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WHAT DO WE NEED IN THE FUTURE – EFFECT BASED CONTROL STRATEGIES OR DEATH OF SPECIES ?

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ABSTRACT

The critical load approach is a methodology according to which critical loads are used as a criterion to assess whether emission reduction strategies are sufficient. It is now more than a decade since the critical load concept was developed. The concept has been a very successful tool for the development of the effect-based cost-effective regional air pollution strategies in Europe. Different existing methods of the calculation of the critical loads have been discussed and their limitations have been pointed out.

INTRODUCTION

Acidification and eutrophication of lakes and bays may be the result of deposition of inorganic nitrogen and sulphur species that have anthropogenicc origin (Grennfelt and Hultberg, 1986)[1]. In general, NO_x and SO_2 emissions have steadily increased over the last several decades and it is believed that the wet and dry deposition of these species (NO_x and SO_2) have also increased (Skeffington and Wilson,1988)[2]. In the context of pollution abatement the question becomes increasingly relevant of how much emissions should be abated to obtain sufficient protection of natural resources. Knowledge is required to set the environmental quality limits and environmental objectives. Initial attempts at reducing emissions centered on the flat rate reductions, such as Helsinki Protocol which called for a reduction in sulphur emissions of atleast 30% by 1983 compared with 1980 levels. But the main shortcoming of Helsinki Protocol is that these reductions were determined without any ecological rationale (Warfvinge and Sverdrup, 1995)[3]. As further reductions in emissions were seen to be necessary, another approach, which is an attempt to link the emission-abatement strategy with the capacity of ecosystem to withstand and buffer the effects of acidic deposition (Downing et. al., 1993[4]; Sverdrup and de Vries, 1994[5]; Hettelingh et. al., 1992[6]). This approach in which it is considered that there is a damage threshold of response by ecosystem, is based on the derivation of Critical Load (Chadwick and Kuylenstierna,1990[7]).

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Critical Load was first defined by the International Workshop on critical load held at Skokloster, Sweden in 1988, as "**the maximum deposition of acidifying compounds that will not cause chemical changes leading to long term harmful effects on ecosystem structure and function**" (Nilsson and Grennfelt, 1988). Some aspects of this definition are worth special attention. Firstly, the definition focuses on the chemical changes in the environment and establish these as a link between emissions and the biological ecosystem. Secondly, the long-term expresses the fact that there is a time-lag between a change in emissions and a change in chemical effects in environment. At the same time, it is clear that the critical load concept in itself does not treat the temporal aspect of acidification and recovery. Finally, the definition is limited to atmospheric deposition. The general definition is "**A quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to the present knowledge**" (Nilsson and Grennfelt, 1988) [8].

To understand the concept of critical load some of the required elements are receptor biological indicator, chemical criteria and critical limit. Receptor is the type of ecosystem considered such as surface water (lakes and streams), forest soils and groundwater. Biological indicator is the type of organism that has been selected to represent the receptor like fish for surface water, vegetation for soils, forest, sand and human health for groundwater. Chemical criterion is the chemical measure affected by the acid deposition that is used to predict the risk of damage to biological indicator. Critical limit is the most unfavourable value that the chemical criterion may attain without long-term harmful effect on ecosystem and function.

In practice, critical loads are estimated as estimates of the maximum pollutant level at which harmful effects of specified aspects of particular objects are unlikely to occur. They are established through experimental studies, observations and measurements in field and by application of various modelling techniques (Sverdrup et al., 1994[9]; Sverdrup and Warfvinge, 1988[10]; Alcamo et al.,1990[11]; de Vries,1988[12]). Critical loads will vary from ecosystem to ecosystem depending on a range of environmental site factors. Thus, one way of proceeding in establishing target deposition levels is first to identify the major environmental factors that determine the site (ecosystem) sensitivity, these factors are then weighted and combined together to give an overall index of relative sensitivity (Chadwick and Kuylenstierna, 1990)[7].

The purpose of determining critical load is to set goals for future deposition rates of acidifying compounds such that the environment is protected. The goal should be to protect the environment to such an extent that a critical chemical compound or combination of components like ANC (Acid Neutralizing Capacity), pH, Al/Ca ratio, etc. stay above or below a value that does not cause harmful response to the selected indicator (Kamari et al., 1992)[13].

TARGET LOAD

Political negotiations aimed at the reduction of emissions are considered as the term "**Target Load**". Target Load may be higher or lower than the critical loads, depending on the manner in which the situation is judged. They may be set lower, for instance, in order to leave a margin of safety. On the other hand, target load may be allowed to be higher – meaning in effect a deliberate acceptance of a certain degree of environmental damage or risk of damage (Fig. 1). When set higher, they may be regarded as interim targets, reflecting the need for a stepwise approach to reducing emissions in which they should subsequently be progressively reduced to a level at or below the critical load (Acid News, April 1995)[14]. Strategies concentrating on emission reductions relation to site sensitivity are termed "targeted" strategies (Chadwick and Kuylenstierna, 1990) [7].

SENSITIVITY TO ACIDIC DEPOSITION

Sensitivity is defined as "the responsiveness of an important variable to an independent forcing variable". Different parts of the ecosystem respond in different ways to acidic deposition. In terrestrial ecosystem changes in the functional attributes, such as photosynthetic rates, growth rates and needle loss are dependent on the changes in soil which bring the soil chemistry close to critical value of certain soil parameters (Warfvinge and Sverdrup, 1992[15]; Sverdrup et al, 1994[9]).

The critical load concept applied to ecosystem assumes a threshold response to acid deposition in terms of the onset of harmful effects (Sverdrup and Warfvinge, 1993). Below the threshold it is postulated that acidic deposition will not give rise to deleterious effect on animals, plants and other life and these will only occur once the critical load is exceeded. The critical load is thus a site specific, pollutant specific and ecosystem specific value (Chadwick and Kuylenstierna, 1990) [7].

SETTING CHEMICAL CRITERIA FOR DIFFERENT ECOSYSTEMS

To set a critical load, an indicator organism is chosen, for which the response to different levels of acidification is known. A limit can be set for alkalinity, pH or Al depending on what the organism is sensitive to, a limit that is not to be transgressed due to impact of acid deposition and the critical load is maximum load of acid input that will keep the system at this defined limit. Once the limit is set, this can be expressed as an alkalinity concentration in the solution that must be maintained, equivalent to certain alkalinity production in the system. The chemical criteria for limits of damage must be established for each indicator organism of interest.

A set of criteria for calculation of the critical load from the European literature, have been reviewed and average values are summarized in table 1. The values found in the literature contain considerable amount of uncertainty. These chemical limits are based on the assumption that an indicator organism is appointed to represent the ecology of the system investigated. Suggestions for such indicators are the most sensitive for fish species of substantial size in a stream or lake, trees for forest ecosystems and human for ground water. Different receptor have different critical limits, depending on the chemical and environmental conditions of the similar region.

AVAILABLE METHODS AND MODELS

A number of methods (Fig 2 and Fig 3) have been used to derive critical level values ranging from a formal statistical approach based on ecotoxicology to empirical field observation. Exposure response relationships are central to the estimation of critical level values. These relationships are derived from field observation or range of experimental approaches. Special is to be taken in the selection of an indicator organism as the experimental details are based on it.

Some of the common methods used for the calculation of critical load today are as under:

(a) Water Chemistry Method

The water chemistry approach will indicate whether a lake or stream is receiving acid deposition above or below its critical load. The model assumes the sulphate concentration is run-off to be in steady state with the atmospheric deposition of sulphate and include nitrate in the run-off water. Some of the chemical criteria used for setting critical loads are given in the table 1.

To assess the original lake sensitivity, the pre-acidification base cation concentration $[BC_O]$ is calculated. This is estimated using the present base cation concentration $[BC_t]$, the F factor and the estimated background.

$$[BC_O] = [BC_t - F * - [SO_4^{2-}{}_O])$$

The F-factor is defined as the change in the base cation concentration with a change in strong acid concentration due to change in the atmospheric deposition of sulphates and nitrates.

$$F = \sin([BC] * 90/S)$$

Generally the value of S is set at 400 μEq/l [17]. The deviation of the lake from the critical load is then given as :

$$\triangle CL = [BC_O] - [ANC]_{Limit} - [SO_4^{2-}{}_t]$$

Where ANC = Acid Neutralizing Capacity

Positive values of ΔCL indicates that the acid deposition is below the critical load and negative value signifies that the acid deposition is above the critical load.

(b) Steady-State Method

It is the most commonly used method. The steady state approach for calculating the critical load implies that only the final result of the certain deposition level is considered the basic principle[18] of the method is to identify the long term average sources of acidity and alkalinity in the system and to determine the maximum acid input that will balance the system at a bio-geochemical safe limit.

The critical value of alkalinity[9] leaching is defined from the maximum allowable critical hydrogen ion leaching and critical aluminium ion leaching as follows:

$$ANC_L = -\left[\frac{1.5\, X_{Ca+Mg+K}\, ANC_W + BC_D - BC_U}{(BC/Al)_{crit}\, K_{gibb}}\right]^{1/3} Q^{2/3} - \left[\frac{1.5\, X_{Ca+Mg+K}\, ANC_W + BC_D - BC_U}{(BC/Al)_{crit}}\right]$$

$$CL(AC) = ANC_L \qquad \text{(ii)}$$

Substitution of the equation (i) in equation (ii) gives the Steady State Mass Balance equation based on the plant response (BC/Al) criterion is

$$ANC_L = ANC_W + \left[\frac{1.5\, X_{Ca+Mg+K}\, ANC_W + BC_D - BC_U}{(BC/Al)_{crit}\, K_{gibb}}\right]^{1/3} Q^{2/3} - \left[\frac{X_{Ca+Mg+K}\, ANC_W + BC_D - BC_U}{(BC/Al)_{crit}}\right]$$

Where

ANC_W	=	Alkalinity produced by weathering
ANC_L	=	Critical Alkalinity Leaching
$(BC/Al)_{crit}$	=	Critical Molar Base Cation to Aluminium Ratio
K_{gibb}	=	Gibbsite solubility constant
Q	=	Runoff
BC_D	=	Base Cation Deposition
BC_U	=	Base Cation uptake

The Steady State Mass Balance Equation based on the soil response is:

$$CL = 3ANC_W + \left(\frac{2ANC_W}{K_{gibb}}\right)^{1/3} Q^{2/3} \qquad \text{(iv)}$$

The critical load is finally computed as the minimum of the result of equations (iii) and (iv).

On the basis of the above stated methods, the available mathematical models include the SMB (Simple Mass Balance) (Sverdrup and de Vries, 1994)[5], PROFILE (it is based on the conceptual model of a forest soil which may represent a profile or the catchment (Sverdrup and Warfvinge, 1988)[10], RAINS (Regional Acidification INformation and Simulation) (Alcamo et al, 1990)[11] and MACAL (Model to Assess a Critical Acid Load) (de Vries, 1988)[12].

MODEL USED TO ASSESS CRITICAL LOAD IN INDIA

In Indian context, very few works have been done on critical load[20,21]. Foell et al have used RAINS-Asia model to calculate critical load for Asian countries on emission basis. RAINS-Asia model predicted that West Bengal, Delhi and South Bihar are the main vulnerable areas. The main reason for south Bihar and some parts of West Bengal are facing such threats due to the location of the largest coal belt and thermal power plants in the region.

RAINS-Asia[19] (Regional Air Pollution Information and Simulation model for Asia) is a user-friendly, integrated, PC-based model for regional policy analysis and decision-making regarding energy sector development. It is a tool used to assess and project future trends in emissions, transport and deposition of air pollutants and their potential environmental impact. It was developed by a team of Asian, European and North American scientists, under the leadership of the World Bank and the Asian Development Bank[17].

The RAINS-Asia model covers 23 Asian countries in East, South and South-East directions, which are divided into 94 regions. The model uses 1990 data as a base and calculates future energy emissions and environmental parameters through 2020 in 10 year increments. The RAINS-Asia consists of three modules, each addressing a different part of the acidification process. The Regional Energy and Scenario Generator (RESGEN) module estimates energy pathways based on socioeconomic and technological assumptions; the Energy and Emission (ENEM) module uses the energy scenarios to calculate S and N emissions and cost of control strategies; and the Deposition and Critical Load (DEP) module which consists of the Atmospheric Transport and Deposition (ATMOS) sub-module and the Environmental Impact and Critical Loads (IMPACT) sub-module, calculates levels and patterns of sulphur deposition resulting from a given emission scenario and the ecosystem critical loads and their environmental impacts based on these patterns.

The atmospheric module (ATMOS) of RAINS-Asia analyses long-range transport and deposition of sulphur in Asia. ATMOS combines information on emission rates, levels and source locations (from ENEM) with meteorological, chemical and physical data to calculate the resulting sulphur deposition patterns. The ATMOS model, which is a three-dimensional, multiple layer lagrangian model, is used for calculations. The model provides annual average (wet + dry) sulphur (sulphur dioxide and sulphate) deposition values and monthly average sulphur dioxide concentration values for each 1 degree by 1 degree grid cell. The model allows the user to assess the spread of pollution from an individual source or region. The emission sources that contribute to sulphur deposition at a particular site can also be identified.

The IMPACT sub-module assesses the sensitivity of various ecosystems to acid deposition and compares this information to the deposition data generated by the ATMOS module. The carrying capacity of acid deposition of 31 types of ecosystems is estimated. Values of sulphur deposition are based on a yearly average and are calculated at a 1 degree by 1 degree resolution. The Steady State Mass Balance method determines the maximum level of a substance that will not damage an ecosystem over the long run.

FUTURE SUGGESTIONS

In trying to establish the targets based on critical load and level values to ensure sustainability of environmental systems, the uncertainties should make the workers to work on the following lines:

1. The excess of the critical load of acidity from sulphur and nitrogen should be determined simultaneously.
2. The work should be done to assess the excess of the critical load of nutrient nitrogen by nitrogen oxides and ammonia and ozone by the interaction of nitrogen oxide with volatile organic compounds.
3. Complexities due to interaction of the pollutants, such as acidity with the heavy metals and the possibility of climate change and associated changes should be taken in consideration for the derivation of the critical load results.
4. Further improvements of existing results and maps by national contributions based on carefully designed field work on local scales should be done.

Apart from these, it is necessary to set certain chemical criteria for Indian region.

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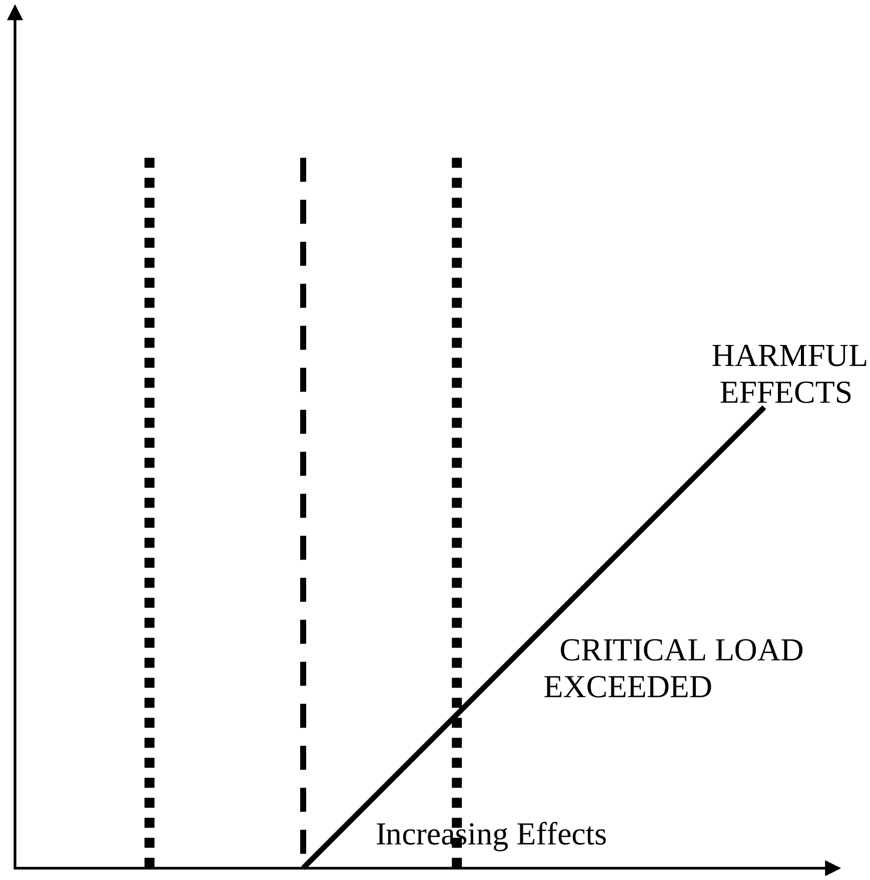

Figure 1: Relationship between critical load and target load (Source: Acid News, 1995)

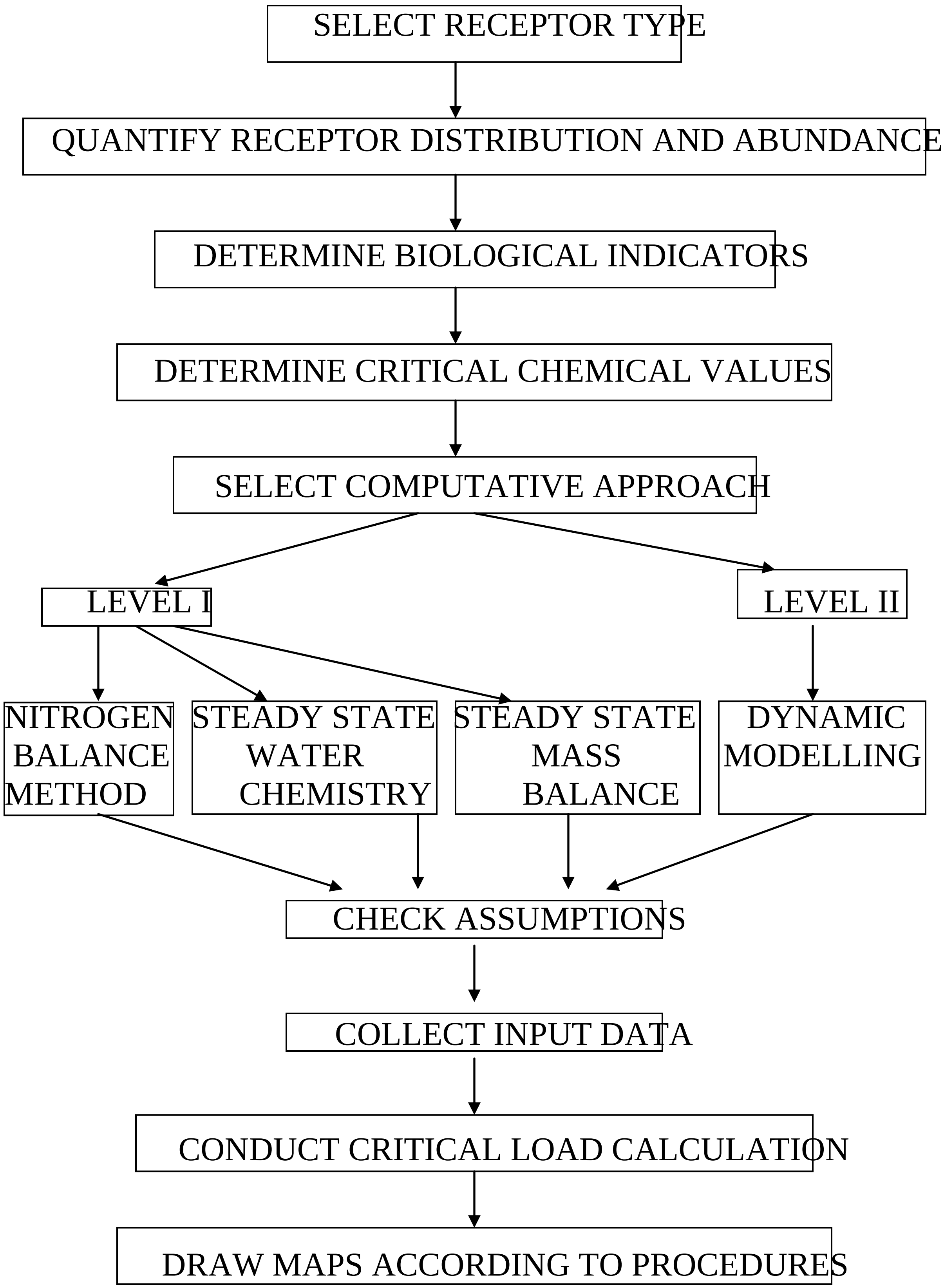
SELECT RECEPTOR TYPE
QUANTIFY RECEPTOR DISTRIBUTION AND ABUNDANCE
DETERMINE BIOLOGICAL INDICATORS
DETERMINE CRITICAL CHEMICAL VALUES
SELECT COMPUTATIVE APPROACH
LEVEL I
LEVEL II
NITROGEN BALANCE METHOD
STEADY STATE WATER CHEMISTRY
STEADY STATE MASS BALANCE
DYNAMIC MODELLING
CHECK ASSUMPTIONS
COLLECT INPUT DATA
CONDUCT CRITICAL LOAD CALCULATION
DRAW MAPS ACCORDING TO PROCEDURES

Figure 2 : General Flowchart for calculation and mapping of critical loads

Table 1 : Chemical criteria

Criteria Location of application	Soil Root Zone (0-50 cm.)	Groundwater At ground water	Lakes and Streams Lake volume weighted Stream transect weighted
pH	E-layer: > pH 4.0 B-layer: > pH 4.4	> pH 6.0 (1.0 m level)	>pH 6.0
Alkalinity	> -300 µ Eq/l	>100-140 µ Eq/l	>50 µ Eq/l
ANC : SO_4	__	71.0	__
Total Al	< 4.0 mg/l	<0.1 mg/l	<0.08 mg/l
Labile Al	<2.0 mg/l	__	<0.03 mg/l
NH_4:K molar ratio	<5	__	__
Ca : Al molar ratio	>1.0	__	>5
NO_3 eutrophication	__	<50 mg/l	<0.5 mg/l