SIMPLIFIED ANALYTICAL METHOD FOR

WASTE LOAD ALLOCATIONS

This method represents the minimum level of analysis acceptable to EPA as justification for requiring treatment beyond secondary. It cannot be used by itself to justify limits more stringent than 10 mg/L $CBOD_5$ and 1.5 mg/L NH_3-N. Furthermore, it may be applied only when all four of the following conditions are met:

1. The discharger must be a POTW receiving predominantly sanitary wastewater or wastewater of similar character.
2. The discharge must be to a free-flowing stream in which the design low flow (usually 7Q10) is approximately equal to or less than the design discharge flow of the POTW.
3. The design discharge flow of the POTW must be 10 MGD (15.5 cfs) or less.
4. There must not be any significant interaction between the discharger and any other upstream or downstream discharger.

I. Gather Necessary Data

A. Stream Design Flow - usually 7Q10 flows are available from the USGS

B. Upstream Water Quality (from STORET, USEPA, DEQE, etc.)
>   **1. DO**
>   **2. BOD**
>   **3. pH**
>   **4. Alkalinity**
>   **5. Ammonia**
>   **6. Temperature**

C. Stream Physical Characteristics for each Stream Segment
>   **1. Stream Depth**
>   **2. Stream Slope**
>   **3. Nature of Stream Bottom**
>   **4. Site Visit and General Observations**

D. Stream Flow Velocity for each Stream Segment (from dye studies or direct velocity measurements)
   1. One set of measurements near the design conditions, or two sets of measurements under differing conditions.

E. Effluent Design Flows

F. Effluent Characteristics
    1. DO
    2. BOD
    3. pH
    4. Alkalinity
    5. Ammonia
    6. Temperature

II. Ammonia Toxicity Analysis

Since the maximum ammonia concentration is expected to occur at the point of mixing of upstream water with an effluent, a simple mass balance may be used to check for compliance with ambient ammonia limits.

$$C_D = [C_{WQS}(Q_D+Q_U) - C_U Q_U]/Q_D$$

Where:

C_D = allowable design discharge concentration of total ammonia-N

C_{WQS} = ambient water quality standard for total ammonia-N at the appropriate pH
    and temperature

C_U = upstream concentration of total ammonia-N

Q_D = design POTW discharge flow rate

Q_U = upstream design flow (usually 7Q10)

Usually ambient water quality standards for ammonia refer only to the most toxic form, un-ionized ammonia. Therefore, corrections for temperature and pH must be made so that a total ammonia-N concentration (C_{WQS}) can be calculated that will give an unionized fraction which is just in compliance. This is done by first calculating the expected temperature and pH at the point of mixing; then finding the percent of unionized ammonia under these conditions (see table below); and finally, dividing the un-ionized ammonia ambient standard by this value.

Percent Un-ionized Ammonia in Aqueous solution

Temp (°C)	pH								
	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
5	0.013	0.040	0.12	0.39	1.2	3.8	11	28	56
10	0.019	0.059	0.19	0.59	1.8	5.6	16	37	65
15	0.027	0.087	0.27	0.86	2.7	8.0	21	46	73
20	0.040	0.13	0.40	1.2	3.8	11	28	56	80
25	0.057	0.18	0.57	1.8	5.4	15	36	64	85
30	0.080	0.25	0.80	2.5	7.5	20	45	72	89

Temperature at the point of mixing (T_R) may be calculated from a simple mass balance:

$$T_R = (Q_U T_U + Q_D T_D)/(Q_U + Q_D)$$

Using upstream and effluent alkalinities and pHs, pH at the point of mixing may be estimated using a simple nomagraph. Alkalinities must be in terms of milliequivalents per liter. These units may be obtained from the more conventional units as follows:

$$Alk\ (meq/l) =\ Alk\ (mg/l\ as\ CaCO_3)\ /\ 50$$

Both alkalinity and total carbonate (C_T) are conservative at the point of mixing. Their concentrations may therefore be calculated using a simple mass balance approach as the one used for temperature or ammonia. The following steps are recommended for calculating pH at the point of mixing for waters in the range of pH 4.5-8.3.

1. Determine C_T's for both the upstream water and the effluent using the attached nomagraph and data for pH and alkalinity.
2. Calculate the concentration of alkalinity and C_T in the blended water.
3. Determine pH of the blended water using the nomagraph and the calculated alkalinity and C_T.

If, based on the mass balance analysis, it is decided that nitrification is required to meet the ambient ammonia standard, two other issues must be considered before setting an effluent standard. In cases where the ammonia levels are only slightly above the maximum, and DO minima are not violated, acidification of the effluent may be considered in lieu of nitrification. Also nonpoint sources of ammonia must be examined. If they are significant, water quality objectives may not be attainable under any point source control scenario.

III. Dissolved Oxygen Analysis

A Streeter-Phelps type of analysis is used to predict DO minima. The analytical solution accounts for CBOD oxidation, NBOD oxidation, and sediment oxygen demand.

$$D = D_O \exp(-k_a t)$$

$$+ [(k_d L_O)/(k_a - k_r)][\exp(-k_r t) - \exp(-k_a t)]$$

$$+ [(k_N L_O^N)/(k_a - k_N)][\exp(-k_N t) - \exp(-k_a t)]$$

$$+ (S_B/H k_a)[1 - \exp(-k_a t)]$$

The stream is divided into reaches of relatively uniform characteristics (e.g., channel geometry, reaeration, significant inflows, etc.). The sag points may be located by trial and error, or a computer program could be written to search for the minima. To facilitate this process, the following equation may be used to obtain a good first estimate of the sag location.

$$t_c = [1/(k_a-k_{avg})]ln[\{k_a/k_{avg}\}\{1-[D_O(k_a-k_{avg})k_{avg}L_O)]\}]$$

Where:
$$k_{avg} = (k_d+k_N)/2$$

Once the minima are located, minimum dissolved oxygen concentrations can be determined. If these are found to be in violation of the standard, various combinations of higher degrees of waste treatment may be applied in accordance with the procedures outlined in the sensitivity analysis section.

A. Design Flow

Both low flows and high flows must be considered when deciding on the critical flow conditions. Rivers susceptible to severe nonpoint source pollution may suffer the greatest degree of water quality degradation under conditions of high flow. In such circumstances, nonpoint loadings must be carefully evaluated. Otherwise, the 7-consecutive day, 10-year low flow (7Q10) should be adopted as the critical condition.

B. Target Dissolved Oxygen Concentration

Ambient dissolved oxygen criteria are generally based on the designation of a water body as supporting warm water fish or cold water fish. This information is generally available from state regulations (e.g., Code of Massachusetts Regulations). When D.O. criteria are expressed as instantaneous minimum concentrations rather than daily average minima, a factor of safety of 0.5 mg/l should be added. This is necessary, because steady state water quality models will predict a daily average concentration only. Due to variations in waste flow, and diurnal photosynthetic cycles, temporal variations in dissolved oxygen at a given location may be as great as 0.5 mg/l.

C. Waste Loads

At the very least, waste loads should be assumed to comply with the effluent standards set by the Clean Water Act (e.g., secondary treatment for POTWs). More advanced treatment will result in lower loadings depending on the particular processes employed. Experience has shown that the following effluent quality can be expected for POTWs.

Publicly Owned Treatment Works
Average Effluent Quality

Treatment	BOD$_5$(mg/l)	NH$_3$-N (mg/l)
Secondary	30	25
Oxidation Ditch	15	1.5
Nitrification	8	1.5
Nitrification + Tertiary Filtration	4	1.5

Ratios of ultimate BOD to 5-day BOD (i.e., "f" ratios) can be assumed to be 1.5 for poorly-operating secondary plants, 2.0 for well-operating secondary plants, and 2.3 for advanced plants.

D. Reaeration Rate Constant

For reaches of average depth less than 2 feet, the Tsivoglou formula is preferred. Otherwise either the O'Connor-Dobbins or Churchill formulae should be used. Employ O'Connor-Dobbins when the stream velocity (in fps) is less than 1.2 times the height (in feet) raised to the 0.34 power. At higher velocities use the Churchill formula.

Tsivoglou Formula
$$k_a = CUS$$

O'Connor-Dobbins Formula:
$$k_a = 12.9 \ U^{0.5}/H^{1.5}$$

Churchill Formula:
$$k_a = 11.6 \ U/H^{1.67}$$

Where:
U = velocity in fps
H = stream depth in feet
S = stream slope in ft/mi
C = 1.8, for Q=1-10 cfs
1.3, for Q=10-25 cfs
0.88, for Q=25-300 cfs.
k_a = reaeration constant in reciprocal days.

E. Carbonaceous BOD Decay Coefficient

In the absence of site-specific data, the Hydroscience formula is preferred. Also, the CBOD settling rate is assumed to be negligible.

$$k_d = C(H/8)^{-0.434}, \qquad \text{for } H < 8\text{ft}$$
$$k_d = C, \qquad \text{for } H > 8\text{ft}$$

Where:

$C = 0.3$ for streams with mostly stable, rocky bottoms
$C = 0.2$ for streams with mostly unstable bottoms of fine sediment
H is in feet, and k_d is in days^{-1}.

F. Nitrogenous BOD Decay Constant

Stream nitrification rates will be highly variable depending on the available attachment sites for these slow-growing bacteria, and on general water quality. These rates may be roughly estimated as follows:

k_N (/day)	Stream Characteristics
0.2	deep water, sediment bottom
0.4	shallow, mixed rocky bottom
0.6	shallow, all rock bottom

G. Sediment Oxygen Demand

Although SOD will be highly site-specific, Thomann suggests the following values when specific data are lacking:

	Sediment Oxygen Demand $(g/m^2/d)$	
Treatment Level	Near Outfall	Downstream of Outfall
Poor Secondary	3	1
Secondary	1.5	0.5
Advanced	0.4	0.2

IV. Sensitivity Analysis

The sensitivity of instream responses to the various model parameters should be investigated before a final decision is made. First, all variables are simultaneously adjusted to give the best, average and worst case prediction. If a situation of non-compliance exists for all three, the next level of treatment may be applied without further justification, and the process repeated. If not, each of the input variables should be varied, one-by-one, in accordance with their uncertainty. If it is found that a given input variable is so uncertain that it does not permit the identification of a unique requisite treatment level, additional information must be gathered to reduce the uncertainty of that variable. If, on the other hand, a higher level of treatment is needed to meet stream standards for the entire range

of an input variable; this level of treatment may be adopted. As a guide, the following ranges may be used in the sensitivity analysis.

Input Variable	Typical Range
k_d	+/- 75%
k_N	+/- 50%
k_a	+/- 65%
SOD	+/- 50%
Temperature	use observed range
pH	use observed range

V. Interpretation of Results and Establishment of Effluent Limitations

Based on the above analysis, an NPDES permit can be written. Effluent limits should be expressed as BOD_5 and NH_3-N standards in mg/l.

Reference:

"Technical Guidance Manual for Performing Waste Load Allocations: Simplified Analytical Method for Determining NPDES Effluent Limitations for POTWs Discharging into Low-Flow Streams" US EPA Office of Water Regulations and Standards, Monitoring and Data Support Division; September, 1980.