Report no: 6/2002.

ERONOR/USLENO -
Empirical erosion models for Norwegian conditions.

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ISBN: 82-483-0022-6

ISSN: 1500-3469

Mai 2002

NLH
AGRICULTURAL
UNIVERSITY OF NORWAY
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Agricultural University of Norway

Report no. 6/2002

Editor: Knut Werner Alsén

Publisher: Agricultural University of Norway
P.O.Box 5003
N-1432 Ås
Norway

ISBN: 82-483-0022-6

ISSN: 1500-3469

Mai 2002

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Summary.

In connection with the MILDRI interdisciplinary research program for a more environmentally friendly agriculture, it was decided also to include simulation of soil- and P-loss and loss of particulate N. Testing of WEPP , an American process based erosion model, led to the conclusion that WEPP did not work properly under Norwegian conditions. It was decided to develop a simpler, empirically based erosion model (ERONOR) where particle concentrations were empirically related to the most important factors. ERONOR calculates soil loss as the product of simulated particle concentrations and runoff. Both surface runoff and drain water is treated. The model operates on a dayly basis, and the particle concentrations are calculated as the product of several factors taking into account soil erodibility, slope steepness, slope length, snowcover, runoff, precipitation, soil saturation, plant cover and residue cover, consolidation and some structural effects. The simulation of surface runoff and drain water is either provided by the Swedish SOIL model or it is made internally in ERONOR. Output from the SOIL model is however always used, since simulated Leaf Area Index, soil temperatures, frostdepth and soil water tension are always used in ERONOR. Alternative values for total runoff and evapotranspiration are simulated in a special model named AVRJUST. From AVRJUST and SOIL a hydrology file used for a region is prepared before running ERONOR.
ERONOR also needs input of soil data, standard tillage dates for a region, special dates of tillage and crop rotations for a specified site, information on start and end of frost.

ERONOR simulates as a standard 23 basic systems at the same time. If an actual system differs from the standard ones, the losses from the actual system is calculated in a simple routine run just after the main program has finished using the information produced in the first program. Total P-loss is calculated based on soil loss and empirical regression between total-P and soil loss. Different equations are used for surface and drain water and in different regions. Particulate N-loss is calculated based on soil loss and N-content in the soil and some enrichment adjustments.
Run over some years, ERONOR has been able to come up with reasonable average estimates of soil loss. The runoff and soil losses have been reasonably distributed over the year, and therefore the effects of different tillage systems most often have been estimated in good accordance with experienced effects. The estimated variation in soil loss has been of the same magnitude as observed. The model has been able to pick years when erosion was known to be high. The model has been successfully applied to analyse effects of climatic change on soil loss, and has provided data series of soil erosion that reveals possible shorttime trends.

ERONOR can also easily be used to calibrate USLENO, a Norwegian variant of the Universal soil loss equation. The K, L, and S-factors in the American USLE have all been changed, and the rain factor in USLE is replaced by a hydrological factor in USLENO, which can be found for a climatic region by running ERONOR for the standard agricultural system, fallow. ERONOR can also be used to produce cropping factors (C-values) for USLENO. After calibration, USLENO can be used within a climatic region to quickly simulate average soil losses on most kinds of soils, slopes and cultivation systems. USLENO can also provide P-loss estimates. Both surface and drain water is treated.
USLENO is supposed to be a valuable tool in planning of agricultural systems with respect to soil conservation, and also water quality in Norway.

Samandrag.

I samband med det interdisiplinære forskingsprogrammet MILDRI (Miljøvennlege driftsformer i landbruket) vart det avgjort å inkludere simulering av jord- og P-tap og tap av partikulært N. Ein testa fyrst den prosessbaserte amerikanske erosjonsmodellen, WEPP, men konkluderte med at den ikkje passa for norske tilhøve. Det vart difor naudsynleg å utvikle ein enkel empirisk erosjonsmodell (ERONOR) for norske tilhøve. I ERONOR relaterast partikkelkonsentrasjonen empirisk til eit tal viktige faktorar. ERONOR reknar ut jordtapet som produktet av partikkelkonsentrasjon og avrenning. Tap både på yta og gjennom grøfter er med.

Modellen opererer på døgnbasis, og partikkelkonsentrasjonane vert utrekna som produktet av fleire faktorar relaterte til jorderodibilitet, hellingsgrad, hellingslengde, snømagasin, avrenning, regn, vassmetning i jorda, dekke av planter og planterestar, jordkonsolidering og nokon struktureffektar. Simuleringa av yteavrenning og drensvatn vert anten gjort ved hjelp av den svenske SOIL-modellen eller ved rutiner internt i ERONOR. Men utdata frå SOIL er likevel naudsynlege for å køyre ERONOR, for di det i alle høve trengst opplysningar om bladarealindeks, jordtemperatur, teledjup og bindingsstyrke for jordvatnet. Men det er òg laga ei eiga rutine, AVRJUST, som simulerer totalavrenning og evapotranspirasjon som alternativ til SOIL. Opplysningane frå SOIL og AVRJUST samlast i ei hydrologifil før ERONOR vert køyrd. Ofte nyttast ei standard hydrologifil for ein klimatisk region, slik at same hydrologifila vert nytta for fleire ERONOR-køyringar, som er ei vesentleg forenkling.

I tillegg til hydrologidata, treng ERONOR jorddata, standard jordarbeidingsdatoar for ein region og spesifikke driftsopplysningar for skifte med spesiell praksis og informasjon om start og slutt på frostperioden

ERONOR simulerer som standard 23 faste dyrkingssystem på ein gong. Om eit aktuelt system avvik frå standardsystema, utreknast det aktuelle systemet i ei enkel rutine som fylgjer etter hovudprogrammet og der opplysningar frå hovudprogrammet vert brukte.

Tap av total-P utreknast med basis i simulert jordtap og regresjonslikningar mellom total-P og jordtap. Det nyttast ulike likningar for yte- og drensvatn og mellom regionar. Tap av partikulært N utreknast med basis i simulert jordtap og N-innhald i jord med noko justering for anriking av organisk materiale.

Ved å køyre over nokon år har ERONOR gjeve rimelege medelestimat for jordtap. Vidare fordeler ERONOR både avrenning og jordtap rimeleg rett over året, og dette er svært viktig når det gjeld å simulere effekten av dyrkingssystema rett. Dei fleste dyrkingssystema har vorte simulerte i rimeleg samsvar med praktisk røynsle. Variasjonen i estimerte jordtap har vore av same storleiksorden som observert. Modellen har vore i stand til å plukke ut kjende erosjonsår, og modellen har simulert effekten av klimendringar på jordtap på ein truverdig måte. Modellen kan brukast til å simulere erosjon over mange år og kan då påvise eventuelle kortvarige trendar.

ERONOR kan òg brukast til å kalibrere den nyutvikla norske versjonen av den Universelle jordtapslikninga (USLENO). K, L og S-faktorane i USLE har alle vorte forandra, og regnenergifaktoren (R) i USLE er erstatta med ein hydrologifaktor. Denne hydrologifaktoren kan enkelt finnast ved å køyre ERONOR under standardvilkår med klimadata for ein region. Standardsystemet er brakk, og faktorane som tilsvarar K, L og S setjast lik 1. Dessutan kan ERONOR brukast til å rekne ut dyrkingsfaktorar (C) til bruk i USLENO. Etter kaliberering som må gjerast regionvis, kan USLENO nyttast til raskt å rekne ut medels jordtap på dei fleste jordtypar, hellingsgrader, hellingslengder og dyrkingssystem. P-tap kan òg utreknast. Både yte- og drensvatn vert handsama. USLENO er tenkt å verte ein verdfull reiskap i planlegging av dyrkingssystem med tanke på jordressursar og vasskvalitet.

1. Introduction.

When the MILDRI interdisciplinary modelling research program for an "Environmentally Friendly Agriculture" (21) started 1996/1997 it was also decided that modelling of soil loss, P-loss and N-loss should be included. The MILDRI research program was supposed to build on the achievements gained under a previous similar program "Economics and Ecology – Resource Management and Pollution in Agriculture" (EcEc-program) (7).
The MILDRI modelling system consists of economy modules where the farmers decisions concerning choise of crop, amount of fertilizer, type and time of tillage, pesticide spraying etc. are made based on crop yields, prices, subsidies, taxes, laws and regulations etc. Depending on the chosen cultivating system, the resulting losses are then calculated in several models concerning plant growth, humus- and N-turnover, hydrology, erosion, P-loss and use of pesticides.
Concerning erosion modelling in the EcEc-program, the physical based episode oriented erosion model EUROSEM (9) using the SOIL model (10) to simulate winter hydrology was used to simulate erosion on 30m * 30 m square grids. Then a terrain model GRIDSEM (8) was used to route the water through the landscape. However, sedimentation was not accounted for, so that the value of the routing procedure was questionable.
Unlike in the EcEc-program where real landscapes were used, there are only hypothetical farms and farm fields in the MILDRI program. Each farm field must then be considered homogenious as to soil type and topography. The cultivation system is the same all over each farm field each single year. However, the cultivation system may differ from year to year.

These hypothetical farms and farm fields then had to be treated as individual homogenious fields with no connectivity. Losses had to be calculated at the end of the slope for each field and no routing procedure afterwards was possible or necessary.

Since the EUROSEM model is episodic, it does not update several important parameters regarding infiltration, permeability or erodibility and the model is thus not easy to use in the continous case. It was not designed for winter conditions although Botterweg (22) found a method by using SOIL output as input to EUROSEM in winter. EUROSEM is not well adapted to handle clay soils which are common in Norway.

Because of the mentioned circumstances and also because the Norwegian experts on EUROSEM and GRIDSEM left their research institutions, the EROSEM and GRIDSEM approaches where discarded in MILDRI.

2. A new approach.

First, an attempt was made to find a physically based erosion model that worked in continous mode and included winter conditions and was capable of handling a large number of tillage systems, crops and soil types. The WEPP model (6) developed in USA seemed to possess all the wanted properties. It had a winter component which at first sight seemed reasonable, it could be run in continous or in episodic mode, it could be run for fields (Hill mode) and for watersheds (SHED mode).
However, testing of the WEPP model under Norwegian conditions (13, 14) showed that it did not work very well. The empirical equations in the model which should be used to estimate important hydrological and erodibility soil parameters, were often in error on important

Norwegian soil types, for instance levelled clay soils. The model seldom produced any surface runoff in winter, and even if it was forced to do so by setting infiltration to low values, it seldom produced appreciable erosion. Since winter erosion is important in Norway, this was a serious failure. The model also had trouble in producing saturated surface runoff by relatively moderate rainfall in autumn. This is also an important reason for soil erosion by water in Norway. It seemed that the model performed best under climates with rather high rainfall and little or no frost in winter which is the case in South-western Norway. It was much less suitable for South-eastern Norway where water erosion in Norway is highest. Furthermore it was difficult to obtain the necessary precipitation data for the model and also complicated to construct the very special climatic files and management files. The plant growth parameters had to be changed to be adapted to Norwegian climate and Norwegian crop plants, otherwise plant growth and plant cover was simulated erroniously.

It was obvious that the WEPP model had to be changed if it was to be used in Norway. However, it takes a lot of work and expertise to change and test a complicated prosess based model. We did not have the necessary time or resources to do such a job, and the experts in USA thought WEPP worked well enough under the major wheater and soil conditions over there and would not make any appreciable changes in the model within the timeframe of the MILDRI program.
It seems that models developed in other countries with rather different climatic and soil conditions may not be easily adaptable to Norwegian conditions. Even though the models are process based, they often have a lot of empirical based relations included which may not be correct in Norway.

Thus it was decided that a new erosion model adapted to Norwegian conditions had to be made. Because of limited time and resources, the model had to be simple.

2.1. The ERONOR and USLENO approach.

In 1990 Lundekvam (3) suggested a method to calibrate the Universal Soil Loss Equation (USLE) (11) for use in Norway. The Norwegian equation was written:

2.1. $A=X*K*L*S*CR*P$, where.

-A is measured or estimated soil loss,
-X is a hydrology factor found by calibration and different from the R factor in USLE.
-K is soil erodibility factor using the USLE (11) equation
-L is slope length factor using USLE equation
-S is a slope steepness factor, somewhat changed from USLE
-CR is a relative cropping factor set to be 1 by autumn ploughing, harrowing and sowing in spring and growing of spring cereals (barley, oats). This is different from USLE where C is equal to 1 by fallow (soil kept bare by tilling up- and downslope several times during the year).
-P is the protection factor which usually is 1 under Norwegian conditions.

In a case where A is measured over several years, K, L, S are calculated with their proper equations and CR=1 (standard cropping system) and P=1 (no special protection) the hydrology factor X can be found from the above mentioned equation.

This defines the mean climatic erosion risk within a climatic region. The reason for this approach instead of the usual procedure of calculating rain energy (R) was that snowmelt erosion is important in Norway, and the R-factor does not account very well for this type of erosion. Furthermore, this approach calibrated the equation to give values of reasonable magnitude when it was subsequently used to calculate erosion within the same climatic region.
From Norwegian erosion plot trials (3, 15), CR-values for the most common cultivating systems in Norway could be obtained.
This method has successfully been adopted by The Norwegian Institute of Land Inventory (NIJOS) which from their soil data base have produced erosion risk maps by autumn ploughing. These maps have subsequently been used by agricultural advisors and agricultural authorities to give erosion risk dependent subsidies to farmers for notill in autumn.

However, there were serious limitations with this method. To calculate the climatic erosion risk (X), erosion measurements over several years were necessary, and such data were very scarce. Thus the regional variation in climatic erosion risk was not known. Second, the method gave no estimates of yearly variation, and it was difficult to obtain CR-values for crops which had not been used in experiments or for crop rotations. It was also a problem that the USLE equations for K, L, S might not be entirely valid for Norwegian conditions.

It was thus decided that a more dynamic erosion model had to be made, but where some of the USLE factors were kept although in a possibly modified form. It was decided that an improved Norwegian soil loss equation also was to be developed due to the popularity of the existing equation.

The dynamic model should respond to factors that experience had shown was important in Norway. It should respond to soil erodibility, slope length and slope steepness, rain, snowmelt, runoff, snowcover, some time variation in soil erodibility, time variation in infiltration rate, tillage and consolidation after tillage, plant cover and residue cover. It was also considered necessary to introduce a penalty factor for some cropping systems like for instance winter wheat, which often show high erosion losses (17) in spite of some plant cover in autumn.
The model should furthermore be able to use readily available climatic data and should thus operate on a daily basis. And it should operate on soil data found in the NIJOS data base, and be able to simulate the most important crops, tillage systems and rotations.
Since soil also may be lost through drainage systems, it was decided to make a try in modelling such losses based on experience obtained in Norway.

As to P-losses, it was decided to develop empirical relations between P-loss and soil loss, since particulate P often constitute a major part of losses of total P. Considering N, only particulate N was considered, since the dissolved N (mineral N) was taken care of in the model for humus and nitrogen turnover.

Finally the dynamic model should be used to calibrate a new Norwegian soil loss equation.

3. Basic principles and basic equations for ERONOR and USLENO.

3.1. ERONOR.

The empirical and dynamic erosion model with resolution of one day was termed ERONOR. The types of erosion to be modelled are sheet and rill erosion on surface and soil loss through tile drains. Gully and main rill erosion and sedimentation will not be considered. The basic principle for soil loss simulation in ERONOR is to regard the loss as the product of runoff and particle concentration in water.

ERONOR surface:

3.1.1. $LO_{SU} = Q_{SU} * CON_{SU}/100$, where

LO_{SU} is dayly soil loss on surface in kg/ha.
Q_{SU} is dayly surface runoff in mm
CON_{SU} is dayly concentration of soil particles in surface runoff in mg/l.

ERONOR drain water:

3.1.2. $LO_{DR} = Q_{DR} * CON_{DR}/100$,
where subscripts now stand for drain water, but otherwise the meaning is the same as for surface runoff.

Thus, surface and drain runoff had to be simulated on a dayly basis, and empirical relationships between particle concentrations and several factors had to be established. This will be explained in more detail later, but the principal equations for particle concentrations in surface and drain runoff will be given here.
It was decided to choose equations that described the concentrations as the product of several factors like in USLE (11) and the Revised USLE (RUSLE) (12). It can also be seen in the WEPP model (6) that when rill erosion occurs it is a function of the detachment capacity (D_c). $D_c = K_r * (\tau_f - \tau_c)$, where ($K_r$) is a rill erodibility parameter and (τ_f) is the flow shear stress and τ_c is a critical shear stress. K_r is again a product of several subfactors. Thus it is seen that the important rill erosion process in WEPP (a process based model) is in fact a product function as long as it is not limited.
A product function was also convenient when the relative effects of several factors was to be compared with observed relative variations in particle concentrations. Then the relative effect of each causal factor had to vary within reasonable limits so that the product of all of them were able to describe the observed variation in particle concentrations.

The equation describing the particle concentrations in surface runoff in the ERONOR model thus became:

3.1.3. $CON_{SU} = SCALE_{SU} * K_{NO,SU} * L_{NO} * S_{NO} * QFAK_{SU} * RAINFAK_{SU} * SNOWFAK_{SU} * SATFAK_{SU} * COVFAK_{SU} * CONSFAK_{SU} * STRUCT_{SU}$.

$SCALE_{SU}$ is a scale factor to convert from relative values to mg/l.
$K_{NO,SU}$ is a Norwegian soil erodibility factor that can be different for surface and drain runoff. This factor is based upon, but different from the K-factor in USLE.
L_{NO} is a Norwegian slope length factor, based upon but different from L-factor in USLE.

S_{NO} is a Norwegian slope steepness factor , based upon but different from L-factor in USLE.
$QFAK_{SU}$ is a factor which describes a relationship between dayly surface runoff and particle concentration.
$RAINFAK_{SU}$ describes a relationship between dayly rainfall and particle concentration.
$SNOWFAK_{SU}$ describes a relationship between snowstorage and particle concentration.
$SATFAK_{SU}$ is a "saturation factor" which is supposed to describe the effect of thawing topsoil or supersaturated conditions.
$COVFAK_{SU}$ describes the effect or plant cover or residue cover on particle concentrations.
$CONSFAK_{SU}$ describes the effect of soil consolidation on particle concentrations.
$STRUCT_{SU}$ is a "structure factor" that has been introduced for some tillage systems, especially for standard winter wheat, to account for the fact that these systems often led to higher soil losses than expected due to negative effects on soil structure.

For drainage water a similar equation was produced:

3.1.4. $CON_{DR} = SCALE_{DR} * K_{NO, DR} * QFAK_{DR} * RAINFAK_{DR} * SNOWFAK_{DR} * SATFAK_{DR} * COVFAK_{DR} * CONSFAK_{DR} * AGEFAK_{DR}$.

The subscript $_{DR}$ stands for drainage, otherwise most of the factors present for surface water are also present for drain water, but the effects are reduced. Furthermore the effects of slope length and slope steepness and structure have been removed in the drainage equation, because it was reasoned that these factors mostly have an effect on surface. But an effect of time since drainage ($AGEFAK_{DR}$) has been added to the drainage equation.

3.2. USLENO.

As explained earlier, a simpler model for advisers and policy makers is also needed, and for this purpose a USLE-like equation calibrated for different climatic regions in Norway would be sufficient. The ERONOR model could be used to calibrate such an equation. Soil losses both on surface and through drains should be calculated.

For surface the USLENO equation becomes:

3.2.1. $A_{SU} = R_{NO,SU} * K_{NO,SU} * L_{NO} * S_{NO} * C_{NO,SU} * P$, where

A_{SU} is the soil loss in kg/ha in surface runoff.
$R_{NO,SU}$ is a regional hydrology factor for surface runoff (kg/ha)
$K_{NO,SU}$, L_{NO} , S_{NO} are relative factors, same as for surface runoff in the ERONOR model (equation 3.1.3).
$C_{NO,SU}$ is a Norwegian cropping factor which now will be set to 1 under a fallow system defined in ERONOR, and for other systems the value will be relative to fallow.
P is a special protection factor as in USLE.
The subscript $_{NO}$ is to distinguish from the American USLE/RUSLE factors.

For drain water the USLENO equation became:

3.2.2. $A_{DR} = R_{NO, DR} * K_{NO, DR} * C_{NO, DR} * P * AGEFAK_{DR}$

Where the subscripts now stand for drainage. The effects of slope length and slope steepness have been removed as in the ERONOR model, and the effect of time since drainage have been introduced.

The regional hydrology factors $R_{NO,SU}$ and $R_{NO,DR}$ will be defined by ERONOR for standard soil type, standard slope length, standard steepness and a standard cultivation system.
This will be achived by setting $K_{NO,SU}$, L_{NO} , S_{NO} equal to 1 in ERONOR and calculate soil loss for standard fallow in ERONOR. By also setting $K_{NO,SU}$, L_{NO} , S_{NO}, $C_{NO,SU}$ and P equal to 1 in the USLENO equation for surface (equation 3.2.1) it is seen that $A_{SU} = R_{NO,SU}$. Thus regional hydrology factors for surface can easily be found by running ERONOR with relevant climatic data for the regions under standard conditions as described.

In the same way regional hydrology factors for drain water can be found.
Considering the cropping factors $C_{NO,SU}$ and $C_{NO,DR}$, they can be found by running ERONOR for different cultivation systems. Erosion plot trials may also be used, but such data will be scarce. The P-factor so far is not used but set equal to 1.

4. The individual factors in ERONOR and USLENO.

4.1. The K_{NO}, L_{NO} and S_{NO} factors.

Since these factors are common to both ERONOR and USLENO, they will be treated consecutively.

4.1.1. The K_{NO} – factor.

In USLE (11) the K-factor is calculated as follows:

4.1.1.1 $K=2.1*M^{1.14}*10^{-6}*(12-a) +(3.25*(b-2)+2.5*(c-3))/100$, where

-K is the soil loss pr erosion index unit for a slope 72.6 ft long, steepness 9% and continuously in clean-tilled fallow.
-M is (%siltus)*(100-% clay<0,002mm),
where siltus is particle size between 0,002 and 0,1mm.
-a is percent organic matter
-b is a structure code (1-4) where 1 is the best structure
-c is a profile-permeability class (1-6), where 1 denotes the highest permeability.

Using equation 4.1.1.1 on Norwegian soils where soil loss and average particle concentrations were measured in USLE-plot trials, revealed that the equation was not able to describe the observed differences adequately.
Relating observed particle concentrations= (total soil loss/total runoff) to several factors like sand, silt, clay, humus, levelling of land using multiple regression, showed that that the relative concentrations for the different sites could best be described by the following equation:

4.1.1.2. $KSE2= 1/(e^{(1.3536*(1-level))}*e^{(0.83972*log(hum))})$, $R^2=0.933$, $n=9$, where

-level is a factor 0-1, describing the degree of land levelling, where 1 is fully levelled
-hum is precent organic matter, and log(hum) mean that natural logarithms were used
-e is the base of natural logarithm

Even if R^2 was high, the material is limited, and the exclusion of texture was probably not a good solution. It was thus decided to try some kind of combination of equations 4.1.1.1 and 4.1.1.2. It was reasoned that the effect of humus in the K-factor of USLE had to be increased, and that the effect of land levelling on soil erodibility was not fully accounted for by common soil analysis.
To calibrate the new K-factor, two USLE-sites were used, one fully levelled and the other not levelled. First the "humus parts" of the equations 4.1.1.1 and 4.1.1.2 were calculated, and the "humus part" of equation 4.1.1.1 was changed so that the effect was the same as obtained in the "humus part" of equation 4.1.1.2. The new equation for the humus effect thus became:

4.1.1.3 $humfak=(12-hum)*e^{(-0.39178*log(hum))}$, where
hum is % organic material, and log(hum) is as stated before.

Using humfak instead of the expression (12-a) in the equation 4.1.1.1, new estimates of K for the two soils were calculated. The K-factors were still not able to describe fully the relative particle concentrations in surface runoff from the on two soil types. It was necessary to multiply with a levelling effect=(1+1.17*level). This expression is equal to 1 if level=0, and then have no effect on not levelled soils.

The new K-factor in USLENO thus became:

4.1.1.4
$$K_{NO}=\{3.4*(M_{NO})^{1.14}*(12-hum) * e^{-0.39178*log(hum)}*10^{-6} + (3.25*(struc-2)+2.5*(perm-3))/100\}*(1+1.17*level)$$
, where

-M_{NO} = % siltus2 * (100- %clay2), where %siltus2=%siltus*100/(100+coarse*coarsefak) and %clay2=%clay*100/(100+coarse*coarsefak).
-coarse = %material greater than 2mm (material less than 2mm is used in ordinary texture analysis)
-coarsefak is a factor (0-1) to decide the relative amount of coarse material that should be used
-%siltus is particles between 0,002 and 0,1mm as before
-%clay is particles less then 0,002mm
-hum=% organic matter, not allowed to go beyond 10%
-struc is structure class (1-4), where 1 is best structure
-perm is permeability class (1-6) where 1 is highest permeability
-level is the relative proportion of the land that has been levelled.

There is special arrangement to take care of cases where %siltus2 goes beyond 70% which is the validity range in equation 4.1.1.1. Furthermore, K_{NO} is not allowed to go below 0.006. Normally the range of K_{NO} will be between 0,05 and 1,1 which is wider range than for the K-factor in the American USLE. The standard value of $K_{NO}=1$, used in calibrating USLENO will thus be a very erodible soil under Norwegian conditions.

It should be noted that K_{NO} is regarded as a relative value independent of R_{NO}, which is different from the USLE K-factor which is expressed relative to R (the rain energy index).

The differenciation between $K_{NO,SU}$ and $K_{NO,DR}$ mentioned in sections 3.1 and 3.2 can be achieved by using different values for humus and texture in topsoil and subsoil. The reason for this is that it is sometimes observed higher particle concentrations in drain water than in surface runoff.

4.1.2. The L_{NO}-factor.

In USLE the L-factor used to be calculated as :

4.1.2.1. $L=(\text{length}/22.1)^m$, where m=0.5 when slope was greater than or equal to 5%. Length is the slope length in meters.

In South-eastern Norway there have been two USLE-plot trials with 13% slope and different slope lengths which could be used to verify this relationship in Norway. Data from 9 and 13 years respectively were available. Since there were some differences in texture between the different plots within the trials, this was corrected for by using the K_{NO} factor, described in equation 4.1.1.4.
In one of the plot trials it was thus found that m should be 0.8 or higher, in the other one it was found that m should be between 0.6 and 0.9. Since both experiments showed significantly higher m-values than in USLE it was decided to set m equal to 0.75. The slope length equation in USLENO and ERONOR thus became:

4.1.2.2. $L_{NO} = (\text{length}/22.1)^{0.75}$, where length is slope length in meters. The standard situation with $L_{NO} = 1$ occurs when length=22.1 m, the length of a standard USLE plot.

It should be mentioned that in RUSLE (12) the value of m can vary greatly due to the ratio between rill and interrill erosion, so that high values of m should be used when the ratio is high. In Norway, rilling is believed to be far more important than interrill erosion which could explain the high m values found in this investigation. Erosion in Norway usually takes place in late autumn and in winter and spring as a result of saturated runoff by moderate rain intensity on frozen or not frozen soil, or by snowmelt with or without rain mostly on frozen ground.

4.1.3. The S_{NO} – factor.

The slope steepness factor in USLENO and ERONOR is:

4.1.3.1: $S_{NO} = 0.065 + 0.0455 * \text{slope} + 0.0065 * \text{slope}^{1.8}$, where

slope is the steepness of a slope in percent.

This is different from USLE where the last term is raised to the power of 2 instead of 1.8. The number 1.8 was chosen by Lundekvam (3) simply because this gave more reasonable erosion estimates. There is not sufficient experiments on effects of steepness in Norway to make a new calibration of this relationship. However, in RUSLE (12) the effect of steepness has also been reduced compared to USLE. Calculations show that equation 4.1.3.1 gives results similar to those obtained by RUSLE (table 4.1.3.1). It was concluded that equation 4.1.3.1 operated satisfactorily. Standard conditions $S_{NO}=1$ is obtained at a slope of 10.6 %.

Table 4.1.3.1. Effects of steepness on S-factors calculated by rules of USLE, RUSLE and USLENO. Values made equal at 10% slope.

Slope (%)	S-USLE	S-RUSLE	S_{NO}
2	0.115	0.247	0.225
5	0.455	0.569	0.516
10	1.17	1.17	1.17
15	2.18	1.99	2.01

4.2. The factors special for ERONOR.

These factors are mentioned in equations 3.1.3 and 3.1.4.

4.2.1. The snow factor (SNOWFAK), and the saturation factor (SATFAK).

Several observations in Norway had shown that particle concentrations usually were low when runoff occurred with a fairly thick snowcover, and usually were much larger when erosion occurred with little or no snowcover (table 4.2.1) . The reason was that snow and ice protected against detachment both by rain and runoff.

Table 4.2.1. Suspended solids (mg/l) in surface runoff from 3 USLE-plot sites by different snowcover conditions (0 is no snow and no frost in soil, 1 is little or no snow and frozen soil, 2 is relatively deep snowcover). Tillage is autumn ploughing and crop is spring grain.

Snowfactor	Site Bjørnebekk	Site Askim	Site Hellerud
0	3436	2535	5720
1	1811	2409	1664
2	136	183	124

In figure 4.2.1 some variables during snowmelt at site Hellerud are shown. It turns out that during the period 8/3 to 8/4 the particle concentration in surface runoff was relatively low and did not increase in spite of 200mm of runoff. During this periode the snowcover was more than 230mm deep. However, after 8/4 the concentration increased while the snowdepth decreased. There was no precipitation during this periode, so the surface runoff of about 50mm was due to melting of snow and ice and frozen soil water and the resulting erosion due to rilling only. Similar effects of snowcover on soil erosion has been observed several times.

On the basis of these results the effect of snowcover on particle concentration in surface runoff was defined as follows:
If snowstorage was greater than 60mm, then $SNOWFAK_{SU}=0.02$. If snowstorage was less than 1mm, then $SNOWFAK_{SU}=1$. Between these values of snowstorage the following equation was used:

4.2.1.1 $SNOWFAK_{SU}=1.236514-.236514*snowst^{0.4}$, where snowst is snowstorage in (mm) water equivalents. This gives a maximum relative effect of snowstorage of 50 (maximum value/minimum value). There is an option in the computerprogram to chose a lower value of SNOWFACK of 0.03 with an equation different from 4.2.1.1. The snowfactor for drain water was related to the surface factor as follows:

4.2.1.2. $SNOWFAK_{DR} = SNOWFAK_{SU}^{0.3}$.

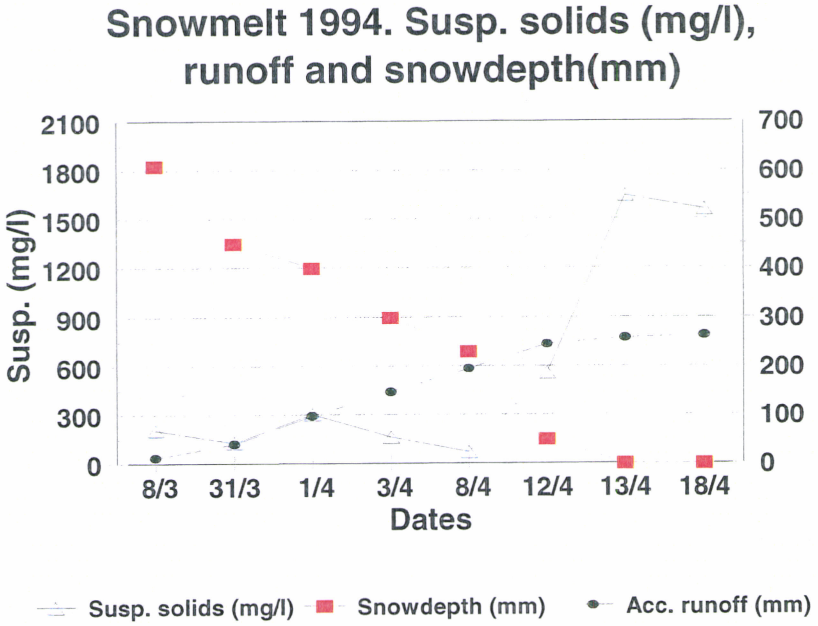

Figure 4.2.1. Suspended solids, accumulated surface runoff and snowdepth spring 1994 at Hellerud, South-eastern Norway.

The impression was however that the concentrations could vary even more than could be explained by equation 4.2.1.1 alone. In the last stage of snowmelt when the upper few cm of soil is melting and supersaturation often occurs, erodibility is increased. This probably also may occur to some degree during saturated surface runoff without frost in soil. To handle this situation some results from the SOIL hydrology model (10) which always was run before ERONOR, were used. The pF-value ($\log_{10}$ of the soil water tension in cm of the 0-5 cm soil layer) was calculated in such a way that negative tension was given a positive pF-value, while supersaturation was given a negative pF value. pF was set to zero when tension had an absolute value of less than 1 cm.

The standard value of the saturation factor for surface runoff ($SATFAK_{SU}$) is 1, that is: no effect. During late autumn and winter when the following situation occurs: air temperature greater than zero, snowstorage less than 5 mm, frost in soil and surface runoff >zero then $SATFAK_{SU}$ =4.5. In cases with no frost, surface runoff and supersaturated soil, soil water tension>+3cm (pf<-0.5), then $SATFAK_{SU}$ =3. In cases with no frost and tension between +3cm and –40cm (-0.5<pF<1.6) and surface runoff the saturation factor was defined by the following equation:

4.2.1.3: $SATFAK_{SU} = 2.54 - 0.95238 * pF$,

which smoothed the transition from a value of 3 to 1. pF is defined in the text above.

The saturation factor improved the performance of ERONOR, but it is however very difficult to describe the true situation of snowcover, snowmelt, soil temperatures, runoff, frost in soil and soil water tension correctly. So relatively great discrepancies between observed and simulated values may occur, but over several years this levels out.
The standard value of $SATFAK_{DR}$ is also 1, but varies between 2.5 and 1 in the cases described above.

4.2.2. The runoff factor (QFAK) and the rain factor (RAINFAK).

Surface runoff can both detach and transport soil particles, and the rate of both processes will usually increase with runoff intensity. In Morgan (23) several equations relating detachment or transport capacity to surface runoff are given. Most of the equations are of the type $y=k*x^m$, where y may be detachment rate or transport, k is a constant, x is the runoff intensity and the exponent m often varies between 1.67 and 1.9 for the transport process and is set to 0.67 for the detachment process. Exponents outside these limits may also be found.

In ERONOR, the runoff factor is supposed to describe the variation in particle concentration. Since transport is the product of concentration and runoff, a value of 1 has to be subtracted from the exponents in the transport equations above, that is the concentrations should vary with runoff raised to a power of 0.67 to 0.9. Since however the erosion process also may be detachment limited, it was decided to use a smaller value of 0.4 for the exponent. Thus the following equation was used to simulate the relative effect of surface runoff on concentration of soil particles in surface runoff:

4.2.2.1: $QFAK_{SU} = 1 + 7* Q_{SU}^{0.4}$, where

Q_{SU} is dayly surface runoff in mm.

For drain water the following relation was used:

4.2.2.2: $QFAK_{DR} = 1 + 2.1* Q_{DR}^{0.4}$, where subscripts stand for drainwater.

Concerning the effect of precipitation, the rainfall intensity is known to have a great effect on soil loss as can be seen in the calculation of rain energy in USLE (11) and RUSLE (12). However, the surface runoff is not used in these equations. In ERONOR the RAINFAK factor shall represent the effect of rainfall on the particle concentration in runoff, not on soil loss. Since the effects of surface runoff and precipitation both are included in the product function, the effect of precipitation itself must be rather small since a large part of its effect must already be included in the runoff effect. Furthermore it was reasoned that the effect of rainfall often had to be smaller in winter than in summer due to generally lower rain intensities in winter and often extra protection of snow and ice . Therefore the effect of rainfall on particle concentration in surface runoff was formulated as follows:

4.2.2.3: $RAINFAK_{SU} =1 + 0.99 * Rain^m$, where

Rain is dayly rainfall in mm, and m=0.4 during summer season and m=0.2 during late autumn and winter.
The total effect of runoff and rainfall thus will be that particle concentration will increase with a power of between 0.6 and 0.8 of surface runoff or rainfall when their values are of similar

magnitude. During high rainfall in summer with relatively low surface runoff, the effect of rainfall will be relatively high. For drainwater the effect was calculated as follows:

4.2.2.4: $\mathrm{RAINFAK}_{DR} = 1 + 0.99*0.3 * \mathrm{Rain}^{m}$, where
m has the same value as for surface runoff, but the constant term is reduced by 0.3.

4.2.3. The cover factor (COVFAK) and consolidation factor (CONSFAK).

The protection of soil surface by living plants or plant residues is of great importance, the same is the effect of plant roots which bind the soil particles. In the WEPP model (6) the effect of plant cover and plant roots are devided on several subfactors which altogether were too complicated to be included in the simple ERONOR model. In ERONOR it was reasoned that plant cover whether living or dead has a similar protective effect of the soil surface. The plant cover can be simulated using the leaf area index (LAI) which for spring grain is obtained from the SOIL model (10) which is run before ERONOR.

Thus, during the growing season the plant cover increases proportionally to LAI until its maximum value. If no tillage occurs in autumn and straw of grain is not removed, this maximum value is retained most of the autumn, but is somewhat reduced in December and the next year due to decay. However, growth of weed and emergence of spilt grain will more or less counter this effect. Different kind of tillage will reduce the protective plant cover.

In the SOIL model LAI increases until a maximum of 5, but this maximum value is used only for grassland in ERONOR, for other crops the maximum value is set to 5*0.95. Due to plant growth and tillage, dayly values of a LAIFAK for different tillage systems are evaluated, where LAIFAK may vary between 0 and and 4.75 (5 for grassland). The cover factor is then calculated as follows:

4.2.3.1: $\mathrm{COVFAK}_{SU}=[e^{(-2.5*\mathrm{LAIFAK}/5)} * 2 +1-0.18*\mathrm{LAIFAK}] / 3$, where

COVFAK_{SU} is the cover factor for surface runoff, and LAIFAK is as defined above.

COVFAK_{SU} will vary from 1 to 0.088 as LAIFAK varies from 0 to 5. Equation 4.2.3.1 is a combination of an exponential expression taken from the WEPP model (6) weighted by 2 and a linear relationship. For drain water the effect of cover is reduced and calculated as:

4.2.3.2: $\mathrm{COVFAK}_{DR} = (\mathrm{COVFAK}_{SU})^{0.5}$.

Some effects of tillage on cover:
By moldboard ploughing LAIFAK is set to 4% of the value of LAIFAK before ploughing.
By harrowing the wanted value may be set as a parameter in the model, but the default value is 0.45 of LAIFAK before harrowing. If the field is harrowed twice, LAIFAK is either by default multiplied by 0.45*0.45 or multiplied twice with the parameter value set.
By direct drilling, LAIFAK is set to 0.7 of the value before the operation. In December most of the LAIFAK-values are reduced by 10%, during the periode from January to spring tillage the LAIFAK-values are further reduced. During spring tillage the LAIFAK-values are set to values according to the treatment the previous autumn and the actual kind of spring tillage. Treatments that retain some residue cover after spring tillage will have a proportion of this cover added to the new plant cover.

LAI-values for winter wheat have not been provided by the SOIL model which is run for spring grain only. Based on sowing dates and temperatures, rules for creating a reasonable development of LAI for winter wheat have been made. Established grassland has been set to the maximum value of LAIFAK=5 all year. When grassland has been ploughed, some aftereffect has been taken into account. This has also been done, but to a lesser degree when catchcrops like ryegrass have been ploughed.

In ERONOR, several tillage systems are run simultaneously, many of those are pure systems (no rotations). Other systems simulate transitions from one system to another. During the ERONOR runs, each year is divided into three periods and all the output is stored. If rotations are to be simulated that were not one of the standard systems, this can be done afterwards by picking the correct system for each year and each period from the values produced in the first run.

The consolidation of the soil is simply regarded as a time dependent function where consolidation starts on its maximum value after each tillage. The equation describing the consolidation for surface runoff is:

4.2.3.3: $\mathrm{CONSFAK}_{SU} = 1 - 0.0404145 * \mathrm{time}^{0.5}$,

where time is number of days since the last tillage. The maximum value of time is 300 days when CONSFAK reaches its minimum value of 0.3, the maximum allowed value is 0.93.
In the WEPP model (6) consolidation is affected both by accumulated rainfall, number of days since last tillage and the bulk density of the soil. Since accumulated rainfall tends to increase with time, it was assumed that in the simple case of ERONOR a time function was adequate.
For drain water the consolidation effect was reduced and set to:

4.2.3.4: $\mathrm{CONSFAK}_{DR} = (\mathrm{CONSFAK}_{SU})^{0.5}$.

4.2.4. The stucture factor (STRUCT).

When ERONOR-estimates were compared with measurements it was observed that some treatments like autumn harrowing of spring grain and winter wheat ploughed and harrowed in autumn, tended to be underpredicted. It was believed that harrowing reduced aggregate size and the sowing of winterwheat afterwards led to increased compaction. This could lead to reduced infiltration, more surface runoff and increased erosion. This has been especially evident in winter wheat fields, which also has been reported by Hansen (24). To account for this effect, the erosion estimates for winter wheat and autumn harrowing have been multiplied by reasonable structure factors varying in magnitude from about 1.05 to 1.3.
It was also evident that this effect of tillage on soil structure varied between years depending on soil- and weather conditions during tillage and after tillage. This would be the case for any kind of tillage at any time through the year. But the effect in autumn would generally be most important due to higher precipitation and higher water content in soil in autumn. Due to difficulties, this varying effect was not modelled. This is also the case for erosion models known to the author.

4.3. The hydrology part, estimating surface runoff (Q_{SU}) and drainwater (Q_{DR}).

At start it was believed that the process based SOIL model (10) would be adequate for simulating total runoff separated in surface runoff and drain water. This model simulates both heat and water flow, treats frost and snowmelt and should therefore be well suited for winter conditions. However, the model contains a lot of parameters, many of which cannot be calculated and must be set from experience where such exist or by trial and error. In cases where sufficient measurements of surface- and drain runoff existed, it was possible to parameterize the model to give reasonable results. However, in areas where no such measurements were made, it was difficult to set parameters, and the estimated surface runoff was thus less reliable. Nevertheless, SOIL has always been run prior to ERONOR, so that SOIL-estimates of surface and drain runoff, LAI, soil temperatures, frost depth, snowdepth, soil water tension etc. always were available.
It was however felt that an alternative approach would be appropriate.

4.3.1. Modelling of total runoff by the AVRJUST model.

The AVRJUST model is a simple water balance model that produces dayly evapotranspiration and total runoff. It calculates dayly storages of snow, drainable water, easily- and heavily plant available water. It has no groundwater storage, and should therefore not be used if groundwater is an important part of total runoff. It melts snow by a day degree routine with time dependent day degree factor and an additional effect of wind at air temperatures above zero when windspeed is above some limit.

Potential evapotranspiration for grassland is calculated by the Penman method (25), where incoming solar radiation is calculated from theoretical values and cloudiness, longwave outgoing radiation by the Stefan-Bolzman law reduced by cloudiness and absolute humidity. The aerodynamic part of the Penman equation used here is: (eat)=(0.26+0.14*wind)*hdef, where eat is in mm/day, wind is in m/sek at 2 m height and hdef is saturation deficit in millibar.

The actual evapotranspiration was calculated from the potential evapotranspiration as follows: Negative values which might occurs during cold winters were set to zero. Since the actual crop most often was small grain and not grass, the Penman values generally were believed to be too high during winter and spring and too low during intensive growth during parts of June and July. Therefore the potential values were reduced in winter and early spring, but this reduction was gradually reduced after emergence of the sown crop and than allowed to be greater than the potential evapotranspiration for some period. Soil water could limit evapotranspiration. This was handeled by deviding total plant available soil water in an easily- and heavily available part. Outside the growing season when plants were dead or roots poorly developed, not more then half the amount of easily available water was allowed to be used before reductions in evapotranspiration vere introduced. Inside the growing season, all the easily available water could be used before any reduction from the maximum value was made. Within the region of heavily available soil water, actual evapotranspiration was set proportional to the remaining amount of available water. This procedure seemed to give reasonable results.

Runoff was generated when rainfall +snowmelt was greater than actual evapotranspiration and capillary soil water storages were filled. Soil water storages were filled in the sequence:

heavily available, easily available and drainable water, and emptied in the reverse sequence. Not all the excess water was allowed to produce runoff the same day it was created, only a portion. In this way runoff could happen also a few days after the excess water was produced. If a "slow storage" is introduced, the runoff will last longer depending on the size and runoff characteristics of this storage. However, on many Norwegian clay soils which also usually are artificially drained, most of the runoff is quickflow during which most of the soil losses occur. Under such conditions the model performed reasonably well.

Climatic data necessary to run AVRJUST are dayly precipitation, type of precipitation (snow, rain), snowdepth, air temperature, relative humidity, wind speed, cloudiness. Furthermore the size of the soil water storages depending on soil water retention curves, must be set, in addition to various factors controlling snowmelt and evapotranspiration. However, default values are automatically used when no values are given.

The precipitation data are windcorrected the following way: $P_{corr}=P_{obs}*e^{(k*wind)}$, where P_{corr} is corrected precipitation, P_{obs} is observed precipitation, k is a factor varying from 0,03 to o,13 as type of precipitation goes from rain to snow and wind is windspeed (m/sek) at 2 m height above ground. The windcorrected precipitation data are used in AVRJUST and ERONOR.

4.3.2. Simulating surface and drain water within ERONOR based on total runoff.

Infiltration capacity varies greatly between soil types and with time due to swelling and cracking and due to frost or no frost in soil. ERONOR receives estimates of total dayly runoff both from the SOIL model and from the AVRJUST model. The task was to find out how much of this total runoff that had infiltrated and produced drain water and how much was surface runoff. Since dayly runoff values were available, the infiltration rates had to be valid for whole days even if the precipitation and runoff often is produced in showers of 3 to 12 hours duration. As an example: an average infiltration capacity of 2 mm/hour would give no surface runoff with 48mm of total runoff produced evenly during 24 hours, but would produce 24mm of surface runoff if the runoff occurred evenly during 12 hours. However, the same would be achived if the whole day infiltration was reduced to 1mm/hour or 24mm/day.

Some of the principles of the Curve number method of the Soil conservation service in USA (20) were adopted. It was decided that when total runoff was above som threshold, surface runoff would start and an increasing part of the total runoff above the threshold would be surface runoff as total runoff increased. The problem remained to find the magnitude of this threshold and how it varied due to soil type and time.

Infiltration capacity usually is related to soil properties like texture, structure, content of humus, bulk density and so on. Since the K_{NO} factor used in both USLENO and ERONOR already contain effects of texture, humus, permeability and structure it was belived that this factor might also be used to calculate the effect of soil on the threshold value.

The expression $XX=(1/K_{NO})^{0.4}$ was used to relate soil properties to the infiltration threshold.

To simulate the variation within year, it was believed that the period between thawing of frost or saturation in spring and soil saturation or new frost in autumn, the variation in infiltration capacity could be simulated be a flat and maybe skew upper part of a sine curve. The flatness was varied using an amplitude factor, and the skew by using a different lower value in spring

than in autumn. To find out when the soil had become frozen or saturated in autumn and spring, graphs of snowdepth, runoff, air temperature, soil temperature were studied at the same time. It was thus possible to set starting dates in spring and ending dates in autumn and to decide wheter the soil had been frozen or not during main part of the winter. A method used in the GLEAMS model (19) was found not to be accurate enough.
The sine function was defined as follows:

4.3.2.1: sinus=sin((dayn-dayst)/(dayen-dayst)*π), where:

sinus is the positive sine value (0 to 1)
dayn=actual day number
dayst=day number at start of unsaturated or unfrozen period
dayen=day number at end of unsaturated or unfrozen period

The threshold infiltration value was thus calculated:

4.3.2.2: Inf=(sinus*amp+(dayn-dayst)*(base2-base1)/(dayen-dayst)+base1)*XX.

Where
Inf=the calculated thershold value above which surface runoff starts
Amp= amplitude of the flattened sine curve
Base1=minimum value by saturated not frozen soil at start of season
Base2=minimum value by saturated not frozen soil at end of season
XX = a soil property factor defined in text above.

Used values of base1, base2 and amp have been between 2 and 5 mm/day. XX will vary between 2.5 and 1 as K_{NO} goes from 0.1 to 1. In the period with saturated soil the minimum inf values will be from 3 to 7.5 mm/day if base-values are 3 mm/day. If the soil is moderately frozen, inf is set to 1/3 of the nonfrozen value and with stong frost in soil inf is set to 0.1 of the saturated value (0,3-0,75 mm/day) in the example.

When total runoff is greater then inf, the fraction of surface runoff is calculated as

4.3.2.3: fracsurf=0.85-0.8/$\sqrt{}$(runotot-inf), where

fracsurf is the fraction of total runoff above inf that is surface water
runotot=total runoff in mm/day and must be greater than inf+1 for eq. 4.3.2.3 to be valid.

Fracsurf will thus vary from 0.05 to 0.715 as runotot-inf varies from 1 to 40 mm/day.
Surface runoff is finally calculated as

4.3.2.4 surface runoff=(runotot-inf)*fracsurf, and drain water finally is calculated as

4.3.2.5: drain water=total runoff-surface runoff

Some additional adjustments have been made, but are not mentioned here.

When running ERONOR, it can be chosen wheter to use only SOIL data or calculate surface and drain water within ERONOR based on total runoff from either SOIL or AVRJUST2.

Usually the option using ERONOR-calculated surface runoff based on AVRJUST2-estimates have been chosen. The reason for this is that SOIL-estimates are questionable when the model is used under situations where little calibration data are available. The other method is much simpler, since it does not involve a lot of parameters, and is thus easier to use and more consistent. An additional advantage is that within a climatic region, ERONOR can be run for several soil types based on just one basic hydrology file created from SOIL and AVRJUST.

The total runoff produced by AVRJUST and surface and drain runoff produced internally in ERONOR have on average given quite reasonable values.

4.4. Estimating losses of total phosphorus and particulate N.

Regression analysis between concentrations of total P and suspended solids have produced equations of the type:

4.4.1: Tot-P= a + b * susp, where

Tot-P is total –P in µg/l
Susp is suspended solids in mg/l,
A is the constant term, greater than zero
B is the coeffisient, which can be less than or greater than 1 depending on P-conc. in the soil

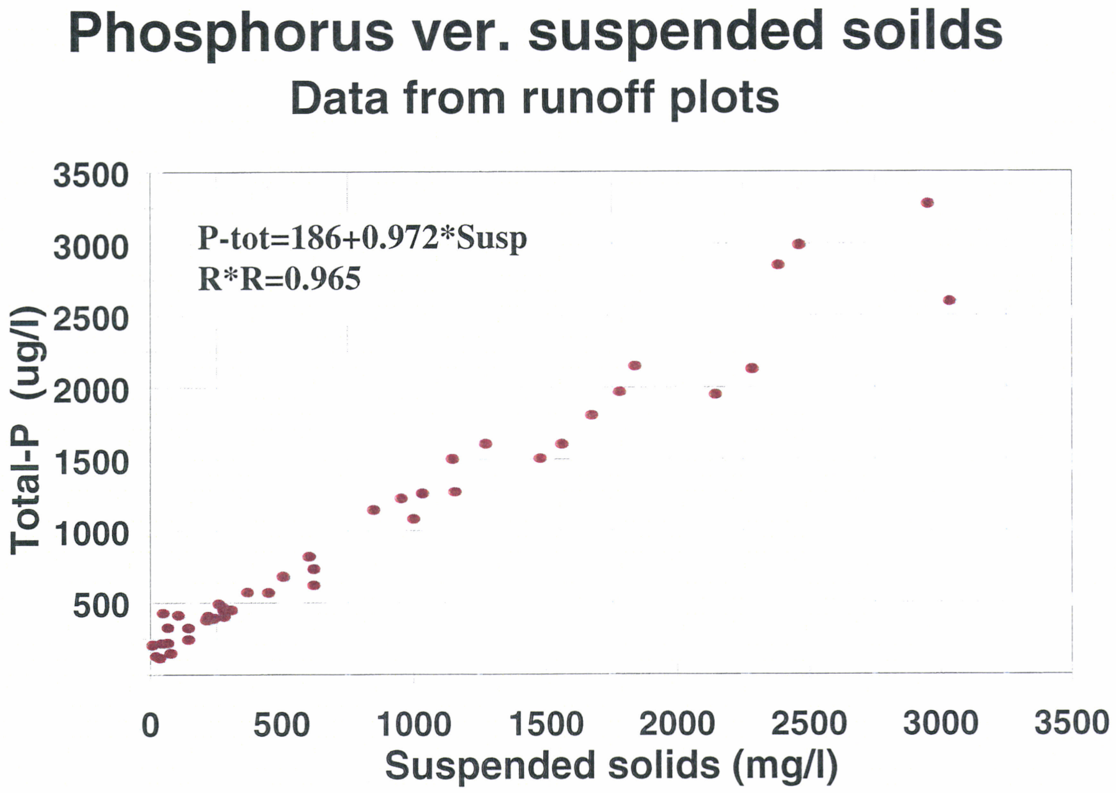

Figure 4.4.1. Total P versus suspended solids. Data is surface runoff from USLE-plot studies. Every point is mean value over some years for a treatment.

After analysis of surface runoff from USLE-plots on arable land and clay soils, Lundekvam (26) found (a) to be 186 µg/l and (b) to be 0.972 (µg/l)/(mg/l), see figure 4.4.1. These parameter values have been used for surface runoff in South-eastern Norway and in Mid-Norway on clay soils. The linear relationship seems to be valid on soils with similar P-content due to similar fertilizing practise for a long time and moderate use of manure.

For Hedmark both the parameters had higher values then for South-eastern Norway , and there were also differences between cultivating systems. The equations for Hedmark vere based on data from Eide (1) and Eltun (5).
The cultivating systems in South-western Norway are rather different from the other regions used in the MILDRI program. Here, husbandry has been very common for a long time, and thus manure is abundant and used regularely, increasing the concentrations of dissolved P in surface water. An analysis of data on surface runoff from Undheim (2) revealed a very high constant term of about 1000 µg/l and a coefficient of 1.1 (µg/mg). The sites used in the analysis had been manured, and the large constant term revealed that a large part of total P was most likely dissolved.
For water from tile drains, the equations were different from surface water. Similar equations were used for all districts.

Losses of particulate N were calculated from the soil losses from surface and drain water added together, the N-content in the soil taken from the NIJOS/MILDRI data base and some assumptions on enrichment.

The general equation for loss of particulate N was:

4.4.2: $\text{N-LOSS}=(\text{LOSS-SOIL}_{SU} + \text{LOSS-SOIL}_{DR})*(k1* \text{ORGC} +k2*\text{ORGC}^2)*k3*k4*nc.$

Where,
N-LOSS is particulate N-loss in kg/ha
LOSS-SOIL_{SU} is Soil loss with surface runoff in kg/ha
LOSS-SOIL_{DR} is soil loss with drain water in kg/ha
ORGC is content of organic C.
NC is the ratio N/C,
k1, k2, k3, k4 are coefficients.

5. Running ERONOR.

Figure 5.1 shows a flow chart of programs and files involved in running ERONOR. First a wheather data file of dayly values for the time period must be prepared. In the case of MILDRI one file for each of the 4 districts for the time period 1976-1997 was prepared. Then soil data files and parameter settings of the SOIL model was done for a common soil type in each district. The SOIL model was then run and the output file stored for later use in ERONOR.
The most important information from the SOIL model used in ERONOR was surface and drain runoff, LAI, soil temperatures, soil water tension, frost depth, snowstorage.

Snowstorage, total runoff and evapotranspiration was alternatively simulated in the computer programs PENMAN and AVRJUST. These two programs used the same climate file as

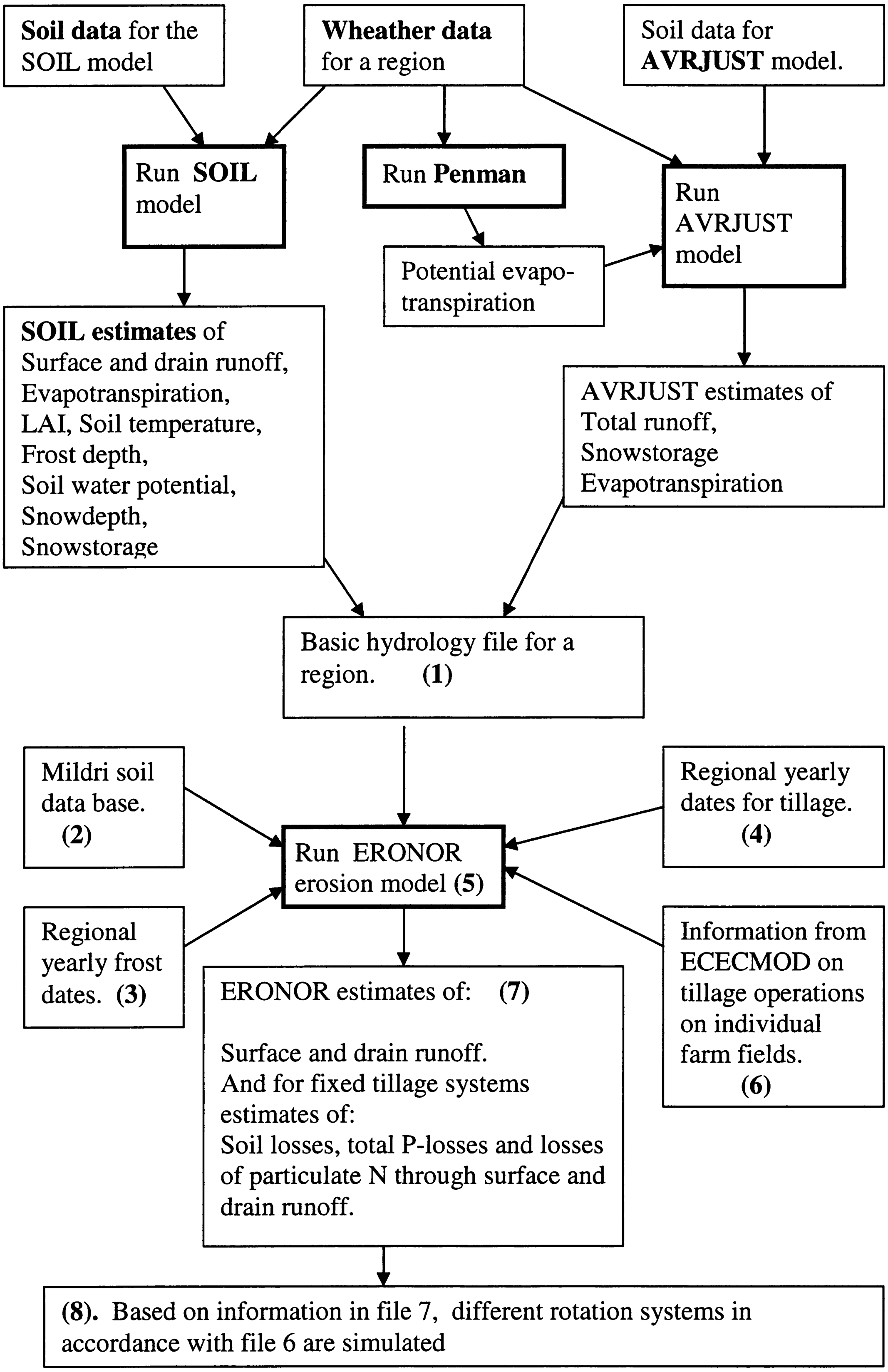

Figure 5.1. Flow chart showing steps in running the ERONOR model.

SOIL. Also information on soil water storages, and sowing dates would normally be required, although default values are available. SOIL, PENMAN and AVRJUST were normally run for one common soil type within each district and the results combined to produce one basic hydrology file used by ERONOR within each district.
The best thing would be to run SOIL and AVRJUST for every soil type and preferably also for every cultivating system within a district. This would mean either running all three models at the same time which for the time being is not possible or running the models on beforehand for all soil types and storings results which would take a lot of disk storage. Since ERONOR provides opportunity to handle the effect of soil type on surface runoff internally, one basic hydrology file for each district was found to be sufficient.
However, the effect of different tillage and crops on surface runoff is not taken into account, so the same amount of surface and drain runoff is used for one soil type irrespective the cultivating system.
This way of producing hydrology data makes the running procedure much easier and faster than by running SOIL and AVRJUST for every soil and crop.

When the hydrology file has been prepared, ERONOR can be run for a number of soil types and cultivating systems within a region. The soil type must be given as a number referring to the MILDRI soil data base, furthermore yearly frost dates are read. The model in this first step produces the K_{NO}, S_{NO} and L_{NO} values and new values for surface and drain runoff.
In the next step the model reads common regional yearly dates for tillage operations, and when run for a MILDRI scenarium, specific yearly information on crop rotations and types of tillage and dates are provided by the ECECMOD. (ECECMOD is the modelling system where the farmer makes decisions concerning agricultural practices). During this run ERONOR produces dayly values for 23 standard systems simultaneously and the results are stored for further use in the final step.
Since the standard systems will not cover all rotations asked for by ECECMOD, a special program is run immediately after the main ERONOR program has terminated. In this special program values from the standard systems are combined each year in such a way that the wanted rotations are simulated.
It is often wanted to compare standard systems, and for this purpose ERONOR is very efficient since it simulates 23 systems at the time instead of running the model 23 times. For the purpose of running special rotations this is less efficient. However, to do it otherwise it will be necessary to reprogram the whole model.
After the hydrology file is prepared, the running time for the model during a 22 years rotation system is 25-28 seconds on a relatively slow computer. So running 200 different farm fields during 22 years will take less than 110 minutes.

6. Some results.

In the following, some results of the model performance will be given.

6.1. Results concerning hydrology.

The model is sensitive to snowcover combined with rainfall and runoff. If the snowstorage is greater than 60 mm the SNOWFAK parameter is set to its lowest value, while this factor increases to its highest value when snowstorage is zero. High rainfall and runoff during periods with little snow will give high soil losses, so the timing of snowstorage, runoff and rainfall must be reasonable correct. Figure 6.1.1. shows dayly average snowstorage over 24 years simulated by the SOIL model and the simpler AVRJUST model compared with observed snowdepth. The absolute values of snowstorage in millimeters and snowdepth in cm cannot be directely compared, since it involves bulk density of snow. It is the timing that is important. It is seen that the average timing has been satisfactorily simulated by both models. However, individual years will show discrepancies, therefore the models must be run for several years to give reliable average results.

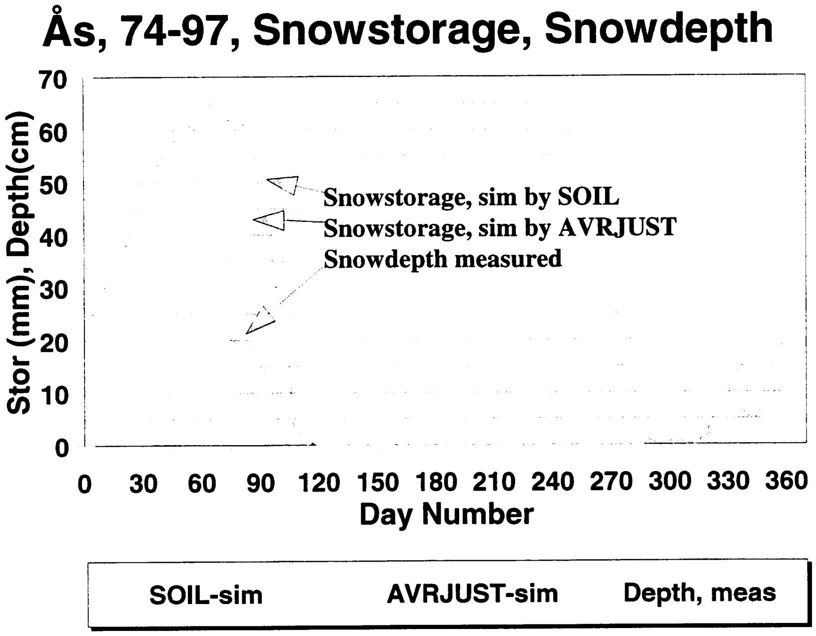

Figure 6.1.1. Dayly avreage snowstorage simulated by the SOIL modell and the AVRJUST model compared with observed snowdepth, 1974-97 at Ås.

If simulated total runoff is close to measured values, it generally means that the hydrological components in the models in total performs rather well. In table 6.1.1 simulated values for each of the 4 districts are compared with values taken from hydrological maps (27) from the regions.

Table 6.1.1. Simulated total runoff compared with runoff values taken from hydrological maps. Since the maps refer to the normal period 1931-60, the simulated values are adjusted to the same precipitation as the normal period assuming equal evapotranspiration for the two periods. All numbers are in mm/year.

Region	Sim SOIL 1974-97	Sim AVRJUST 1974-97	Precip 1974-97	Normal Precip 1931-60	Adjusted SOIL 1974-97	Adjusted AVRJUST 1974-97	From maps
Follo	521	460	793	785	513	452	442
Hedmark	305	247	574	585	316	258	252
Trøndelag	559	627	881	892	570	638	600
Jæren	849	977	1263	1254	840	968	950

The map values are somewhat approximate in Trøndelag and at Jæren, however, it is seen that the adjusted simulated values from AVRJUST are close enough to the map values to be quite acceptable. The values simulated by SOIL are generally not so close.

Simulated versus measured yearly values are found in figure 6.1.2.

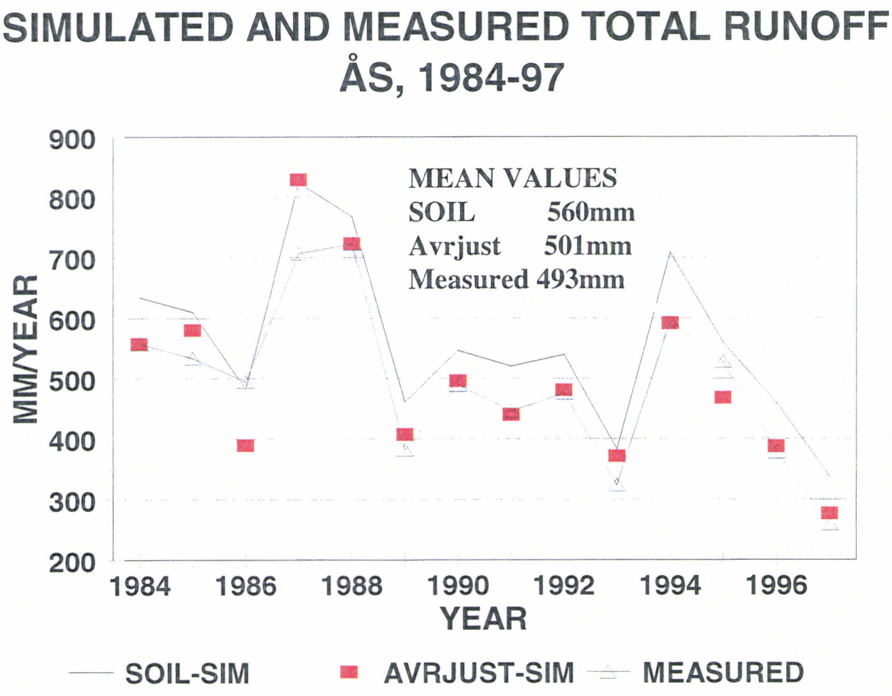

Figure 6.1.2. Simulated versus measured yearly runoff at Ås, 1984-97.

Considering total average, AVRJUST is closer to the measured values than SOIL. The yearly variation is reasonably well described by both models.

The monthly distribution of runoff is shown in figure 6.1.3.

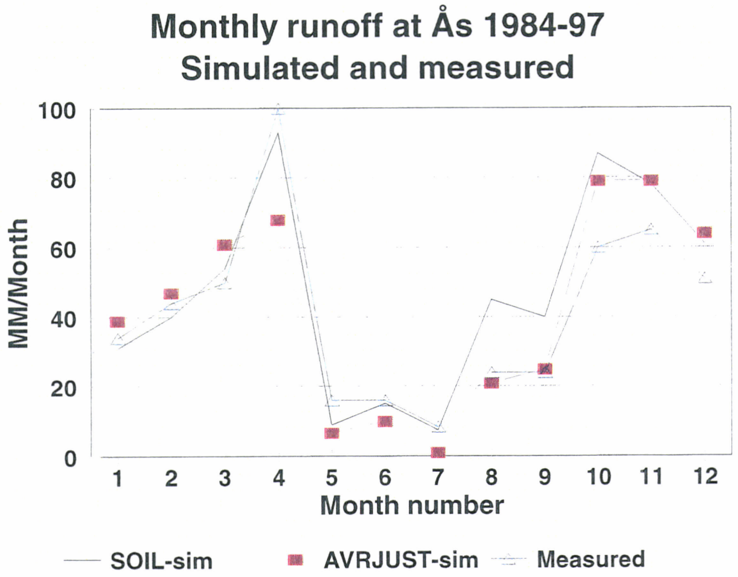

Figure 6.1.3. Monthly simulated and measured total runoff at Ås, average 1984-97.

Since the AVRJUST-model does not simulate groundwater storage and runoff, or meltwater storage in the snow, it produces too much runoff in early winter and late autumn and too little in april and during summer. SOIL has been working better in winter, but creates too much runoff late summer and autumn. Since groundwater runoff at this site was greater than would be expected due to morainic deposits, the models work reasonably well as to the distribution of runoff during the year.

Surface runoff has been measured at USLE plots at Ås and at other sites in South-Eastern Norway. Yearly simulated and measured values are shown in figure 6.1.4.

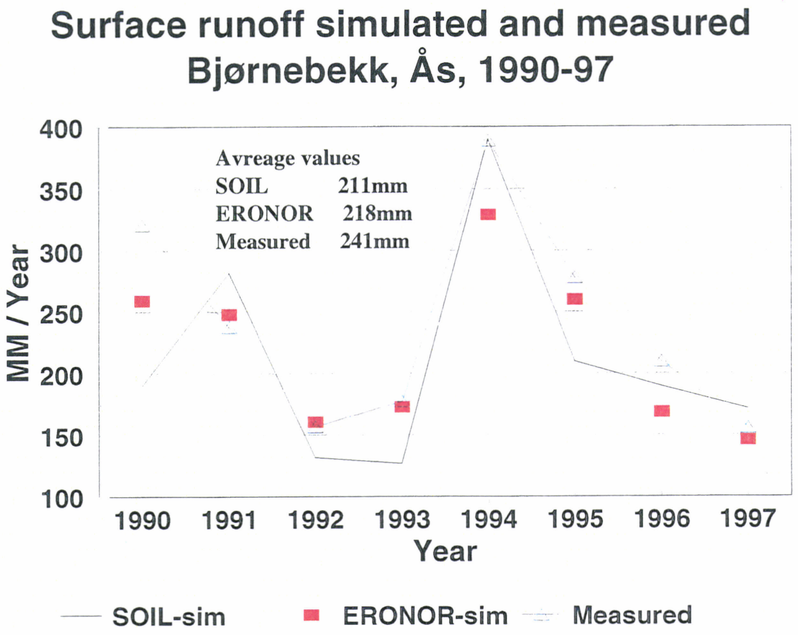

Figure 6.1.4. Yearly surface runoff at Bjørnebekk, Ås. Simulated by SOIL and ERONOR compared with measured.

In this case there was put great effort into parameterizing SOIL, so both SOIL and the routine within ERONOR have worked reasonably well simulating surface runoff on a yearly basis. Even though simulated values are somewhat lower than measured ones it should be taken into account that compaction is greater on these plots than under normal farming practices. This is because the tractor has to be backed onto the plots and then driven forwards to do the tillage. Therefore the level of simulated runoff is quite acceptable.

The distribution of surface runoff within a year is very important for the overall performance of an erosion model. The measured values are from plots where runoff counters usually were read with a time interval of two weeks or longer. The runoff was put on the date of reading, the last date. Therefore the observed values often show the runoff to happen somewhat later than it did in reality, especially during winter and spring. This must be kept in mind when looking at monthly values in figure 6.1.5. Taking this into accout, the overall impression is that the models have been able to distribute the surface runoff reasonably well over the year, and well enough for the ERONOR model to simulate the effect of time of tillage on erosion.

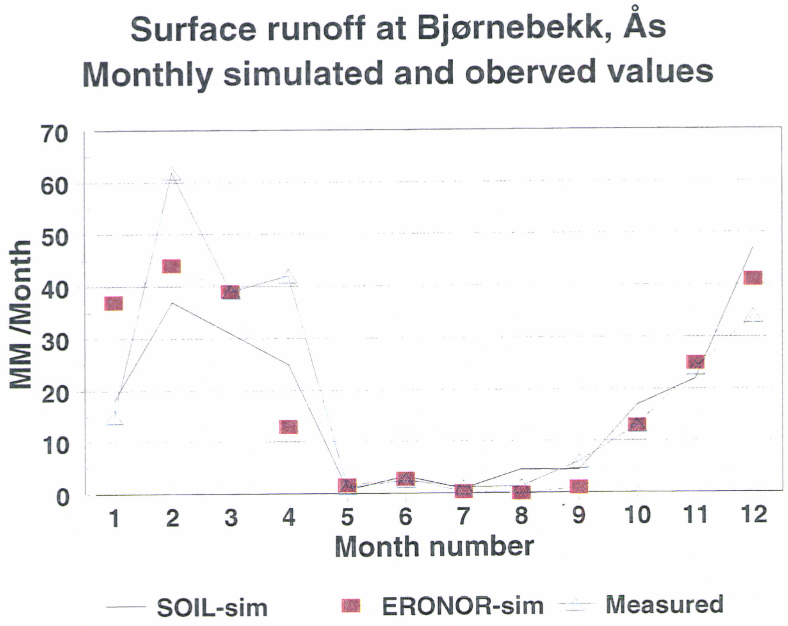

Figure 6.1.5. Monthly surface runoff at Bjørnebekk, 1990-97. Simulated values by SOIL and ERONOR and values measured at runoff plots. Some of the measured values, especially in winter and spring occurred earlier than shown. See text.

6.2. Results concerning erosion.

At two USLE plot sites surface runoff and the relative factors simulating variation in particle concentration were evaluated and the product sum simulating relative soil loss were calculated and then calibrated against the measurements. In this way the SCALE factors for

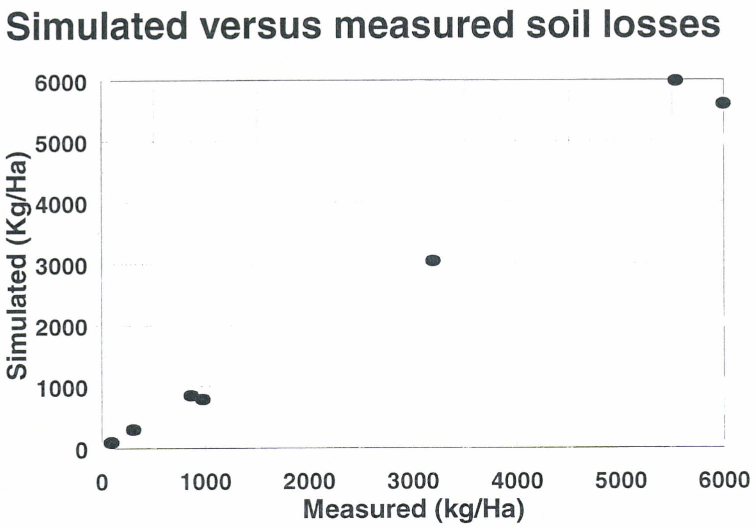

Figure 6.2.1. Soil losses through surface runoff simulated by ERONOR versus measured values. Each point represent mean values from 7 to 11 years from 3 sites and 2 to 3 tillage systems.

surface and drainage were calculated. Figure 6.2.1. shows mean values for 7 to 11 years comparing simulated and measured values at USLE plot sites in South-Eastern Norway. As can be seen, the simulation of the mean losses has been rather good. Since the span in erodibility of the involved soils is rather great, it is hoped that most of common Norwegian

Distribution of monthly values as means over 8 years are shown in figure 6.2.2.

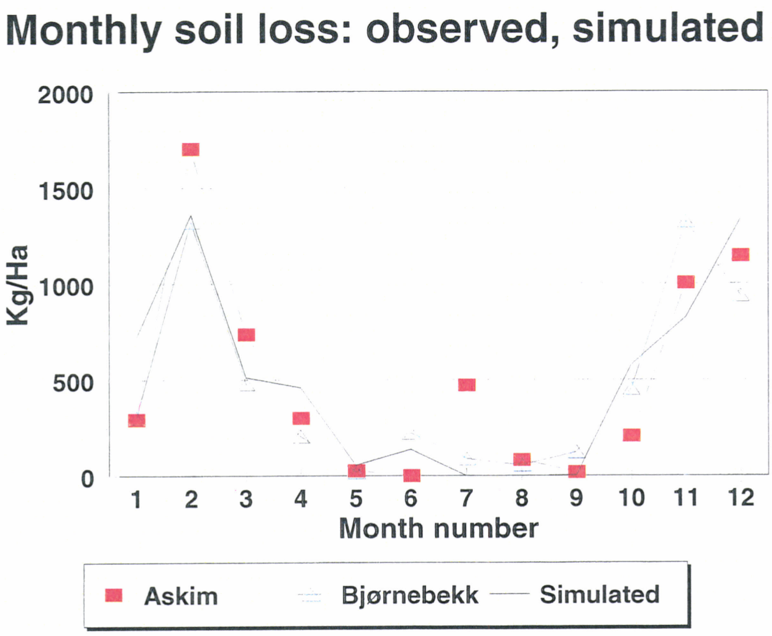

Figure 6.2.2. Simulated and observed monthly soil loss at two sites in South-eastern Norway. Sites are situated 30 km apart, with equal soil types. Treatment is autumn plowing.

soils will fall between the calibrated vaues. This is an advantage considering that extrapolation outside the calibrated range is more uncertain.
The same climatic file has been used for both sites so the simulated values were approximately the same. Only simulated values for Bjørnebekk are shown. The sites were situated 30 km apart, but the soil type was the same for both sites. Wheather is about the same, but there are some differences in winter temperatures and snowcover and timing of showers. It is however seen that the observed and simulated soil losses are distributed relatively similar, which means that the model has been able to pick up the main causes for erosion.

Yearly values are found in figure 6.2.3.
The same sites have been used as in the previous figure. The observed values from the two sites show similarities but also dissimilarities when compared to each other. The simulated values do not follow the observed ones too well. However, since the observed values also differ, it does show that even relatively small differences in weather conditions can produce relatively large differences in yearly soil loss. With this simple model it was to be expected that each year could not be simulated correctly, therefore it has to be run over some years to come up with reasonable estimates.
It must also be mentioned that soil and weather conditions at the time of tillage may have a large effect on soil structure, infiltration and erosion. These effects are not included in this model, and will be one important reason for the differences. Furthermore, errors in estimating snowcover may also lead to errors in estimated soil loss, because the model is very sensitive to these conditions. Sometime there is ice formation which protects the soil from erosion.

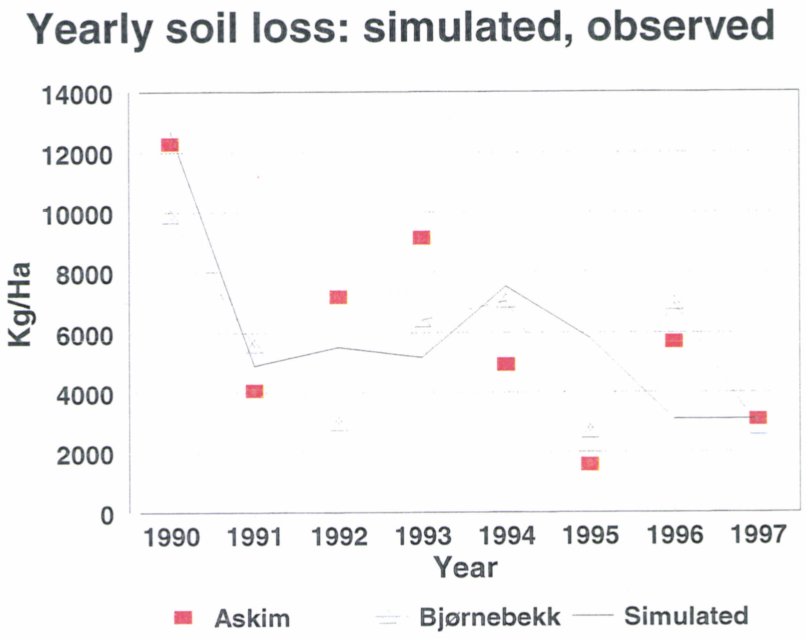

Figure 6.2.3. Simulated and observed yearly soil loss at two sites in South-eastern Norway. Sites are situated 30 km apart with equal soil types. Treatment is autumn ploughing.

This condition is not simulated. Also the use of dayly precipitation is very crude, since the rain intensity can vary and produce varying soil loss even if the dayly precipitation is the same. Considering all the uncertainties, the model performes reasonably well.

6.3. Time series simulated by ERONOR.

Total and surface runoff may be seen in figure 6.3.1. Considering total runoff there is an increasing trend from about 1975/76 to 1987/88, then a downward trend to about 1997 and then increase with very high runoff in the year 2000. These trends are in accordance with observations

Soil loss for three different tillage systems compared with permanent grassland are shovn in figure 6.3.2. Even though soil loss for individual years may not be too accurately simulated, the model is able to pick up trends and also shows significant yearly variation of the same magnitude as observed values. It clearly shows that autumn ploughing is very risky in many years, harrowing once in autumn is also risky, while it is much safer to wait with any tillage until springtime.

These results are well in accordance with measurements.

The time series shows very great yearly variations with especially large peaks in 1987, 1990 and year 2000. The large losses in 1990 and 2000 are well documented by Usle plot measurements on this type of soil. The reason for the large soil losses in 1990 was heavy winter erosion due to rainfall on thawing soil almost free from snow, while in the year 2000 it was rainfall erosion during an extremely wet autumn that was the reason.The model has been able to pick these very important years.

The reason for the large losses in 1987 was high rainfall in last half of October. In the simulations the autumn ploughing date was set before the runoff events, so the losses are thus most reasonable because we then have a similar situation as in year 2000. If the ploughing date was set later, the simulated soil losses were greatly reduced. This is also in accordance with measurements.

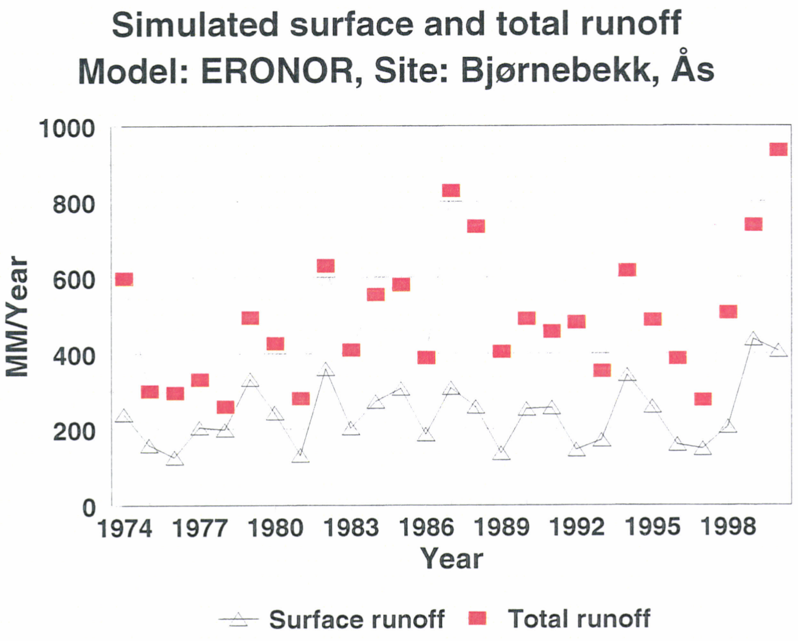

Figure 6.3.1. Total runoff simulated by AVRJUST and surface runoff simulated by ERONOR at the Bjørnebekk site at Ås, South-Eastern Norway. The soil type is erodible with a K_{NO} – value of 1.055.

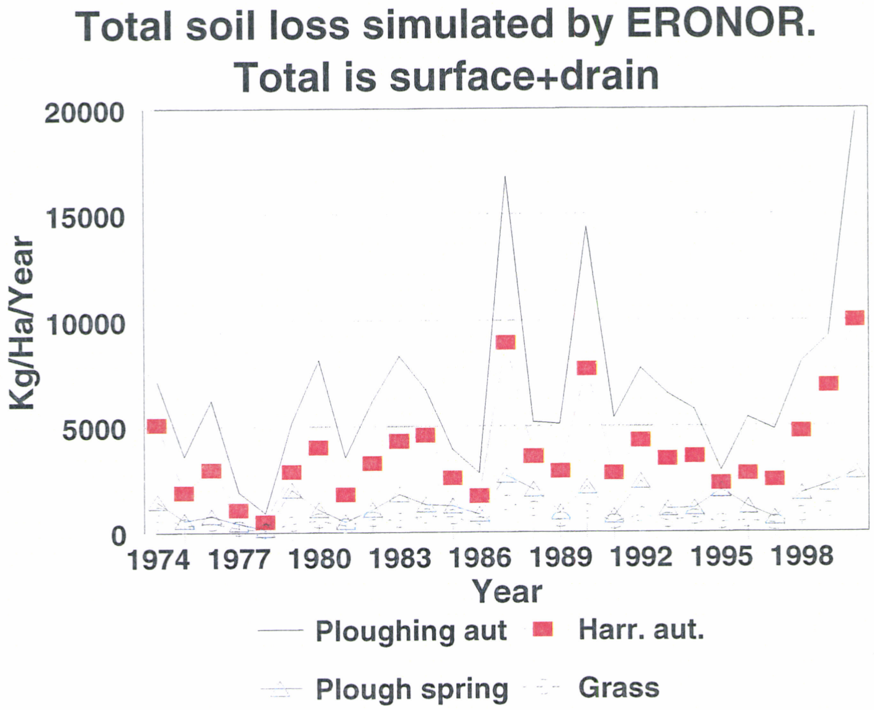

Figure 6.3.2. Soil loss for four treatments simulated by ERONOR. The total of losses through surface and drainage are included.

There may be an increasing trend from 1977/78 to 1987/1990, decreasing trend until 1995/97 and increasing the last years.

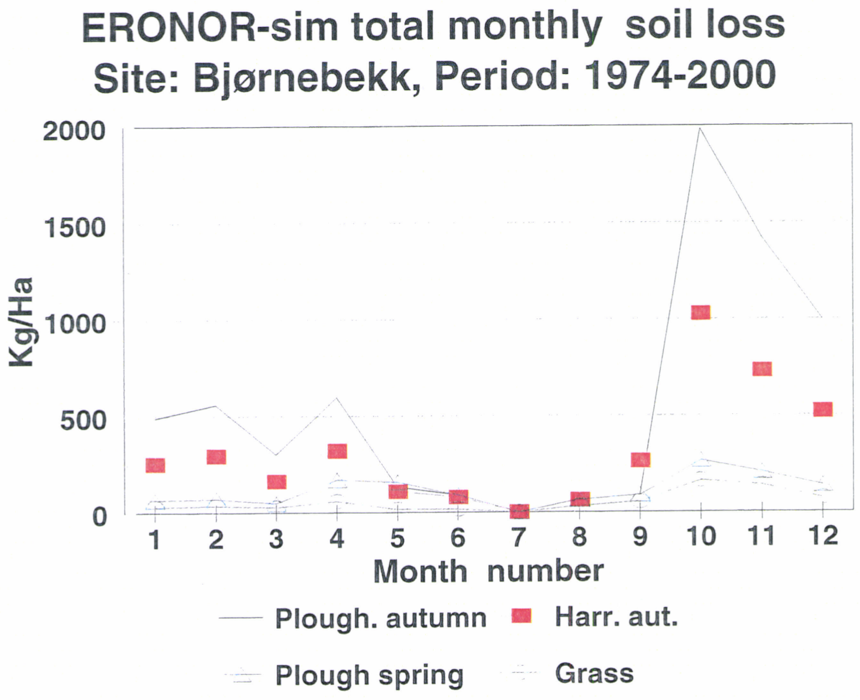

Figure 6.3.3. ERONOR-simulated monthly total soil loss for the Bjørnebekk site at Ås, 1974-2000 for four different treatments. Erodible soil, K_{NO}=1.055.

The simulated data for the Bjørnebekk site are also set up as monthly values in figure 6.3.3. The effects of ploughing and harrowing in autumn are clearly seen. On this little permeable and erodible soil, losses in late autumn are very important. Years like 1987 and 2000 naturally count heavily in this context.

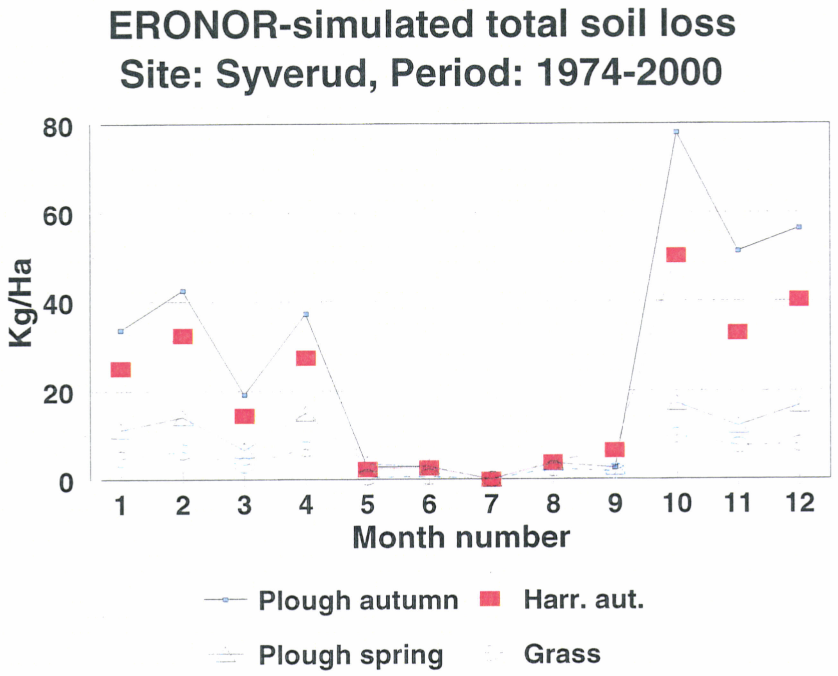

Figure 6.3.4. ERONOR-simulated monthly total soil loss for the site Syverud at Ås. The soil is relatively permeable and little erodible with a K_{NO}-value of 0.084.

On permeable soils with low erodibility the total soil losses will be greatly reduced and the losses in autumn will be less important while losses during periods with frozen soil will be more more important. This is seen comparing figure 6.3.4 with a little erodible soil with figure 6.3.3.

6.4. Effects of climatic change.

One advantage of models is that different climatic scenario may be simulated. From GCM-models run by the REGCLIM-group (28) in Oslo, we have got two simulated climates for an area in South-Eastern Norway. One scenarium is supposed to represent the time 1980-99 (present climate), while the other represent the period 2030-2050 (future climate). In figure 6.4.1 mean monthly values of simulated soil loss are presented based on simulated climate and real weather data from Oslo-Blindern 1980-1999. The cultivating system is fallow, which best shows the erosion risk. The soil type is Bjørnebekk (an erodible soil).

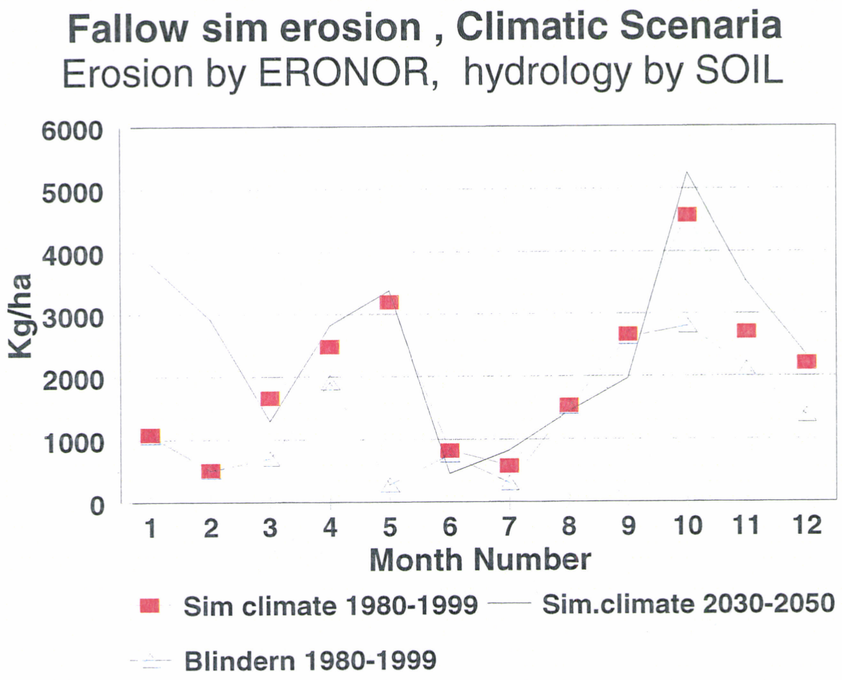

Figure 6.4.1. ERONOR-simulated total soil losses by fallow for 2 simulated climatic scenaria and observed climate at Oslo-Blindern. Hydrology is in this case simulated by the SOIL model. The soil is from Bjørnebekk, an erodible soil (K_{NO}=1.055).

Only the two simulated climates may in fact be compared, since they both are rather different from existing climate at Oslo-Blindern. The future simulated climate differ from present simulated climate with respect to temperature and precipitation during autumn/winter, both increasing in future. This increases the probability of surface runoff and erosion in autumn, and also in winter when a large part of the snowfall will be replaced by rainfall but often on frozen soil. Both these effects have been measured. Examples: The very wet autumn the year 2000 soil losses were high, the same was the case during the mild and rainy winter 1990 (see figure 6.3.2. Figure 6.4.1 demonstrate that the erosion model has been fully able to simulate these increases in soil erosion risk, supposing the described climatic change is correct.
Some of these effects will also be present, but may be to a lesser degree, on less erodible soil types than the Bjørnebekk soil.

7. Example of use of USLENO.

USLENO is supposed to be a useful tool for planning cultivating systems when erosion risk is considered. From soil type data it is possible to calculate the erodibility (K_{NO}) and slope steepness (S_{NO}) factors, and on an actual field it is also possible to set the slope length and calculate the slope length factor (L_{NO}).
As outlined earlier it is possible to calibrate USLENO by running ERONOR for the standard condition which is chosen to be: K_{NO}, S_{NO} and L_{NO} are all set equal to 1 and the model is run for the fallow system with the actual climate for the region. The hydrology factor for the region (R_{NO}) is then defined. Different climatic regions will have different hydrology factors. ERONOR is also used to calculate erosion risk for different cultivating systems and those numbers are than devided by the value for the standard system. Those relative numbers will

be the cropping factors (C_{NO}) to be used in USLENO. The factors R_{NO} and C_{NO} will be different for surface and drain water, but can be found in the same run of ERONOR. Once the regional factors of R and C have been found, erosion can be calculated on most sites within the region with USLENO.

Table 7.1. Hydrology factor (R_{NO}) found by ERONOR, erodibility (K_{NO}) and slope in the 4 regions used in the MILDRI research program.

Region	Climatic factor Kg/Ha/Year	K_{NO}, Mean, (min-max)	Slope (%), Mean, (min-max)
Follo	7960	0.36 (0.12-0.7)	9.7 (2-27)
Hedmark	2066	0.19 (0.06-0.3)	8.8 (2-27)
Trøndelag	6145	0.28 (0.06-0.7)	9.3 (2-27)
Jæren	15130	0.07 (0.006-0.24)	5.3 (2-27)

Table 7.1 shows that Jæren in South-western part of Norway has the highest climatic erosion risk, Follo in South-eastern Norway comes second, then Trøndelag (Mid-Norway) and last Hedmark with the most continental climate of the four regions. However, even if climate at Jæren is erosive, the erodibility of the soils is very low in this region, slopes are flatter and growing of grass is common on a great part of the area. Grassland has a low cropping factor as seen in table 7.2. Thus the real soil erosion in the Jæren area is low.

In figure 7.1 soil erosion has been calculated by USLENO for 3 different soil erodibility and 11 different cultivation systems. Soil losses both on surface and through drainage pipes are included. In addition a line showing a soil loss of 1000 Kg/Ha/Year is drawn. Losses exceeding this value may be reconed not to be sustainable. The figure shows that on the very erodible soil, soil losses will exceed the limit for all systems, while on the less erodible

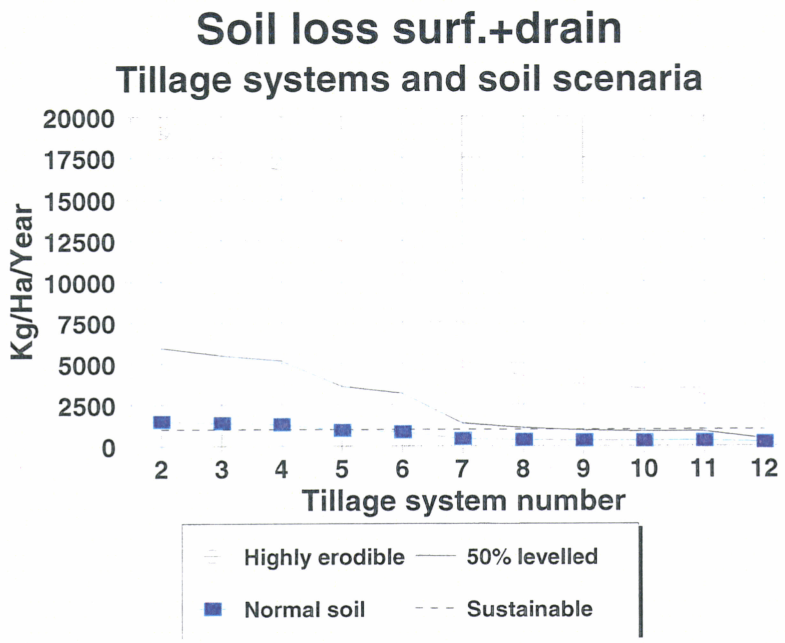

Figure 7.1. Soil losses for the Follo region calculated by USLENO for a very erodible soil (K_{NO}=1.178), a less erodible soil (K_{NO} =.547) and a "normal" soil (K_{NO} =.197) for different tillage systems. L_{NO}*S_{NO} factor is 2.867. Systems described in table 7.2.

Table 7.2. Description of systems used in figures 7.1 and 7.2 with C-factors for surface runoff evaluated for the Follo region by ERONOR. The C-values are relative to fallow as defined in ERONOR. [1]

System number	$C_{NO,SU}$	System description
2	.543	Spring grain, ploughed in autumn harrowed spring
3	.505	Winter wheat, ploughed and harrowed in autumn.
4	.466	Spring grain, harrowed twice in autumn, harrowed spring
5	.314	Winter wheat, harrowed twice autumn
6	.271	Spring grain, harrowed once autumn, harrowed spring
7	.104	Winter wheat, direct drilled
8	.0774	Spring grain, plouged and harrowed spring
9	.0653	Spring grain, harrowed twice spring
10	.0593	Spring grain, direct drilled spring
11	.0591	Spring grain, with catch crop, plouged and harrowed spring
12	.0252	Permanent grassland

systems better than number 7 will do the job, and on the least erodible soil most systems would be acceptable.

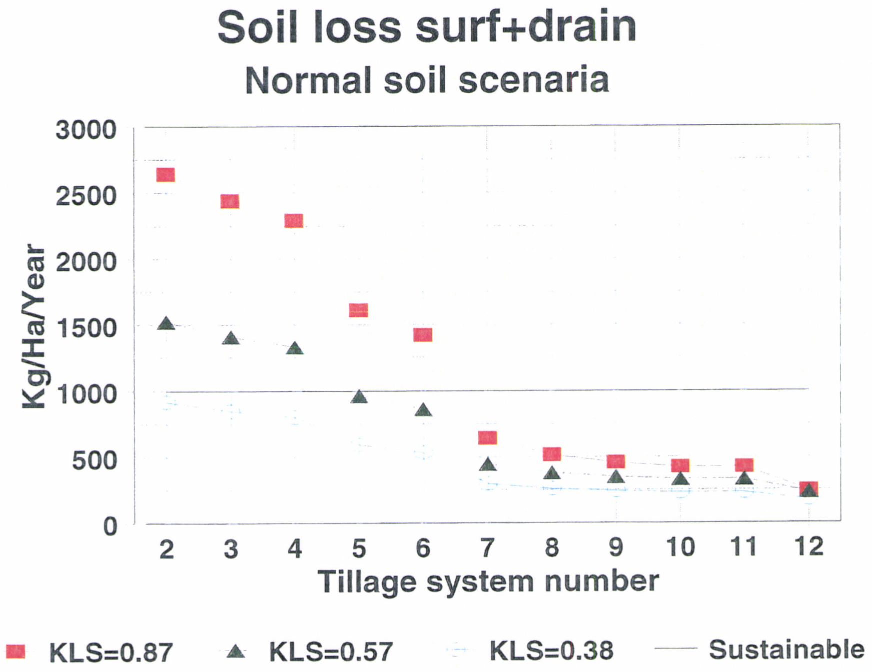

Figure 7.2. Soil losses calculated by USLENO for different combinations of $K_{NO}*S_{NO}*L_{NO}$ within a very "normal" range. Values can be far outside the ones used here. Systems explanation in table 7.2.

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[1] It must be noted that both the C-values in table 7.2 and the R-values in table 7.1. may be changed if changes are made in ERONOR or in the climatic data.

Figure 7.2 shows the situation in more "normal" situations. The farmer with the most erodible soil will have to use system 7 or better, the farmer with the medium erodible soil can use system 5 or better, while the farmer with the least erodible soil can chose any system.

The USLENO has been elaborated furher to calculate losses of total P, particulate N and allow calculation of erosion due to concentrated flow after a rough classification of the risk of this type of erosion.

8. Discussion.

There are several improvements to be made, but those will take a lot of work and make the model more complicated and more timeconsuming to run.
With a time resolution of precipitation of one day it is of course not possible to simulate the effect of intense rainshowers on erosion. But typical Hortonian surface runoff events are however not common in Norway, still a higher resolution would be better, because rain intensitiy and surface runoff intensities also vary within episodes with saturated surface runoff.
Snowcover, snowmelt, frost depth, permeability and erodibility of frozen soil are of great importance for soil erosion. The combined effect of runoff and rainfall on erosion on thawing soils have been rather roughly simulated. Correct timing of snowmelt is important for simulating this combined effect. The SOIL model has been difficult to parameterize correctly, and there are assumptions in this model as to for example surface temperatures that are not always valid. Use of air temperature to assess whether it is snowing or raining is not always correct. The erodibility of frozen but thawing soil is not well known, neither how fast the erodibility changes on thawing soil often combined with supersaturation, nor how erodibility is affected by subsequent drainage of this water and regneration of the soils fermness.
During winter, melted water may not run off before it freezes, and then an icecover is formed which protects the soil from erosion until the ice melts. This is very difficult to simulate, but will undoubtedly have an effect from time to time. Likewise will supercooled rain freeze on the ground and not flow or erode.
The effect of plant and residue cover on soil erosion is not always so straightforward and sometimes seems to be lower than expected. The effect of weeds and germination of spilt grain should be taken into account, but knowledge of this growth and its importance for soil erosion will then be necessary.
Local climate may vary, and slope and direction of slope affects solar radiation especially during late autumn winter and spring. Wind affects snowcover. Snowmelt when snowcover is rather thin is affected by the surface below the snow, dark soil absorbes more radiation then a strawcovered soil. Straw cover may also affect evapotranspiration. None of these effects have been taken into account.
The consolidation effect on soil is no doubt important, and this effect may be needed to strengthen and improve. There is no doubt an effect of tillage on soil structure, permeability and erodibility which differs with the conditions when tillage was done. So far I have not seen this effect being modelled, but it should. The general variation in soil permeability and erodibility during the year as an effect of wetting and drying and other processes is also not very well known, and how to be modelled.
In spite of these and many unmentioned problems it is amazing that the model has worked reasonably well. It means that the empirical relations has been able to cover the most important effects on soil erosion although not a single process has been described.

However, all the differences between simulated and observed erosion point out that these empirical relations are not always valid and need to be refined or replaced by processes.

However, the process based model WEPP which a lot of experts have worked out, did not work by far as good as ERONOR under Norwegian conditions. This means that the process based approach is a very difficult one, and does not necessarily lead to better soil loss simulations than an empirical approach.

9. Acknowledgements.

Lars Egil Haugen, Department of Soil and Water Sciences, Agricultural University of Norway, has made a great effort in calibrating and running the SOIL model to provide necessary input data to ERONOR.
Heidi A. Grønsten, Department of soil and water sciences, tested the WEPP erosion model.
Trond Børresen and John Karlstad, Department of soil and water sciences made physical analyses of soils from runoff experiments.
Department of soil and water sciences, Agricultural University of Norway, has provided some technical assistanse in running runoff experiments and lab. facilities and other infrastructure.
Meteorologisk Institutt, Blindern, Oslo has provided most of the necessary climatic data free of charge.
Department of agricultural engineering, Agricultural university of Norway, has provided climatic data for Ås, (Follo), free of charge.
NIJOS, (Norwegian institute of land inventory), Ås, Norway, has provided the necessary soil data used in the MILDRI soil data base also used in ERONOR.

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11. Appendix. Options in ERONOR and USLENO, programming language.

Both ERONOR and USLENO are at the moment written in SAS (Statistical Analysis System) ver. 6.12. The models thus can easily be changed.

A number of options are available when running the models.

*In both models it can be chosen to use soil data from the data base or input own soil data.

*Hydrologically any of the regional files that so far have been produced may be used, and it may be chosen to use data from SOIL only or to also use data from AVRJUST and to simulate surface and drain runoff within ERONOR.
*The amount of surface runoff simulated inside ERONOR can be regulated by changing the parameters regulating INF by saturated soil in spring and autumn and the amplitude of the upper half sine curve during the nonfrozen period.

*Considering snow, it can be chosen to use snowstorage simulated by either SOIL or AVRJUST or use observed snowdepth. Furthermore two options for SNOWFAK are available, and it can also be chosen to use simulated or observed snow for the actual day or the day before.

*It can be chosen to use different erodibilities for surface and drain water in both ERONOR and USLENO.

*In calculating K_{NO} it can be chosen to include material greater than 2 mm or not. ERONOR and USLENO are now run with this coarse material included.

*The time since drainage can be set both in ERONOR and USLENO.

*Considering harrowing in autumn, the residue cover after one harrowing may be set, and it may be chosen to harrow 1 or 2 times.

*It can be chosen to use standard tillage dates for the regions or read in special dates for actual crop rotations.

*The date of tillage operations in autumn may be moved a chosen number of days back or forth from the standard date.

*ERONOR can also be set in the mode of calibrating USLENO (standard conditions) or not.

*In USLENO there has been included the option to chose between three levels of erosion due to concentrated flow. Furthermore the slope steepness and slope length of the concentrated flow path may be set in addition to the slope steepness and slope length of the area.

*USLENO now automatically calculates 34 different cultivating systems or effects.

*In the AVRJUST routine there also are possibilities to chose the size of different storages, to change parameter affecting snowmelt, evapotranspiration and the the relative amount of remaining water in drainable pores that is allowed to run off.