations and temperature. The specific location and characteristics of some smaller wastewater discharges are often unknown and are determined from field investigations or during special stream surveys. Most wastewater discharge information is available in Departmental files.

River Miles - The first step in modeling a river system is determining the locations of all tributaries, wastewater dischargers, dams and other critical points along the river. The total length of the main channel of the river to be modeled must be established and river miles need to be located such that the location of tributaries, etc., can be determined to the nearest one-tenth of a mile. Often the U.S.G.S. or Corps of Engineers have located river miles on larger streams, but in some instances these river miles are incorrect or do not correspond to the existing stream channel. Experience has shown that it is best to start from the beginning with the best available base map and establish river miles by use of appropriate measuring techniques. The best maps to start with are U.S.G.S. topographic maps. These consist of section maps (scale: 1:250,000) and quadrangle maps (scale: 1:24,000). Section maps are available for the state while quadrangle maps are not completed for some areas. Other maps such as state and county road maps can also be used to supplement the U.S.G.S. maps.

Field Reconnaissance - During special stream surveys the following data can be easily collected:

1. The precise location of wastewater discharges.
2. The location, condition, height and type of dams and the nature and approximate length of the pool created by the dam.
3. Approximate river widths at bridge crossings.
4. Approximate shape of channel cross sections.
5. Channel characteristics that will be an aid in determining channel roughness coefficients.

The special stream survey should be performed, if possible, during flow conditions that represent the flows used in the modeling effort. Stream discharge information during stream surveys may be verified from data obtained from the U.S.G.S. Discharges observed during stream surveys are almost greater than 7 day, 10 year low flows. Data such as river widths need to be extrapolated downward to represent 7 day, 10 year low flow conditions. Shapes of channel cross sections are an aid in this determination.

River Channel Slopes - After river miles and locations are established the next step is determination of river channel slopes. During low flow it can be assumed that river channel slopes are essentially the same as the slope of the water surface and channel profiles can be used as representative of water surface slopes. In some cases profiles of the river have already been determined.

This is usually done by the U.S. Army Corps of Engineers as part of work conducted prior to proposal or construction of flood control reservoirs. Without accurate profiles, river slopes can be determined from U.S.G.S contour maps by locating the points where contour lines cross the river. Stream slopes calculated from contour maps only represent an average value over the distance of the river between contour intervals. U.S.G.S. quadrangle maps (if available) are a more reliable source of slope data. Often, these are the only sources available and are the best method of slope determination without an extensive field survey.

River Widths and Roughness Coefficients - Estimation of river widths and roughness coefficients can occur in the field reconnaissance. Roughness coefficients can be estimated using charts and techniques in hydraulic texts and handbooks. One of the best references is Chow (Open-Channel Hydraulics, McGraw-Hill).

The variation of river widths with discharges can often be determined from data at U.S.G.S. gauging stations. The U.S.G.S periodically calibrates each gauge. The results from these calibrations are available on U.S.G.S form 9-207 and includes widths, cross-sectional area, mean velocities and discharges.

Reasonably accurate estimations of river widths at the desired discharge can usually be made with this gauging station information along with river widths measured during special stream surveys.

Stream Flow - In the determination of flow conditions throughout the river system to be modeled, all available data from U.S.G.S. flow measuring stations as well as flow rates of all wastewater discharges must be obtained. River flows need to be allocated among tributary, groundwater and wastewater inflow sources. The 7 day, 10 year low flows are used as the modeling basis, and are determined from a statistical analysis of the flow records at each of the gauging stations in the river system. Low flows have already been determined for partial and continuous gauging stations (e.g. Iowa Natural Resources Council, Annual and Seasonal Low-Flow Characteristics of Iowa Streams, Bulletin No. 13, 1979). The low flows at gauging stations must then be allocated to tributaries based on drainage areas. Tributary drainage areas may be available from existing publications e.g., Larimer, O.J., "Drainage Areas of Iowa Streams", Iowa Highway Research Bulletin No. 7, 1957) or they can be determined from U.S.G.S. contour maps.

A summation of tributary inflows and wastewater discharges often is less than the gauged flow. The difference is usually distributed along the main channel of the river as a uniform inflow in terms of cfs per mile of river reach length. If the gauged flow is less than the summation of tributary and wastewater inflows then it is possible to allot a uniform outflow from the main river channel.

Tributary and Groundwater Quality - Values for BOD, NH_3-N and DO of tributary and groundwater inflow are required for stream modeling. Often a main tributary to the stream being modeled has also been modeled. In this case the water quality of the tributary just before discharge into the main stream (as determined by the model) is used. If the tributary is small and has several wastewater discharges, hand calculations can be done to determine its water quality just before entering the main stream.

If the tributary is free of continuous discharging wastewater facilities, water quality has been assumed to be good. The tributary water quality input values are: ultimate BOD - 6 mg/l; NH_3-N concentrations - 0.0 mg/l (summer), 0.5 mg/l (winter); and DO at saturation.

Groundwater is also noted to be of high quality. The model input values for groundwater are ultimate BOD of 6 mg/l and NH_3-N at 0 mg/l. Groundwater DO's may be quite low depending on how it enters the stream. If it is subsurface flow, DO may be close to zero. Groundwater DO of 2 mg/l is used in wasteload allocation work in Iowa.

Rate Constants - The reaeration rate constant (K_2) is usually determined from one of many available predictive formulas. The one primarily used in the computer programs is based Tsivoglou formula.

Carbonaceous and nitrogenous deoxygenation rate constants are best determined experimentally for a specific wastewater effluent and/or calibrated for a specific stream. However, when specific values are not available "typical" values from similar streams may be used. In most cases the carbonaceous deoxygenation rate constant, K_1 will not be less than 0.2 per day (20°C). Values as high as 3.4 per day (20°C) have been reported in the literature.

Less information is available on the nitrogenous deoxygenation rate constants or nitrification rate in streams. Experimental work in Illinois (State of Illinois, Environmental Protection Agency, Guidelines for Granting of Exemptions from Rule 404(C) and 404(F) Effluent Standards, Oct., 1974) determined that the nitrogenous deoxygenation rate constant, K_n, ranged from 0.25 to 0.37 per day with an average value of 0.29 per day at 20°C. The current model uses a K_n value based on stream calibration from the modeled stream or similar streams. Other rate constants for benthic and algal kentics are based on calibration data or literature values. Specific explanation of these rate constants are in the user manuals for the modified Iowa and QUAL-II programs.

Dams and Impoundments - The damming of a stream creates special conditions for water quality modeling. For modeling purposes, dams and the resulting impoundments can be put into one of two classifications.

1. Large dams that back up rather extensive impoundments. Flow through the impoundment is not "plug flow" and inflow may be dispersed in a variety of vertical and horizontal directions.

2. Low-head dams which essentially make the river channel wider and deeper for a maximum distance of several miles. Flow through the impoundment is primarily "plug flow."

Class 1 dams and impoundments cannot easily be modeled to predict water quality. The modeling effort should be stopped at the beginning of the impoundment and started again below the dam. Water quality below the dam can be estimated from knowledge of the size of the impoundment, the method of water withdrawal and water quality data from stream surveys. Water taken from the lower levels of an impoundment during periods of summer stratification may be low in DO. If water flows over a spillway or an overflow weir it may be close to the DO saturation point. One can expect the BOD and NH_3-N concentrations in the discharge from large impoundments to be low unless the impoundment is highly eutrophic.

Class 2 dams and impoundments can be modeled by treating the impoundment as an enlarged or slower moving reach of the river. The length of the pool backed up by the dam may be divided into one or more reaches. Widths can be approximated from field observations. Slopes are taken as the water surface elevation and are quite small, generally elevation drops off no more than a foot over the length of the pool.

The dam may be treated as a reach 0.001 miles or 5.28 feet in length. The slope of this reach then becomes the dam height divided by 5.28 feet. The only water quality parameter that is significantly affected through the dam reach is the DO. Tsivoglou's reaeration rate constant prediction formula can be used to quite effectively predict reaeration over a dam. The equation for change in the DO deficit with time is:

$$D_t = D_0 e^{-K_2 t}$$

where:

D_t = DO deficit at time, t
D_0 = DO deficit at time zero
K_2 = Reaeration rate constant

Tsivolglou's reaeration rate constant predictive equation (neglecting ice conditions) is:

$$K_2 = \frac{c \Delta H}{t}$$

where:

c = escape coefficient
ΔH = change in elevation in time, t

Substituting into the DO deficit equation one obtains:

$$D_t = D_0 e^{-c \Delta H}$$

With a dam 10 feet high and c = 0.115/ft the ratio of D_t/D_0 is 0.32 or the deficit is 32 percent of the deficit at time zero. This is a DO deficit recovery of 68 percent.

Winter Conditions - Often the most critical period for maintaining water quality standards is winter low-flow periods instead of summer. Rates of deoxygenation are greatly reduced at the low temperatures, but ice cover also greatly reduces reaeration so that DO levels may be critical. Nitrification is significantly reduced at freezing temperatures. Consequently, ammonia concentrations may remain elevated over long stream reaches. Some loss of ammonia may occur in stream reaches due to algal uptake.

During winter periods reaeration rates may need to be reduced in proportion to the extent of ice cover. Even with 100 percent ice cover a small amount of reaeration undoubtedly takes place. In the waste load allocations reaeration rates were reduced in direct proportion to the estimated ice cover. The ice cover factor is assumed to vary in relationship to the amount of heated water in the discharge. The values range from 95% ice cover to 0% ice cover over the stream dams. Research and field investigations are needed on the effects of ice cover on stream reaeration rates and the extent of ice cover on specific stream reaches, in order to more precisely define the applicable reduction factor.

WASTELOAD ALLOCATIONS

Using the computer, wasteload allocations are determined for discharges in order to meet applicable State Water Quality Standards within the basin. Wasteload allocation analyses were performed for several seasonal conditions using projected year 2000 average dry weather wastewater discharge flows at the 7 day-1-in-10 year low stream ($7Q_{10}$) flow regime. Care must be taken in selecting the design discharge flow which would be expected during the $7Q_{10}$ stream flow or protected flow conditions. Some situations may warrant the use of average or wet weather design flows. Design flows will be obtained from facility plans, engineering reports or constructed permits.

Analysis is performed on stream designated either Class A, B or C with existing wastewater discharges and the tributaries classified for general uses only which receive wastewater discharge. This analysis is warranted to insure accurate consideration of field conditions for each type of stream. Some specific assumptions and considerations that are part of the analysis are discussed below.

Assumptions

In order to determine wasteload allocations for discharges within the state, specific assumptions are required. Identification of the major items required to evaluate and determine wasteload allocations are identified in the following list:

1. The major objective of the present hand calculations and the modeling activities is to assure that Iowa Water Quality Standards are met with the current and future effluent discharge flows. Modeling activities determine an allowable wasteload allocation by varying the allocation for point source discharges until the water quality model demonstrated that the oxygen concentrations would be maintained above 5.0 mg/l and ammonia nitrogen concentrations maintained below the water quality criteria levels in the designated stream segments at the 7 day, 1-in-10 year ($7Q_{10}$) or protected low flow. Hand calculations directly set the wasteload allocation through a dilutional relationship.

   One hundred percent of the low flow is used to assimilate the nonconservative pollutant (CBLD) in the wastewater discharge. The stream flow contained in the defined mixing zone is used to assimilate the conservative and toxic pollutants, such as ammonia nitrogen, TRC, metals, cyanide and toxics.

   The resulting wasteload allocation to meet stream standards will be the basis for establishing both maximum and average loading which the facility could discharge.

Specific $CBOD_5$ and NH_3-N will be noted as long as the values are less than those assumed for standard secondary (paragraph 7 below). If the average daily load exceeds the standard secondary level than the wasteload allocation would be set at standard secondary with no ammonia limitations. Only continuously discharging sources of wastewater are included in the modeling procedure. Waste stabilization ponds having controlled discharge capabilities were assumed not be discharging at low flow conditions.

2. Determination of 7 day, 1-in-10 year flow is required for each stream segment modeled. This low flow is tabulated in the USGS publication, "Annual and Seasonal Low Flow Characteristics of Iowa Streams," March 1979. On some very low flow stream segments which are predominantly wastewater, it may be important to determine the natural stream flow, not including Wastewater flow. The difference between the $7Q_{10}$ low flow and the wastewater discharge is assumed to be the result of groundwater inflow (or outflow) to the stream. This amount of groundwater inflow is assumed to remain constant over the planning period. Since most wastewater discharges will increase during this time period, the $7Q_{10}$ low flow in the year 2000 is grater by the amount of this increase. Groundwater contribution to the stream flow is distributed throughout the basin in proportion to the drainage area contribution to the stream along the length of its channel.

3. Ultimate carbonaceous CBOD is assumed to be 1.5 times the $CBOD_5$. This ratio may be changed if data indicates a different value would exist for a particular treatment process or waste characteristic.

4. Average stream temperature and pH is assumed to be approximated by the following table unless impacted by a thermal type discharge. This table represents monthly average values from ambient monitoring data contained in the EPA STORET data system.

Table IV-5
Statewide pH and Temperature Values

Month	pH	Temp °C
Jan	7.8	0.6
Feb	7.7	1.2
March	7.9	4.3
April	8.1	11.7
May	8.1	16.6
June	8.1	21.4
July	8.1	24.8
Aug	8.2	23.8
Sept	8.0	22.2
Oct	8.0	12.3
Nov	8.1	6.0
Dec	8.0	1.6

5. In order that the reaeration rate constant be applicable to wintertime ice conditions, the amount of ice cover on the stream is estimated. It is assumed that the effective amount of aeration should be inversely proportional to the percentage of ice cover. The winter reaeratior rate constant for each reach of the stream was then determined by multiplying

the temperature corrected rate constant by the adjusted fraction of open water in the reach. From experimental data the adjusted fraction of open water in the reach is equivalent to approximately one minus one half of the percent of ice cover (1-.5 x % ice cover).

Ice cover estimates were based upon general climatological conditions for the basin and upon field observations. Complete ice cover was assumed to be noncoincidental with the $7Q_{10}$ low flow. The percent of ice cover used for winter conditions in the computer analysis ranged from zero percent to 95 percent.

6. Since limited data is available describing each individual wastewater treatment facility's effluent dissolved oxygen concentrations, the following values were assumed for each class of wastewater dischargers:

Discharge limitations	Summer DO (mg/l)	Winter DO (mg/l)
Secondary Treatment	3.0	4.0
Advanced Treatment	5.0	6.0
Aerated Effluents	6-8	6-8
Industrial Plant	Each Discharge Handled Individually	

7. From analysis of available effluent data it has been assumed that a well operated and maintained secondary treatment plant should be able to achieve 10-15 mg/l and 15-20 mg/l of ammonia nitrogen under summer or winter conditions, respectively.

8. Best practicable or available technology effluent limitations described by EPA guidelines were used for industrial dischargers when available and sufficient. Otherwise, the actual allowable wasteload required to meet

stream standards is determined and identified as the wasteload allocation for that discharger. For municipal and industrial discharges with toxic parameters on streams classified as only general use, the allowable wasteload will be based on data contained in the U.S. EPA 304(a) criteria documents to determine instream toxic criteria. Calculations will follow the procedures presented in the Mixing Zone section item 2 (Toxic Conditions) of this chapter).

9. Water quality of tributaries (without wastewater sources) discharging to the streams being modeled was assumed to have saturated dissolved oxygen concentrations, an ultimate CBOD concentration of 6.0 mg/l and an ammonia nitrogen concentration of 0.0 mg/l in the summer of 0.5 mg/l in the winter.

10. Values of 4.0 mg/l, $CBOD_5$; 0.0 mg/l (summer) and 0.5 mg/l (winter) ammonia nitrogen; and 2.0 mg/l dissolved oxygen concentration were assumed as the water quality of the groundwater contribution.

11. Mixing of wastewater and tributary flows with the main body of water are site specific and calculated by the mixing zone equations noted in the Section. Mixing is not assumed to be complete and instantaneous.

12. Uniform lateral and longitudinal dispersion (plug flow) was assumed for the stream constituents as they move downstream.

Wasteload Allocation Procedures

The wasteload allocation procedures section is divided into two subsections, conventional pollutants and toxics. This division is necessary because the Water Quality Standards (Chapter 62) require different instream conditions or criteria to be met at different locations in the receiving stream.

A. Conventional Pollutants. The calculation of a wasteload allocation for conventional pollutants will consider the instream dissolve oxygen impacts of carbonaceous biochemical oxygen demand (CBOD), ammonia nitrogen, or any other oxygen demanding material. The wasteload allocation for ammonia nitrogen and possibly some other oxygen demanding materials is also addressed in the Toxics section, as these pollutants are also defined as toxics. It should be noted that this section of the wasteload allocation procedures does not consider other types of conventional pollutants, such as suspended solids, pH, temperature, or oil and grease.

The wasteload allocation of the oxygen demanding pollutants are determined directly from the results of water quality models which account for the fates of the pollutants as they move down the receiving stream.

The use of the two water quality models, QUAL-II and Modified Iowa, for determining wasteload allocations now requires additional data on algal kinetics and is limited to short stream reaches. Due to a lack of algal kinetic rate constants on many stream reaches, the extensive number of designated stream reaches in Iowa and other factors, a sequencing or screening approach is being used to arrive at the final wasteload allocation (WLA). The sequencing of calculating a WLA is divided into three different steps, hand calculations, use of the Modified Iowa model, and use of the QUAL-II model. Any WLA, new or recalculated, for any continuous discharging treatment facility is determined following the sequence. Requests for a WLA will be handled as soon as possible. However, if a back log begins to occur, all requests will first be hand calculated (if necessary). This should address at least 50% of all requests. The remaining will next be modeled with the Modified Iowa program and finally by the QUAL-II, if required.

1. Hand Calculations

The use of hand calculations are intended to provide a quick method to determine if a CBOD discharge of standard secondary or BPT/BAT from the treatment facility is causing a water quality violation. This step could be skipped if it is causing a water quality violation. This step could be skipped if it is felt that the facility obviously would require advanced treatment. This calculation as with the use of the water quality models, will be performed using the $7Q_{10}$ stream flow or protected flow, the treatment facilities design dry weather flow (if applicable) and the appropriate standard secondary $CBOD_5$ and assumed ammonia levels. With the alternative treatment limits allowed in the definition of standard secondary, the specific permitted $CBOD_5$ levels for the selected (or expected) type of treatment must be used in the hand calculations. This hand calculation approach uses a conservative assimilation rate of $CBOD_5$ (20 lbs/d/cfs) which has been derived from past modeling results.

a. Available Stream Capacity

Staff will calculate the available stream capacity for $CBOD_5$ below the discharger in question by the following relationships.

For $CBOD_5$

$$(Qu + Qd)\ 20.0\ \text{lbs/d/cfs} = CBOD_L$$

where:

Qu = $7Q_{10}$ stream flow (cfs)
Qd = Dry weather design discharge flow (cfs)
$CBOD_L$ = Stream capacity carbonaceous BOD_5 (lbs/day)

The loading from the treatment facility at its specific standard secondary level is given by the following equation.

b. Treatment Facility loadings

For BOD_5

$$(CBOD_5)(8.34)(qD) = CBOD_e$$

where:

$CBOD_5$ = Permitted standard secondary $CBOD_5$ (mg/l)
Qd = Dry weather discharge flow (mgd)
$CBOD_e$ = Carbonaceous BOD_5 in the effluent (lbs/day)

c. Stream Capacity vs. Effluent Loading

If the stream $CBOD_5$ capacity ($CBOD_L$) above is larger than the effluent standard secondary $CBOD_5$ ($CBOD_e$), the stream is termed effluent limited for CBOD and no additional modeling is required. The effluent limitation for $CBOD_5$ will be the level set for standard secondary.

If the above comparisons finds the stream not to be effluent limited, the stream would require modeling using the Modified Iowa model. Additionally, unusual factors or stream conditions might warrant undertaking the next calculation step even if the stream is effluent limited. These unusual conditions might include: several dischargers within close proximity, discharge of large algal concentrations, discharge of elevated ammonia nitrogen levels and loadings to the stream at or near stream capacity.

2. Use of Modified Iowa Model

For those treatment facilities found not to be able to discharge at a standard level, staff will set up and run the Modified Iowa model described above. For most dischargers,, the previous model runs (run streams) of 1976-1982 can be used as the basis input data. Minor modifications in data formatting are required to incorporate the new algal relationships. The Modified Iowa program will only be used on the stream reach below the discharge, not the entire river basin.

For each discharger, a spring/fall, summer and winter run normally will be made using the same dry weather design flow as used in the hand calculations above. These multi-seasonal runs are necessary because of the potential seasonal ammonia nitrogen wasteload allocations developed in the Toxics sections. It is necessary to calculate the toxics based wasteload allocation for ammonia nitrogen for use in the modeling of conventional pollutants. In many instances, the protection of the ammonia acute and chronic criteria will be more restrictive than the oxygen demand exerted by the ammonia.

Previously calibrated rate constants and literature values found in Table IV-1 will be used for the modified model. Detailed calibrations will be carried out only for the QUAL-II model. The use of the modified model is to be a quick modeling exercise with minimum staff time. Reiterative model runs will be made varying effluent $CBOD_5$ from standard secondary, and NH_3-N to more stringent levels until model responses shows that dissolved oxygen water quality standards are met in the designated reach.

If the modeling demonstrates that standard secondary will meet water quality standards, then that level will be the effluent limits for the treatment facility. If the modeling shows that advanced treatment is required, then the stream reach will be modeled using the QUAL-II program to determine final wasteloads allocations.

3. Use of the QUAL-II Model

For those treatment facilities found not to be able to discharge at a standard secondary level as evaluated by the above two calculations, then staff will set up and run the QUAL-II model described above. As with the Modified Iowa model, QUAL-II will be run only on the stream reach below the discharger. It is within this short reach that the steady state assumptions used in the model are valid.

Setting up the run stream under QUAL-II format requires additional staff effort. However, some of the physical stream data found in the Modified Iowa model's run stream will be used with the QUAL-II run stream. Whenever possible, calibrated rate constants will be used. These calibrated values can come from data obtained from intensive stream surveys on the receiving stream, from calibration data on similar streams or from literature values shown in Table IV-4. The same dry weather design flow and ammonia nitrogen values will be used, as above.

For each discharger, spring/fall, summer, and winter model runs normally will be made varying the effluent $CBOD_5$ (and NH_3-N if necessary) until the model response shows that dissolved oxygen water quality standards are met in the designated reach. The final wasteload allocation will be the combination of $CBOD_5$ and NH_3-N which just meet the standards.

Specific NH_3-N limitations will be noted in the WLA up to the standard secondary range mentioned above (15 mg/l summer and 20 mg/l winter and spring/fall). This will indicate the available stream capacity for NH_3-N and allow for careful design of nitrification facilities. $CBOD_5$ limitations will be noted as carbonaceous or inhibited values except for certain industrial facilities for which BPT/BAT limits are expressed as BOD_5. An attempt will be made to establish a $CBOD_5$ to BOD_5 relationship for each industry for use only in modeling of the stream's assimilative capacity.

B. Toxic Parameters. The wasteload allocation for toxics parameters will not require the use of the two above mentioned models. However, it is necessary to determine the characteristics of the regulatory mixing zone and zone of initial dilution (ZID). The regulatory mixing zone will be determined from data supplied by the applicants, or from use of the mixing zone model noted in the Appendix, Mixing Zone Characteristics. Department staff will use stream characteristics obtained from file information unless additional data is provided by the applicant which demonstrates that the characteristics of the outfall or the discharge location do not match the assumptions used in the development of this model. Other models will be used where appropriate or as they become available.

The Appendix presents the basic field data requirements of a mixing zone study to be provided by an applicant for recalculation of the local mixing zone. The purpose of the recalculation is to more closely approximate the local mixing zone using site specific data instead of statewide data. Contact should be made with the department's Water Quality Planning Section prior to beginning any field study.

The calculations of toxic wasteload allocations involves the incorporation of the 'regulatory' mixing zone and zone of initial dilution for each wastewater treatment facility, the design effluent flow rates, and the applicable acute and chronic water quality criteria. The determination of the mixing zone and zone of initial dilution are presented in a separate section. This Toxics section uses these defined zones and the corresponding flow in establishing the wasteload allocations for toxics.

1. Calculations: As noted in Subrule 61.2(4) of the Water Quality Standards, the chronic criteria must be met at the boundary of the mixing zone and the acute criteria must be met at the boundary of the zone of initial dilution. The method for meeting these boundary conditions will be to use a simple mass balance of the pollutants.

$$(Q_z-Q_d)\ (C_u) + Q_d\ (C_d) = Q_z\ (C_s)$$

where:

Q_z = Stream flow in the mixing zone or zone of initial dilution (cfs)

Q_d = Discharge flow (cfs)

C_u = Background concentration (mg/l)

C_d = Discharge wasteload allocation (mg/l)

C_s = Applicable water quality standard (mg/l)

This equation is solved for C_d, with the results being a wasteload allocation for the protection of the acute criteria and a wasteload allocation for the protection of the chronic criteria. The wasteload allocation value is then carried forward to the Permit Derivation Procedures section.

C. Ammonia Nitrogen: Special consideration must be given to the calculations for a wasteload allocation for ammonia nitrogen. First, water quality standards list the ammonia criteria as a function of pH and temperature because of the influence these parameters have on the toxic form of ammonia (unionized). Therefore, it is necessary to establish the applicable 'average' instream pH and temperature values of the designated stream segment receiving the effluent before the acute and chronic ammonia criteria can be selected.

Second, the mixing zone flow and the zone of initial dilution flow are a function of the dilution ratio of the receiving stream to the effluent. This dilution ratio is defined in Chapter 60 of the department rules for a specific discharger as the ratio of the 7Q10 stream flow to the effluent design flow.

1. Dilution Ratios. The discharger will be separated into one of three types dependent upon the river and discharge flows:

   (1) Types 1: The ratio of stream flow to discharge flow is less than or equal to 2 to 1.

   (2) Types 2: the ratio of stream flow to discharge flow is less than or equal to 5 to 1 and greater than 2 to 1.

   (3) Type 3: the ratio of stream flow to discharge flow is greater than 5 to 1.

2. Mixing Zone Boundary pH and Temperatures. For all of these types, the pH and temperature used to calculate the water quality standards for the boundary of the mixing zone are defaulted to the statewide background values (for statewide values, see Table IV-5) unless local values or regional values are provided by the discharger.

(1) Local Values: If the applicant desires that local values be used, they must supply a minimum of 72 sets of hourly pH and temperature readings for each of the three seasons of the year. Preferably the readings will be obtained during the lowest flows during these periods and typical of 24 hour conditions. Monitoring values may be obtained either from upstream of the outfall and the discharge or from the approximate location of the downstream limits of the ZID and the Mixing Zone.

(2) Regional Values: If a facility, at reasonable distance upstream of the applicant, has supplied background readings of pH and temperature which the department believes can be used as background, these readings will be used instead of the statewide averages. Normally readings at the end of an upstream facilities mixing zone will not be used as background for the facility unless these are from close proximity to the applicants outfall.

3. Zone of Initial Dilution Boundary pH and Temperatures. The acute water quality criteria for ammonia will be based upon one of three methods for the three types of dilution ratios.

(1) For Type 1 facilities, the acute water quality criteria for ammonia will be calculated based on the effluent pH and temperature values.

(2) For Type 2 and 3 facilities, the acute water quality criteria for ammonia will be based on a pH calculated using the following equation.

$$\text{ZID pH} = 10^{\{(\text{LOG(background pH)}+\text{LOG(discharge pH)})/2\}}$$

$$\text{TEMPERATURE} = \frac{(BF * BT + DF * DT)}{BF + DF}$$

BF = Background Flow in ZID (cfs)

BT = Background Temperature (°C)

DF = Discharge Flow (cfs)

DT = Discharge Temperature (°C)

(3) From actual field data gathered during the mixing zone study, discussed above, (1) Local Values.

4. Mixing Zone and ZID Flow. The flow used in the wasteload allocation calculations for the mixing zone and zone of initial dilution vary with the type of dilution ratio.

(1) Type 1: The river flow included in the mixing zone flow will be 100 % of the 7Q10 river flow. The river flow included in the zone of initial flow will be 5% of the river flow.

(2) Type 2: The 7Q10 river flow included in the mixing zone flow will be 50% of the river flow. The river flow included in the zone of initial flow will be 5% of the river flow.

(3) Type 3: The 7Q10 river flow included in the mixing zone flow will be 25% of the river flow. The river flow included in the zone of initial flow will be 2.5% of the river flow.

5. The calculation of the wasteload allocation uses the relationship:

$$(Q_z - Q_d) * C_u + Q_d * C_d = Q_z * C_s$$

where:

Q_z = Stream flow in the mixing zone or zone of initial dilution (cfs)

Q_d = Discharge flow (cfs)

C_u = Background Concentration (mg/l)

C_d = Discharge wasteload allocation (mg/l)

C_s = Applicable water quality standard (mg/l)

This equation is solved for C_d, with the results being a wasteload allocation for the protection of either the acute or chronic criteria. The most stringent wasteload allocation value is then carried forward to the Permit Derivation Procedures section.

6. Where visible dye studies have been done, the ammonia WLA calculations will use the mixing zone flow contained in the visible dye plume. If an analytical Fluorometer dye study is performed, the study results projected to the 7Q10 flow regime will be used to calculate the mixing zone flow. This mixing zone flow will be that value associated with diluting the effluent concentration to the maximum dye concentration at the mixing zone boundary. This is the required stream flow necessary to assure that the water quality standards are not exceed at any location across the mixing zone boundary.

   Once these ammonia values are determined, the above mass balance calculations or the use of ammonia decay relationship and algal uptake can be used to arrive at the applicable ammonia nitrogen wasteload allocations. The ammonia decay and algal uptake equations used in the modified Iowa model will account for the limited loss of ammonia in the mixing zone. These equations will be used when a WLA indicates an ammonia limit more stringent than secondary treatment. Using the allowed stream flow of the zone of initial dilution, the WLA calculations will assure that the acute criterion is met. Using the dilution of the flow contained in the mixing zone and the loss within the mixing zone, the WLA will assure that the chronic criterion is met.

D. Total Residual Chlorine. Total residual chlorine (TRC) effluent limits will be calculated for any wastewater treatment facility discharging TRC into or impacting one of the four Class B waters. The applicable stream standard criteria are listed in Table 1 of Chapter 61.

a. Background Levels

The calculations for TRC effluent limits must incorporate any background levels of TRC. Very limited water quality data exists on background TRC levels and in most cases the level will be assumed to be zero.

b. Calculations

Two types of calculations are available for determining effluent limits: hand calculations, noted above for toxics, and time dependent decay of TRC. For facilities discharging TRC directly into or within one-fourth mile of a Class B water, hand calculations for toxics should be applied. For facilities off the Class B segment, the decay model should be used. In some cases, the decay model may be used to show impacts between two dischargers in close proximity. Most calculations will use the hand calculation for toxics method.

1) First Order Decay

The decay model uses a standard first order expression in which time of travel in the stream is incorporated into the calculations. Using the model expression noted in EPA's "Technical Guidance Manual for Performing Wasteload Allocations; Book 2, Chapter 3, Toxic Substances" June 1984, Appendix D, the TRC decay equation becomes:

$$C_t = (C_m)\ e^{-kt} \qquad (5)$$

Where:

$C_m = (C_b\ Q_b + C_o\ Q_o)/(Q_o + Q_b)$

C_t = TRC concentration at time t, ug/l

C_b = Background TRC concentration in Class B stream, ug/l

Q_b = Stream flow in the mixing zone, zone of initial dilution, or general class stream, cfs

C_o = WLA TRC concentration, ug/l

Q_o = Effluent flow, cfs

k = Decay rate constance, day^{-1}

t = Time of travel in modeled reach, day

Solving for C_o

$$C_o = [C_t\ e^{kt}\ (Q_o + Q_b) - C_b\ Q_b]/Q_o$$

The normal use for equation 6 would be to first determine the applicable TRC concentration "C_t" at the first Class B stream reach. "C_t" is the applicable acute or chronic criteria if the Class B stream is a continuation of the same stream receiving the discharge. If the discharger is off on a tributary to the Class B stream or if a major tributary is encountered prior to the Class B reach, "C_t" must be calculated based on the dilution within the Class B reach. Dischargers to a general class segment of the Class B stream use 100% of the $7Q_{10}$ at the upper most Class B segment for dilution. For facilities discharging into a tributary to the Class B stream, the flow contained in the regulatory mixing zone and zone of initial dilution in the Class B segment would be used for dilution.

The next step would be to determine "t", the time of travel (in days) from the outfall to the Class B segment.

The rate constant "k" can be calibrated from Iowa stream data, if available, or from literature values. The above referenced TRC document notes a value of 100 day^{-1} (or greater) found on a slow moving warm water stream similar to Iowa rivers of less than 500 cfs. Very limited field data has been gathered to date due to the difficulty in field measurement of TRC at low instream concentrations. A value of 20 day^{-1} should be used unless site specific data is available.

E. Fecal Coliform: Fecal coliform effluent limits will be calculated for any wastewater treatment facility discharging directly into or impacting a Class A water. The applicable stream standard for Class A waters is 200 organisms/100 ml (Chapter 61.3(3)a(1).

1. Background Levels: To assure compliance with this standard, all calculations will incorporate background fecal coliform levels associated with nonrunoff periods. Available STORET data will be used to determine the background levels (the 50th percentile value of all non-runoff influenced data points at the sampling site.) For some streams there may

not be enough data to provide valid numbers. In these cases, data from a similar stream, having similar upstream pollution sources, will be used. Historic review of existing data from above wastewater facilities indicates that the background fecal coliform levels on key Class A streams usually equal or exceed the Class A standard of 200 org./100 ml.

2. Calculations: Two types of calculations are available for determining effluent limits: hand calculations and first order decay. For treatment facilities discharging directly into or within one-half mile of the Class A stream, hand calculations should be applied. For treatment facilities off the Class A stream, the decay model should be used. In some cases, the decay model may be used to show impacts between two discharges.

   a. Hand Calculations

   Hand calculations use a basic mass balance relationship incorporating upstream $7Q_{10}$ stream flow, discharge flow and upstream fecal coliform levels.

$$C_u Q_u + C_D Q_D = (Q_u + Q_D)\ 200$$

   Where:

   C_u = Background fecal coliform level, # organisms/100 ml
   Q_u = Flow in mixing zone, cfs
   Q_D = Discharger average dry weather flow, cfs
   C_D = Discharger fecal coliform level, # organisms/100 ml

   To obtain the discharge fecal coliform level (C_D) the equation is rearranged, so that:

$$C_D = ((Q_u + Q_D) + 200 - C_u\ Q_u)/Q_D$$

Note that in no case can the effluent limits be more restrictive than 200 organisms/100 ml.

b. First Order Decay

The decay model uses a traditional relationship in which time of travel in the stream is incorporated into the calculations. Using the model formulated in the EPA publication "Rates, Constants and Kinetics Formulation in Surface Water Quality Modeling" (Second Edition), June 1985, the equation used is as follows:

$$C_t = C_m\ e^{-kt}$$

where:

$C_m = (C_b\ Q_b + C_o\ Q_o)/(Q_o + Q_b)$

C_t = Coliform concentration at time t, # organisms/100 ml

C_b = Background coliform concentration in non-Class A stream, # organisms/100 ml

Q_b = Background stream flow, cfs

C_o = WLA coliform concentration, # organisms/100 ml

Q_o = Effluent flow, cfs

k = Die=off rate constant, day^{-1}

t = Time of travel in modeled reach, day

To solve for C_o the above equation is organized to:

$$C_o = (C_t\ e^{kt}\ (Q_o + Q_b) - C_b\ Q_b)/Q_o$$

The normal use of Equation 3 would be to first determine applicable fecal coliform concentration "C_t" at the lower most stream segment (prior to becoming Class A). "C_t" is 200 organisms/100 ml if the stream segment is the same stream as the Class A segment. If the stream segment is a tributary to the Class A segment or if a major tributary is encountered prior to the Class A segment, "C_t" must be calculated based on the dilution within the Class A segment. See 2.a. above to determine the mass balance relationships for calculating "C_t" or C_d.

The next step would be to determine "t" time of travel (in days) from the outfall to the Class A segment. This usually will be based on the distance (feet) to the Class A segment divided by the average velocity (ft/sec) at low flow. Stream velocities vary with each segment; however, typically, they range from .1 to .5 feet per second.

The rate constant "k" can be calibrated from Iowa stream data, if available, or from literature values. The EPA reference indicates rate constants from .96 day^{-1} to above 6.0 day^{-1}. The EPA document notes that 90% of rate constants are below 5.28 day^{-1}. This later value should be used unless other Iowa based constants are available.

As an example, assume a city is five miles upstream from a major Class A stream; Class A stream flow, 50 cfs; tributary stream flow, 10 cfs; discharger flow, 2cfs; stream velocity, .2 fps; background fecal coliform, 50 organisms/100 ml in tributary and, 70 organisms/100 ml in Class A segment.

$$Ct = \frac{(62 \text{ cfs})\ 200 - 50 \text{ cfs } (70)}{12}$$

$$= 742 \text{ organisms/100 ml}$$

$$t = \frac{(5 \text{ miles})\ (5{,}280)}{.2 \text{ fps } (86{,}400 \text{ sec/day})} = 1.53 \text{ days}$$

$$\text{then, } C_o = \frac{[742\ e^{5.28(1.53)}]-70(10)}{2} = 1.43 \times 10^7 \text{ organisms/100 ml}$$

Therefore, this city could discharge up to 1.43×10^7 organisms/100 ml without exceeding the WQS in the Class A segment.

F. Stream Considered Under the General Criteria

The water quality standards specifically mention seven criteria which apply to all surface waters (61.3(2)). These criteria have been considered in setting the standard for those streams in one of the six designated uses. In waters not in one of the six designated uses, these seven criteria must still be met.

Of particular importance in setting wasteload allocations is the criterion (61.3(2)"d") which states that waters must be free of any substance which is acutely toxic to human, animal or plant life.

The nature of streams covered only by the seven general criteria vary widely. The stream being evaluated may be a perennial stream or an intermittently flowing channelized drainage ditch. Each flow regime and habitat has its own resident species present and the specific acutely toxic levels can only be determined with a case by case evaluation. Some of the items which are considered in an evaluation are the applicable flow regime, resident species present and acutely toxic levels associated with those species.

In order that acutely toxic conditions are not exceeded in the stream the concept of extablishing a no-effect level or LC_0 is introduced. The LC_0 is determined by calculating the value of 1/2 the 96 hr LC_{50} for the most sensitive resident species.

The establishment of a protected flow - that stream flow regime at which the critical resident species of the aquatic organisms which may reside in the stream will be present - is done using a similar approach to that used to set protected flows for Class B streams. For many general streams their intermittent nature will not support a viable aquatic life. Therefore, a case by case determination of the flow regime will be made based on: the amount of discharge from wastewater treatment facilities; the reoccurrence of low flow; minimum flow necessary to support the normally occurring aquatic species and the season. Typically a flow regime of 1 to 2 cfs would support the resident aquatic species during summer and winter periods.

The evaluation of resident aquatic species should include species found during the critical low flow periods not those species found during spawning, (higher flow) periods when adequate dilution occurs. Once the resident species are established (or projected), the LC_o or 96 hr LC_{50} values are obtained for the species from the EPA documents, "Ambient Water Quality Criteria for (the toxic of concern)", Table 3. From the toxicity data contained in these documents, the most sensitive specie and associated concentration would be considered as the water quality criterion used in the following mass balance equation.

$$C_u Q_u + C_D Q_D = (Q_u + Q_D) \frac{WQC}{2}$$

where:

C_u = Background pollutant concentration, mg/l

Q_u = $7Q_{10}$ in the general classified segment (about the outfall), cfs

C_D = Wasteload allocation for the pollutant of concern, mg/l

Q_D = Discharge flow, cfs

WQC = Genus Mean Acute Value for most sensitive species in receiving stream, mg/l

Solve the equation for C_D. This value will be compared to the acute and chronic wasteload allocation calculated in the previous Toxics section. The most stringent of the wasteload allocations will be used in the Permit Derivation Procedure section.

Minimum Protected Flow Policy Statement

The department will use the exception clause in Section 61.2(5) (departmental rules) to develop wasteload allocations for dischargers on intermittent and low flow streams. The department will establish a minimum protected flow for the calculation of wasteload allocations in selected Significant Resource and Limited Resource streams where it has been determined that the aquatic resources of the receiving waters are of limited significance at flows less than the established minimum. The use of minimum protected flows to calculate wasteload allocations on intermittent and low flow streams will supersede the use of the $7Q_{10}$ stream flow. Calculation of wasteload allocations will still use the procedures described previously.

Only the Significant Resource and Limited Resource stream segments with a natural background low flow ($7Q_{10}$) of less than 2 cfs will be considered for establishing a protected flow. For the low flow streams, DNR Fish and Wildlife Division staff members will evaluate the fisheries' potential and other related aquatic organisms in the stream at the $7Q_{10}$ flow. The staff evaluation of the aquatic resources of low flow streams would place the streams in one of three categories:

Category 1: The first stream category would be typical meandering to channelized streams with silt to silt/sand beds in which water temperature equaled or exceeded 32°C during low flow periods. At this low flow condition most higher tropic aquatic life has moved to deeper pools or to the main stream reaches. Thus aquatic life for which the design use was considered for, would not be present in significance numbers in the stream.

Category 2: The second stream category would consist of reaches where the background flow originated largely from spring or bedrock outcrops. Stream beds consist of silt/sand to sand and gravel. The stream temperature may range between 20° to 32°C with high tropic level aquatic life staying in the stream reach in small pools and underbank cuts.

Category 3: The third stream category would consist of reaches capable of supporting cold water aquatic organisms. Stream flow originates from springs with water temperatures less than 20°C. Stream bends consist of sand to sand and gravel. These stream reaches may be classified as cold water or tributaries to such stream reaches.

For those stream reaches under the first category staff will recommend the specific protected flow level for each stream reach. This value may range from 1 to 2 cfs of natural background flow depending upon the normal aquatic organisms inhabiting the reach. Protected stream flows higher than 2 cfs would be considered if unique conditions have limited the normal aquatic organisms from inhabiting the stream reach at 2 cfs. Such conditions as depth of water, temperature, velocity, substrate may be considered. Careful documentation on such limiting conditions will be made by department staff. For the second category streams, a protected flow of 1 cfs or less may be allowed. For the third category of streams, no protected flow will be used to calculate the wasteload allocation.

The effluent limitation, including ammonia, for any domestic discharger would be based upon this protected flow level of natural background flow added to any discharge flow originating from a point source discharger.

The protected flow level will only be required along downstream reaches until the naturally occurring $7Q_{10}$ level was demonstrated to be greater than the protected flow level as determined above, or a significant source of stream flow entered the reach to support the designated aquatic uses. The establishment of protected flows will not apply to facilities that discharge to High Quality Resources waters.

FLOW VARIABLE AMMONIA LIMITATIONS PROCEDURES

Purpose

To provide domestic wastewater treatment facilities, designed to provide advanced treatment, the option of discharging higher concentrations of ammonia as the stream flows increase without causing impacts to the receiving stream's biological communities or violating water quality standards.

Procedure

This procedure will provide guidance to department staff on which treatment facilities could be considered for variable ammonia limits, the rationale for the basic requirements and the methodology to calculate specific limitations.

This procedure will be considered for domestic treatment facilities designed and constructed to remove ammonia nitrogen. Flow variable ammonia limits procedures for industrial facilities will be considered separately. The domestic facility must demonstrate to this department its ability to meet design ammonia effluent limits or wasteload allocation (WLA) under all climatic conditions. It is important to be able to achieve WLA levels during winter conditions because of the sensitivity of nitrification units to cold temperatures. Also, most low flow conditions occur during winter periods.

Depending on the design flexibility of the nitrification units (number of basins, piping, monitoring equipment, etc.), the methods to achieve flow variable ammonia limits must be tested and mastered by the operator. The facility must be able to establish a consistent recovery time from no or partial nitrification to complete nitrification under various temperature conditions.

Since the calculations for flow variable ammonia limits rely heavily on stream flow, it is important that a stream gauge upstream of the treatment facility be available to provide daily stream flow readings. The gauge should be near enough to the treatment facility to accurately represent the stream flow at the outfall.

The specific effluent limits are determined by department staff by first calculating instream acute and chronic total ammonia nitrogen criteria applicable to the designated stream uses then applying the preceding wasteload allocation procedures. The flow variable calculations will consider incremental increases in stream flow while following the same wasteload allocation procedures, including, recalculation of mixing zone flows at the increased stream flows. Additional observations of the stream at higher flow rates may be required by the department.

MIXING ZONE PROCEDURES

Objective

The objective of this procedure is to provide guidance on the methods to be used in considering a mixing zone while determining applicable effluent limitations for a wastewater discharge.

Background

Chapter 61.2(4) of the department's water quality standards provide for defining the mixing zone of a wastewater discharge. It is at the downstream edges of the zone of initial dilution and the mixing zone that the water quality standards are to apply. The standards contain specific criteria and considerations which are to be used in determining the extent and nature of a mixing zone. The most restrictive of the provisions establishes the mixing zone dimenisions and flow. The following is a summary of the key provisions of the standards, additional policies and the sequence used in defining the regulatory mixing zone and zone of initial dilution.

1. The maximum flow in the mixing zone for toxic parameters will be set as 25% of the 7Q10 for interior streams, Big Sioux River, Des Moines River and the Mississippi and Missouri Rivers. The maximum flow in the mixing zone for ammonia is discussed on page 53.

2. In addition, the flow in the mixing zone will be restricted by natural boundaries of mixing, such as islands, semi-permanent sandbars, and manmade obstructions, which limit how much water can mix with the discharge effectively. How these limits affect the regulatory mixing zone are:

   a. For rivers which fall under 1. above, we will use 25% of the portion of the flow in the main or side channel into which the facility discharges or the mixing zone travels, where that flow is separated from flow in the other channels of the river by sandbars or islands which have remained in place for more than three years.

3. Length of the mixing zone may not exceed the most restrictive of the following seven conditions:

   a. The distance to the juncture of two perennial streams.
   b. The distance to a public water supply intake.
   c. The distance to the upstream limits of a heavily used recreational area.

d. The distance to the middle of a crossover point in a stream where the main current flows from one bank across to the opposite bank.

e. The distance to another mixing zone.

f. A distance of 2000 feet.

g. The location where the mixing zone contained the percentages of stream flow noted in one and two above.

4. The length of and flow in the zone of initial dilution for toxics may not exceed 10% of the mixing zone values. For ammonia, the length and flow of the zone of initial dilution is discussed on page 54.

The chronic criteria for toxics and ammonia nitrogen will be met at the boundary of the mixing zone. The acute criteria for toxics and ammonia nitrogen will be met at the boundary of the zone of initial dilution. Although not specifically discussed in the standards, the effects of the biological oxygen demand (BOD) are not expected to be observed until after the end of the regulatory mixing zone. This is because the movement of water through the mixing zone normally will occur faster than the biological uptake of oxygen due to the BOD.

These two zones will be determined in one of two manners, by actual field measurements at low stream flow conditions or by use of a dispersion model. It is the goal of the department to obtain all necessary information of these zones from the information submitted in a wastewater treatment facility's NPDES permit application. A field procedures protocol is being developed which will be used by a NPDES applicant to obtain actual field data. Until data is submitted as part of the NPDES permit application, the limited field data obtained at a few sites by EPA, University Hygienic Laboratory and the department staff and the use of the dispersion model will be the only means to determine these zones.

Calculations

When conditions at the discharge violate model assumptions, the mixing zone model used by the department staff is a Far Field Plume Model. The model equations use the predicted or observed stream width, average stream depth, average stream velocity and channel slope to develop through the use of a lateral dispersion coefficient and shear velocity relationship, a prediction of the mixing zone size and flow. A copy of the model program on Lotus 123 software is available from the department. Further information on the equations used is shown in the Appendix. Where data warrants its use, a more complex model using a Fortran code may be used. It also is available from the department. A list of models used by the department in setting wasteload allocations is available.

THERMAL DISCHARGERS

Numerous thermal dischargers impact Iowa rivers and streams. The significant thermal dischargers result from electric power generation facilities and industrial facilities requiring cooling of equipment or process systems. Specific instream temperature changes are noted in the water quality standards along with the requirement that the standards be met beyond the mixing zone. The complex nature of heat transfer and dispersion make accurate predictions of a thermal plume nearly impossible. However, there still is a need to calculate the expected temperature rise and the distance to recover to (near) initial conditions.

Several technical approaches are available to address the thermal impacts. Extensive evaluations have been performed under EPA effluent guideline requirements for electric generating facilities - Part 316(a). The results or findings of these studies will serve as the primary method for staff to evaluate thermal impacts. For locations where 316(a) information is not practical to apply, the following mathematical approach will be used by staff.

The temperature elevation after the stream and discharge flows have initially become well mixed is given by the following relationship. (Source: U.S. EPA, "Water Quality Assessment", pg. 451, eq. IV-66).

$$T_{wm} = (Q_p/Q_r)\ (T_e - T_r)$$

where:

T_{wm} = temperature elevation after initial well mixing (°F)
Q_p = flow rate of the cooling water (cfs)
Q_r = flow rate of river in mixing zone (cfs)
T_e = temperature of heated effluent (°F)
T_r = temperature of river above discharge (°F)

This relationship does not account for heat losses that occurs as the two flows become mixed. For interior streams, the value of T_{wm} should be equal or less than 3°C (5.4°F) as required in the Water Quality Standards.

Procedures are available from the EPA "Water Quality Assessment" document to calculate instream distances from the point of initial mixing until the stream temperature recovers to levels allowed by water quality standards. The mathematical relationships presented in the EPA document have not been verified for Iowa stream and river conditions. Several alternative calculation approaches should be considered along with data generated from Part 316(a) studies.

Example distance calculations can be found in the U.S. EPA "Water Quality Assessment" document on pages 423 to 461.

The mixing zone cross sectional area and volume discussion above also applies to the calculations for thermal dischargers. The reduction of the percent of river area or volume in the mixing zone (below the 25% requirement) for the Mississippi and Missouri Rivers has additional justification when the heated plume influences the highly productive fish habitat areas and identified clam beds often located along the stream bank or near bank areas.

PERMIT DERIVATION PROCEDURE

Introduction. This section of the Support Document describes the method used to translate a wasteload allocation into an NPDES permit limit. The procedures are applied to any discharger in the state, municipal, industrial, or semi-public, for which a water quality-based permit limit is required. The purpose of these procedures are to provide an effluent limit which will statistically assure that the wasteload allocation will not be exceeded due to the variations in facility operation, monitoring and parameter analysis. The more restrictive of the acute or chronic wasteload allocation will be used in the following calculations.

1. Simplified Procedure:

Maximum Permit Limit = Wasteload Allocation Concentration

Monthly Average Permit Limit = 0.67 X Wasteload Allocation Concentration

2. Statistical Based Procedure:

The Maximum Permit and Average Permit Limits will be calculated using the statistical procedure noted in the Appendix. This procedure will consider the required sampling frequency for each water quality based parameter noted in Chapter 63 of the department rules, and any known coefficient of variation (CV) for each parameter. This CV may be based on the individual treatment facility's operations or where the CV data is lacking a value of 0.6 will be used. If a wastewater treatment facility selects to increase the monitoring frequency, the corresponding permit limits will be calculated to reflect this increase frequency.

The more lenient of the permit limits from the two procedures will be the values included in the NPDES permit process. Technology based requirements must also be met.

REFERENCES

1. Streeter, H. W., and Phelps, E. B. "A Study of the Pollution and Natural Purification of the Ohio River. III., Factors Concerned in the Oxidation and Reaeration," Public Health Bulletin No. 146, U.S. Public Health Service, Washington, D.C. (1925).

2. Dougal, Baumann, and Timmons, "Physical and Economic Factors Associated with the Establishment of Stream Quality Standards," Volume No. 2, March, 1970.

3. Tsivolgou, E. C. and Wallace, J. R., "Characterization of Stream Reaeration Capacity," U.S. Environmental Protection Agency. EPA-R3-72-012, October, 1972.

4. Leopold, Luna B. and Maddock, Thos. Jr., "The Hydraulic Geometry of Stream Channels and Some Physiographic Implications," Geological Survey Professional Paper (#252), U.S. Government Printing Office, 1953.

5. U.S. Environmental Protection Agency, "Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants - Part 1," EPA-600/6-82-004a, September, 1982.

APPENDIX

Mixing Zone Studies

The following are the basic field data requirements for two types of mixing zone studies which are to be provided by an applicant for recalculation of the local mixing zone. The purpose of the recalculation is to more closely approximate the local mixing zone using site specific data instead of statewide data. Contact should be made with the department's Water Quality Planning Section prior to beginning any field study.

A. Simplified Mixing Zone Study.

1. Stream Characteristics. It should be noted that the terms low flow and low stream flow are used in the following discussion. These terms are not synonymous with the 7Q10 flow or protected flow. Stream surveys to gather mixing zone data should be collected as near to the 7Q10 or protected flow as is normally feasible during the summer months of the year. A normal limit of 5 times the 7Q10 or 2 times the protected flow is desirable for the observations. Stream flow conditions closer to the 7Q10 are desirable for those locations where normal flows during the year approach the 7Q10 or where the flows are controlled by impoundments.

   a. A description is needed of the stream upstream and downstream from the outfall at low flow, preferably include pictures. Include in the description, the following items for a distance of 2000 feet downstream (unless other distance limitation is known to apply) and 200 feet upstream of the outfall:

(1) Description of the stream bed material: sand, fine or coarse gravel, mud, or rock.

(2) Note pools and riffles, areas of uniform depths, estimate length and number thereof, and the rapidity of the variations; i.e., gradual, alternating occasionally, or alternating frequently.

(3) Describe the amount of weed growth and snags in the stream, in terms of negligible effects on the stream flow to severe effects on the stream flow.

(4) Describe the amount of meandering within the 2000 foot distance.

(5) Describe other features which might effect the mixing zone such as delta formation at the stream mouth, other discharges or perennial springs, etc.

b. A description of the outfall during a low stream flow period, include an indication of the discharge flow during the period being described, preferably include pictures. Describe such things as the size and configuration of splash pools, outfall height or depth, outfall diameter (if normally filled during discharging), and/or average velocity of flow exiting outfall when submerged.

c. Field data should include at least two cross sections of the stream at low flow, an upstream location and at the anticipated mixing zone. Each cross section should including a minimum of 10 depths measurements (depths taken at least every two feet if stream width is less than 40 feet and at least every 5 feet if less than 100 feet, otherwise every 10 feet). Stream velocities should be measured using a velocity meter. Three cross sections should be provided if the dilution ratio is less than 3:1, one upstream, one at the anticipated mixing zone, and one spaced evenly downstream of the outfall and the mixing zone. If there is several pools and riffles, additional cross sections are needed to provide a more accurate indication of average depths.

2. Instream Water Quality Data. Where the discharge is into a shallow or marshy area which has no clear channel or their is considerable backwater effects from a downstream dam or river, information should be obtained on the stream and discharge density and temperature. Information should be obtained in a similar manner to that stated in the Ammonia section. Information about collecting pH and temperature is contained in the Ammonia section.

B. Mixing Zone Studies Using Dye Injection.

An applicant may elect to provide additional filed data on the actual dispersion of their effluent into the receiving stream. This field data, if adequate, will be used in place of the departments data. The objective of the dye studies is to prove that a more rapid degree of mixing occurs due to local conditions (very high river complexity) than the degree of mixing assumed by the department. The normal type of dye study will be to characterize the visible dye plume. However, a more complex dye study may be considered where the dye concentrations are measured florometerically with the objective to project the maximum dye concentration at the boundary of the mixing zone and zone of initial dilution.

Dye studies should be performed under non-ice conditions. Non-ice conditions are considered to be worst case conditions for diffusion, though, they are possibly the conditions under which 7Q10 is reached. The maximum flow limits for all dye studies will be set by the department on a case by case basis. In general, 5 times the 7Q10 flow as the upper bound for a dye study will be selected. Where a protected flow is the flow used for the wasteload allocation, it is likely that the limit used will be 2 times the protected flow.

All dye studies require a department approved quality assurance plan and work plan.

1. The minimal dye study requirements are described below. This dye study, using visually determined mixing zone limits, should only be used where river complexity and outfall complexity is minimal. River complexity being low when there is: little meandering, even river depths and cross sections, few snags, or other causes of diffusion changes within the 2000 foot maximum distance for the mixing zone. For streams and rivers with complexity, the dye studies should follow the procedures noted in item 2 below.

If the mixing zone will be limited by one of the other length limitations noted in the rules, the features of the length limitation must be noted, including the distance to the limitation. The study should contain the following information:

a. Since different dyes may be used and river conditions change, the minimum concentration at which the selected dye is visible shall be reported. Methods for determining this may be refined and modified as they are improved, but, will require at least one quantitative analysis, and may require analysis of samples taken at one cross section of the stream.

b. Dye input to the discharge shall be such that it provides a fairly stable outfall concentration. Dye input to the river at other points downstream from the outfall, if required, shall be at a set rate. The input dye concentrations and discharge dye concentrations shall be indicated in the report.

c. Describe the lateral limits of visible dye in the stream at all distances up to 2000 feet, in most cases dye visibility will not reach 2000 feet. Methods for reintroduction of dye or measurements for determining the visible portion may vary and warrant discussion with department staff.

d. Discharge flow rates during the study. One stream flow rate during the study. Flow rates and depth-velocity profiles at preselected points in the plume. Depth-time record for the stream at a single location during the study.

2. Following are the requirements for dye studies for streams and rivers with significant complexity and do not meet the qualifications for the limited study described in 1, above.

a. Complete the activities in items 2 b and d, above

b. For at least six locations in the first 500 feet downstream of the outfall, the stream will be marked for sampling and plume depth-velocity profiles during the study.

c. An additional stream location will be marked for each additional 500 foot of distance downstream from the outfall.

d. Dye will be introduced into the discharge and permitted to stabilize in the river prior to sampling.

e. Samples at each of the locations marked under b. or c. above, will be taken at intervals across the stream chosen so that a good representation of the plume at each distance is obtained.

f. Other information may be required from the study as complexity of the mixing zone warrants.

Mixing Zone Calculations

The mixing zone dispersion model used by the department staff is based upon an equation obtained from EPA contractors involved with toxics modeling. This equation is a 'Far Field' analytical solution for mixing in a river where the discharge is uniformly mixed from top to bottom of the river. The original equation has been adjusted to incorporate a near shore discharge rather than a mid-channel discharge.

The Equation used is

$$C = \frac{Q_e * C_e * e^J}{2*d*K} \qquad (1)$$

where C = Concentration in the river at location x,y, mg/l;

C_e = Concentration of the Discharge, mg/l;

Q_e = Discharge flow in cubic feet per second;

d = average stream depth, feet;

u = average stream velocity, feet per second;

x = distance downstream from the discharge, feet;

y = distance from the discharge side of the shore, feet;

$K = (\pi*D_y*u*x)^{0.5}$

$J = (-u*y^2)/(4*D_y*x)$

D_y = the lateral dispersion, square feet per second.

The lateral dispersion is found from the equation

$$D_y = \alpha*d*u_s \qquad (2)$$

where α = a proportionality variable which varies with the stream, it is normally about 0.6 + or - 0.2, but, it can vary from a value of 0.1 which has been found in experimental plumes to larger than 0.8 which has been found in natural channels. For most rivers in Iowa it is expected to be larger than 0.4, and will normally be assumed to be 0.6.

$$u_s = \text{the shear velocity} = (1/8*f*u^2)^{0.5} \qquad (3)$$

f = the Fanning or Darcy-Weisbach friction factor, which can be found from diagrams in various references. Note: To facilitate the development of wasteload allocations an approximation for f was developed. The developed equation is not accurate for f at all Reynold's numbers or (e/d)'s. The equation is:

$$f = 4 * 0.01895 * (e/d)^{0.5} + 0.001701 \qquad (4)$$

e = is the size of the roughness of the channel. An equation was developed from limited experimental data which indicated reasonable fit to an equation for

$$(e/d) = 1/(L + 0.001 * Q_r + 2.6) \qquad (5)$$

$$L = 15{,}000^{1.2} * Q_r^{2}$$

Q_r = River flow rate in cfs.

Equation (1) is solved for C at varying x,y locations and rounded to five decimal places. The y locations where C equals zero are then taken to be the width of the plume. The flow in the plume at that point is calculated to be the plume width times the average river depth times the average river velocity.

The acute and chronic wasteload allocations are determined using the flow in the mixing zone (or zone of initial dilution) determined using the previous criteria, the discharge flow, the background concentration and the water quality standard. The equation for the wasteload allocation is

$$WLA= (C_s * Q_m - (Q_m - Q_e) * C_b)/Q_e \tag{6}$$

where C_s = the acute or chronic water quality standard;

Q_m = the zone of initial dilution or mixing zone flow;

C_b = the background concentration.

Inputs Into the Mixing Zone Calculations

Development of the flow, width, average depth, and average velocity used in the above equations is developed from a separate set of equations or actual field data. Where a cross section of the river and flow rate is known at or close to the point of discharge at a higher stage, the field obtained cross section and velocities are used along with slopes obtained from USGS topographic maps to determine Manning's n for the river at that flow. (If slope is measured in the field this may improve the quality of the information from these equations since significant differences in slope from the topographic map may occur). The equations used are

$$Q_r = W * d * u \tag{7}$$

W = Width of river

$$d = W / (W/d) \tag{8}$$

Where (W/d) = a ratio determined from the field data.

$$r_H = \text{Hydraulic Radius} = W * d / (2*W + 2*d) \tag{9}$$

Note: The hydraulic radius is actually a ratio of the area of stream cross section to the wetted perimeter of the stream and improvements in the equation used to obtain the hydraulic radius will probably improve the quality of the information from this set of equations. The above equation is based on the hydraulic radius for a rectangle given in Perry's Chemical Engineers Handbook 4th edition page 5-20.

$$u = 1.49/n * r_H^{(2/3)} * S^{0.5} \tag{10}$$

where n = Manning's n

S = Slope

The Manning's n and (W/d) ratio determined from the above equations are then adjusted to the 7Q10 flow using:

$$n_{7Q10} = n_{orig} * Q_r/Q_{7Q10} \qquad (11)$$

$$(W/d)_n = (W/d)_{orig} * (Q_r/Q_{7Q10}) * (d/d_a) \qquad (12)$$

where d_a = The average depth without the first and last reading in the cross section.

These are then used with the above equations to determine the average velocity and average depth of the river at the 7Q10. A line can then be plotted across the previous cross section which represents the new surface level. The new surface level is found using the old average depth minus the new average depth to change the location of the surface level. The method used has normally shown less than 10 percent difference between the length of the new line representing the new surface width and the calculated width of the river obtained using equation (7).

Where no field information exists it is difficult to predict the width, depth and velocity of a river since many variables influence these. The department will normally adjust W, (W/d), and n to predict a width, depth and velocity using equations (7), (9) and (10) to provide a range of acceptable numbers.

Iowa Permit Derivation Methods

The Iowa permit derivation methods, the simplified or the statistical based, are discussed below. The more lenient of the average and maximum permit limits from either of the procedures will be the recommended values for use in the permit process to assuring that water quality standards are met.

1. Simplified Procedure:

Maximum Permit Limit = Wasteload Allocation (Acute or Chronic)

Average Permit Limit = 0.67 x Wasteload Allocation

2. Statistical Based Procedure:

The statistical based procedure requires the following four input values to calculate the permit limits.

CV = Coefficient of Variation
MF = Monitoring Frequency, samples per month
AWLA = Acute Wasteload Allocation
CWLA = Chronic Wasteload Allocation

The CV value will be 0.60 unless applicable data is provided by the wastewater treatment facility. The monitoring frequency (MF) will follow the requirements noted in the departments rule, Chapter 63. However, an applicant may request increased monitoring frequency considerations in this statistical procedure. The following equations are available on Lotus 123 from the department, upon request.

DAILY MAXIMUM PERMIT LIMIT (DMPL) is derived as follows:

For $ML \geq AWLA$ $DMPL = AWLA$

For $ML < AWLA$ $DMPL = ML$

For $MF \leq 1$ $DMPL = DAPL$

DAILY AVERAGE PERMIT LIMIT (DAPL) is derived as follows:

MIN = minimum of the AWLA or CWLA

For $AL \geq 1/1.5*MIN$ $DAPL = AL$

For $AL < 1/1.5*MIN$ $DAPL = 1/1.5*MIN$

Calculation equations.

ALTA = Acute Long Term Avg = exp(MU_A + H_SIG_SQ)

MU_A = LN(AWLA) - ZSIGMA

ZSIGMA = Z_STATISTIC * SIGMA

SIGMA = (SIGMA_SQ)$^{0.5}$

SIGMA_SQ = LN(CV^{2} + 1)

CLTA = Chronic Long Term Avg = exp(MU_C + H_SIG_SQ)

MU_C = MU4 - H_SIG_SQ + 0.5 * AC

MU4 = LN(CWLA) - Z95 * ABC

H_SIG_SQ = 0.5 * SIGMA_SQ

AC = LN(AB)

ABC = AC$^{0.5}$

AB = AA/4 + 1

AA = exp(SIGMA_SQ) - 1

ML = exp(MU_MAX + 1.645 * SIGMA)

MIN = Minimum of ALTA or CLTA

MU_MAX = LN(MIN) - 0.5*SIGMA_SQ

CCC = $1.645 * \text{SIGMA\_MT}^{0.5}$ + MU_AVE

SIGMA_MT = LN(CC)

MU_AVE = (SIGMA_SQ - SIGMA_MT)/2 + MU_MAX

CC = AA/(34.6501 - MF) + 1

Z_STATISTIC = z_G

z_G is the value of z from the table of values of the Standard Normal Distribution Function for the value G.

G = (100 - F)/100

F = MF/(34.6501/7)

AL = exp(CCC)