The Incorporation of Ambient Concentration With That Due to Effluent for Wasteload Allocation

Technical Report 96-1

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Water Quality Programs Division
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Introduction

Water quality management in Oklahoma requires the use of a wasteload allocation, WLA. The WLA is the effluent concentration which will yield a maximum concentration on the mixing zone boundary equal to the numerical criterion to protect aquatic life. There will be no exceedances outside the mixing zone if this maximum concentration is less than the criterion. Therefore, it is important for wasteload allocations that ambient concentration and that due to the effluent be properly combined, in order to obtain the maximum concentration on the mixing zone boundary.

The simplest way to combine ambient concentration and that due to the effluent is to add the two. However, it will be shown that simple addition does not yield the correct maximum concentration on the mixing zone boundary. This report develops appropriate wasteload allocations to protect Oklahoma's aquatic life.

The Mass Balance Approach

Ambient concentration is accounted for correctly in mass balance because it is incorporated into the fundamental equation. Therefore, the mass balance approach will be extended to develop a general equation which applies anywhere in the receiving water, not just after complete mixing has been achieved.

The mass balance equation may be written

$$C_a Q_u + C_e Q_e = C(Q_u + Q_e) , \qquad (1)$$

where C_a is ambient concentration, Q_u is the regulatory receiving stream flow (OWRB, 1995), C_e is effluent concentration, Q_e is the regulatory effluent flow (ODEQ, 1994) and C is concentration after complete mixing.

Rearranging (1)

$$C = C_a\left(\frac{Q_u}{Q_u + Q_e}\right) + C_e\left(\frac{Q_e}{Q_u + Q_e}\right). \qquad (2)$$

When there is no ambient concentration $C_a = 0$, so

$$C = C_0 = C_e\left(\frac{Q_e}{Q_u + Q_e}\right), \qquad (3)$$

where C_0 is the concentration due to the effluent. Substituting (3) into (2),

$$C = C_a\left(\frac{Q_u}{Q_u + Q_e}\right) + C_0. \qquad (4)$$

Since $C \neq C_a + C_0$ after complete mixing, it cannot be assumed that the concentration anywhere in the receiving water may be obtained from simple addition of ambient concentration and that due to the effluent.

Converting The Mass Balance Equation Into A General Equation

A relationship between flow and volume may be obtained. In Eq. (4)

$$\frac{Q_u}{Q_u + Q_e} = \frac{V_u/t}{V_u/t + V_e/t} = \frac{V_u}{V}, \qquad (5)$$

where t is time and $V \equiv V_u + V_e$. Eq. (5) is only valid after complete mixing. V_u/V will not equal $Q_u/(Q_u + Q_e)$ before complete mixing has occurred. However, (5) will be used to develop a general equation.

Envision a parcel of volume V being discharged to a receiving stream. At the moment of discharge the parcel is composed entirely of effluent. As the parcel is carried downstream, some of the effluent is exchanged with receiving water.

$$\therefore V = V_e + V_u, \qquad (6)$$

where V_u is the volume of receiving water within the parcel and V_e is the volume of effluent. From (6)

$$\frac{V_u}{V} = 1 - \frac{V_e}{V}. \qquad (7)$$

Substitution of (7) into (5) yields

$$\frac{Q_u}{Q_u + Q_e} = 1 - \frac{V_e}{V}. \qquad (8)$$

Substitution of (8) into (4) yields

$$C = C_a\left(1 - \frac{V_e}{V}\right) + C_0. \qquad (9)$$

Because (5) is only valid for mass balance, it has not been proven that (9) is generally appropriate. However, it is assumed that this is the case.

Developing A General Equation For Integrating Ambient Concentrations And That Due To The Effluent

Assume that our parcel is so small that effluent and receiving water mix instantaneously within the parcel. A mass balance for the parcel may be expressed as

$$V_u C_a + V_e C_e = VC. \qquad (10)$$

When $C_a = 0$, $C = C_0$ and (10) becomes

$$\frac{V_e}{V} = \frac{C_0}{C_e}. \qquad (11)$$

Eq. (11) holds even when C_a is significant. Substitution of (11) into (9) yields

$$C = C_a - \frac{C_0}{C_e} C_a + C_0. \qquad (12)$$

Eq. (12) is the general equation for integrating ambient concentration and that due to the effluent.

Development Of Mixing Zone Wasteload Allocations

Eq.(12) may be rearranged to obtain

$$C_e = C_a + df(C - C_a), \qquad (13)$$

where df is defined as the dilution factor $\equiv C_e/C_0$ (Hutcheson, 1992b). For wasteload allocation purposes, WLA $\equiv C_e$ and $C_c \equiv C$, where C_c is the numerical criterion to protect the fish and wildlife propagation beneficial use.

$$\therefore WLA = C_a + df(C_c - C_a). \qquad (14)$$

It is not anticipated that $C_a > C_c$. This constitutes a water quality standards violation.

The dilution factor must be substituted for to obtain wasteload allocations for the maximum concentration on the mixing zone boundary.

For streams Hutcheson (1992a) showed that

$$df = \frac{1 + Q*}{1.94Q*}, \quad Q* \le 0.1823 \qquad (15)$$

$$df = 6.17 - 15.51Q*, \quad 0.1823 < Q* < 0.3333 \qquad (16)$$

$$df = 1.0, \quad Q* \ge 0.3333 \qquad (17)$$

where $Q^* \equiv Q_e/Q_u$ (the dilution capacity). When the dilution capacity is large (Q^* small) the dilution factor is also large, and vice-versa.

For lakes (ODEQ, 1994)

$$pipe: \quad df = \frac{20.15}{D}, \quad D \geq 3ft. \quad (18)$$

where D is pipe diameter.

$$canal: \quad df = \frac{4.2}{\sqrt{W}}, \quad W \geq 3ft. \quad (19)$$

where W is canal width. Substitution of (15) through (19) into (14) yields the appropriate wasteload allocations to implement Oklahoma's numerical criteria to protect the fish and wildlife propagation beneficial use.

Conclusions

The wasteload allocations expressed in the CPP (ODEQ, 1994) do not appropriately implement Oklahoma's numerical criteria to protect fish and wildlife propagation when background concentration is large. Modifying the wasteload allocations in the manner developed in this report will produce the appropriate implementation.

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