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Modelling the Effects of Acid Sulphate Soils on River Acidity in Finland

Jukka Palko
Water and Environment District of Oulu, Finland

Kjell Weppling
Nordkalk Oy Ab, Pargas, Finland

Acid sulphate (AS) soils cover extensive areas of the coastal plains in western Finland. These soils constitute an environmental hazard due to their ability to release acidity when exposed to atmospheric oxygen. Acidification of soil and water can be reduced or prevented if the factors influencing the release and transport of acidity in AS soils are known. The objective of this study was to develop mathematical models describing the acidity load from AS soils, thus providing tools for accurate soil and water management in the affected areas. The work resulted in a static and a dynamic model for predicting the runoff acidity from catchments containing AS soils. The main features of the models are described in the paper. Both models require significant catchment characteristics and hydrological monitoring results as input data, but no ion balance information is needed. Model applications showed that the static model is able to give good estimates of the mean acidity level to be expected during specific flood periods in the studied river, while the dynamic model, after calibration, is capable of predicting the daily acidity with appreciable accuracy. The information provided by the models can be used to assess adequate mitigration strategies for the watercourses affected by AS soils.

Introduction

Typical acid sulphate (AS) soils in Finland are recognised by the presence of a sulphidic soil horizon below the aerobic horizon and the highly acidic oxidation zone in the upper soil layers. Over 350,000 hectares of cultivated AS soils have been estimated to exist along the Finnish coast (Palko, unpublished data). The amount of total sulphur in the sulphide sediment seldom exceeds 1% (Purokoski 1958), which allows the soils to be used for cultivation after liming and drainage. A problematic feature of AS soils is their ability to release acidity. Profile ripening due to regional uplift and reclamation of agricultural land initiates a number of chemical processes that release acidity and cause serious environmental problems in soils and rivers (Palko and Weppling 1993).

Acidification hazards caused by soil and water management works can be reduced or even prevented if the amount and location of AS soils is known. Reliable information on acidity formation and leaching rates facilitates the planning of adequate mitigation strategies. AS soil surveys and measurements of potential soil acidity are carried out with well documented methods (Dent and Young 1981; Palko *et al.* 1988). The amount of acidity generated in the soil profile depends on the penetration of oxygen into the AS soil sediment and on the time in which the sediment is exposed to oxygen. The leaching of acidity from the soil is a very complicated process due to many different buffering systems, such as reactions with aluminium and iron. Chemical weathering caused by acidity releases potentially toxic soluble aluminium (Al^{3+}), which carries acidity to the topsoil and makes the surface runoff waters acid. Subsurface drainage pipes may also carry acidity directly from the soil horizon to the watercourses in the form of ferrous iron (Fe^{2+}) (Palko 1988; Palko and Weppling 1993).

During the past decade, mathematical models have become increasingly important in evaluating the environmental impacts of acid depositon as well as in assessing the effects of different countermeasures (*e.g.* Cosby *et al.* 1985; Davis 1988; Warfvinge 1988; Warfvinge and Sverdrup 1988; Forsius 1992). Models designed for ecosystems affected by acid rain cannot, however, be directly applied in areas containing large amounts of AS soils.

To date, models especially designed or modified for AS soils and waters, have been scarce. Simple regression models based on sulphate (Alasaarela 1982) and electrical conductivity (Palko *et. al.* 1985) have been made to predict the effects of AS soils on runoff acidity. Simulation models for the estimation of runoff pH within a given time and place have been used in the river Kyrönjoki in western Finland (Laitinen 1993).

The amount of acid and potentially toxic compounds released as a result of soil and water management in catchments containing AS soils is assumed to be predicted by quantitative simulation models (Dent 1986). In recent years, an attempt has been made to construct a simulation model of this kind for the evaluation of water management strategies in AS soil regions (Bronswijk and Groenenberg 1993; van Wijk *et. al.* 1993). This ion balance model requires many input variables as well as a parametrization of thermodynamic equilibrium constants for several chemical reactions. The data obtained from normal environmental monitoring are usually inadequate for successful ion balance modelling, which emphasizes the need for a special monitoring programme. Thus, the applicability of such a model in the routine planning associated with AS soil management is highly questionable.

Objectives and Scope

The objective of this study was to develop adequate mathematical models describing the acidity load from AS soils. Once proved to be successful, such models would provide the decision-makers and water authorities with important practical instruments facilitating accurate soil and water management in AS soil containing catchments. Thus, a simple static model and a more sophisticated dynamic "black box" model were designed to evaluate the acidity hazard often associated with such catchments.

The static model is mainly intended for a general classification of rivers according to their state of acidification and their average neutralisation demand. The dynamic model, on the other hand, has been constructed for more detailed mitigation planning, permitting predictions of daily titratable runoff acidity in the affected rivers. The input data required by the models consist of significant, but easily obtainable catchment characteristics and hydrological monitoring results to assure wide applicability in routine use.

This paper describes the theoretical considerations behind the models, the input requirements and the modelling procedure as well as the results of some practical applications.

Theoretical Considerations

Ecological modelling will always call for compromises regarding both input variables and model complexity. The relation between the number of variables and the descriptive accuracy of the model will sooner or later reach a limit where the modeller, according to Jørgensen (1988), has to find a balance between "knowing much about little and little about much". This was carefully kept in mind when the boundaries for the AS soil models were defined.

The release and transport of acidity from AS soils into adjacent brooks and rivers includes an array of complicated chemical and microbial processes. These processes are significantly influenced by the hydrological properties of the catchment (Palko and Weppling 1993). Quantitative modelling of such a system would inevitably imply a highly complex model design on the ion balance level. Due to obvious shortcomings in the quality of the available data, the ion balance approach was excluded from the models presented in this paper. The theoretical basis of the models was considered acceptable despite this simplification.

Static Model Description

The static model is designed to calculate the mean runoff acidity (meq l^{-1}) during the fall and spring floods from the relative amount of AS soils in the catchment (X_{ASS}) and from the duration of the dry summer period (T-value). The amount of AS soils in the catchment is by far the most important parameter explaining the mean runoff acidity. The degree of explanation is, however, somewhat better when parameter T is included.

Fluctuations in the groundwater level (GWL) is usually the main factor controlling acidity release in AS soils. In large catchments GWL, however, exhibits considerable local fluctuations, which means that a correct average GWL for the total area is hard to obtain. The parameter T is introduced to describe the average hydrological conditions in the area during periods with favourable conditions for sulphide oxidation. Although the relationship between GWL and parameter T still is a hypothetical one, the T-value is assumed to provide a reasonable means to estimate the water saturation of the soil upper layers. This is in turn related to the runoff quantity and thus to the transport of acidity (Palko *et.al.* 1988; Palko and Yli-Halla 1993).

The T-value is determined by the number of days during the preceding summer when the runoff in the area is less than 1.0 $dm^3\ s^{-1}\ km^{-2}$. This information is preferably obtained from the existing network of small hydrological drainage basins. The value from the nearest basin should be used in the calculations. Thus, the T-value influences the mean runoff acidity from year to year. Due to these fluctuations, the limit T-values should be assessed. When these values are used in the calculations, the model provides information about the lowest and highest acidity levels to be expected (Fig. 1).

The estimation of the mean runoff acidity by the static model should be made separately for fall and spring due to the substantially different corresponding hydrologies. The regression equations and R^2 values for estimating the mean acidity in fall and spring have been calculated from existing monitoring data

$$[A]_{\mathrm{fall}} = 8.7\ X_{\mathrm{ASS}} + 0.025\ T - 0.775 \qquad R^2 = 0.806 \tag{1}$$

$$[A]_{\mathrm{spring}} = 3.7\ X_{\mathrm{ASS}} - 0.009\ T + 0.565 \qquad R^2 = 0.652 \tag{2}$$

$[A]$ – acidity concentration (meq l^{-1})
X_{ASS} – the amount of AS soils in the catchment (%/100)
T – the length of the preceding summer drought (days)

When the T-value is very low, the regression equation gives too low acidity values for large catchments with small quantities of AS soils. In spring a high T-value in regression Eq. (2) actually decreases the mean acidity. This discrepancy may be caused by the fact that the T-parameter is subjected to disturbing factors such as

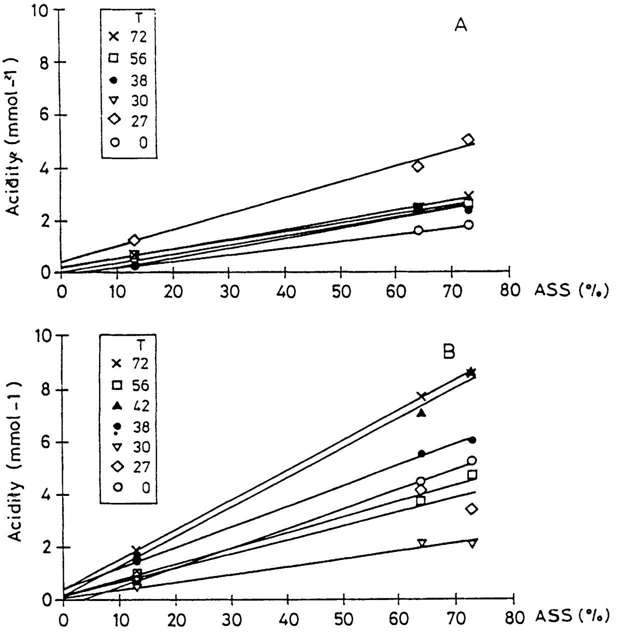


Fig. 1. The relationship between the mean runoff acidity and the percentage of AS soils in the Tupos basins in spring (A) and fall (B) in 1986-1992.

varying spring hydrologies (*e.g.* due to the severity and duration of the ground frost) and a possible lack of distinguishable flooding periods after the summer seasons. These factors are supposed to explain the observed disorder among the different "*T*-years" (Fig. 1).

The model does not consider the effects of cultivation practices (*e.g.* types of drainage or soil liming) and the time period after the drainage on the quantity of released acidity in the catchment. These effects are not taken into account because they seem to be covered by hydrological factors.

The minimum amount of AS soils in the catchment should be 10% for the model to be used relatively reliably. The mean acidity for rivers containing smaller amounts of AS soils should be evaluated by adding the calculated acidity of the subcatchments containing AS soils to the background acidity in relation to the total drainage area (Palko *et.al.* 1988)

$$[A]_R = [A]_S\, X_{ASS} + [A]_B\, (1 - X_{ASS}) \qquad (3)$$

$[A]_R$ – Mean acidity in the river (meq l^{-1})
$[A]_B$ – Background acidity (0.15-0.25 meq l^{-1})
$[A]_S$ – Predicted mean acidity for AS-containing – subcatchments (from Eqs. (2) or (3))

The static model can be used to classify the rivers and river basins according to their state of acidification and neutralisation demand under varying hydrological conditions. However, any evaluation of the daily runoff acidity is impossible with this model.

Dynamic Model Description

Basic Principles

The model was designed to predict the daily runoff acidity $[A]_d$ for catchments containing cultivated AS soils drained by open ditch and/or subsurface drainage. The quantity of AS soils, cultivated non-AS soils and AS soils with subsurface drainage, as well as the background acidity from non-AS soils is needed to predict the $[A]_d$ for the whole catchment.

The basic assumption in the model is that the active acidity pool (S_d) in AS soils is related to the groundwater level (GWL). An increase in S_d is connected to a decrease in the GWL below a constant depth limit expressed by parameter 4 (Eq. (4)). The limit value indicates that no acidity is released from sulphide sediments when the GWL is above that level. The increase in S_d is defined in the model to occur between June 1st and August 30th, when the temperature and hydrological conditions are usually favourable for sulphide oxidation. The daily decrease of S_d is calculated by the daily acidity and the runoff quantity (Eq. (5), Fig. 2).

In the model structure the sum of the daily runoff quantity and quality (acidity) from the different subcatchments in the studied river basin is indicated by A_{dq}. Correspondingly, the total runoff quantity from these subcatchments is indicated by q (Eq. (7), Fig. 2). The daily runoff acidity in the whole catchment $[A]_d$ is calculated by dividing the term A_{dq} by the term q (Eq. (8), Fig. 2). The definitions for the abbreviations are presented in the notation.

$$\frac{dS_d}{dt} \equiv P3\,(GWL-P4) \tag{4}$$

$$-\frac{dS_d}{dt} = [A]_d\, q_d \tag{5}$$

$$\begin{aligned} A_{dq} = {} & X_{\mathrm{ASS}}\,((1-X_{sd})\,[A]_{od}\,(q_{odp}+P7\,q_{ods}) + X_{sd}\,[A]_{sd}\,(q_{sdp}+P7\,q_{sds}))+ \\ & + X_{\mathrm{NASS}}\,[A]_f\,q_{od}+(1-X_{\mathrm{NASS}}-X_{\mathrm{ASS}})\,[A]_f\,q_f \end{aligned} \tag{6}$$

$$q = X_{\mathrm{ASS}}\,((1-X_{sd})\,q_{od}+X_{sd}\,q_{sd})+X_{\mathrm{NASS}}\,q_{od} + (1-X_{\mathrm{NASS}}-X_{\mathrm{ASS}})\,q_f \tag{7}$$

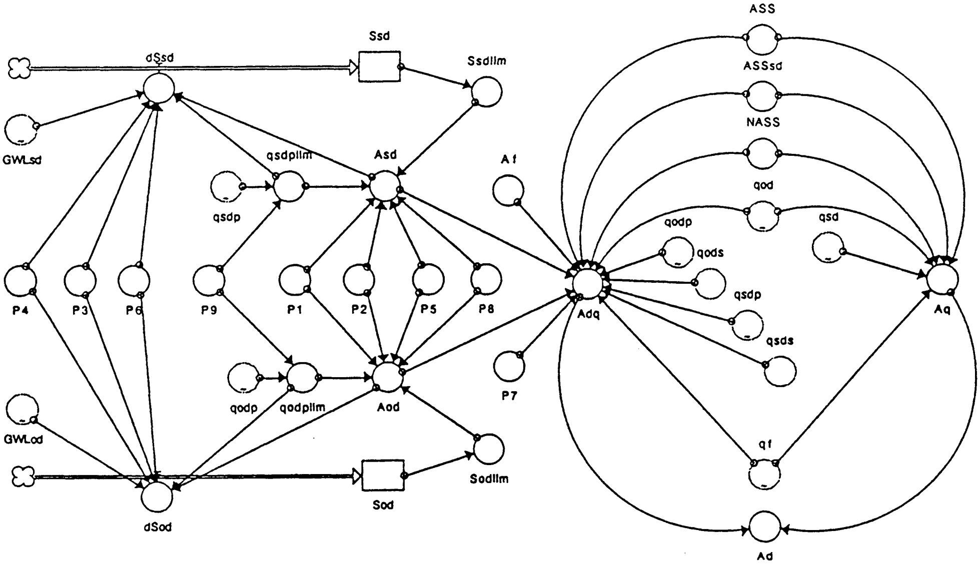


Fig. 2. The structure of the dynamic model for estimating the daily runoff acidity $[A]_d$ in rivers or river basins affected by AS soils.

$$[A]_d=\frac{A_{dq}}{q} \qquad (8)$$

The daily acidity for the subsurface drainage and open ditch areas ($[A]_{sd}$ and $[A]_{od}$) was calculated in relation to the corresponding daily runoffs (q_{sd} and q_{od}) using parameters 1 and 2 (Fig. 2). The limit for runoff dependence (P 9) is calibrated in the model. Only the net oxidation of sulphide is calculated by the model, while the decline in acidity by sulphate reduction during waterlogging can be omitted from the calculations. As the pool of active acidity cannot be replenished during the winter months, there will always be less acidity available for the spring flood than the fall flood (Palko and Weppling 1993). This has been taken into account in the model by the correlation between S_d and $[A]_d$ (parameter 5). In spring, the runoff mainly consists of snowmelt waters, which do not penetrate into the frozen soil profile, but are discharged directly into the watercourses. These runoff waters are not able to wash out the leachable acidity stored in AS soils (Palko *et.al.* 1988; Palko and Weppling 1993). This fact has to be considered in the model by reducing the $[A]_d$ in spring in comparison to the fall $[A]_d$ through an iterated parameter 8 (Fig. 2).

Hydrological Considerations

A hydrological submodel was used to calculate the daily water budget for the dynamic model by using daily precipitation, mean temperature and cloudiness data obtained from the nearest meteorological stations as input parameters (Karvonen and Skaggs 1993; Alasaarela *et. al.* 1993).

The hydrological submodel calculates the daily water balance of the cultivated soil areas. The calculation includes the infiltration of water through the soil profile, the surface runoff from open ditches as well as the runoff from subsurface drains. In addition, the daily runoff from forest soils and the depth of the groundwater level for each day are calculated by the submodel. The hydrological submodel was uncalibrated when implied, which provided the dynamic model with a possible source of error.

Calculation Procedures

The dynamic model calculation includes the following steps:

1) The data, containing daily runoffs, depth of the groundwater level and measured acidity values, are entered in the computer memory.
2) The initial values are given for the model parameters.
3) The model parameters are optimised with the simplex procedure as given by O'Neill (1971).
4) The goodness of fit for the measured and calculated acidity values are evaluated by comparing the corresponding mean values or by the R^2 value calculated by Eq. (9).

$$R^2 = \frac{\sum (M_i - \bar{M})^2 - \sum (M_i - C_i)^2}{\sum (M_i - \bar{M})^2} \tag{9}$$

M – measured value
C – calculated value

The dynamic model contains nine parameters, seven of which can be calibrated against measured acidity values. Such a calibration was performed in two model applications. The Stella software tool for Apple Macintosh computers was used as an auxiliary to facilitate the applicability of the dynamic model (Richmond *et al.* 1992).

Table 1 – Relevant characteristics of the Tupos basins used in the modelling

Area name	T7	T8	T9
Catchment area, km^2	2.8	2.2	6.6
Cultivated non-AS soils, %	87	27	36
AS soils, %	13	73	64
Subsurface drainage, %	0	0	0

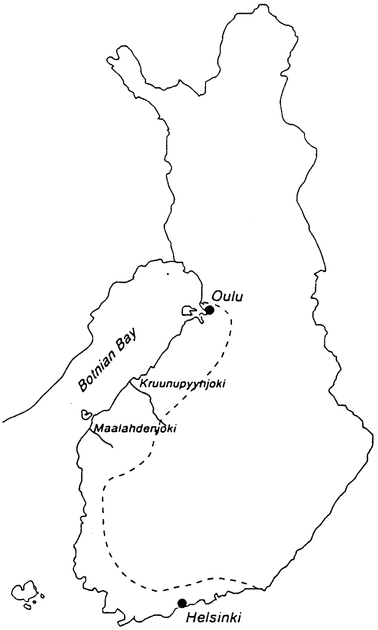


Fig. 3. The location of the AS soil areas and the experimental sites on the coast of Finland.

Model Applications

Site Descriptions

Most of the data required for the mathematical expressions within the models were obtained from three small catchments (the Tupo basins) situated about 20 km south of the Oulu city on the northwestern coast of the Bothnian Bay (Fig. 3). The catchments were completely cultivated and homogeneous with regard to soil type, contour lines and cultivation practices, but contained different amounts of AS soils (Table 1). The sulphide sulphur content in the sediment was about 0.5%, and the sediment extended below the chemical drainage depth, the depth below which iron sulphide occurrence is determined by the Eh/pH conditions in the soil (Palko *et. al.* 1988). The catchments were originally drained in 1955 with 0.7 m deep open ditches. In 1983 the main ditches were deepened by 0.5 m to facilitate subsurface drainage in the area. The AS soils were located by drilling and measuring the pH and Eh profiles on the study sites, each site representing an area of about 0.2 km^2 (Palko *et. al.* 1988).

From 1986 till 1992, water samples were taken from the outlet of each basin twice a week during four months (15 April to 15 June and 1 September to 30 October), when the runoff quantity was expected to exceed 10 $dm^3 s^{-1} km^{-2}$. The samples were analysed for titratable acidity (SFS 1981).

The static model was applied and tested on the river Maalahdenjoki (F = 493 km^2) and five of its subcatchments located in central Ostrobothnia (Fig. 3). Runoff sampling was restricted to fall 1988, thus limiting the model test to that particular period. The soil surveys, the samplings and the analyses were done using the methods described for the Tupos basins. The *T*-value (37 days) was obtained from the nearest hydrological basin (Norrskogsdiket).

The dynamic model was tested and calibrated against data from one of the Tupos basins (T8) and from the river Kruunupyynjoki (F = 767 km^2, Fig. 3). In the latter, the soil survey and the runoff monitoring were conducted as in the Tupos basins, but the sampling period was restricted to the falls of 1986 and 1987 and the spring of 1987 (Palko 1988; Palko and Yli-Halla 1993). The meteorological input variables needed in the hydrological submodel (daily precipitation, mean temperature and cloudiness) were obtained from the Oulu and Kruunupyy airports close to the study sites.

Table 2 = The catchment area, the amount of AS soils, the measured and calculated mean acidity values and their differences in fall 1988 in the basins of Maalahdenjoki. The *T*-value was 37 days as measured from Norrskogsdiket measuring weir.

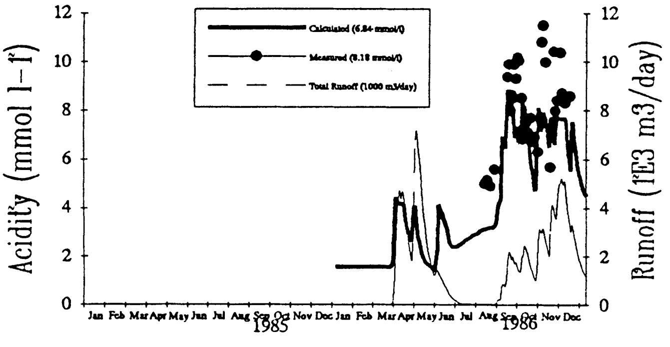
Catchment	Area km^2	X_{ASS}	Measured meq l^{-1}	Calculated meq l^{-1}	Difference %
Korslomdiket	36	0.085	0.86	0.89	+ 3
Storsjöbäcken	63	0.205	1.56	1.93	+24
Ribäcken	80	0.073	1.15	0.79	−31
Helgeå	128	0.062	1.05	0.69	−34
Sarvijoki	130	0.042	0.51	0.52	+ 2
Maalahdenjoki	493	0.103	1.10	1.05	− 5

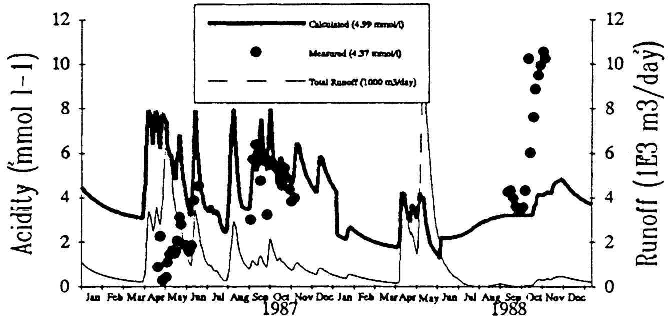
Static Model Output

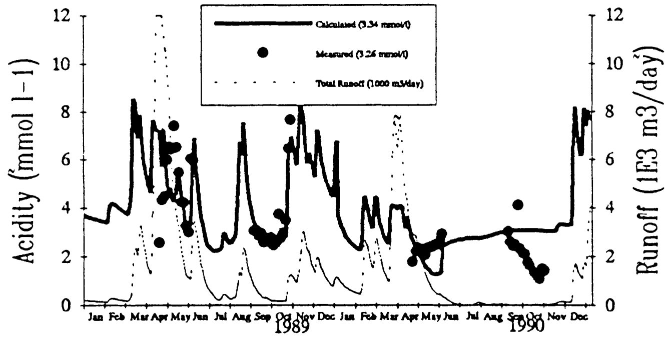
The results obtained by the static model for the river Maalahdenjoki are summarised in Table 2. The differences between the measured and the calculated mean acidities in the Maalahdenjoki and its subcatchments varied between -31 and +24% (Table 2). No systematic difference could be found in relation to the quantity of AS soils or to the catchment area. The values show that the main river, as well as each subcatchment, is severely acidified. The mean acidities clearly exceed 0.3 meq l^{-1}, which corresponds to an approximate pH of 5.5 (Weppling 1993). These acidity and pH levels have been proposed as limits for undisturbed fish reproduction in waters affected by AS soils (Palko *et. al.* 1988).

The theoretical lime addition needed to reduce the acidity below the limit 0.3 meq l^{-1} can easily be calculated from the mean acidity and the runoff. In the fall 1988 the total lime need for the Maalahdenjoki amounted to approximately 1,700 t calculated as pure calcium oxide.

Fig. 4. The measured and calculated $[A]_d$ values (meq l^{-1}) as well as the total runoff (1000 $\mathrm{m}^3\ \mathrm{d}^{-1}$) in the Tupos basin *T8* in 1986-1992.


Acidity (mmol l−1)
0
2
4
6
8
10
12
Runoff (1E3 m3/day)
Calculated (6.84 mmol/l)
Measured (8.18 mmol/l)
Total Runoff (1000 m3/day)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
1985
1986


Acidity (mmol l−1)
0
2
4
6
8
10
12
Runoff (1E3 m3/day)
Calculated (4.99 mmol/l)
Measured (4.37 mmol/l)
Total Runoff (1000 m3/day)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
1987
1988


Acidity (mmol l−1)
0
2
4
6
8
10
12
Runoff (1E3 m3/day)
Calculated (3.34 mmol/l)
Measured (3.26 mmol/l)
Total Runoff (1000 m3/day)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
1989
1990

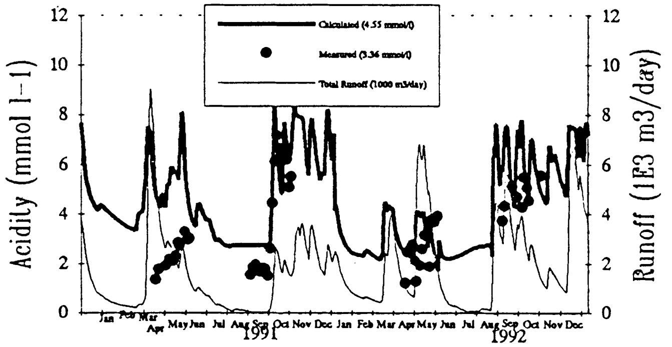

Acidity (mmol l−1)
0
2
4
6
8
10
12
Runoff (1E3 m3/day)
Calculated (4.55 mmol/l)
Measured (3.36 mmol/l)
Total Runoff (1000 m3/day)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
1991
1992

Table 3 – Definitions and calculated values for the parameters P used in the two applications of the dynamic model. The P_T values were obtained through iteration of data from the Tupos basin T8 (X_{ASS} = 73%, X_{NASS} = 27 % and X_{sd} = 0%), while the P_K values were defined by calibration the model with measured acidity values of the river Kruunupyynjoki (X_{ASS} = 2.5%, X_{NASS} = 2.3% and X_{ds} = 40%). S_d = active acidity potential in the soil, GWL = ground water level.

P	P_T	P_K	*Definition*
P1	0.9606	0.2003	Correlation between acidity and runoff (slope)
P2	3.6141	1.0432	Correlation between acidity and runoff (intercept)
P3	1.1356	1.3065	Increase of S_d (depth of GWL)
P4	36	36	Limit value for the increase of S_d
P5	0.0002	0	Correlation between S_d and runoff acidity ($[A]_d$)
P6	1	1	Daily decrease of S_d
P7	0.7767	2.7013	Ratio between surface runoff and seepage runoff in subcatchments with open ditches
P8	0.5451	0.3839	Reduction of $[A]_d$ during the spring flood
P9	9.006	6.5657	Limit value of the runoff

Dynamic Model Output

The iteration of the dynamic model paramters for a seven-year period (1986-1992) in the Tupos basin (T8) seems to predict the daily acidity for the flood periods reliably, if a distinct flood surge occurs during the season. The means of the measured and predicted daily acidities for the whole 7-year period were 4.40 and 4.69 meq l^{-1}, respectively, while the R^2 value for their difference was as high as 0.511 (Fig. 4). When runoff is low during the fall flood, the measured values are much higher than the predicted ones. A situation of this kind occurred in fall 1988. When runoff is totally lacking, like in September and October 1990, the model calculates the acidity well. In two spring seasons (1987 and 1991), the prediction of $[A]_d$ was unsatisfactory, which can be explained by difficulties in predicting the quantity of snowmelt waters in relation to infiltrated waters due to the different timing of frost melt in spring.

The model was applied to the river Kruunupyynjoki for the years 1986-1987 using the parameter values of the Tupos basin (Table 3). The means for the measured and calculated acidity values were 0.293 and 0.482 meq l^{-1}, respectively (Fig. 5). The greater percentage of subsurface drainage used in this area as compared to the Tupos basin (40 *vs.* 0) seems to give an overprediction of the calculated $[A]_d$ values during the runoff peaks, while the basic $[A]_d$ level seems to be correct.

After calibration against the measured acidity values, the corresponding means were 0.293 and 0.302 meq l^{-1} and the R^2 value was as high as 0.625 (Fig. 6). This model run gave a very good prediction of the $[A]_d$ under constant hydrological conditions.

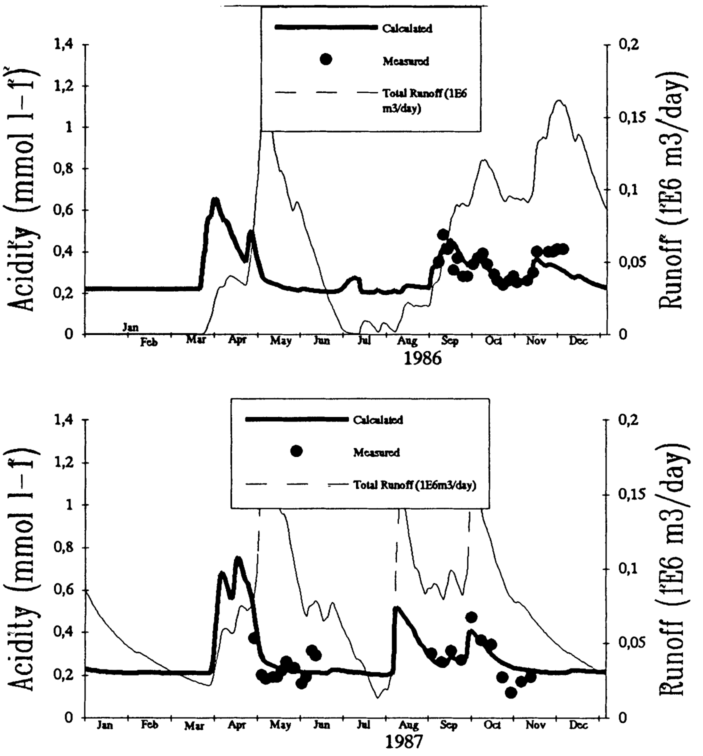


Fig. 5. The measured and calculated $[A]_d$ values (meq l^{-1}) in the river Kruunupyynjoki in 1986-1987. The parameter values from the Tupos basin iteration were used in the model run.

The theoretical lime additions required to maintain a constant acidity level below the limit value 0.3 meq l^{-1} were calculated from the predicted $[A]_d$ values. In 1986, the lime need, expressed as pure calcium oxide was 16.2 t for the spring flood and 72.6 t for the fall flood. The corresponding amounts for 1987 were 104.2 t and 67.0 t, respectively.

The predictions obtained by the dynamic model can surely be improved by calibrating the hydrological submodel. The model might also be improved by determining the acidity potential, soil type and/or water-holding capacity of the soil in each cultivated subcatchment and to use these values as input variables for the modelled basin. Finnish AS soils are very similar in those respects, and thus the positive influence of such measurements on the predictions is not evident. A better prediction of the runoff acidity in spring requires an accurate method to model the diluting effect of snowmelt waters on the daily runoff acidity. The use of a frost submodel should also give a better prediction of the spring flood acidity, especially in subsurface drainage areas.

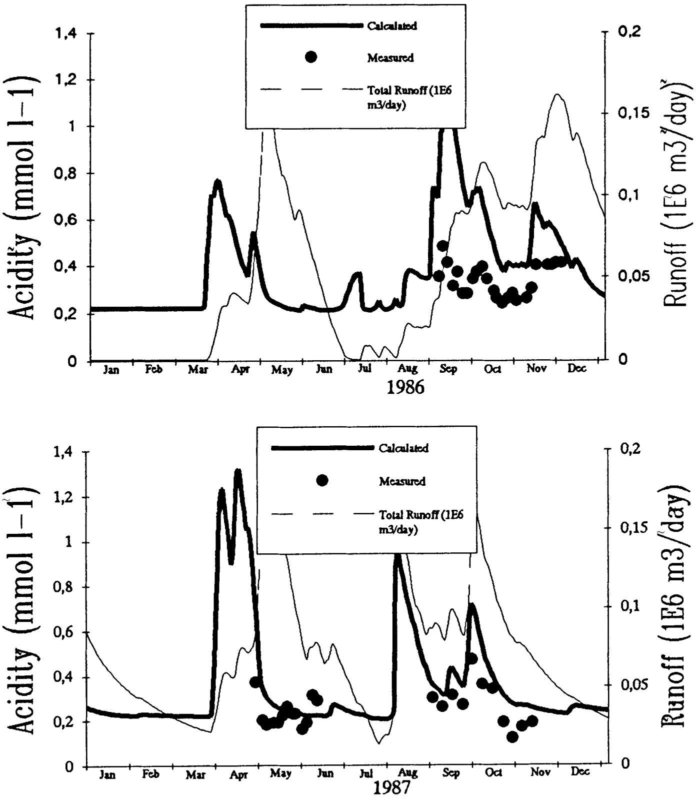


Fig. 6. The measured and calculated $[A]_d$ values (meq l^{-1}) in the river Kruunupyynjoki in 1986-1987. The parameter values were iterated with the measured values.

The existing hydrological forecasts for flood protection purposes in coastal rivers can be used as input data for the hydrological submodel. A limit value for the acidity, which must not be exceeded, can be given for the rivers (Palko *et. al.* 1988). The future acidity peaks exceeding this limit can be predicted by the dynamic model and subsequently cut by liming the river.

Conclusions

The basic purpose of the modelling was to predict the quantity and temporal extent of acidity in the rivers and watersheds affected by AS soils. The simple static model can be used as a tool for drainage planning in AS soils, if a rough estimation of the acidity hazard, or a classification of the rivers and river basins according to their state of acidification, is sufficient. The more sophisticated dynamic model is preferable when detailed mitigation strategies are being planned for rivers and catchments containing AS soils. The dynamic model can also be used to estimate the feasibility and expenses of liming measures in the river.

If runoff acidity data are not available, both models can be used to predict the basic acidity level in the river. The dynamic model requires input parameters optimised in a river basin similar to the one being modelled. If good prediction is needed, the parameters in both models should be optimised on the basis of measured runoff acidity values of at least one fall and one spring.

Although the results of the first model applications were fairly encouraging, the need for improvements was simultaneously highlighted. It is, however, obvious that satisfactory predictions of runoff acidity in catchments containing AS soils can be obtained without ion balance modelling.

Notation

The following symbols are used in this paper:

$[A]_d$	Discharge acidity in the catchment	meq l^{-1}
$[A]_f$	Runoff acidity from forested subcatchments	meq l^{-1}
$[A]_{od}$	Runoff acidity from subcatchments with open ditches	meq l^{-1}
$[A]_{sd}$	Runoff acidity from subcatchments with subsurface drainage	meq l^{-1}
X_{ASS}	Amount of cultivated AS soils in the catchment	%/100
X_{sd}	Amount of cultivated AS soils with subsurface drainage	%/100
X_{NASS}	Amount of cultivated non-AS soils in the catchment	%/100
GWL_{od}	Groundwater level in areas with open ditches	cm
GWL_{sd}	Groundwater level in areas with subsurface drainage	cm
q_d	Daily runoff from the catchment area	l d^{-1}
q_f	Daily runoff from forested subcatchments	l s^{-1} km^{-2}
q_{od}	Total runoff from subcatchments with open ditches	l s^{-1} km^{-2}
q_{odp}	Seepage runoff from subcatchments with open ditches	l s^{-1} km^{-2}
q_{ods}	Surface runoff from subcatchments with open ditches	l s^{-1} km^{-2}
q_{sd}	Total runoff from subcatchments with subsurface drainage	l s^{-1} km^{-2}
q_{sdp}	Seepage runoff from subcatchments with subsurface drainage	l s^{-1} km^{-2}
q_{sds}	Surface runoff from subcatchments with subsurface drainage	l s^{-1} km^{-2}
$q_{odp(\mathrm{lim})}$	Limit value for $q_{od\mathrm{p}}$	l s^{-1} km^{-2}
$q_{sdp(\mathrm{lim})}$	Limit value for q_{sdp}	l s^{-1} km^{-2}
S_d	Active acidity pool in the catchment area	meq km^{-2}
S_f	Active acidity pool in forested subcatchments	meq km^{-2}
S_{od}	Active acidity pool in subcatchments with open ditches	meq km^{-2}
S_{sd}	Active acidity pool in subcatchments with subsurface drainage	meq km^{-2}
ΔS_f	Daily increase of S_f	meq km^{-2}
ΔS_{od}	Daily increase of S_{od}	meq km^{-2}
ΔS_{sd}	Daily increase of S_{sd}	meq km^{-2}
$S_{od(\mathrm{lim})}$	Limit value for S_{od}	meq km^{-2}
$S_{sd(\mathrm{lim})}$	Limit value for S_{sd}	meq km^{-2}

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Address:
Jukka Palko,
Water and Environment District of Oulu,
Central Laboratory,
P.O. Box 124,
FIN-90101 Oulu,
Finland.

Kjell Weppling,
Nordkalk Oy Ab,
Research and Development,
FIN-21600 Pargas,
Finland.