

## BACKGROUND INFORMATION ON THE STEADY STATE WATER CHEMISTRY (SSWC) MODEL

### Calculating critical loads

The Steady State Water Chemistry (SSWC) model is based on the principle that excess base cation production within a catchment area should be equal to or greater than the acid anion input, thereby maintaining the ANC above a pre-selected level (Reynolds and Norris, 2001). The model assumes steady state conditions, assumes that all sulfate in runoff originates from anthropogenic deposition and sea salt spray and is not adsorbed or retained in the watershed, and assumes that all chloride in the water comes from sea salt spray. Given a pre-selected critical ANC value, the critical load of acidity is simply the input flux of acid anions from atmospheric deposition, which gives the critical ANC when subtracted from the pre-industrial flux of base cations. Concentrations are multiplied by runoff Q to convert to fluxes. For a more detailed discussion of the SSWC model, see papers by Curtis, et al., 2001; Henriksen and Posch, 2001; and Henriksen, et al., 2002.

The critical load of acidity is expressed as:

$$CL_{ac} = ([BC]_o - [ANC]_{limit}) * Q$$

where:

$CL_{ac}$	= critical load of acidity (S+N);
$[BC]_o$	= pre-industrial concentration of base cations (corrected for sea salt);
$[ANC]_{limit}$	= critical ANC concentration;
Q	= annual runoff (m/yr).

The SSWC model uses in-lake water chemistry for the following inputs:

BC	= sum of base cations (Ca, Mg, Na, K);
SO <sub>4</sub>	= in-lake sulfate concentration;
NO <sub>3</sub>	= in-lake nitrate concentration.

### Sea salt corrections

The model applies a sea salt correction to the water chemistry concentrations. The equations below were applied to the Vermont lakes for their acid TMDL, and was applied to all the New England states and eastern Canadian provinces for the NEG/ECP assessment (Dupont et al, 2002). The equations correct for sea salt and convert concentrations from mg/L to ueq/L for use in the model. An asterisk (\*) indicates the value has been corrected for sea salt (In the equations, \* means multiplied by) and "U" before an ion indicates that it has been converted to ueq/L. [Note: NO<sub>3</sub>-N \* 71.4 converts nitrate nitrogen into mg/L to the nitrate ion in ueq/L.]

UCa*	= (Ca - (Cl * 0.0213)) * 49.9
UMg*	= (mg - (Cl * 0.0669)) * 82.26
UNa	= (Na - (Cl * 0.557)) * 43.5
UK*	= (K - (Cl * 0.0206)) * 25.57
USO <sub>4</sub> *	= (SO <sub>4</sub> - (Cl * 0.14)) * 20.82
UNO <sub>3</sub>	= (NO <sub>3</sub> -N) * 71.4
UCI	= Cl * 28.21

### Pre-industrial base cation concentration and F factor

The pre-industrial (pre-acidification) non-marine flux of base cations from the watershed to a lake needs to be estimated. It cannot be estimated simply by measuring present day runoff concentrations because post-industrial acidic deposition has increased the leaching of base cations through ion exchange in the soils. Empirical relationships are invoked and an F factor is employed, which is defined as ration of the change in non-marine base cation concentrations due to changes in strong anion concentrations (Brackke, et al., 1990). The original F factor equation was modified to account for catchment areas with high and low runoff (Hindar and Henriksen, 1998). A more detailed discussion of the procedure can be found in Curtis et al., (2001) and

Henricksen and Posch (2001). For purposes of this TMDL, we used the same assumptions and equations as used by Vermont for their acid pond TMDL report (Pembroke, 2003).

The equation below presents the procedure for calculating the pre-industrial non-marine flux of base cations, where the subscripts <sub>o</sub> and <sub>t</sub> refer to original (pre-industrial) and current respectively, and the superscript \* refers to corrected for sea-salt.

$$BC_o^* = BC_t^* - F \text{ factor } (USO4_t^* - USO4_o^*)$$

where:

- $BC_t^*$  = a sum of present day non-marine base cations ( $UCa^* + UMg^* + UNa^* + UK^+$ );
- F-factor = annual base cation flux accounting for runoff in the catchment, which is  $= \sin\{[(n/2) * Q * BC_t] / S\}$ . S = base cation flux at which F = 1. S = 400 meq/m<sup>2</sup>/yr was considered appropriate for Ontario lakes, was used by Vermont for their acid pond TMDL and is used here;
- $USO4_t^*$  = current non-marine, in-lake sulfate concentration;
- $USO4_o^*$  = pre-acidification sulfate concentration. Vermont used estimates for Ontario (Henricksen, et al., 2002) that were also used for northeast North America (Jacques, et al., 2002) and are used here.

#### ANC Limit

The  $[ANC]_{limit}$  is based on the lowest ANC concentration presumed not to potentially damage selected biota (Henricksen and Posch, 2001). The  $[ANC]_{limit}$  was recalculated on the basis of the pH-ANC relationship developed in Project Task 2b (see Appendix C). Mean pH values were calculated for each lake using the minimum value observed on each sampling date across stations and depths (see Appendix C for greater information on pH calculation). Using the data from the 158 acid-impaired ponds, a simple linear regression of mean pH vs. mean Gran ANC was generated to derive a target ANC value. The new  $[ANC]_{limit}$  was determined to be 6.24 mg/L (125 ueq/L) at pH 6.5. This value was reviewed and approved by NHDES (e-mail from Margaret Foss, NHDES; dated March 30, 2007) and was inputted into the SSWC model as a means of identifying ponds which are not in compliance with NHDES standards.

#### Annual surface runoff estimates

Estimated annual runoff for the acid ponds were derived from statewide maps of isopleths of annual runoff, extrapolated to GIS files of pond watershed as provided by NH GRANIT. Details and documentation of the derivation of annual runoff values are provided in Appendix B "Estimated Runoff Values for Watersheds in Acid Pond TMDL Study." NH DES reviewed and approved the acid pond annual runoff values.

#### Interpreting critical load values

The calculated critical load for a lake is considered to be an inherent property of the lake and its catchment area. A positive value indicates that the waterbody has some tolerance for acid inputs. The greater the value, the greater the tolerance for acidification. Very high values suggest conditions may be acceptable for sensitive organisms regardless of deposition scenarios whereas low values suggest sensitivity to acidification (Hindar and Henriksen, 1998).

Negative critical load values occur when the selected  $ANC_{limit}$  is higher than the calculated original base cation concentration ( $BC_o^*$ ). Such results imply that the water quality criterion (pH 6.5 as represented by ANC of 6.24) is greater than what nature provides. In other words, the natural conditions were such that the original (pre-industrialization) ANC was lower than the selected ANC for protection of biota (Henriksen, et al., 1992). The critical load for such lakes is converted to zero in order to calculate exceedences. For these lakes with a critical load of zero, the critical load will always be exceeded even assuming the strongest emission reduction scenarios, and the lakes will never attain a pH of 6.5.

Sensitivity of the model

The SSWC model is highly sensitive to two parameters: the ANC<sub>limit</sub> and the F-factor. The ANC<sub>limit</sub> selected was based on the pH water quality criterion of 6.5 and the relationship between pH and ANC. NH DES chose a limit of 124 ueq/L (6.24 mg/L), which is more protective than the 50 ueq/L limit used by Vermont (VTDEC, 2003) and the 40 ueq/L limit used by for the NEG/ECP analysis (Dupont, et al., 2002). Lowering the ANC<sub>limit</sub> would increase the critical load values and decrease the excess load values.

The F-factor accounts for the rate of base cation leaching from the watershed. Vermont, the NEG/ECP analysis for northeast North America, and studies of lakes in Ontario, Canada (Henriksen et al., 2002; Hindar and Henriksen, 1998) all used an F-factor based on a Norwegian estimate that takes into account high and low runoff from a catchment area. The same F-factor was assumed appropriate for New Hampshire lakes.

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