Attachment B

Memorandum describing the assumptions and methods for determining fecal coliform loads based on the tidal prism model approach.

Memo

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From: John Brawley, Corey Wisneski (Battelle, Duxbury, MA)

CC: Aslam Mirza (NYDEC)

Date: February 20, 2007

Re: Assumptions and methods for determining FC loads based on the tidal prism model approach.

Introduction and Background

Battelle is currently providing technical support to the development of total maximum daily loads (TMDLs) of fecal coliform associated with up to 46 coastal shellfish harvest areas classified as SA waters in New York State. The general approach to TMDL development is to (1) evaluate and determine physical boundaries; (2) evaluate and determine degree of water quality impairment; (3) assess contributing point and nonpoint sources of pollutants that are believed to cause impairment; (4) evaluate assimilative capacity of impaired waters through a process sometimes called a "linkage analysis"; and (5) determine the reductions in pollutant loads necessary to meet target water quality standards with an imposed margin of safety.

Battelle has made significant progress in numbers (1) and (2), although some boundary conditions remain to be confirmed. The process of source assessment will be based on land use, waterfowl, marina usage, and stormwater discharge (MS4) information. But loads of fecal coliform will also be estimated by the inverse method of applying a series of tidal prism models in each impaired water body. The tidal prism model approach uses observed water quality data (in this case, years of fecal coliform data), along with physical characteristics and biological attenuation rates to determine loading rates necessary to account for the observed fecal coliform statistics of geometric mean and 90th percentile over several years of record. This approach can be applied to critical periods such as conditionally open or closed seasons or specific years of interest. The resulting loads are further expressed as being attributed to various likely point and nonpoint sources through an evaluation of watershed characteristics and other supporting data as described above.

The purpose of this memo is to outline and describe the tidal prism approach that will be applied to the water bodies in this project. The governing model algorithm, input variables, and assumptions necessary to impose in the process are all described.

A steady-state tidal prism model is the approach being applied to determine rates of fecal coliform loading to the waterbodies of interest. This approach incorporates the influences of tidally induced transport, freshwater inputs, and a decay rate of fecal coliform. The following assumptions are made at the onset:

- A single volume can represent a water body;
- The pollutant is well-mixed in the water body.

The mass balance of water can be written as follows:

$$\frac{\partial V}{\partial T} = (Q_o - Q_b + Q_f) \quad (1)$$

where Q_o is the quantity of water that enters the embayment on the flood tide through the ocean boundary (m^3T^{-1}); Q_b is the quantity of mixed water that leaves the bay on the ebb tide that did not enter the bay on the previous flood tide (m^3 per tidal cycle); Q_f is total freshwater input over the tidal cycle (m^3); V is the volume of the bay (m^3); T is the dominant tidal period (hours).

It is further assumed that Q_o is pure ocean water that did not flow out of the embayment on the previous ebb tide, and that Q_b is the embayment water that did not enter into the system on the previous flood tide. The mass balance for the fecal coliform can then be written as follows:

$$\frac{\partial VC}{\partial T} = Q_o C_o - Q_b C + L_f + L_l - kVC \quad (2)$$

where L_f is the loading from upstream; L_l is the additional loading from the local area within the tidal cycle, k is the fecal coliform decay rate (or damped parameter for the net loss of fecal coliform), C is fecal coliform concentration in the embayment, and C_o is the fecal coliform concentration from outside the embayment.

In a steady-state condition, the mass balance equations for the water and fecal coliform concentration can be written as follows:

$$Q_b = Q_o + Q_f \quad (3)$$

$$Q_b C + kVC = Q_o C_o + L_f + L_l \quad (4)$$

The fecal coliform concentration in the embayment can be calculated as follows:

$$C = \frac{Q_o C_o + L_f + L_l}{Q_b + kV} \quad (5)$$

From Equation (4), assuming $L_f + L_l = Load_t$ and letting C_o be the criterion of fecal coliform in the embayment, the loading capacity can be estimated as:

$$Load_T = C_c (Q_b + kV) - Q_o C_o \quad (6)$$

The daily load can be estimated based on the dominant tidal period in the area. For the New York Long Island and Long Island Sound area, the dominant tide is lunar semi-diurnal (M_2) tide with a tidal period of 12.42 hours. If fecal coliform concentration is in MPN/100ml, the daily load (counts day^{-1}) can be estimated as:

$$Load = Load_T \times \frac{24}{12.42} \times 10000 \quad (7)$$

In practice, one may not know Q_o *a priori*. Instead, one is given the tidal range of the tidal embayment. From that, Q_T, the total ocean water entering the bay on the flood tide, can be calculated. From this, Q_o, the volume of new ocean water entering the embayment on the flood tide can be determined by the use of the ocean tidal exchange ratio β as:

$$Q_o = \beta Q_T \tag{8}$$

where β is the exchange ratio and Q_T is the total ocean water entering the bay on the flood tide. The exchange ratio can be estimated from salinity data:

$$\beta = \frac{S_f - S_e}{S_o - S_e} \tag{9}$$

where S_f is the average salinity of ocean water entering the bay/estuary on the flood tide, S_e is the average salinity of the bay water leaving the bay, and S_o is the salinity at the ocean side. The numerical value of β is usually smaller than 1, and it represents the fraction of new ocean water entering the embayment. Once Q_o is known then Q_b can be calculated from equation (3).

The residence time, T_L, is an estimate of time required to replace the existing pollutant concentration in a system; it can be calculated as follows:

$$TL = \frac{V_b}{Q_b} \tag{10}$$

where V_b is mean volume of the embayment. From the definition, the denominator can either be Q_T or Q_b. However, using Q_T assumes that the ocean water enters into the embayment during the flood tide is 100% new, whereas using Q_b takes into consideration that a portion of water is not entirely new. It can be shown that the latter is more realistic. If Q_b is used in the residence time calculation it will result in a longer time scale than if Q_T is used.

Example TMDL Calculation for Brawley's Creek, USA

Case I: The most recent 5-year fecal coliform (or equivalent) median concentration used.

The median load calculation is illustrated as follows:

V = Mean volume of the embayment = 755,000 (m^3)

k = Fecal coliform decay rate = 0.36 (T^{-1})

Q_f = Freshwater discharge = 3,450 (m^3T^{-1})

Q_o = 330,000 (m^3T^{-1})

Q_b = 334,000 (m^3T^{-1})

C_c = water quality criterion = 14 MPN/100ml

C = current fecal coliform 5-year median concentration = 9.1 (MPN/100ml)

C_o = fecal coliform 5-year median outside of the embayment = 2.6

T = tidal cycle = 12.42 hours

C_f = the unit conversion factor

The allowable load is calculated as follows:

Allowable Load = Load = $[C_c(Q_b + kV) - Q_oC_o] \times C_f$

$$= [14 \times (334{,}000 + 0.36 \times 755{,}000) - 330{,}000 \times 14] \times 24 \div 12.42 \times 10{,}000 = 1.47 \times 10^{11}$$

For the current load estimate, the most recent 5-year median fecal coliform concentration is used for the calculation. The current load is calculated as follows:

Current condition = Load = $[C_c(Q_b + kV) - Q_oC_o] \times C_f$

$$= [9.1 \times (334{,}000 + 0.36 \times 755{,}000) - 330{,}000 \times 2.6] \times 24 \div 12.42 \times 10{,}000 = 8.99 \times 10^{10}$$

The load reduction is estimated as follows:

$$Load\ \mathrm{Re}duction = \frac{CurrentLoad - AllowableLoad}{CurrentLoad} \times 100\%$$

$$Load\ \mathrm{Re}duction = \frac{8.99 \times 10^{10} - 1.47 \times 10^{11}}{8.99 \times 10^{10}} \times 100\% = 0\%$$

Example TMDL Calculation for Brawley's Creek, USA

Case II: The most recent 5-year fecal coliform (or equivalent) 90th percentile concentration used.

The median load calculation is illustrated as follows:

V = Mean volume of the embayment = 755,000 (m^3)

k = Fecal coliform decay rate = 0.36 (T^{-1})

Q_f = Freshwater discharge = 3,450 (m^3T^{-1})

Q_o = 330,000 (m^3T^{-1})

Q_b = 334,000 (m^3T^{-1})

C_c = water quality criterion = 49 MPN/100ml

C = current fecal coliform 5-year 90th pct concentration = 158.5 (MPN/100ml)

C_o = fecal coliform 5-year 90th pct outside of the embayment = 100

T = tidal cycle = 12.42 hours

C_f = the unit conversion factor

The allowable load is calculated as follows:

Allowable Load = Load = $[C_c(Q_b + kV) - Q_oC_o] \times C_f$

$$= [49 \times (334{,}000 + 0.36 \times 755{,}000) - 330{,}000 \times 49] \times 24 \div 12.42 \times 10{,}000 = 4.52 \times 10^{11}$$

For the current load estimate, the most recent 5-year 90th pct fecal coliform concentration is used for the calculation. The current load is calculated as follows:

Current condition = Load = $[C_c(Q_b + kV) - Q_oC_o] \times C_f$

$$= [158.5 \times (334{,}000 + 0.36 \times 755{,}000) - 330{,}000 \times 100] \times 24 \div 12.42 \times 10{,}000 = 1.22 \times 10^{12}$$

The load reduction is estimated as follows:

$$Load\ \mathrm{Re}duction = \frac{CurrentLoad - AllowableLoad}{CurrentLoad} \times 100\%$$

$$Load\ \mathrm{Re}duction = \frac{1.22 \times 10^{12} - 4.52 \times 10^{11}}{1.22 \times 10^{12}} \times 100\% = 88\%$$