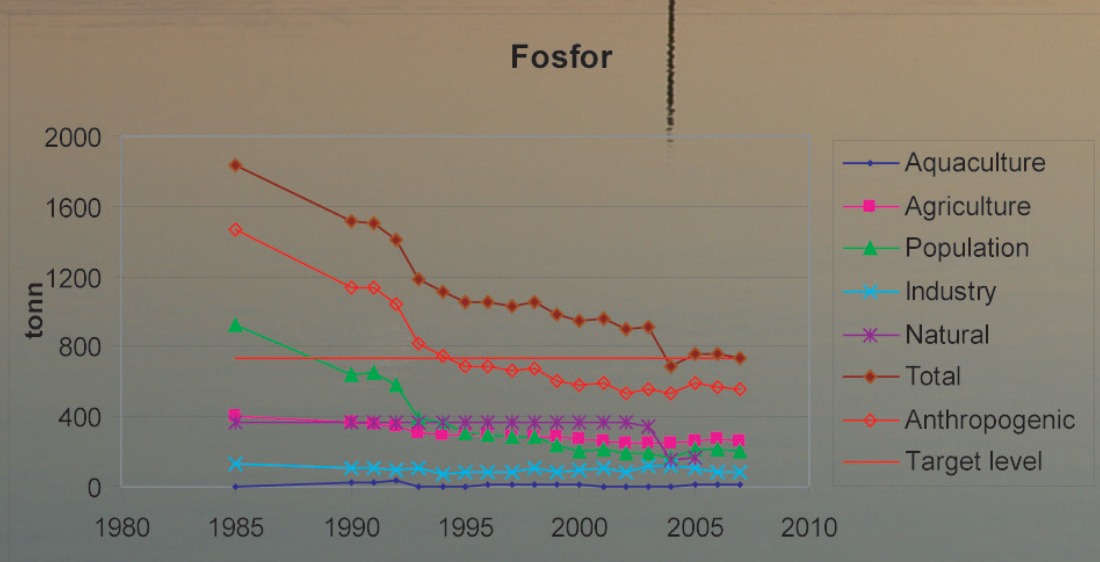


# Teofil

## Model for calculation of source dependent loads in river basins



Norwegian Institute for Water Research  
– an institute in the Environmental Research Alliance of Norway

# REPORT

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Title Teotil Model for calculation of source dependent loads in river basins	Serial No. 5914 - 2010	Date 12. January 2010
	Report No. Sub-No. 27145	Pages Price 58
Author(s) Torulv Tjomsland, John Rune Selvik og Roar Brænden	Topic group Water Resource Management	Distribution Free
	Geographical area	Printed NIVA


Client(s) Research Council of Norway	Client ref.
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<p>Abstract</p> <p>The Teotil software is a model maker tool specialized for calculations of loads in sub-catchments with known interior drainage. The model consists of a package of pre-defined functions that the user may apply to make his own model for transport of a selected constituent in a specified drainage basin or basins. The first part of the report contents tips for a setup of the model and information about its possibilities. The second part is a manual in Teotil programming.</p>
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<p>4 keywords, Norwegian</p> <ol style="list-style-type: none"> <li>1. Teotil</li> <li>2. Forurensningsregnskap</li> <li>3. Nedbørfelt</li> <li>4. Veiledning</li> </ol>	<p>4 keywords, English</p> <ol style="list-style-type: none"> <li>1. Teotil</li> <li>2. Pollution budget</li> <li>3. Drainage basin</li> <li>4. Manual</li> </ol>
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# **Teotil**

Model for calculation of source dependent loads  
in river basins

Oslo, 12 January 2010

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John Rune Selvik

## **Preface**

The project is supported by the Research Council of Norway.

The Teotil model has been used for calculating transport of nutrients in Norway for many years. With the newest version of the model, persons without any knowledge of basic computer programming language can make their own transport models for river basins.

The planning of the model and strategy for the enhancements has mainly been done by John Rune Selvik and Torulv Tjomsland. Torulv Tjomsland has done the programming in Visual Basic.

Roar Brænden has evaluated methods by use of GIS that make the model applicable to the national system of small river reaches named Elvis.

Oslo, 12. January 2010

*Torulv Tjomsland*

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## Summary

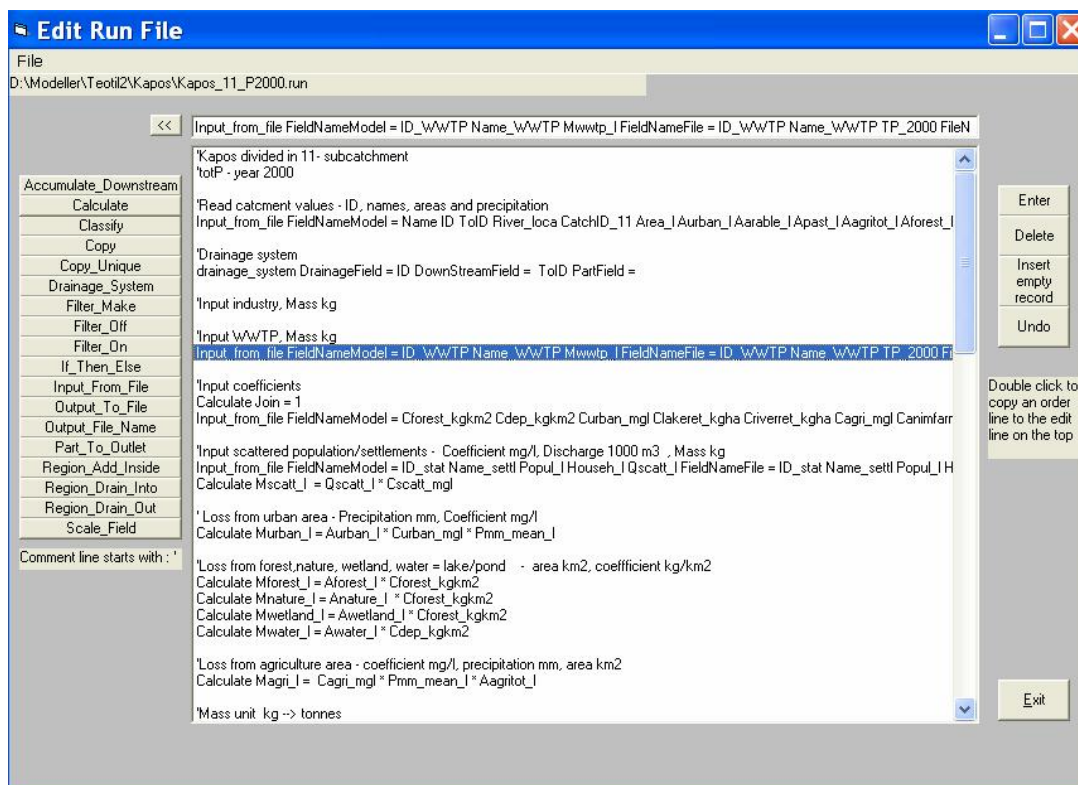
Teotil is a model maker tool specialized for calculation of pollution loads in sub-catchments with known interior drainage. The model consists of a package of pre-defined functions that the user may apply to construct his own model for transport of a selected constituent in one or several drainage basins, **Figure 1**.

The model utilises statistical data (usually annual data) on discharges from point sources (waste water treatment plants and industries), type specific land (forest, mountain, lake, agriculture and populated) combined with area run-off coefficients (export coefficients) and the actual water flow. Transport processes have to be calculated in a simple way. Most often we just handle the retention in lakes.

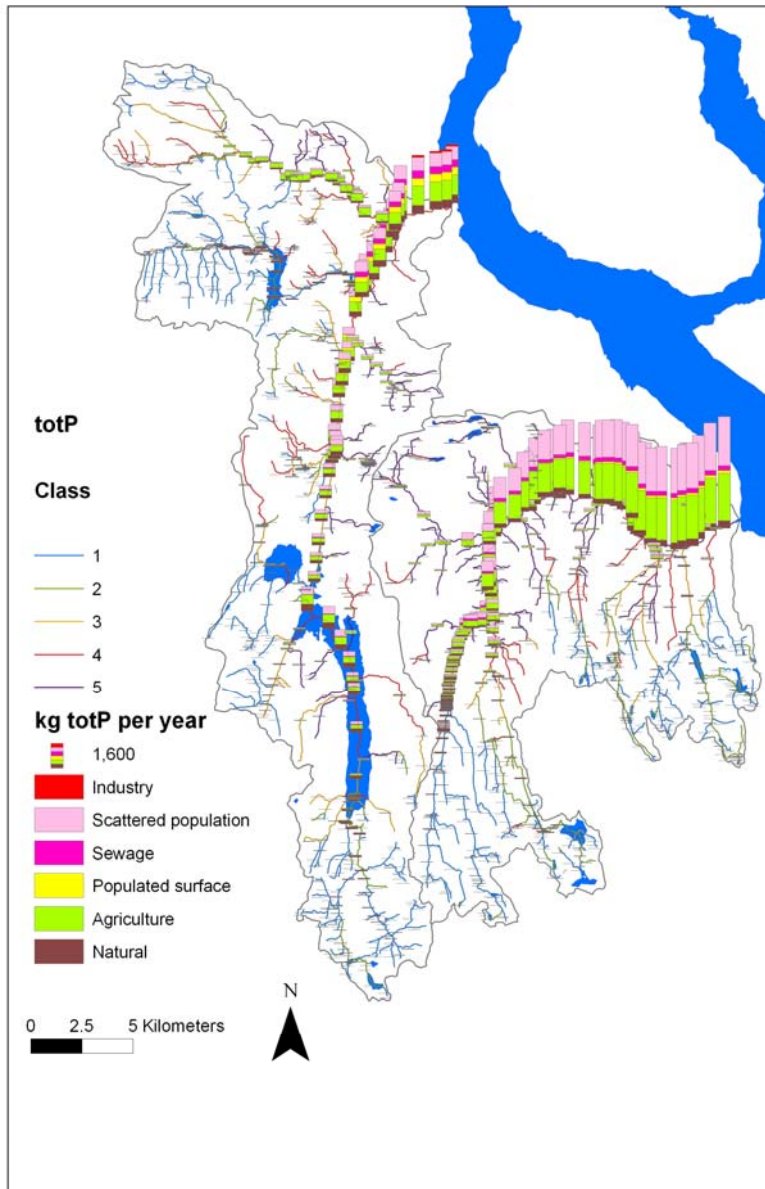
The results may be useful to make a brief surveillance of the pollution situation in a catchment. Results, as shown in the map in **Figure 2**, tells us where we can expect problems in the catchment and which type of sources that have influence. Such information may help stakeholders to identify pollution reducing efforts.

The model is written in Visual Basic.

The purpose of this report is to inform you about the possibilities of using the Teotil model and to enable you to set up a project yourself. The first part of the report include tips for a setup of the model and information about its possibilities. The second part is a manual in Teotil programming.



**Figure 1.** A Teotil programme may be written using pre-programmed functions



**Figure 2.** The map shows source specified loads and water quality classification. The results may help stakeholders to localize problems and prioritize pollution reducing measures

## Sammendrag

Teotil er et ”modell-lager” verktøy som er spesiallaget for å beregne tilførsler fra punktkilder og ulike arealtyper for nedbørfelt med kjent innbyrdes drenering. Brukeren kan uten programmeringserfaring lage en modell ved å velge pre-programmerte beregningsrutiner ved valg i menyer og klikk på komandoknapper med mer.

Hensikten med rapporten er å informere om modellens muligheter og å gjøre brukeren i stand til selv å bruke modellen. Den første delen av rapporten gir eksempler på bruk av modellen. Den andre delen av rapporten er en manual for programmering i Teotil programmering



# 1. Introduction

The Teotil model software appears as a “model maker tool” designed for calculations of yearly nutrient loads in sub-catchments with known interior drainage. The model consists of a package of pre-defined functions that the user may apply to construct his own model for transport of a selected constituent (usually nutrients) in a specified river basin without specific programming skills. The total loads of nutrients are based on national statistical information on population, effluent treatment, industrial and agricultural point sources given as annual figures. It also estimates losses from agricultural fields and natural runoff from forest and mountain areas based on an export coefficient approach. Retention (self-purification) in the water bodies may be taken into account for each sub-catchment.

The purpose of this report is to describe the available user options for the Teotil model and to make the reader able to set up a modelling project. The first part of the report includes advice for a setup of the model and information related to the various options. The second part is a manual in Teotil programming.

The Teotil model was developed in 1991-1992 with the aim of estimating progress towards the target of reducing anthropogenic nutrient discharges and losses entering marine waters with 50% compared to the 1985-situation. The model has since then been used as the national tool to follow the changes in nutrient discharges and losses from sources throughout the whole country and overviews of nutrient discharges and losses has been made available on an annual basis through the National Programme for Pollution Monitoring (Statlig program for forurensningsovervåkning). It has served as the basis for reporting progress on the international obligations related to OSPAR and the North Sea Conferences. The model has over the years been successfully used in a number of pollution load studies both nationally and internationally, inter alia

- National Pollution Monitoring – combination with river monitoring in order to estimate total input to coastal areas for specific years (Skarbøvik et.al 2007)
- Pollution load estimation of Norwegian sub-basins as basis for action plans, in recent years also related to the Water Framework Directive (Selvik et.al 2007)
- Nutrient Input to selected coastal area (e.g. for use in OSPAR classification of coastal waters or modelling of marine eutrophication) (Molvær et.al 2007)
- Comparative modelling exercise in Hungary (Kapos catchment) (Lázár et.al 2005, Bakken et.al 2006)
- Pollution load compilation of the Drim-Drini riverbasin in Albania and FYR Macedonia.

In 2001 the software was rewritten in Visual Basic to encompass larger flexibility with regard to the number of sources, geographical resolution and result reporting. The users could now select predefined functions to design their own models and the Teotil model now appeared as a model maker tool specialized for calculations of loads in sub-catchments with known interior drainage. In this context, the annual load compilation for Norwegian coastal areas should be considered as a ‘user defined model’ within the TEOTIL concept.

The input data requirements can normally be obtained from national registers on pollution sources and hydrology. The process of setting up the model is not labour intensive and the user may soon produce a first screening of the source apportionment of the selected river basin.

The model approach is useful to

- make a brief surveillance of the pollution situation in the catchment
- Indicate where we can expect problems in the catchment and
- establish source apportionment of the various sources that have influence throughout the catchment.

Such information may assist environmental authorities to plan pollution mitigation measures.

## **2. The set up of a project on nutrient loading in Norwegian catchments – Data preparation**

The basins of interest have to be divided in sub-catchments with known interior drainage pattern. Inputs to the model are loads from point sources and losses from various types of landuse/landcover. All the inputs have to be connected to a specified sub-catchment. One feature is to transport the load downstream. Simple processes like retention in lakes may be applied. The results may be presented for a selected group of sub-catchments.

### **2.1 GIS**

The model is strongly coupled to GIS. GIS is an effective tool to set up of a Teotil project. The drainage system may be localized by use of GIS, suitable reaches selected and the drainage basin to each of these reaches found. Further on point sources with known coordinates may be linked to the correct sub-catchment, and areas of the various type of land cover may be found.

GIS is a tool to produce instructive maps that make it easy for the user and stakeholders to evaluate the results that is produced in tables by the model.

We have used ESRI Arcmap as the geographical information system tool. Parts of the model are prepared with Arcview in mind; however this is not a must. The model may be used as a “stand alone model” without GIS or link to GIS.

### **2.2 Drainage and sub catchment**

The region of interest has to be divided in sub-catchments with known interior drainage. Often this network of subcatchments exists fully prepared on shape-files or geodatabase for use in GIS. If this is not available, we have to divide the catchment into subcatchments. We shall give some examples of existing sub-catchment division in Norway and methods of how to create subdivisions.

Norway is divided into a system of sub-catchments. There are 315 main catchments that flow directly to sea or other countries. These main catchments are sub-divided in aprox. 1100 sub-catchments called “Statistical areas” or 20 000 sub-catchments named “Regine units”.

An even further division of subcatchments is possible based on the small river segments “Elvis segments”. There are 1.5 million defined river reaches called “Elvis segments”. The small catchments draining to each segment is not defined and must be created and the internal drainage network defined before use in Teotil.

Without any predefined river segments and sub-catchments we have to start from scratch. GIS is an effective tool of doing this. One possibility is to digitalize the sub-catchment borders directly on the map and enter the drainage directions, but more elegant is of course to use the hydrological routines in ArcGis to establish subcatchments and drainage pattern from a digital terrain model (DTM). This method was used to prepare the Elvis reaches for Teotil modeling. The river system divided in Elvis reaches already existed as shape files, but the catchment of each river reach was found by use script programming in Arcmap from shape file of the river reaches and a 25x25 m DTM.

## 2.3 Sources

Sources for the nutrient loading are described as point or diffuse sources. In the model the point sources have to be located to the correct sub-catchment. When the point sources coordinates are known the surrounding sub-catchment is found by GIS. The diffuse sources usually consist of losses from land areas of various kinds. The area of each of the landcover/landuse types has to be found for each of the sub-catchments. Again, the use of GIS is used for this preparation. For each type of area (forest, mountainous, agriculture etc.) we need methods to calculate the losses.

Below we will give examples of sources used to calculate the loads of phosphorus in Norway. The point sources are waste water treatment plant, industrial plants and aquaculture plants, **Figure 3** to **Figure 5**. The specified land cover types were forest, mountainous, lakes, agriculture land and urban areas, **Figure 7**. For each of these types of land a specific predefined loss coefficient were given. There is a national task to update the agriculture coefficients annually in Norway in order to reflect recent changes in agricultural practise. For losses from natural areas, the available observations of phosphorus concentrations in natural areas was used as a database for creating a map over yearly mean concentrations in the runoff from forest- and mountainous areas in Norway, **Figure 7**. Similar maps or regional information of the loss intensity were made for all kind of areas.

Map with the last 30-year normalized specific annual water flow ( $l/s/km^2$ ) is available from official sources. To find the water flow for a specific year, the 30-years values were scaled according to water flow from representative water flow stations. Then the loss of nutrients from each type of area inside a sub-catchment became the product of area, coefficient and water flow. Losses from other types of areas (agriculture land, lakes and urban areas) were found in similar ways.

For scattered population we received data representing municipality administrative regions. In the model we distributed these loads uniformly on the agriculture land inside the region, assuming that agricultural land is a reasonably representation of where scattered population are localized in Norway.

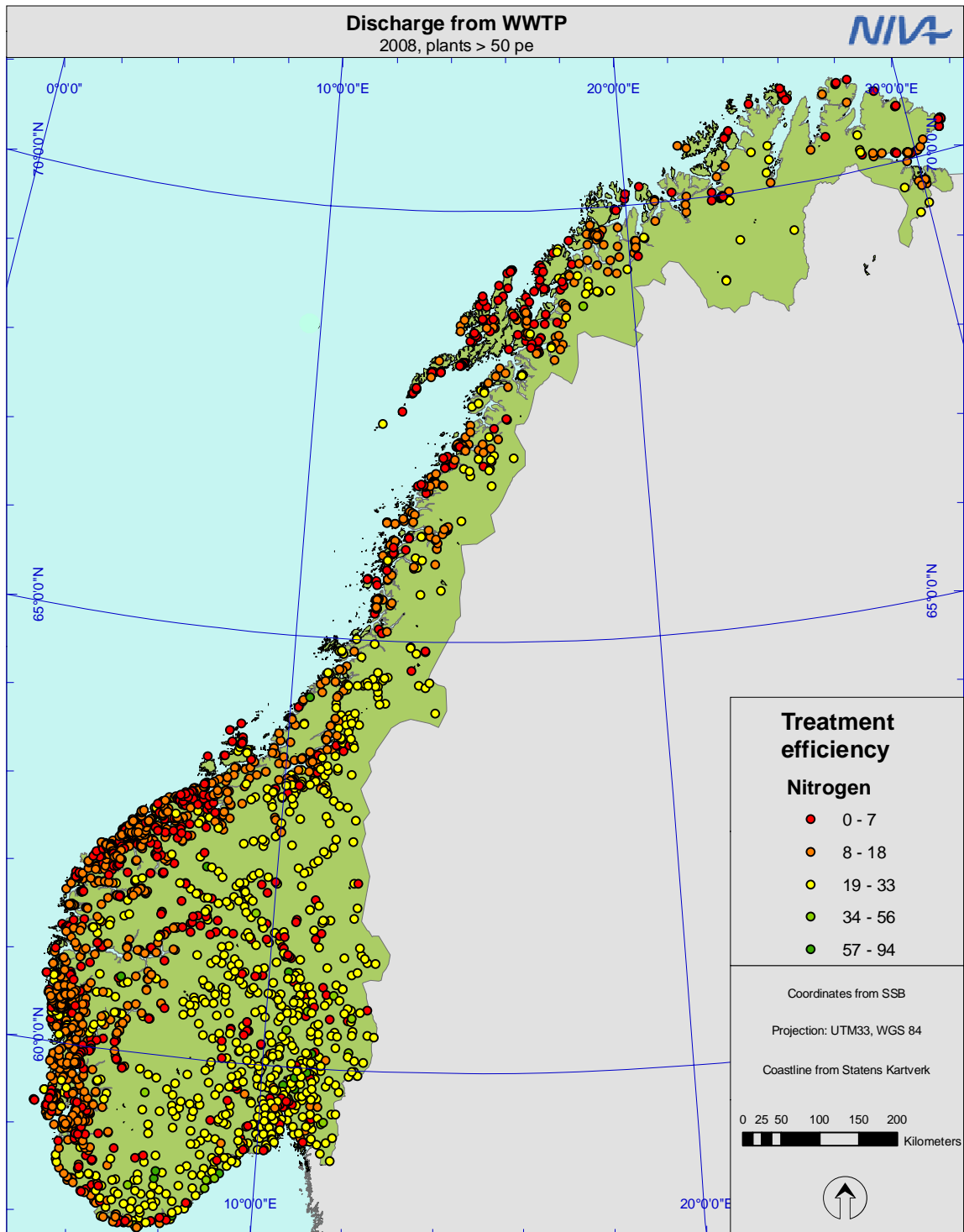


Figure 3. Waste water treatment plant



Figure 4. Industry plants

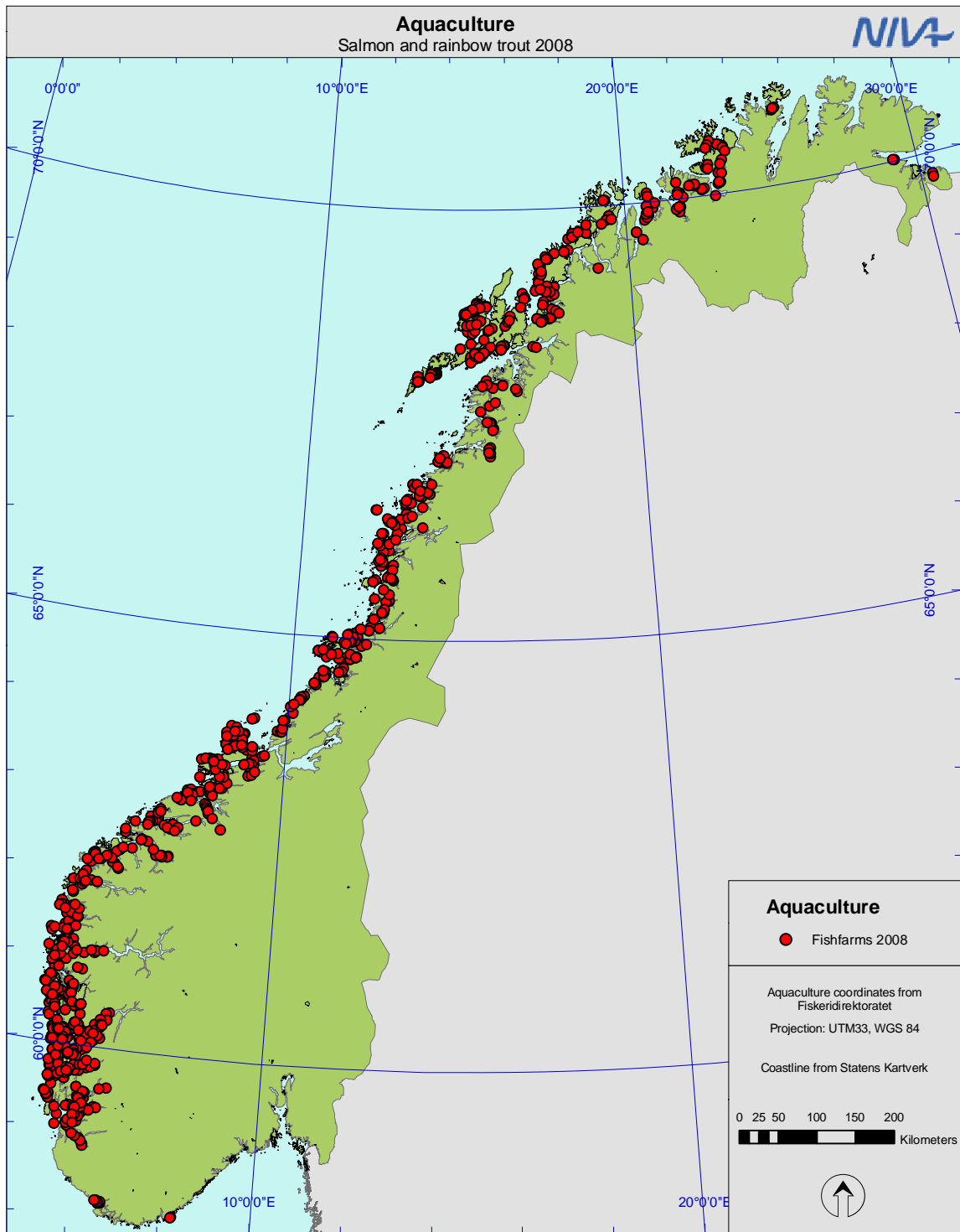
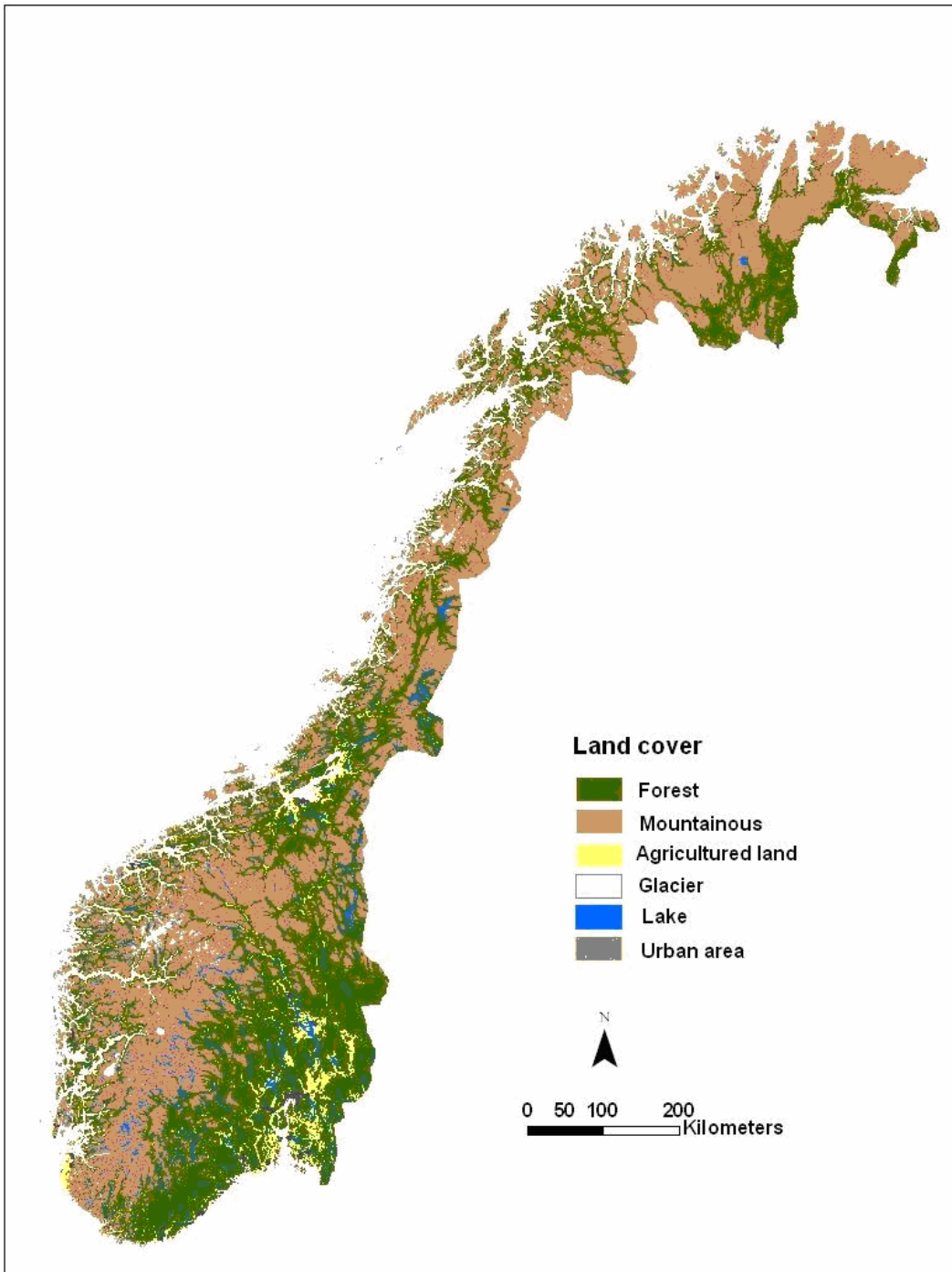
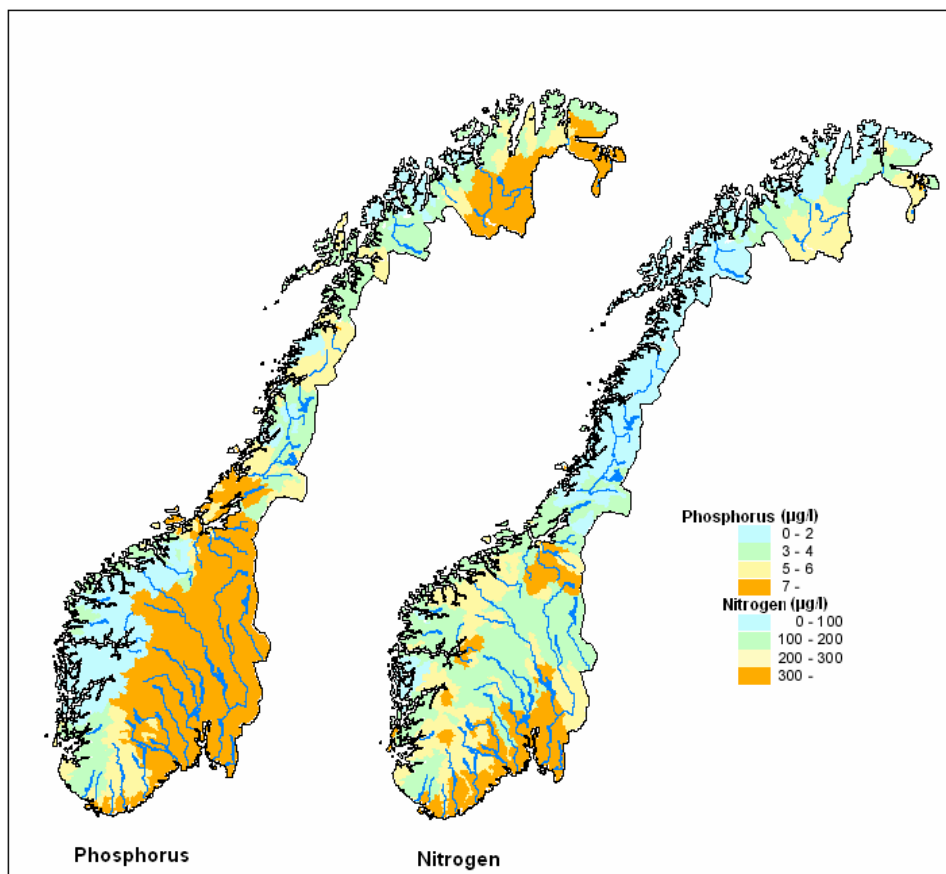


Figure 5. Aquaculture plants



**Figure 6.** Land cover





**Figure 7.** Coefficients of loss of nutrients from natural background in mountainous areas

## 2.4 Processes

The only process in our teutil-model is retention in lakes. The formula used was:

$$\text{Retention} = C1 / (1 + \sqrt{(Q_{\text{year}} / V_{\text{lake}})})$$

$Q_{\text{year}}$ : water flow per year, m<sup>3</sup>/year

$V_{\text{lake}}$ : Lake volume, m<sup>3</sup>

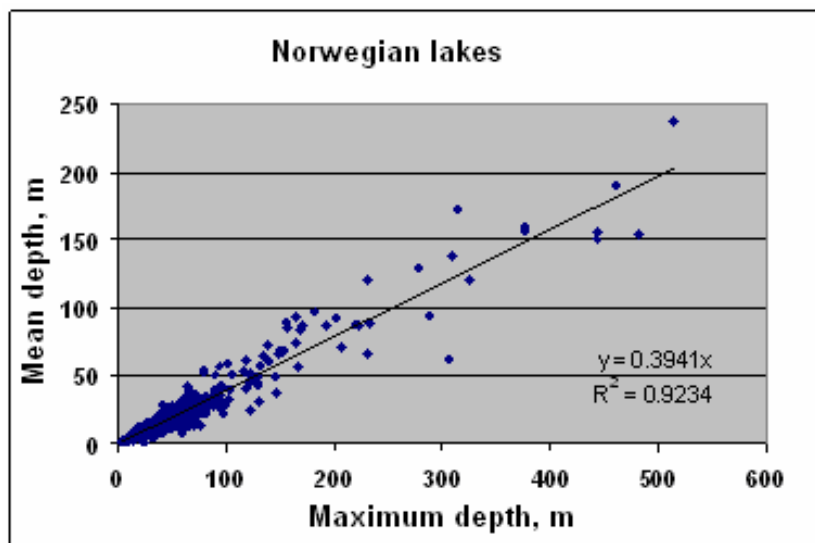
$C1$ : coefficient, 1.0 for total phosphorus, 0.2 for total nitrogen

We calculated annual retention for lakes with surface area over 0.025 km<sup>2</sup>, totally 51 000 lakes in Norway. The water flow through each lake was found by the model. For the greatest and most important lakes a bathymetric map existed. For the rest of the lakes the volumes were calculated as product of area and mean depth. The surface areas were found from digital maps. The problem was to find the depths of lakes where no bathymetric information was available. Data of both volumes, mean depth and maximum depth existed only for 450 lakes. The relation was significant ( $R^2=92\%$ ) with mean depth equal 40% of maximum depth, **Figure 9**. This relation was used for 750 lakes. There was no significant relation between the surface area of the lakes and mean depth ( $R^2 = 0.43$ ), **Figure 9**; however by lack of better information we used the formula:

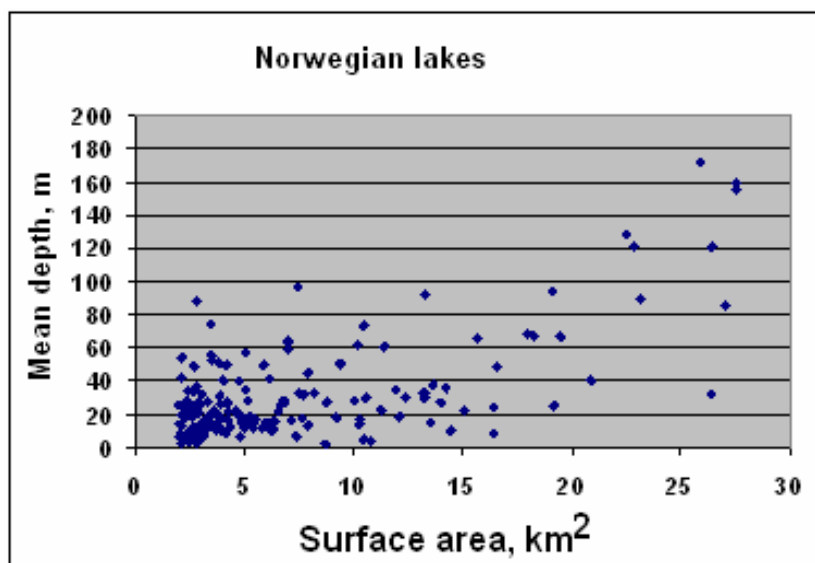
$$\text{Mean depth (m)} = 1,8 * \text{Surface area (km}^2\text{)} + 13 \text{ m}$$

Thereafter the retention in each of the sub-catchment (Regine) were calculated. If several lakes existed inside a sub-catchment, it was taken into consideration if the lakes were localized in chain along the main river, which received runoff from upstream sub-catchment, or not. The localization of the lakes along the main river, the Elvis (1.5 million in Norway) sub-catchments were used. This improved the precision in the retention calculations also for the courser Regine drainage system (20 000 in Norway).

The retention in lake is very important, especially for phosphorus. Due to sedimentation in lakes only half of the total phosphorus input to the water course in the eastern part of Norway reaches the sea.



**Figure 8.** The mean depths in the lakes were significant correlated to maximum depths



**Figure 9.** There were no significant relation between mean depths of the lakes and surface areas.

## 3. Results

Below follows some results from application of the Teotil model in Norwegian catchments. The model was set up for sub-catchment of various magnitudes. Norway was divided in 1100 catchment units (Statistical areas). This was sufficiently to calculate loads to coastal areas or at the outlet of the rivers. For more detailed calculations, where the water quality in all of the catchments were of interest, Norway was divided in 20 000 sub-catchments (Regime). For smaller area of interest we used the Elvis sub-catchments (1.5 million in Norway).

The Teotil model is created for calculating loads for a specified period, normally one year. However we have possibilities to prepare a rough estimate with monthly resolution of the results. The starting point would be the yearly load for each sub-catchment and divide this value in monthly parts. Discharges from waste water plants are expected to have a fairly constant flux which results in 1/12 of yearly loads per month. Monthly losses from natural areas (forest, mountainous etc.) may be proportional with the water flow. For aquaculture the source data resolution is monthly.

The results presented in this report mainly deal with total phosphorus. However the model may handle any constituent as long as we have knowledge about sources and transport processes.

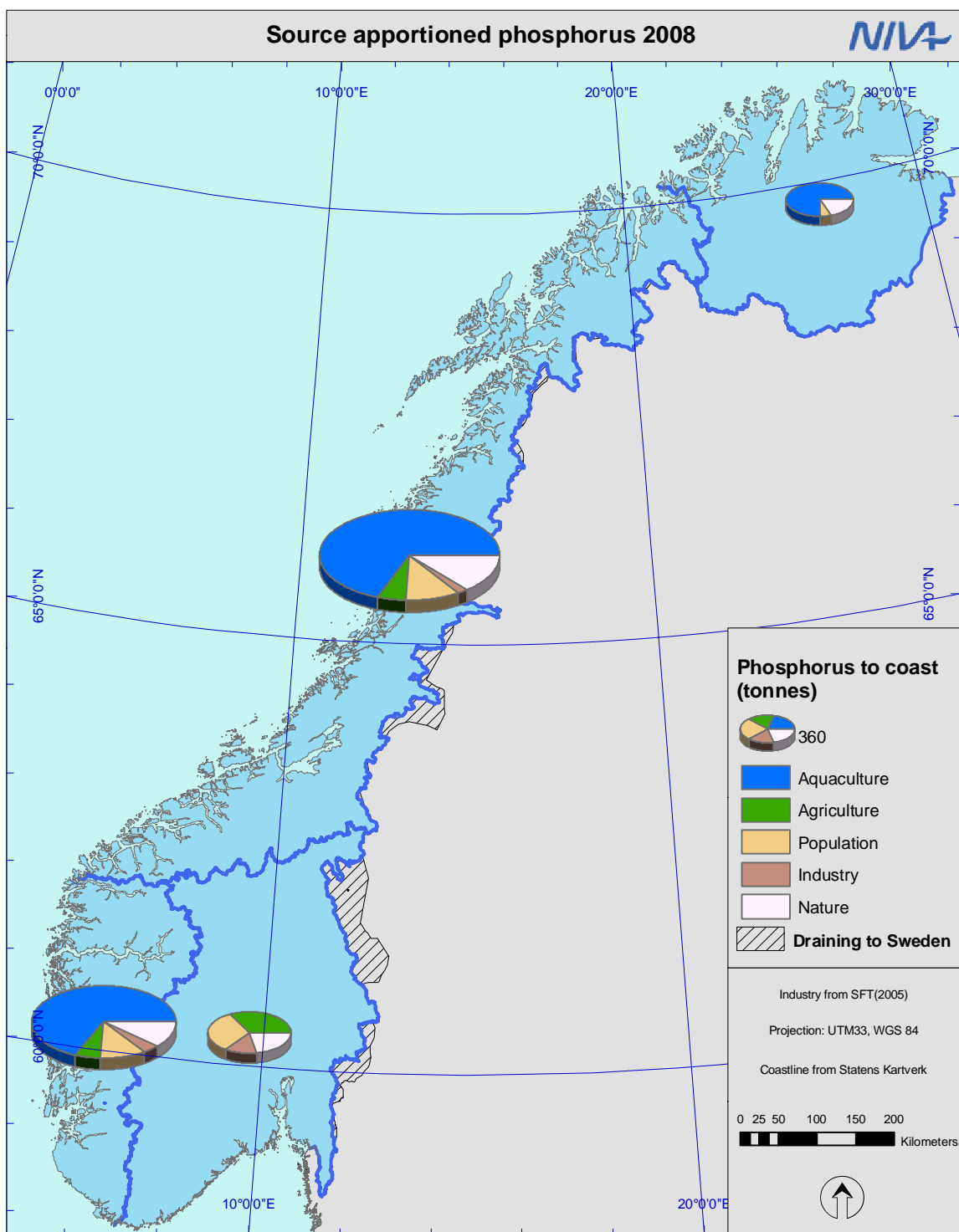
In Norway we have a national programme for production of yearly values for loads of nutrients and metals from land to sea (OSPAR-RID). In the largest rivers these loads were based on water quality and water flow observations. For the rest of the area we calculate the loads with the Teotil model.

In this chapter we will give some examples of various results by use of the Teotil model. A more detailed presentation included test of the results against observations may be studied in Lazar et.al. 2005 and Bakken et.al. 2006. The model used in climate scenarios may be studied in Wright et.al. 2008.

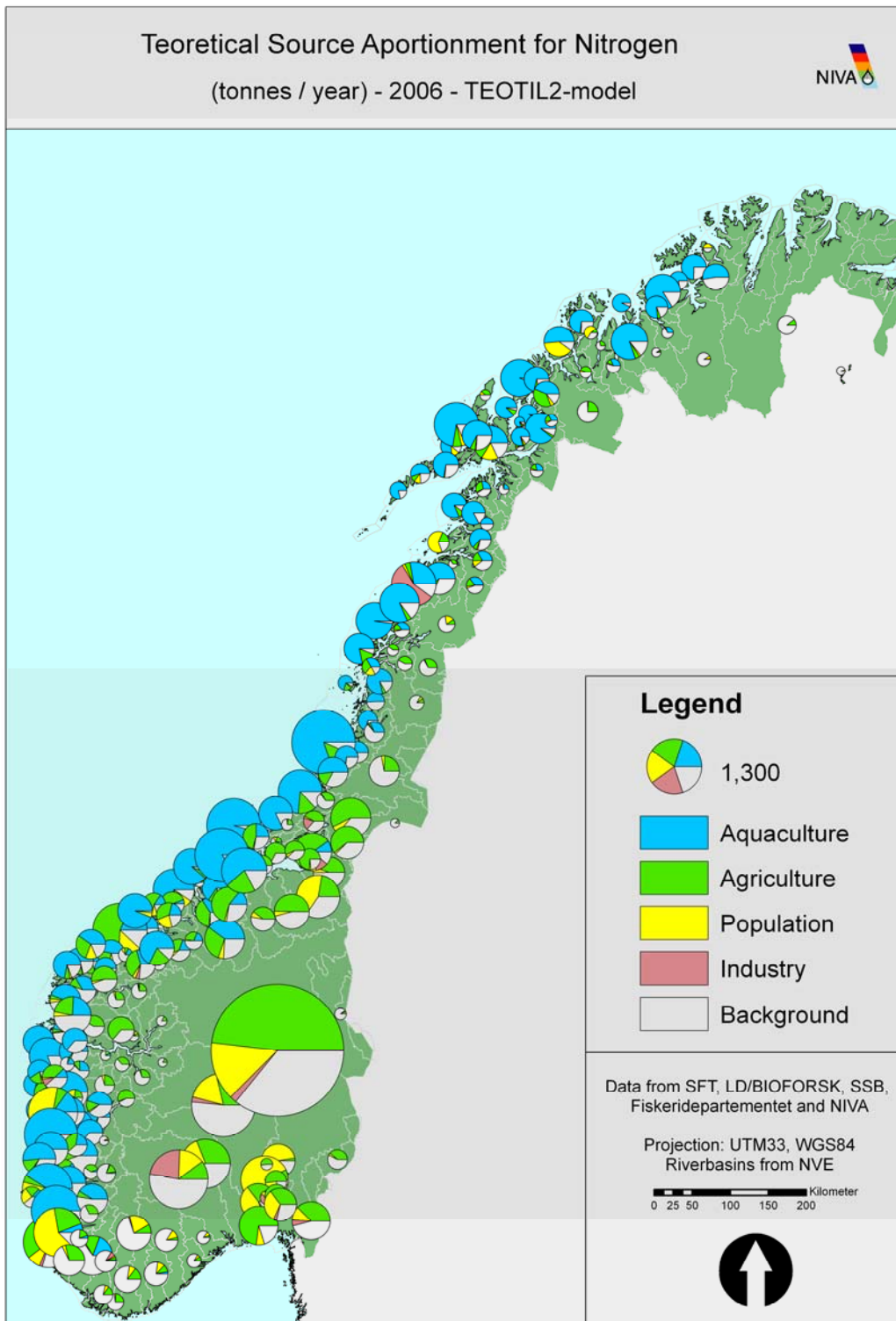
### 3.1 Aggregation for large areas

Based on a model using statistical areas or regime-areas as the smallest response units, data can be aggregated to reflect larger areas like river basins, river basin districts (according to the WFD regulations), transport to the sea for defined coastal region etc.

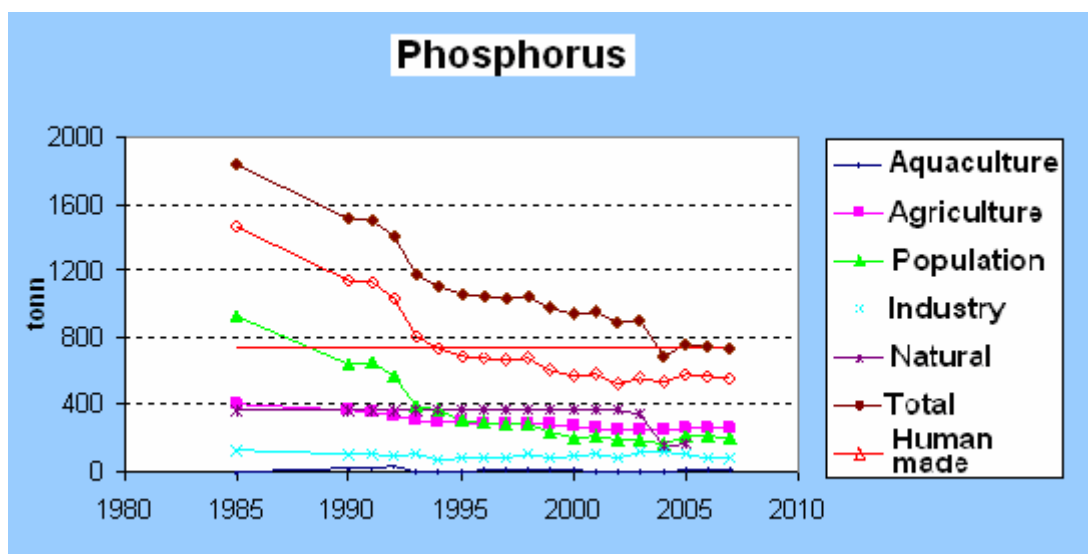
The loads from land to the coast for river basin districts or single river basins are shown on **Figure 10 - Figure 12**. The model was used to calculate the total loads as well as the contribution from each type of sources. Model calculations for many years were used to visualize the trend for each source.



**Figure 10.** Total phosphorus. Source specified loads for river basin districts in Norway.



**Figure 11.** Total phosphorus. Source specified loads for the 315 main catchments in Norway.



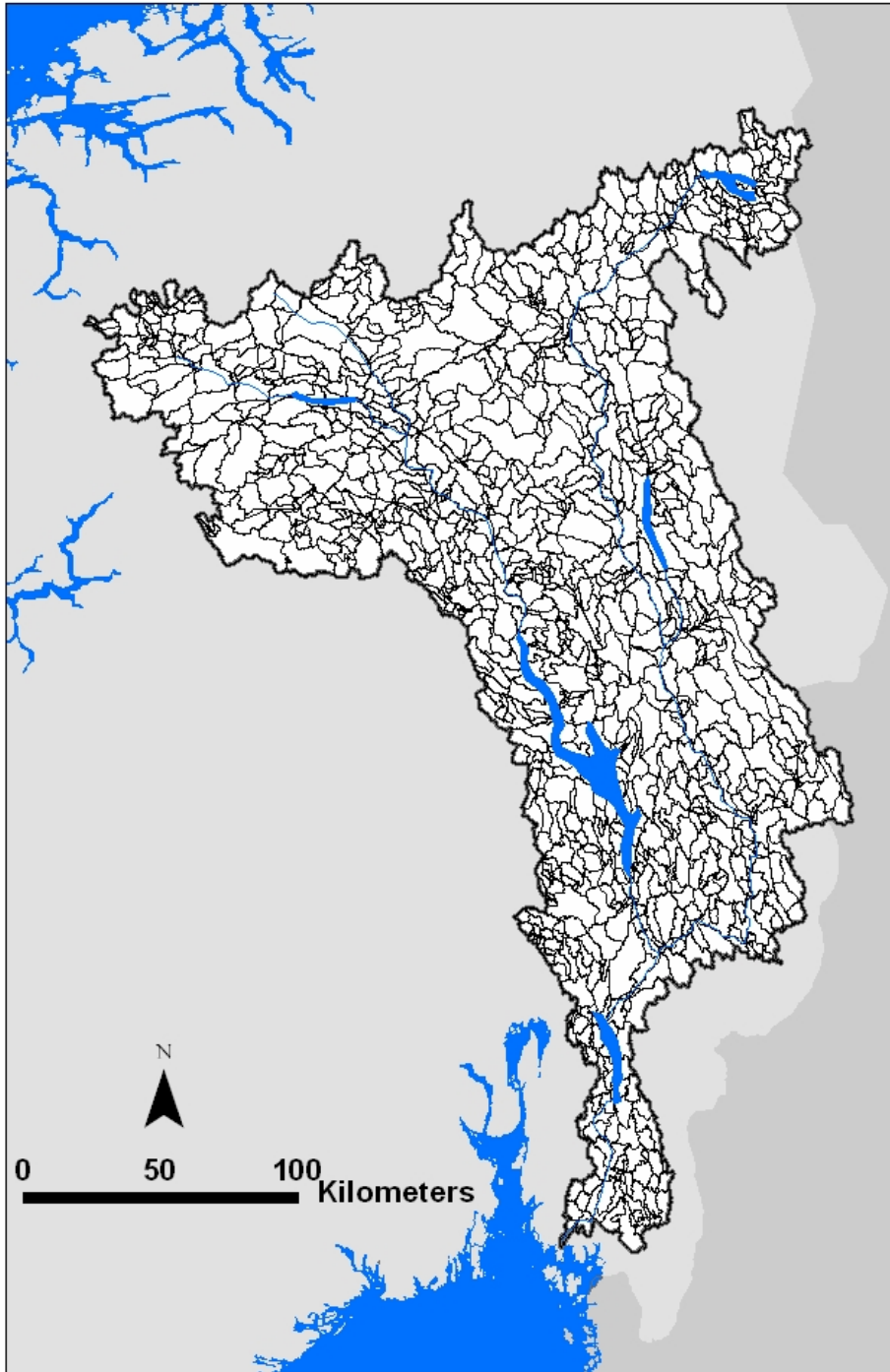
**Figure 12.** Trend of phosphorus transport to Skagerrak Ocean.

River Glomma is an example of modelling a single river basin. River Glomma drains the largest river basin in Norway. The area (42 000 km<sup>2</sup>) was divided in 1400 Regime catchments, see **Figure 13**. The results were useful to make a brief surveillance of the pollution situation in the catchment. The map in **Figure 14** tells us where we can expect problems in the main river (aggregated values) and in the minor tributary (local values), and which type of sources that have influence. For example the good quality in the main river Glomma in the upper mountainous and forest dominated areas continues through more polluted areas downwards. Use of Teofil may be a first step to evaluate pollution mitigating measures.

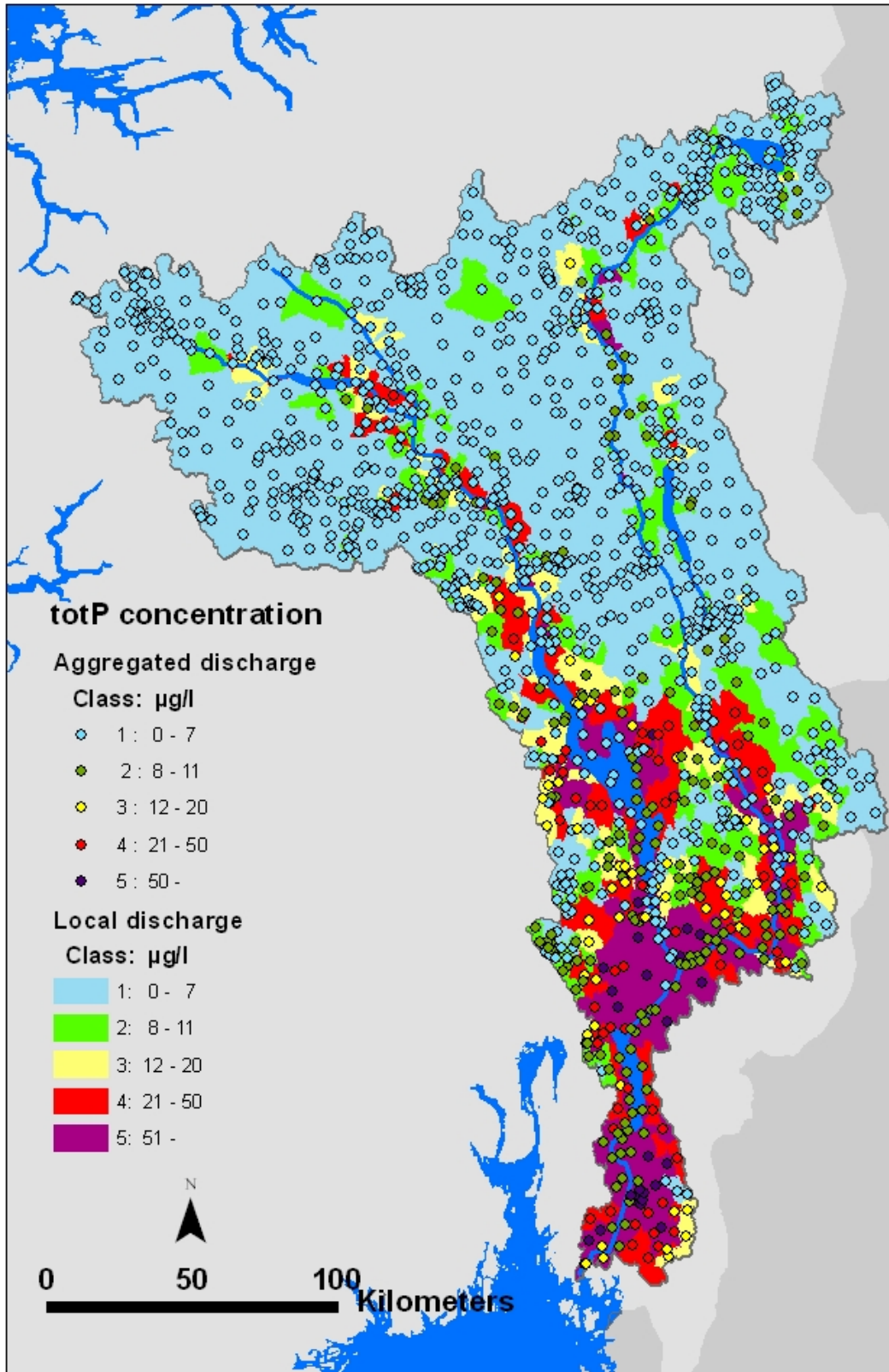
Near the outlet of Glomma, the observed load of total nitrogen and total phosphorus in 2007 were 12620 and 330 ton respectively. The corresponding simulated annual loads were 13840 ton total nitrogen and 248 ton total phosphorus. There was good accordance between the observed and calculated nitrogen loads. The simulated phosphorus load was considerably lower than the observed load. The difference is probably connected to suspended particles. In the lower part of the catchment the soil is dominated by clay. Erosion in this soil leads to high concentrations of particles, especially in year with heavy floods. Especially phosphorus is bound to these particles. The erosion is to a great extent a stochastic process which the Teofil model don't handles in a sufficient way, which explains a large portion of the difference between the two approaches. There is ongoing work to improve the models ability to handle erosion in clay rich soil.

The sources of nutrients for most of the Glomma catchment are dominated of natural sources (forest, mountainous, moor and lakes). In the lower and more populated areas contribution from agriculture are more dominant, **Figure 15**.

**Figure 16** shows how much of the local phosphorus discharge (inside each sub-catchment) that reach the sea. The reason for differences is retention in lakes on the downwards transport. If the purpose is to reduce the amount of phosphorus to the sea, the map tells us how effective nutrient reduction effort may be in different areas. The same reduction effort near outlet may be 10 times more efficient than in the upper part.

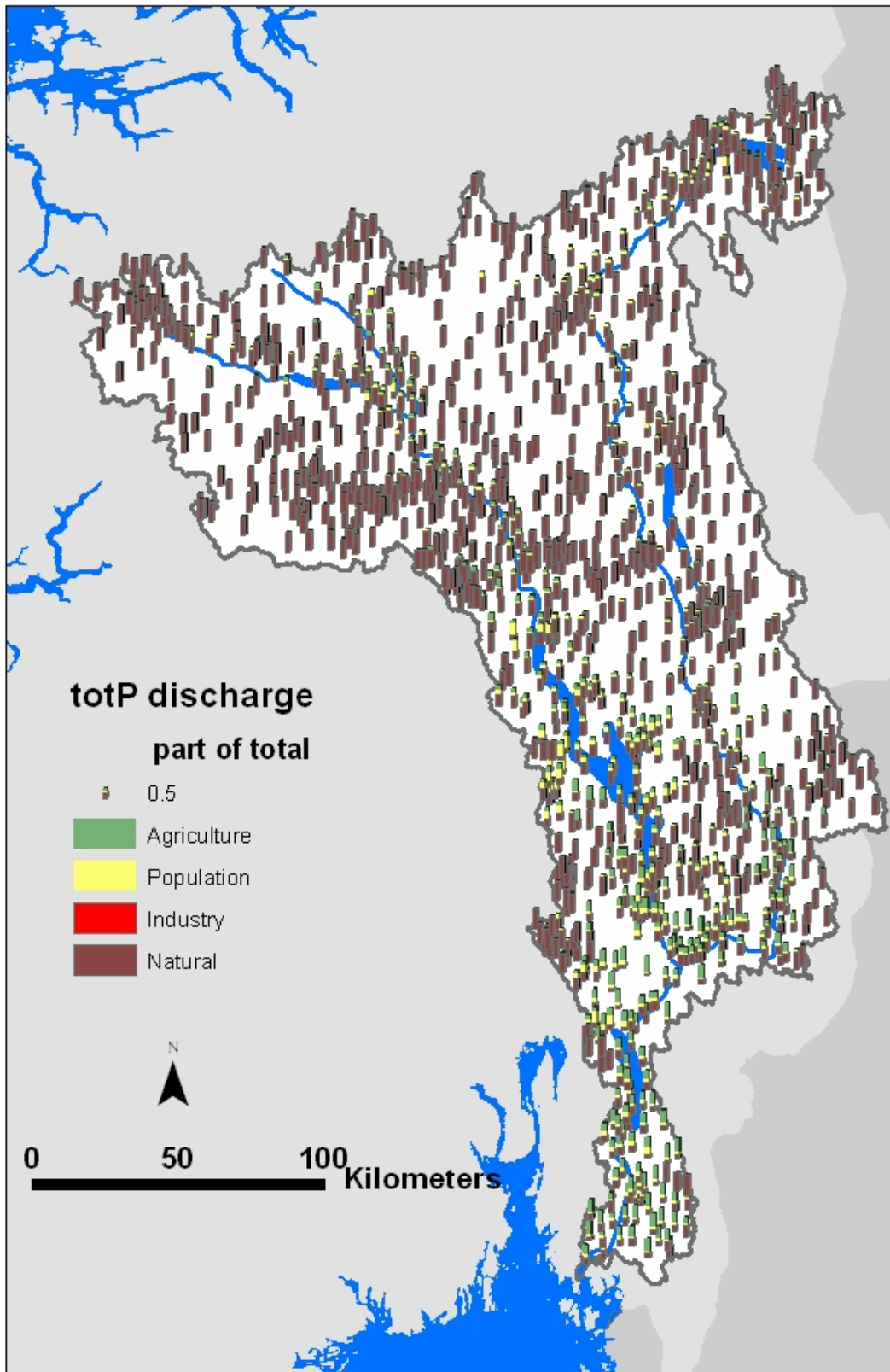


**Figure 13.** The Glomma basin divided in Regine sub-catchments.

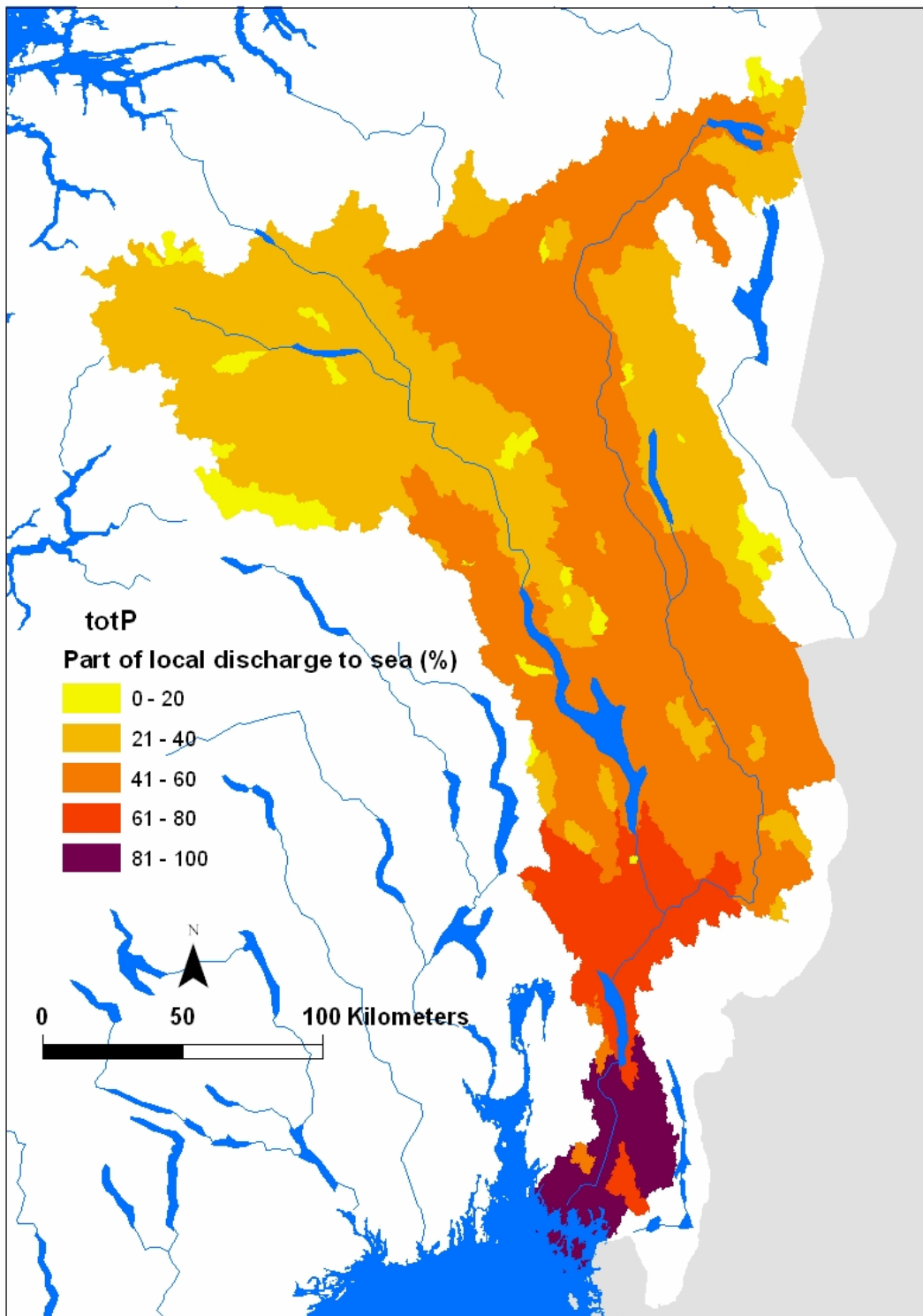


**Figure 14.** Glomma basin. The background colour shows the local concentrations which mean concentrations in the water added inside each sub-catchment with no contribution from upstream areas (local values). The dots represent the actual concentrations in the river which also include water from upstream areas (aggregated values).





**Figure 15.** Glomma river basin. Source specified loads as part of total.



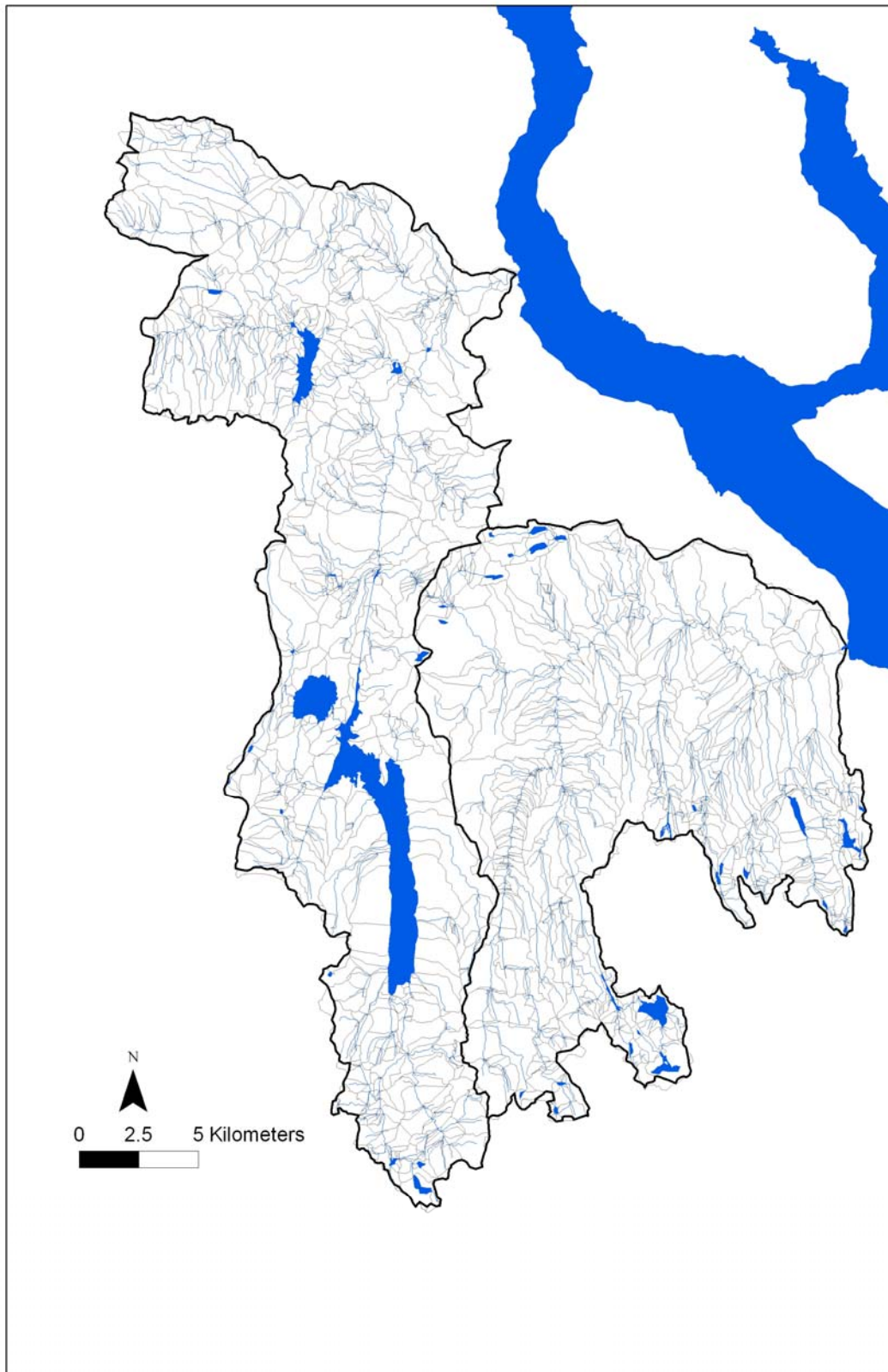
**Figure 16.** Part of the load added in a sub-catchment that reaches the sea.

### 3.2 Small sub-catchments

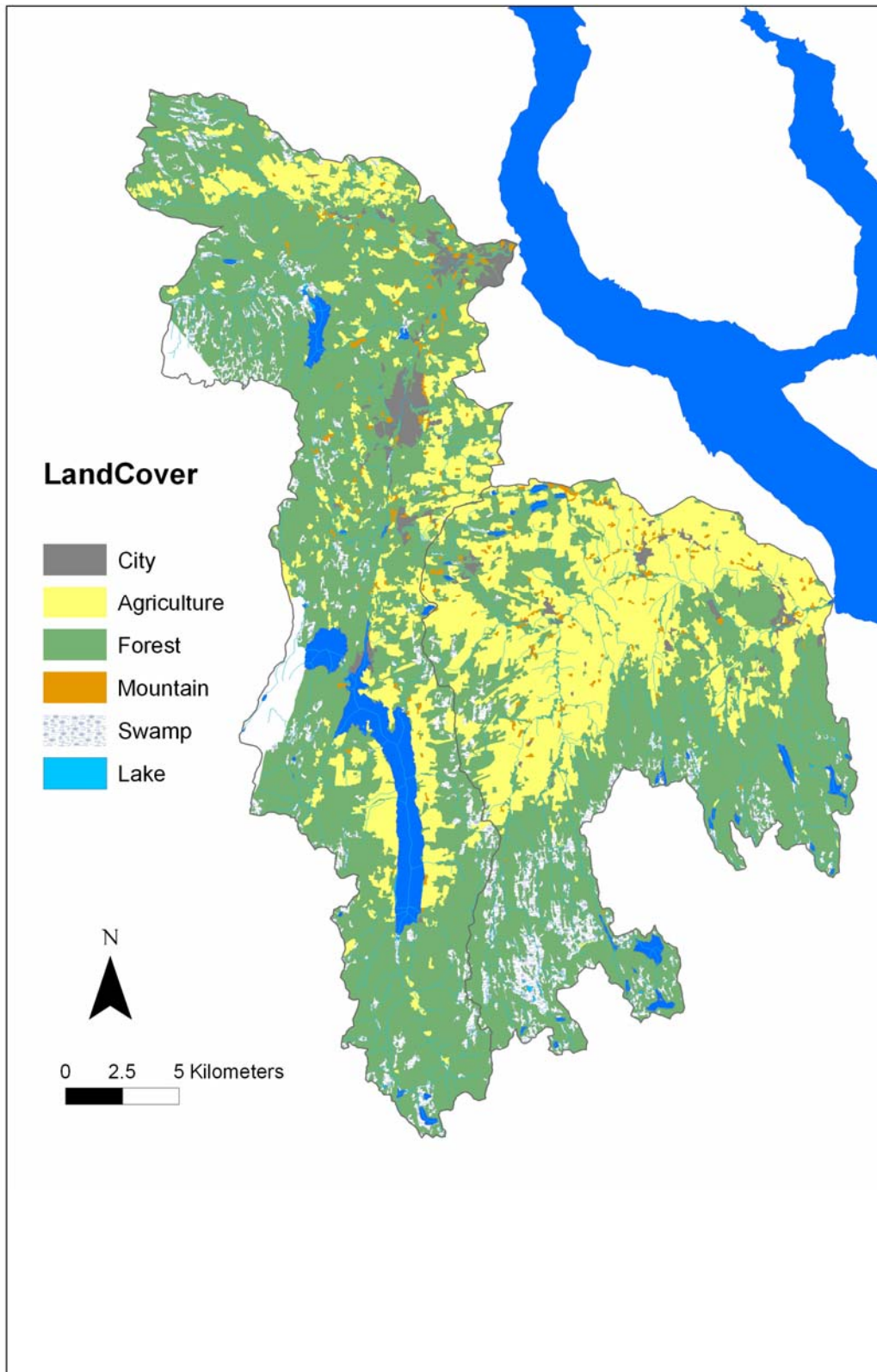
In Norway the river system are divided in 1.5 million Elvis segments. This is the smallest mapped segments that cover the whole country. To use these river segments in the Teofil model, we need a digital map of the catchments to each of these segments. This was found by using GIS techniques. The method is described in Appendix A.

The River basins of Hunnselva and Lena were divided in Elvis sub- catchments, **Figure 17**. Forest is the dominating land cover in the upper parts of the basins. In the lower parts, agriculture is more common, **Figure 18**. Losses from agriculture land and scattered population increased their importance downstream. The water quality in the lower parts was not acceptable (class 4 and 5) and phosphorus mitigating measures are required in order to meet a water quality that supports good ecological status (WFD-target). The map points out where to look more carefully and for what kind of sources.

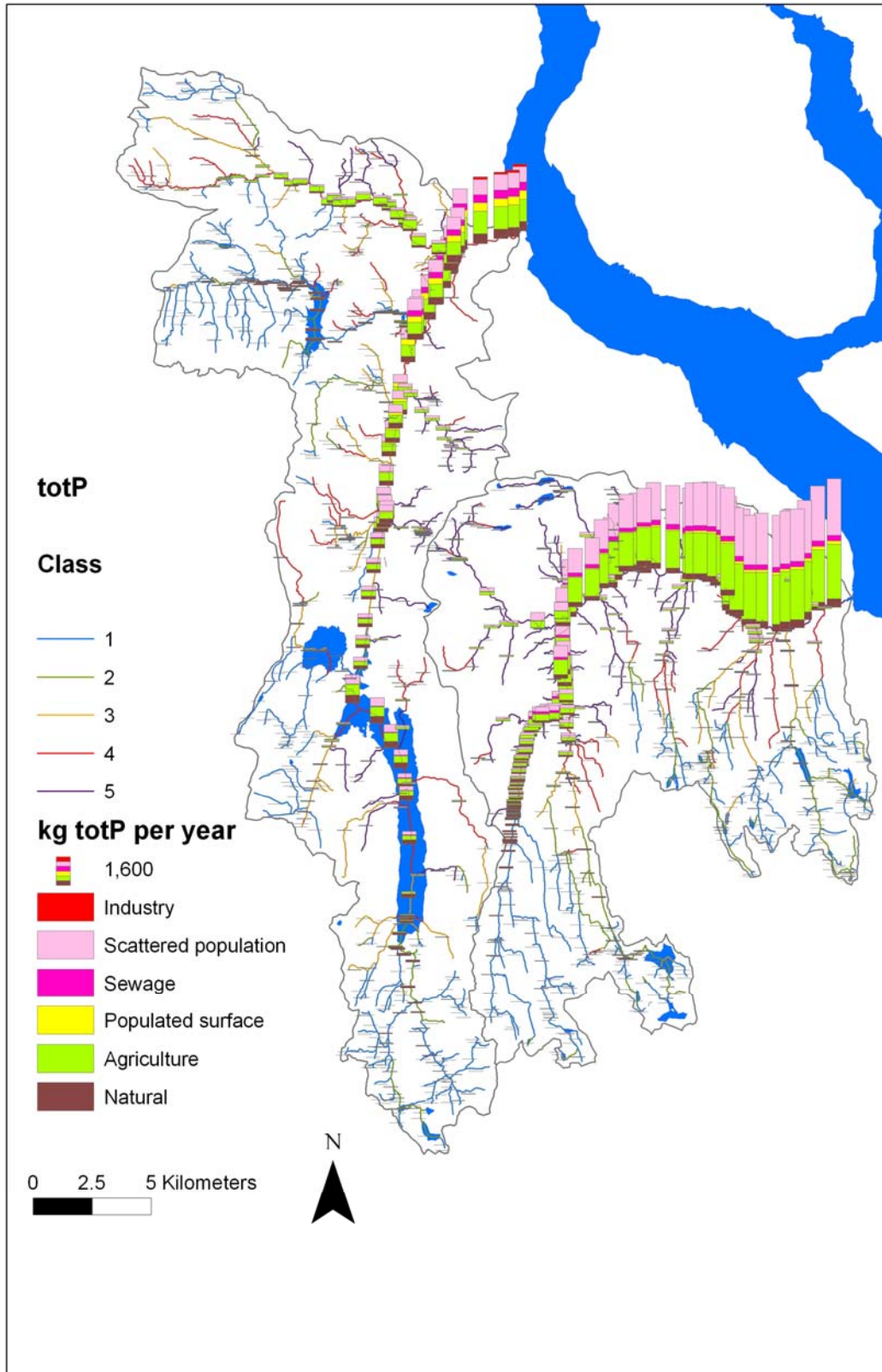
The setup of the model is in principle the same as for the large scale examples. The difference is smaller region of interest and smaller sub-catchments. This leads to better localizing of polluted river reaches and search for “responsible” sources. In Hunnselva the modelled annual loads were smaller than observed. This indicated discharges from unknown sources in the lower parts, e.g. leakage from sewerage pipes. Such results may lead to further investigations and special sampling program in the river in order to localize the leakage.



**Figure 17.** Hunnselva and Lena catchments divided in Elvis sub-catchments.



**Figure 18.** Hunnselva and Lena catchments. Land cover.

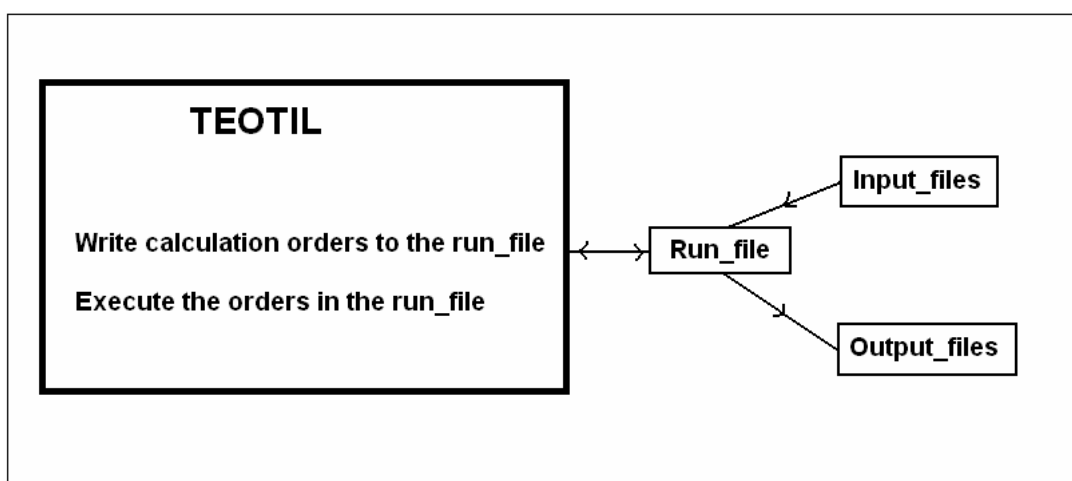


**Figure 19.** Hunnselva and Lena catchments. Source specified loads and modelled water quality classification.

## 4. Manual

### 4.1.1 Introduction

Teotil is a model maker tool specialized for calculations of loads in sub-catchment with known interior drainage. The model consists of a package of pre-defined functions that the user may apply to make his own model for transport of a selected constituent in a specified drainage basin or basins. This user specified programme or list of orders is saved in a file named "Run-file". The model is written in Visual Basic.



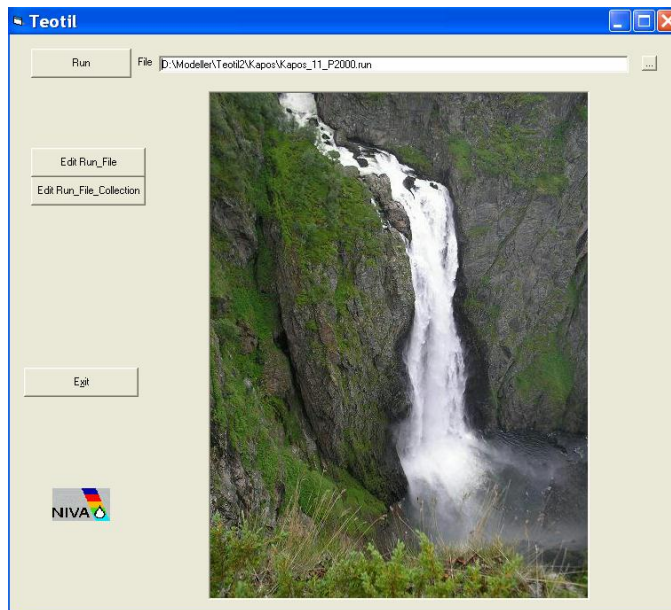
In the model we have an empty two dimensional array. We can think of it as an Excel table. In this description we will call it: **Model table**. The headings or the name of each individual array are in this text called **field** name. Each column in the table represents one field name. Input data that are stored in tables in text files can be read into the model table by use of order lines. The table can be filled for example by code names of individual drainage areas, area in km<sup>2</sup> as shown below. Other order lines may be used to make new variables or change old ones by calculations and to make output. In the order lines only the names of the variables (field names/headings) is entered, then the calculations are done for all its elements.

Model table:

	ID	TO_ID	area	Qspes	Q	← field names/headings
1	Catchment1	Catchment2	10	10	100	
2	Catchment2	Catchment1	5	10	50	
3	Catchment3	Catchment1	15	10	150	
4	Catchment4	Catchment1	20	5	100	
5	Catchment5	Catchment1	30	5	150	
6	Catchment6	Catchment1	50	10	500	
^						

Element numbers/line numbers

#### 4.1.2 The Teotil main form



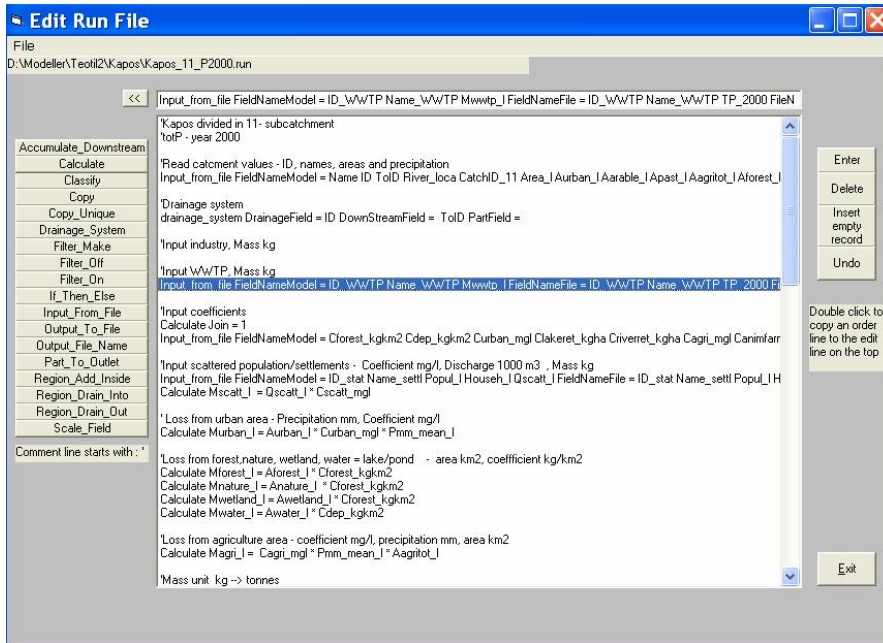
When executing the teotil.exe file, the Teotil main form is shown. Prepared calculations for a region are executed by selecting/writing the run-file name in the run-file window and click on the run-button. The run-file contains order lines which are executed one by one. Inputs are read into the model, calculations are done and results written.

An alternative to the run file is to order a run file collection file. This is a text file that consists of a list of run files, one file name on each line. In that way the run files in the list may be executed one after each other.

From the menu you may choose "Edit run\_File". Here a new run-file may be written or an old one edited. A list of prepared run-files may be made by choosing the button "Edit Run\_file\_Collection"



### 4.1.3 Edit Run File



The user specified programme is written in the run\_file which consists of a list of orders/statements.

The run file is edited in the Edit Run File window. Each line consists of a calculation order or comment. When the model is run, the orders are executed one after each other from top to bottom.

The orders may be written by selecting the order list on the left side of the Edit window. Then a form pops up to help you to write the order.

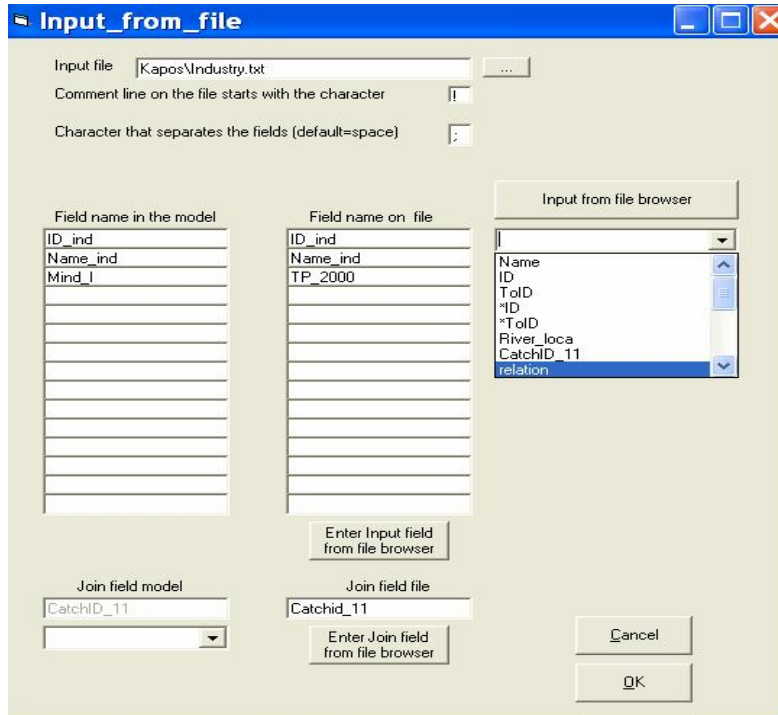
### 4.1.4 Comment line

If the **first** non blank character on the line is the comment character: ‘ ’, the rest of the line is not red.

Example:

‘This is a comment line

### 4.1.5 Input From File



By clicking the OK button, the order line from the form above is written to “Edit run file window” as:  
**Input\_from\_file** FileNameModel = ID\_ind Name\_ind Mind\_1 FileNameFile = ID\_ind Name\_ind TP\_2000  
 FileName = Kapos\Industry.txt CommentChar = ! Field\_Separator\_Char = ; JoinFieldModel = CatchID\_11  
 JoinFieldFile = Catchid\_11

The input order reads specified column in a table from a text file into the model. In the model the data are stored in a 2-dimensional array (you may think of it as in an Excel spread sheet with the field name on the top and the values downward in the column). Lines starting with the entered “comment line” character in the text file are not used by the model. The first readable line must consist of headings/field names, the following of data separated by the entered separator character. Remember to enclose data that consists of the separator character with goose eyes “ ”.

The input file may be selected and the field names/headings may be chosen by clicking by the mouse from the “Input from the browser” list. The “Field name in file” lists the field names in the input file that shall be read into the model. The corresponding field names in the model are entered in the “Field name in the model” list.

If no join fields are filled, the data are copied from the file table into the model table. The join fields may be used to enter data from a file table with few elements into a field with many elements in the model table through a common join field value.

Example :

Join field Model = county and Join field file = county\_file

In the file table the fields "county\_file" and "Pforest" consist of names of counties and run off concentration of phosphorus from forest pr. km2 respectively. The model table consists of fields with data for each computational element including a field "county" with the name of the counties. A value "30" read from the file table with a corresponding county name "4" in the field "county\_file", will be

entered into the model table in the ordered field in each line where the name "4" are found in the field "county".

**Model table:**

ID_catcment	County	totP
Catchment1	1	40
Catchment2	1	40
Catchment3	4	30
Catchment4	4	30
Catchment5	1	40
Catchment6	4	10
Catchment7	3	30
Catchment8	3	30
Catchment9	1	40

**File table:**

County_file	Pforest
1	40
2	10
3	20
4	30

In the Kapos example, from the table in industry.txt the load from a industry plant located in a specified sub-catchment (Catchid\_11 name = 1) is entered into the model table to the column with field name field Mind\_1 and in the line with the same sub-catchment name (Catchment\_11 name = 1).

Point sources are usually stored in a file table with one line per source, for example discharge from an industry plant in one column and the sub-catchment/drainage element code in another. The normal way is to enter this discharge into the model table by use of the drainage element code as join field. If many point sources are localized in the same sub-catchment, the load is **(OBS!) added** to the existing value. That means **each of the model table elements consists of the sum of all the loads added to the sub-catchment/drainage element**. If the value is a string/text the old value is over written by the new.

In the model table fields are of type numeric or string/text. You can for example not do numeric calculations with strings. If one of the values in a field is a string, the field is classified as a string. Be aware of that in the model an empty input value (space, " ") is defined as a string. A safe way is to put in 0 "zero" instead the empty value if the field shall be of numeric type; however the Teotil programme automatical substitute "0" instead of space if all the other elements are numbers. The model will give you a warning before abort if you try to do numerical calculations with a string field value.

### 4.1.6 Drainage system

**Drainage System**

DrainageField	DownStreamField	PartField
Field with ID-codes of drainage elements	Field with ID-codes of downstream elements	Field with Part (0.0-1.0) that drain from the Drainage ID to the Downstream ID (necessary if more than one Downstream field else 1.0 is default value)
id	toid	
	Combo1	Combo1
	Delete	Delete

If the DrainageField element is the most downstream element, its DownStreamField element must be given the "out of system" value: 0 or -

The Drainage ID Field is always handled as STRING values in the model. That means even if all the element values is numbers, the field can't be used in numerical calculations.

Cancel OK

By clicking the OK button, the order line from the form above is written to “Edit run file window” as: **drainage\_system** DrainageField = ID DownStreamField = ToID PartField =

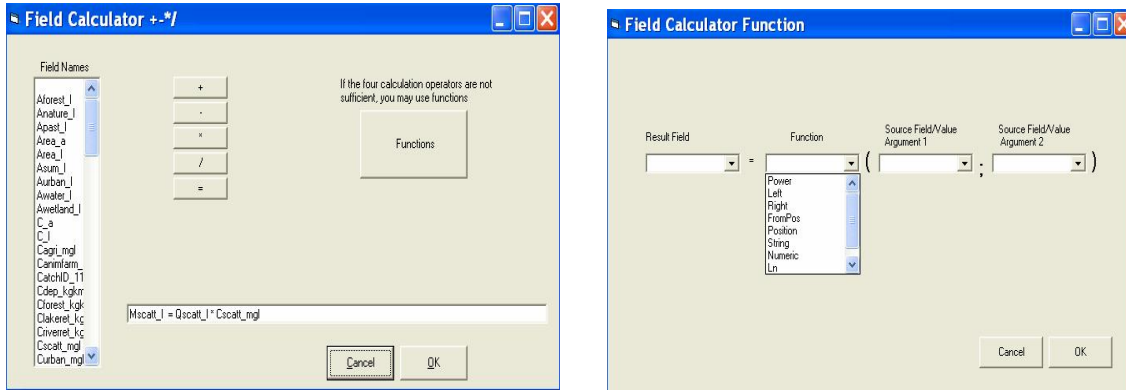
The model may handle a flexible drainage system. The water course may divide and confluent in a flexible way.

The drainage system is defined. We have to enter the field names of the Drainage element codes and the corresponding codes of the downstream elements. A drainage element/sub-catchment may divide in two or more downstream elements. If so, extra “DownStreamField” may be entered along with “Partfield” which tells how much of the flow that enters each parts by downwards transport. The “Part Field” values must be between 0 and 1. If all the drainage elements have only one downstream element, it is not necessary to fill out “PartField”.

**OBS! The most downstream drainage element must be given the “DownStreamField” value = 0 or - (minus sign), which means out of system.**

Many of the orders in Teotil need information about the drainage system. A good custom is to read the “Drainage system” fields in the first order line and define it in the next.

### 4.1.7 Field calculator

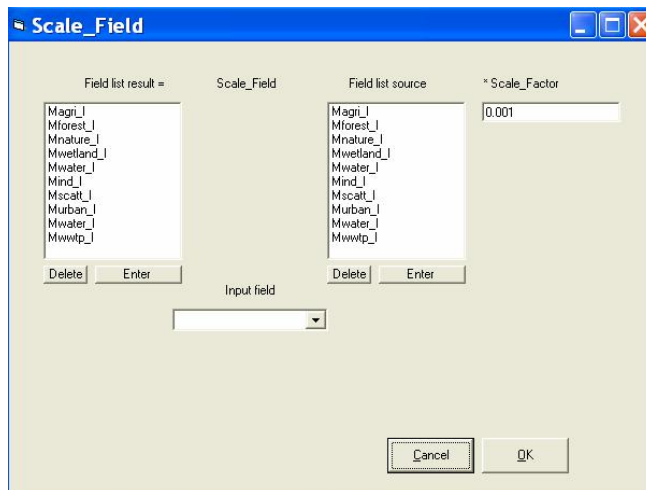


By clicking the OK button, the order line from the form above is written to “Edit run file window” as:  
**Calculate** Mscatt\_1 = Qscatt\_1 \* Cscatt\_mgl

The operations are valid for the whole column in the model-table. In the example above each of the elements that belongs to the Qscatt\_1 field are multiplied with the corresponding value for the Cscatt\_mgl field and the results are stored in a column with field name Mscatt\_1.

The calculator handles the four normal operators : + - \* / **without use of parenthesis**. In addition some functions are available by clicking the function button in the “Field calculator” form. For numeric operation the power and logarithmic function may be useful. The rest of the functions handle string fields.

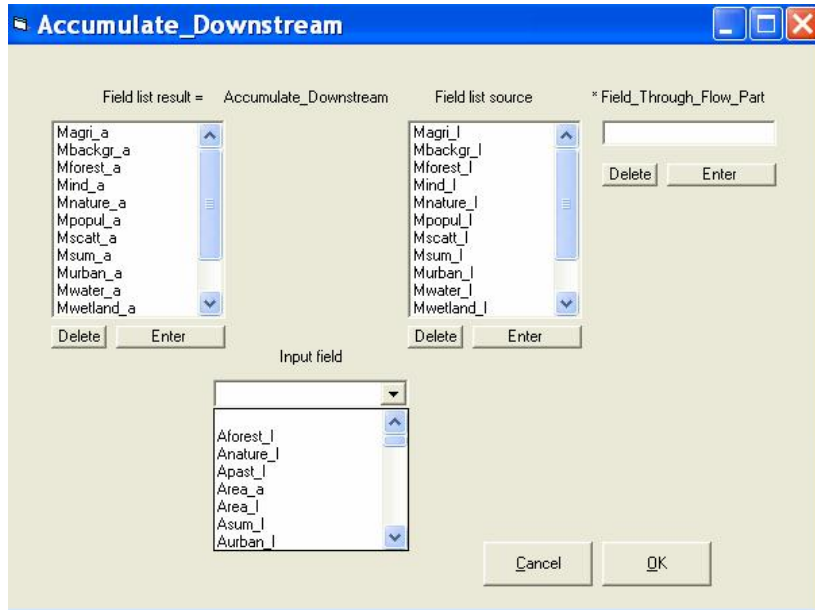
### 4.1.8 Scale\_Field



By clicking the OK button, the order line from the form above is written to “Edit run file window” as:  
**Scale\_Field** ResultField = Magri\_1 Mforest\_1 Mnature\_1 Mwetland\_1 Mwater\_1 Mind\_1 Mscatt\_1 Murban\_1 Mwater\_1 Mwwtp\_1 SourceField = Magri\_1 Mforest\_1 Mnature\_1 Mwetland\_1 Mwater\_1 Mind\_1 Mscatt\_1 Murban\_1 Mwater\_1 Mwwtp\_1 Scale\_Factor = 0.001

The order is useful, as in the example above, to scale units from kg to tonnes for fields in the list. Alternatively we could have used the Calculate order 10 times.

### 4.1.9 Accumulate\_Downstream



By clicking the OK button, the order line from the form above is written to “Edit run file window” as:  
**Accumulate\_Downstream** ResultField = Magri\_a Mbackgr\_a Mforest\_a Mind\_a Mnature\_a  
Mpopul\_a Mscatt\_a Msum\_a Murban\_a Mwater\_a Mwetland\_a Mwwtp\_a Q\_a Area\_a SourceField =  
Magri\_l Mbackgr\_l Mforest\_l Mind\_l Mnature\_l Mpopul\_l Mscatt\_l Msum\_l Murban\_l Mwater\_l  
Mwetland\_l Mwwtp\_l Q\_l Area\_l

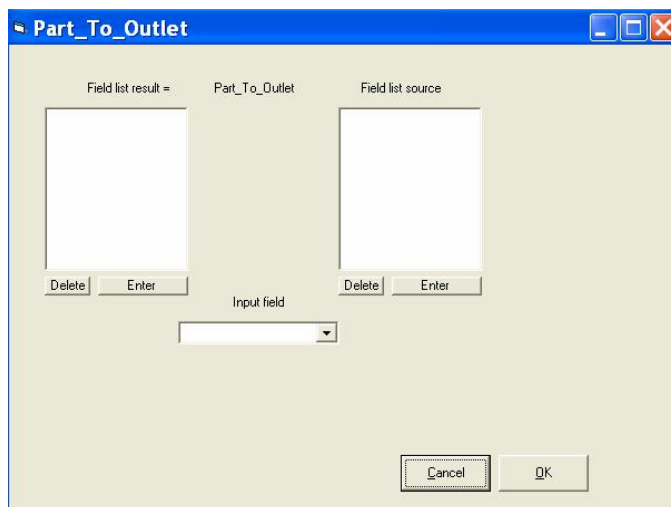
The order calculates the transport downstream. The local value for a field in the upper most drainage element is added to the value in the element downstream etc.

The “Through\_Flow\_Part” field make it possible to handle retention processes, for example phosphorus retention in lakes. In advance a field for the through flow part with values between 0 and 1 must be available. All the loads that pass out of an element = sum of upstream transport into the element, are multiplied with the corresponding “Through\_Flow\_Part” field value for the element just downstream.

OBS! The retention/through flow in an element includes loads from all the upstream elements but not the local loads produced in its own element. That means that the local loads in the model are suggested to be added by the outlet of the element. If you want to include a fixed local retention you may use a Calculate order in advance, for example: Calculate Loadlocal = Loadlocal \* Through\_Flow\_Part \* 0.5

If “Through\_Flow\_Part” field is empty, all of the load will pass the element. The result will be the same with a “Through\_Flow\_Part” field with all elements equal 1.

### 4.1.10 Part\_to\_outlet

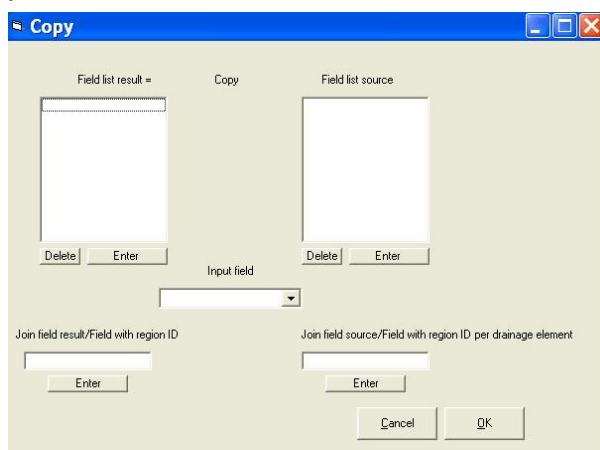


The result in each element is the product of all the source field values in downstream direction. The result is the part of the load from each of the sub-catchment that reaches the most downstream defined element. The entered fields in the source list must have value between 0 and 1 which give information about the part of the load that passes the element. The Field is the same as “Field\_Trough\_Flow\_Part” (1-retention) in the order “Accumulate\_Downstream”. The order has only meaning in water courses with retention.

OBS! The result includes the part downstream own element (result element), it don't include retention in own element.

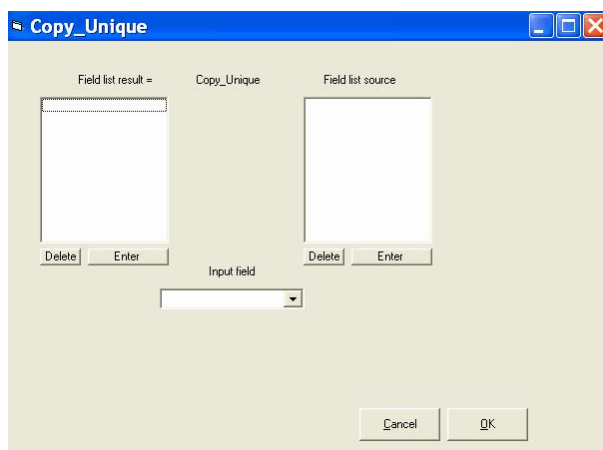
Such calculation may be used to localize cost effective pollution reducing effort.

### 4.1.11 Copy



The “Copy” order handles string fields. The join fields may be left empty. The use of the join fields are described in the “Input From File” order.

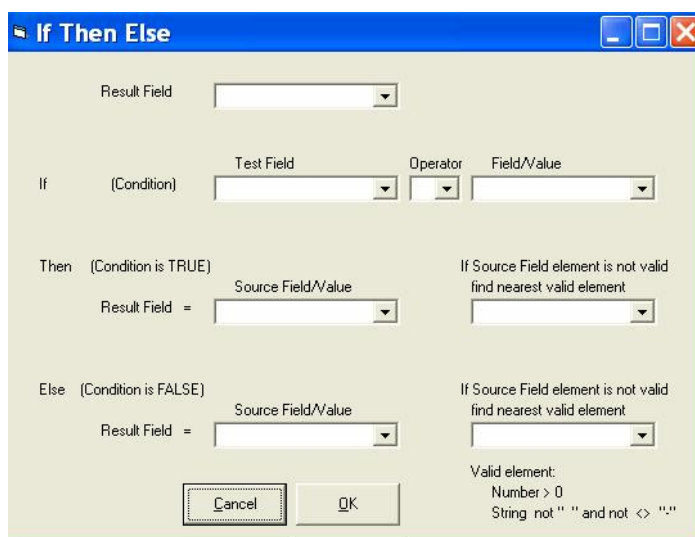
### 4.1.12 copy\_unique



The result field consists of the unique values of the source field values.

Char_source	Char_Result
A	A
B	B
B	
A	

### 4.1.13 If\_Then\_Else

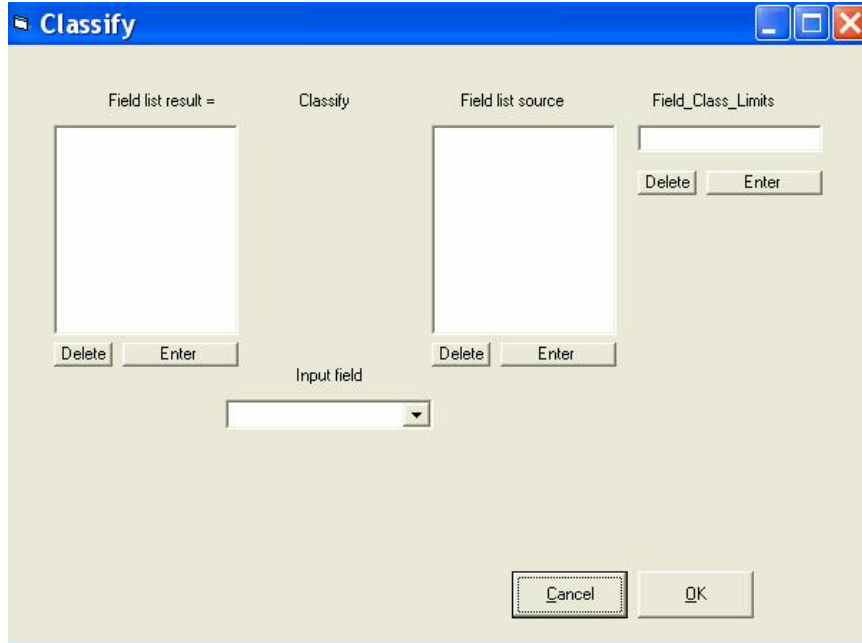


The order may be used to make new fields based on conditional circumstances. The form is self explanatory. We will just make a comment of the two fields marked with “If the Field element is not valid, find nearest valid element”. You may select “Downstream” or “Upstream”. The order is useful to extrapolate scattered known values upstream or downstream in the catchment. For example known water flow per km<sup>2</sup> in some measuring points may be extrapolated to the nearest areas.



The order also may be used to make output filter (look below). For example: To order output only for sub-catchment more then 500 meter above the sea level covered by 50 % forest.

#### 4.1.14 Classify



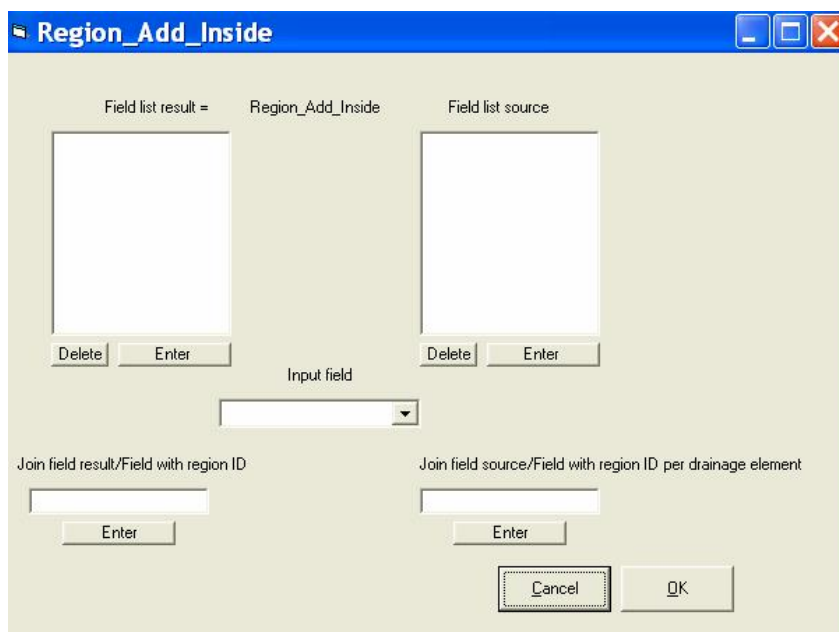
The order is used to classify values in a field against class limit values in a specified classification field ("Field\_class\_Limits").

The class follows the line number in the model table, look at CLASS\_LIMIT\_A and CLASS\_LIMIT\_B in the table below. The first class is always 1, the next 2 etc. The user must define the class limits with increasing values or decreasing values according to that.

Example:

CLASS_LIMIT_A	CLASS_LIMIT_B	X	X_CLASS_A	X_CLASS_B
10	40	5	1	5
20	30	14	2	4
30	20	40	4	2
40	10	16	2	4
		19	2	4
		29	3	3
		89	5	1

### 4.1.15 Region\_Add\_Inside



The order is used to find the sum of a field value inside a region.

Example:

We want to find the sum totP that are added to water inside each county.

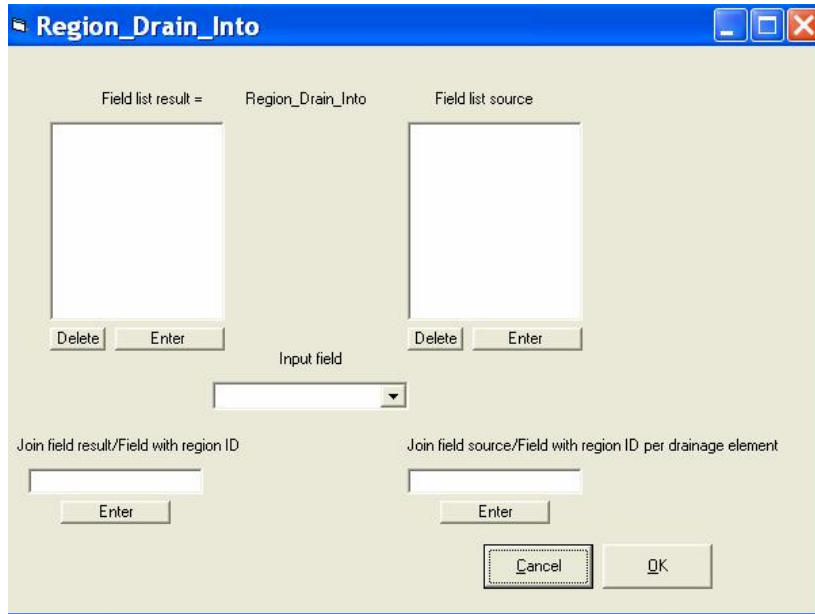
Source field = totP, Join field source = County, Join field result = County\_Unique

From these three known fields, the calculated result field = P\_into is shown in the table below.

The field “County\_unique” may have been made by the order: “Copy\_Unique” by use of “County” as source field.

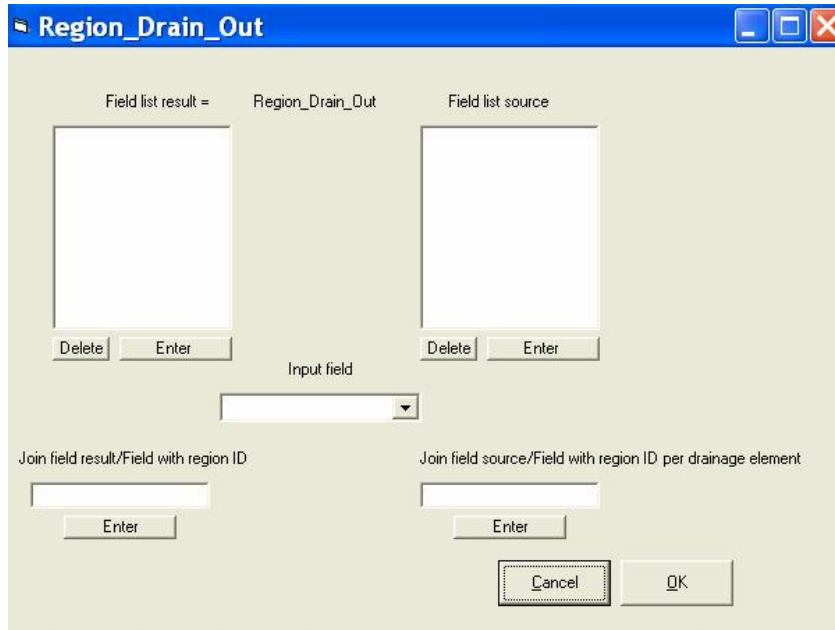
ID_CATCHMENT	COUNTY	TOTP	COUNTY_UNIQUE	P_INT0
Catchment1	1	10	1	40
Catchment2	1	10	2	0
Catchment3	4	10	3	20
Catchment4	4	10	4	30
Catchment5	1	10		
Catchment6	4	10		
Catchment7	3	10		
Catchment8	3	10		
Catchment9	1	10		

#### 4.1.16 Region\_Drain\_Into



The order is used to find the sum of a field value that drain into a region.  
 For example how much of a constituent drain into each county from above.  
 For use of the join field etc., look at the “Add\_inside” order.

#### 4.1.17 Region\_Drain\_Out



The order is used to find the sum of a field value that drain out of a region.  
 For example how much of a constituent drain out of each county.  
 For use of the join field etc., look at the “Add\_inside” order.

#### 4.1.18 Filter\_make

Filter Field/ Result Field

Source Field

with Element value

from

to

The source Field is by default the Drainage Element Field

With the Elements + number of elements upstream

with the Elements + all the elements upstream

Enter

A filter field has element value 1 = True or 0 = False  
 The filter is activated by the order: Filter\_on  
 The following output orders writes only lines with filter field value = 1/true  
 or if several filter field is activated, with the total result of the filter field  
 values = 1/true

Cancel OK

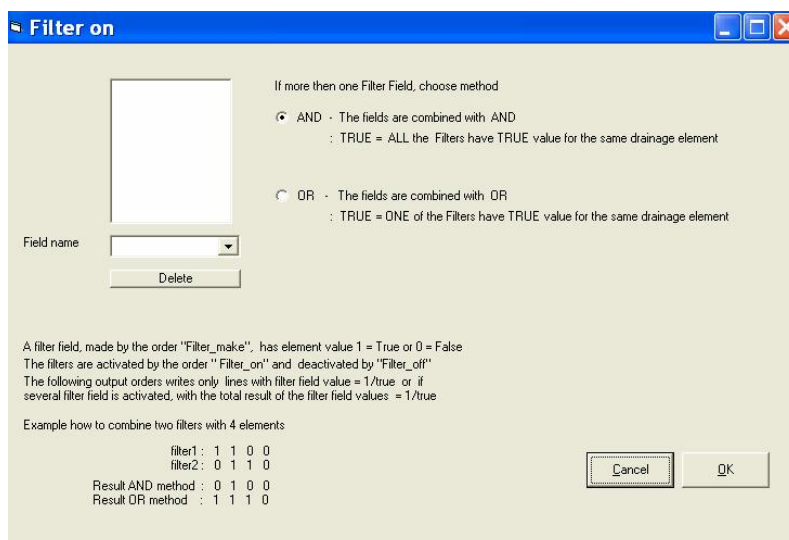
A filter field has value equal 1 = True or 0 = False. The filter is activated by the order “Filter\_on” The following output orders writes only lines in the model table with filter field equal one or if several filter fields are activated, with the total result of the filter fields equal 1.

An output order writes by default the ordered field values for each of the sub-catchment/lines in the model table. If the modelled area consists of thousands of sub-catchments/drainage elements, the output amount may be overwhelming. The purpose of a filter is to reduce the output exactly too what you need.

You may choose the left or the right square in the “Filter\_make” form. In the left square you may order output for given field values. For example choose sub-catchment between 500 and 1000 m above sea level or sub-catchment with covered by over 50% forest. The right square of the form make filter according to the drainage elements. You may chose specific drainage elements or for example choose only the elements that drain to sea by entering the name of the sea element and order one element upstream.

A filter field may not necessary be made by the “Filter\_Make” order. The “If\_then\_else” order may also be suitable or you may use an already existing field with 0 and 1 values.

### 4.1.19 Filter\_on



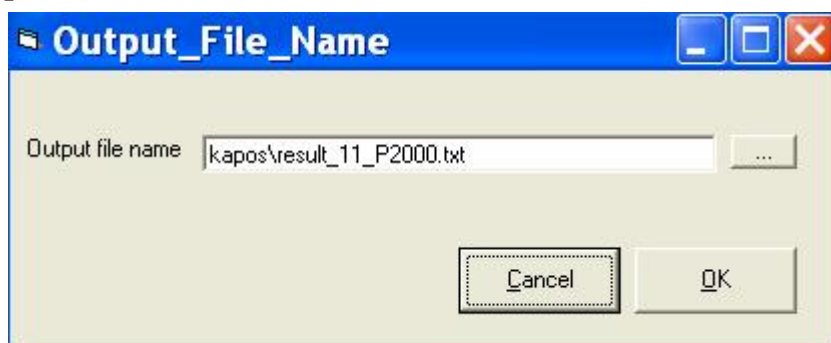
The filters may be activated by the “filter\_on” order. In case of several filters, the total result is dependent of the method “AND” or “OR”. By use of the “AND” method, the total result is the product of the filter fields. If one of the filters for a sub-catchment/drainage element is equal 0, the total result is equal 0. By use of the “OR” method the total result is equal 0 if all of the filter values are equal 0.

### 4.1.20 Filter\_Off

The filter activated by the “Filter\_On” order is deactivated by the “Filter\_Off” order. If a filter is active, a new “Filter\_On” order may be written directly without any “Filter\_Off” order between.

The “Filter\_Off” order is entered directly, no own form, into the edit window by clicking the “Filter\_Off” button in the “Edit Run File” form.

### 4.1.21 Output\_File\_Name



By clicking the OK button, the order line from the form above is written to “Edit run file window” as:  
**output\_file\_name** = kapos\result\_11\_N2000.txt

The following output will be written to the entered file. If the file exists, the content will be over written.

### 4.1.22 Output\_To\_File

By clicking the OK button, the four order lines from the form above is written to “Edit run file window” as:

**output\_to\_file** New\_line = 3

**output\_to\_file** Head\_line = Drainage system

**output\_to\_file** Head\_line = ID ToID CatchID\_11 Name River\_loca

**output\_to\_file** Field = id toid catchid\_11 name river\_loca Format = \*

The output from these orders are shown in Apendix 1, File: result\_11\_P2000.txt

The order writes a table to the file activated by the last “Output\_File\_Name” order. The table consists of one column for each field. If no filter fields are activated, one line is written for each sub-catchment/drainage element. If filter fields are activated, only lines with total filter field value equal 1 are written.

### 4.1.23 The Teutil model integrated by the Arcview

Teutil is a stand alone model. However the model also may be run from Arcview, Arc-GIS version 9. A menu is built with three choices. You may execute the teutil.exe file in the same way as described above. In addition there are a pre- and post processor. The pre processor is used to make input files from existing layers on the map. For example find the sub-catchments codes that surround each of the industry plants. The post processor may help you to present results on the map. For example points classified with special water quality colours or pies proportional to load.

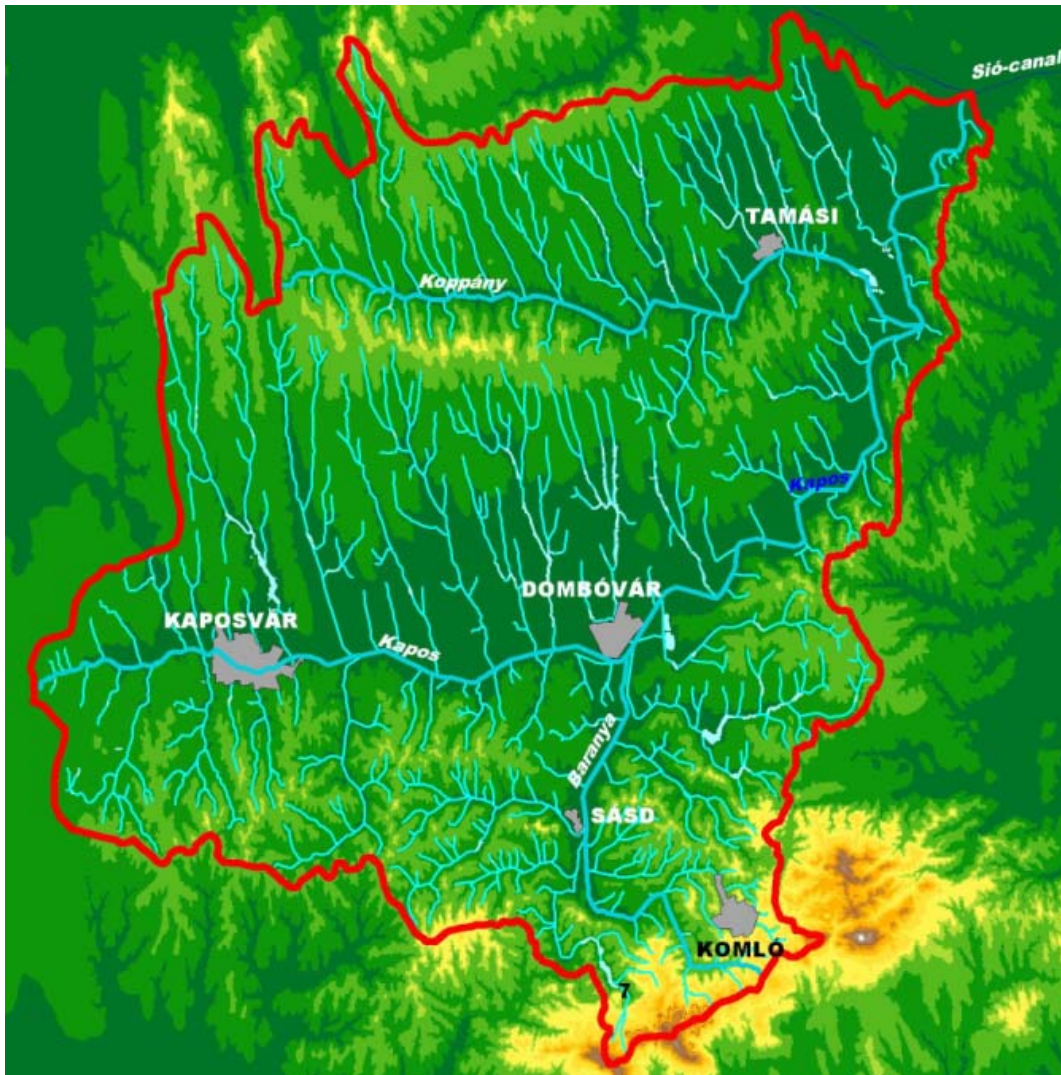
## 5. The Kapos example

### 5.1 Introduction

Teotil was used to prepare a model for calculating annual loads of total phosphorus, totP, for the Kapos catchment. In this chapter you will find a run-file and the corresponding input and output files for the project. A fast way to get experience with the model is to go through the run-file order by order and check the appropriate input files, output files and orders explained above.

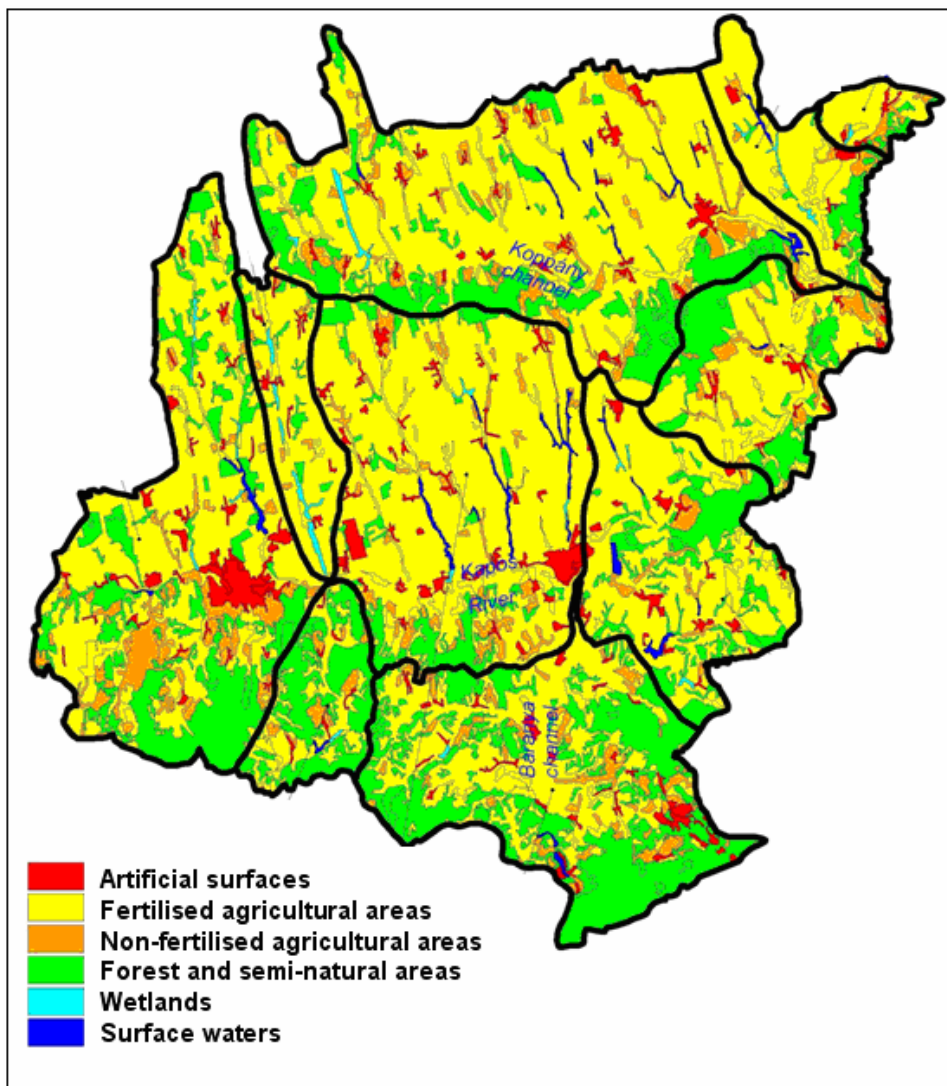
The catchment was divided into 11 sub-catchment with known interior drainage. Each sub-catchment had known value of land use area: forest, agriculture etc, file: Catchment.txt. The loss from each type of land was calculated from known area specific loss coefficients, file: Coefficients.txt. Loads from the point sources industry and municipal waste water plant were added to their sub-catchments, files industry.txt and WWTP.txt. The water flow was calculated from known specific run off. The loads from each source were calculated for each sub-catchment and thereafter transported downstream. The results were written to the file: result\_11\_P2000.txt.

In this chapter we will use the Kapos project as an example of how to make a run file which consists of a section of all the orders. A more detailed description of the project may be read in Lazar et.al. 2005 and Bakken et.al. 2006.



**Figure 20.** The Kapos catchment. Drainage and altitude





**Figure 21.** The Kapos catchment. Main cities, land cover and sub-catchments.

#### Basic data on Kapos catchment.

Property	Value
Catchment area	3170 km <sup>2</sup>
Elevation range	100 – 660 m above sea level
Rainfall	680 - 700 mm (380-400 mm in the growing season)
Specific run-off	4 l/s*km <sup>2</sup> (= 126 mm/km <sup>2</sup> )
Runoff coefficient	18 %
Land use/categories	Arable land (61.9 %), grassland (4.1 %), forest (24.2 %) and open water (0.8 %)

## 5.2 Run-file:

### Kapos\_11\_P2000.run

'Kapos divided in 11- subcatchment  
'totP - year 2000

'Read catcment values - ID, names, areas and precipitation

**Input\_from\_file** FileNameModel = Name ID ToID River\_loca CatchID\_11 Area\_1 Aurban\_1 Aarable\_1 Apast\_1 Aagritot\_1 Aforest\_1 Anature\_1 Awetland\_1 Awater\_1 Pmm\_mean\_1  
 FileNameFile = Name ID ToID River\_loca CatchID\_11 Area\_1 Aurban\_1 Aarable\_1 Apast\_1 Aagritot\_1 Aforest\_1 Anature\_1 Awetland\_1 Awater\_1 Pmm\_mean\_1  
 FileName = Kapos\catchment\_11.txt CommentChar = ! Field\_Separator\_Char = ;

'Drainage system

**drainage\_system** DrainageField = ID DownStreamField = ToID PartField =

'Input industry, Mass kg

**Input\_from\_file** FileNameModel = ID\_ind Name\_ind Mind\_1  
 FileNameFile = ID\_ind Name\_ind TP\_2000  
 FileName = Kapos\Industry.txt CommentChar = ! Field\_Separator\_Char = ; JoinFieldModel = CatchID\_11 JoinFieldFile = Catchid\_11

'Input WWTP, Mass kg

**Input\_from\_file** FileNameModel = ID\_WWTP Name\_WWTP Mwwtp\_1  
 FileNameFile = ID\_WWTP Name\_WWTP TP\_2000  
 FileName = Kapos\wwtp.txt CommentChar = ! Field\_Separator\_Char = ; JoinFieldModel = CatchID\_11  
 JoinFieldFile = Catchid\_11

'Input coefficients

Calculate Join = 1

**Input\_from\_file** FileNameModel = Cforest\_kgkm2 Cdep\_kgkm2 Curban\_mgl Clakeret\_kgha Criverret\_kgha Cagri\_mgl Canimfarm\_mgl Cscatt\_mgl  
 FileNameFile = Pforest\_kgkm2 Pdep\_kgkm2 Purban\_mgl Plakeret\_kgha Priverret\_kgha Pagri\_mgl Panimfarm\_mgl Pscatt\_mgl  
 FileName = Kapos\coefficients.txt CommentChar = ! Field\_Separator\_Char = ;  
 JoinFieldModel = Join JoinFieldFile = Cjoin

'Input scattered population/settlements - Coefficient mg/l, Discharge 1000 m3 , Mass kg

**Input\_from\_file** FileNameModel = ID\_stat Name\_settl Popul\_1 Househ\_1 Qscatt\_1  
 FileNameFile = ID\_stat Name\_settl Popul\_1 Househ\_1 Qscatt\_1  
 FileName = Kapos\settlement.txt CommentChar = ! Field\_Separator\_Char = ; JoinFieldModel = CatchID\_11  
 JoinFieldFile = CatchID\_11  
 Calculate Mscatt\_1 = Qscatt\_1 \* Cscatt\_mgl

'Loss from urban area - Precipitation mm, Coefficient mg/l

**Calculate** Murban\_1 = Aurban\_1 \* Curban\_mgl \* Pmm\_mean\_1

'Loss from forest,nature, wetland, water = lake/pond - area km2, coefficient kg/km2

**Calculate** Mforest\_1 = Aforest\_1 \* Cforest\_kgkm2

**Calculate** Mnature\_1 = Anature\_1 \* Cforest\_kgkm2

**Calculate** Mwetland\_1 = Awetland\_1 \* Cforest\_kgkm2

**Calculate** Mwater\_1 = Awater\_1 \* Cdep\_kgkm2

'Loss from agriculture area - coefficient mg/l, precipitation mm, area km2

**Calculate** Magri\_1 = Cagri\_mgl \* Pmm\_mean\_1 \* Aagritot\_1

'Mass unit kg --> tonnes

**Scale\_Field** ResultField = Magri\_1 Mforest\_1 Mnature\_1 Mwetland\_1 Mwater\_1 Mind\_1 Mscatt\_1 Murban\_1 Mwater\_1 Mwwtp\_1  
 SourceField = Magri\_1 Mforest\_1 Mnature\_1 Mwetland\_1 Mwater\_1 Mind\_1 Mscatt\_1 Murban\_1 Mwater\_1 Mwwtp\_1  
 Scale\_Factor = 0.001

'Group sources ++

**Calculate** Mbackgr\_1 = Mforest\_1 + Mnature\_1 + Mwetland\_1 + Mwater\_1

**Calculate** Mpopul\_1 = Mscatt\_1 + Murban\_1 + Mwwtp\_1

**Calculate** Asum\_1 = Aforest\_1 + Anature\_1 + Aurban\_1 + Awater\_1 + Awetland\_1 + Aagritot\_1

**Calculate** Msum\_1 = Magri\_1 + Mbackgr\_1 + Mind\_1 + Mpopul\_1

**Calculate** Q\_1 = Area\_1 \* Pmm\_mean\_1 \* 1000 / 86400 / 365

**Calculate** C\_1 = Msum\_1 \* 1000000 / Q\_1 / 86400 / 365

**output\_file\_name** = kapos\result\_11\_N2000.txt

**output\_to\_file** Head\_line = totN 2000 for Kapos catchment divided in 11 subcatchment

**output\_to\_file** New\_line = 3

**output\_to\_file** Head\_line = Drainage system

**output\_to\_file** Head\_line = ID ToID CatchID\_11 Name River\_loca

**output\_to\_file** Field = id toid catchid\_11 name river\_loca Format = \*

**output\_to\_file** New\_line = 3

**output\_to\_file** Head\_line = Land use

**output\_to\_file** Head\_line = ID Aforest\_1 Anature\_1 Aurban\_1 Awater\_1 Awetland\_1 Aagritot\_1 Asum

Area\_1 Pmm\_mean

**output\_to\_file** Head\_line = km2 km2 km2 km2 km2 km2 km2 km2

mm

**output\_to\_file** Field = id aforest\_1 anature\_1 aurban\_1 awater\_1 awetland\_1 aagritot\_1 asum\_1 area\_1 pmm\_mean\_1 Format = \*

\*

**output\_to\_file** New\_line = 3

**output\_to\_file** Head\_line = Coefficients

**output\_to\_file** Head\_line = ID Cforest\_kgkm2 Cscatt\_mgl Curban\_mgl Cagri\_mgl Cdep\_kgkm2

**output\_to\_file** Head\_line = kg/km2 mg/l mg/l mg/l kg/km2

**output\_to\_file** Field = id cforest\_kgkm2 cscatt\_mgl curban\_mgl cagri\_mgl cdep\_kgkm2 Format = \*

**output\_to\_file** New\_line = 3

**output\_to\_file** Head\_line = Local yearly load

**output\_to\_file** Head\_line = ID Magri\_1 Mind\_1 Mscatt\_1 Murban\_1 Mwwtp\_1 Mwater\_1 Mbackgr\_1

Mpopul\_1 Msum\_1 Q\_1 C\_1

**output\_to\_file** Head\_line = tonnes tonnes tonnes tonnes tonnes tonnes tonnes tonnes

tonnes m3/s mg/l

**output\_to\_file** Field = id magri\_1 mind\_1 mscatt\_1 murban\_1 mwwtp\_1 mwater\_1 mbackgr\_1 mpopul\_1 msum\_1 q\_1 c\_1

Format = \*

**Accumulate\_Downstream** ResultField = Magri\_a Mbackgr\_a Mforest\_a Mind\_a Mnature\_a Mpopul\_a Mscatt\_a Msum\_a

Murban\_a Mwater\_a Mwetland\_a Mwwtp\_a Q\_a Area\_a SourceField = Magri\_1 Mbackgr\_1 Mforest\_1 Mind\_1 Mnature\_1

Mpopul\_1 Mscatt\_1 Msum\_1 Murban\_1 Mwater\_1 Mwetland\_1 Mwwtp\_1 Q\_1 Area\_1

**Calculate** C\_a = Msum\_a \* 1000000 / Q\_a / 86400 / 365

**output\_to\_file** New\_line = 3

**output\_to\_file** Head\_line = Accumulated yearly load

**output\_to\_file** Head\_line = ID Magri\_a Mind\_a Mscatt\_a Murban\_a Mwwtp\_a Mwater\_a

Mbackgr\_a Mpopul\_a Msum\_a Q\_a C\_a Area\_a

**output\_to\_file** Head\_line = tonnes tonnes tonnes tonnes tonnes tonnes tonnes tonnes tonnes

tonnes m3/s mg/l km2

**output\_to\_file** Field = id magri\_a mind\_a mscatt\_a murban\_a mwwtp\_a mwater\_a mbackgr\_a mpopul\_a msum\_a q\_a c\_a

Area\_a Format = \*

### 5.3 Result file:

#### result\_11\_P2000.txt

totP 2000 for Kapos catchment divided in 11 subcatchment

#### Drainage system

ID	ToID	CatchID_11	Name	River_loca
1	4	1	Kapos-riv1	Kapos_up
2	4	2	Orczi-crek	Kapos_up
3	4	3	Surjan-cre	Kapos_up
4	6	4	Kapos-rir2	Kapos_up
5	6	5	Baranya-ch	Baranya
6	7	6	Kapos-riv3	Kapos_mid
7	11	7	Kapos-riv4	Kapos_mid
8	9	8	Koppany-r1	Koppany
9	10	9	Koppany-r2	Koppany
10	11	10	Koppany-r3	Koppany
11	0	11	Kapos-riv5	Kapos_low

#### Land use

ID	Aforest_l km2	Anature_l km2	Aurban_l km2	Awater_l km2	Awetland_l km2	Aagritot_l km2	Asum km2	Area_l km2	Pmm_mean mm
1	152.440	2.030	35.730	3.170	2.640	378.580	574.590	574.600	647.000
2	8.390	0.000	4.060	0.000	5.260	99.930	117.640	117.650	689.000
3	66.470	0.090	2.180	0.530	0.390	51.080	120.740	120.740	670.000
4	53.410	0.000	33.480	9.040	1.490	478.410	575.830	575.830	695.000
5	213.150	2.310	18.650	1.330	0.410	229.980	465.830	465.830	671.000
6	68.650	2.090	13.380	4.310	1.150	217.430	307.010	307.010	654.000
7	61.730	1.010	7.950	0.320	0.000	148.220	219.230	219.240	653.000
8	61.140	1.480	5.530	0.340	3.560	190.040	262.090	262.100	672.000
9	60.940	0.540	13.210	4.680	0.000	306.010	385.380	385.380	662.000
10	15.820	0.350	2.890	2.550	0.000	71.090	92.700	92.690	654.000
11	23.870	0.070	5.700	1.060	2.440	139.430	172.570	172.570	647.000

#### Coefficients

ID	Cforest_kgkm2 kg/km2	Cscatt_mgl mg/l	Curban_mgl mg/l	Cagri_mgl mg/l	Cdep_kgkm2 kg/km2
1	4.000	10.000	0.600	0.860	0.000
2	4.000	10.000	0.600	0.860	0.000
3	4.000	10.000	0.600	0.860	0.000
4	4.000	10.000	0.600	0.860	0.000
5	4.000	10.000	0.600	0.860	0.000
6	4.000	10.000	0.600	0.860	0.000
7	4.000	10.000	0.600	0.860	0.000
8	4.000	10.000	0.600	0.860	0.000
9	4.000	10.000	0.600	0.860	0.000
10	4.000	10.000	0.600	0.860	0.000
11	4.000	10.000	0.600	0.860	0.000

Local yearly load

ID	Magri_l tonnes	Mind_l tonnes	Mscatt_l tonnes	Murban_l tonnes	Mwwtp_l tonnes	Mwater_l tonnes	Mbackgr_l tonnes	Mpopul_l tonnes	Msum_l tonnes	Q_l m3/s	C_l mg/l
1	210.649	0.000	5.367	13.870	13.453	0.000	0.628	32.690	243.968	11.789	0.656
2	59.213	0.000	1.570	1.678	0.000	0.000	0.055	3.248	62.515	2.570	0.771
3	29.432	0.000	0.722	0.876	0.000	0.000	0.268	1.598	31.298	2.565	0.387
4	285.946	0.000	7.262	13.961	0.175	0.000	0.220	21.398	307.564	12.690	0.769
5	132.712	0.000	3.563	7.508	10.954	0.000	0.863	22.02	155.601	9.912	0.498
6	122.291	0.000	3.170	5.250	0.499	0.000	0.288	8.919	131.498	6.367	0.655
7	83.237	0.000	2.057	3.115	0.000	0.000	0.251	5.171	88.660	4.540	0.619
8	109.828	0.000	1.224	2.230	0.000	0.000	0.265	3.454	113.546	5.585	0.645
9	174.218	0.000	3.381	5.247	0.000	0.000	0.246	8.628	183.092	8.090	0.718
10	39.984	0.000	0.732	1.134	0.000	0.000	0.065	1.866	41.915	1.922	0.691
11	77.582	0.000	1.395	2.213	0.000	0.000	0.106	3.608	81.295	3.540	0.728

Accumulated yearly load

ID	Magri_a tonnes	Mind_a tonnes	Mscatt_a tonnes	Murban_a tonnes	Mwwtp_a tonnes	Mwater_a tonnes	Mbackgr_a tonnes	Mpopul_a tonnes	Msum_a tonnes	Q_a m3/s	C_a mg/l	Area_a km2
1	210.6	0.0	5.4	13.9	13.5	0.0	0.6	32.7	244.0	11.789	0.656	574.600
2	59.2	0.0	1.6	1.7	0.0	0.0	0.1	3.2	62.5	2.570	0.771	117.650
3	29.4	0.0	0.7	0.9	0.0	0.0	0.3	1.6	31.3	2.565	0.387	120.740
4	585.2	0.0	14.9	30.4	13.6	0.0	1.2	58.9	645.3	29.615	0.691	1388.820
5	132.7	0.0	3.6	7.5	11.0	0.0	0.9	22.0	155.6	9.912	0.498	465.830
6	840.2	0.0	21.7	43.1	25.1	0.0	2.3	89.9	932.4	45.893	0.644	2161.660
7	923.5	0.0	23.7	46.3	25.1	0.0	2.6	95.1	1021.1	0.433	0.642	2380.900
8	109.8	0.0	1.2	2.2	0.0	0.0	0.3	3.5	113.5	5.585	0.645	262.100
9	284.0	0.0	4.6	7.5	0.0	0.0	0.5	12.1	296.6	13.675	0.688	647.480
10	324.0	0.0	5.3	8.6	0.0	0.0	0.6	13.9	338.6	15.597	0.688	740.170
11	1325.1	0.0	30.4	57.1	25.1	0.0	3.3	112.6	1441.0	69.570	0.657	3293.640

## 5.4 Input files:

### File Catchment.txt

```
!Name;Catment_ID;Catchment_ToID;;ID;ToID;River_ID;CatchmentID_11;HydrologicalRelation11;TotalArea;Urban;Arab
leLand;Pastures;AgriTotal;Forest;Nature;Wetlands;Waters;P_mean_1;,,,,,;
!,,,,,;km2;km2;km2;km2;km2;km2;km2;mm;,,,,,;
Name;ID;ToID;*ID;*ToID;River_loca;CatchID_11;relation;Area_1;Aurban_1;Aarable_1;Apast_1;Aagritot_1;Aforest_1;Anatur
e_1;Awetland_1;Awater_1;Pmm_mean_1
Kapos-riv1;1;4;KA1;KA4;Kapos_up;1;1;574.60;35.73;299.48;11.84;378.58;152.44;2.03;2.64;3.17;647
Orczi-crek;2;4;KA2;KA4;Kapos_up;2;2;117.65;4.06;91.94;5.21;99.93;8.39;0;5.26;0;689
Surjan-cre;3;4;KA3;KA4;Kapos_up;3;3;120.74;2.18;30.97;11.46;51.08;66.47;0.09;0.39;0.53;670
Kapos-rir2;4;6;KA4;KA5;Kapos_up;4;1+2+3+4;575.83;33.48;418.07;27.87;478.41;53.41;0;1.49;9.04;695
Baranya-ch;5;6;BA;KA5;Baranya;5;5;465.83;18.65;172.39;20.78;229.98;213.15;2.31;0.41;1.33;671
Kapos-riv3;6;7;KA5;KA6;Kapos_mid;6;1+2+3+4+5+6;307.01;13.38;195.80;8.27;217.43;68.65;2.09;1.15;4.31;654
Kapos-riv4;7;11;KA6;KA7;Kapos_mid;7;1+2+3+4+5+6+7;219.24;7.95;114.73;14.63;148.22;61.73;1.01;0;0.32;653
Koppány-r1;8;9;KO1;KO2;Koppány;8;8;262.10;5.53;162.90;8.61;190.04;61.14;1.48;3.56;0.34;672
Koppány-r2;9;10;KO2;KO3;Koppány;9;8+9;385.38;13.21;266.68;10.50;306.01;60.94;0.54;0;4.68;662
Koppány-r3;10;11;KO3;KA7;Koppány;10;8+9+10;92.69;2.89;52.80;6.02;71.09;15.82;0.35;0;2.55;654
Kapos-riv5;11;0;KA7;-
Kapos_low;11;1+2+3+4+5+6+7+8+9+10+11;172.57;5.70;117.00;9.42;139.43;23.87;0.07;2.44;1.06;647
```

### File: Industry.txt

```
!ID;Name;Type;CatchmentID_11;CatchmentID_73;TP_1997;TP_1998;TP_1999;TP_2000;TN_1997;TN_1998;TN_1999;T
N_2000
!,,,,;kg;kg;kg;kg;kg;kg;kg;kg
ID_ind;Name_ind;Type;Catchid_11;Catchid_73;TP_1997;TP_1998;TP_1999;TP_2000;TN_1997;TN_1998;TN_1999;TN_2
000
05-035;KAPOSFIL_thread_producing_and_salling_company;Industry;1;11;233;203;114;37;540;121;559;273
05-037;KAPOSVOLÁN_Plc;Industry;1;13;80;55;81;54.7;447;195;570;285
05-038;KAPOSCUKOR_RT_cooling_water;Industry;1;10;0;0;53;39;2002;1493;4534;1456
05-059;KAPOSCUKOR_RT_emergency_reservoir;Industry;1;14;0;0;14;31;0;84;100;368
05-041;Somogy_County_Cardiology_Hospital;Industry;1;11;365;155;270;249;1007.7;1000;777;2115
05-043;PERT_Zobak_mine;Industry;5;78;0;22;59;0;1215;860;1266;0
05-058;KAPOSCUKOR_RT_oxidation_lake_effluent;Industry;1;11;20;0;412;0;1862;2122;2175;0
05-036;KAPOSPLASZT_brush_and_plastic_plc;Industry;1;12;20;12;0;0;436;131;0;0
```

### File: WWTP.txt

```
!,,,,;kg;kg;kg;kg;kg;kg;kg;kg
ID_wwtp;Name_wwtp;Type;Catchid_11;Catchid_73;TP_1997;TP_1998;TP_1999;TP_2000;TN_1997;TN_1998;TN_1999;T
N_2000
04-016;Dombovar;WWTP;6;31;0;0;0;0;314;1114.16;835.12
04-017;Tamasi;WWTP;10;62;0;0;0;0;5388;149;166.075;2080.5
05-034;Juta;WWTP;1;9;207;79;113;130;402;480;407;1352
05-044;Komlo;WWTP;5;78;1428;10891;8740;10230.2;110645;38766;12217;33087.25
05-045;Sikonda;WWTP;5;76;48;43;53;101.4;1067;275;914;608.82
05-046;Orfu;WWTP;5;77;365;394;326;341.28;2396;2552;2546;4737.7
05-047;Sasd;WWTP;5;79;308;182;98;281.46;4014;455;837;375.23
05-048;Magocs;WWTP;6;26;534;279;910;498.73;3031;2907;3063;3801.84
05-040;Kaposvar;WWTP;1;13;10120;16636;12559;13323;40120;36000;37268;41820
05-042;Igal;WWTP;4;23;135;151;200;175;327;2000;1667;1105
```

### File: Coefficients.txt

```
!kg/km2;mg/l;kg/km2;kg/ha;mg/l;mg/l;mg/l;kg/km2;mg/l;kg/km2;kg/km2;kg/km2;mg/l;mg/l;mg/l
Pforest_kgkm2;Purban_mgl;Pdep_kgkm2;Plakeret_kgha;Priverret_kgha;Pagri_mgl;Panimfarm_mgl;Pscatt_mgl;Nforest_kgk
m2;Nurban_mgl;Ndep_kgkm2;Nlakeret_kgha;Nriverret_kgha;Nagri_mgl;Nanimfarm_mgl;Nscatt_mgl;Cjoin
4;0.6;0;0.000701;0.000055;0.86;335;10;13;6.5;0.016268;0.050947;0.016807;9;1510;40;1
```

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## **Appendix A.**

### **Finding catchment areas of Elvis stream reaches**

Within hydrological modelling one important consideration is the topography. The topography controls the drainage of water. From the precipitation as rain or snow and to the final stage when it flows into the oceans. There are many variables that could be extracted from a topographical model that are useful for a hydrologic model. For this project we have been interested in finding the area of land that is draining through each river segment. For each river segment we used the annual expected water discharge pr. sq. meter. Combined with the area we get the expected waterflow through the river segment.

The topography is a good measure to map the drainage network of a landscape. Especially in our climate and with our geomorphology the drainage is directed by the topography. In other areas the drainage might be influenced by groundwater flow. To model this flow we might consider other inputs than the topography.

How do we find the area of land that drains through a given river segment? The physical attributes are easy to accept. We should find nearby areas that are higher than the point and have a steadily descending path to the point. With a topographic map we could draw a line from the point based on the contour lines. This is the main method when establishing Regine catchments. With the introduction of GIS we have introduced new models to describe the topography. Such a model is often called a digital elevation model (DEM).

DEM's are grouped in three kinds based on storage. We have TIN, grid and contour. A TIN, or triangulated irregular network, covers the area with connected triangles. Each vertex has an elevation and position. A grid covers the area with regular cells, most often these will be squares. For each cell we have an elevation. The last model of storage is contour lines. This is the same as ordinary topographical maps. Often it will be the first stage after scanning an original paper-map. The next step could be to compute one of the two other models.

In Norway this has been done by the Norwegian mapping institution. A nationwide grid has been established by interpolating the elevation for each cell. The cell size is 25\*25 m. Source of this dataset are the contour's from the map set in 1:50 000. This is further prepared by known heights for lakes and road-crossings. These are introduced to ensure good quality within the major usages.

The later description is subjected to DEM's based on grid as this has been the model used in this project. Within the software package ArcMap the tools described can be found within the Spatial Extension toolset.

#### **Waterflow direction**

The first stage in a topographic model is to compute the water flow direction. The water flow direction is used as input for the other computations. There exist different strategies to evaluate the direction within each cell. Often they will have the same input, namely the height of the 8 neighbouring cells.

The simplest approach is to specify the direction as one of 8 major directions: N, NE, E, SE, S, SW, W, and NW.

Maidment (2002) presents an algorithm for finding this direction. The neighbour with steepest decent are chosen. The decent are calculated from the differences in height and the horizontal distance between the two cells. If none of the neighbouring cells have a height lower than the centre cell we have to consider a cell further out. This would also be the solution for situations were two or more directions have the same decent.

Often this approach will result in a discretized result Tarboton (1997). One approach to avoid this is to allow flow in diverging directions. This will lead to a smoother result, but just as often it will be too smooth. Another objection is that it seldom will reflect the drainage network at small scales.

Tarboton (1997) presents approaches were the goal is to use one direction specified as a continual value between 0 and  $2\pi$ , instead of the 8 discrete directions. By this approach we will get one direction for each cell. This will also result in a smoother result, but we will get something that reflects the natural conditions in a better way.

The direction within each cell is found by looking at triangle facets. These are created by the centre cell and two of the neighbours that are themselves neighbours. This means that for each cell we will have 8 facets. For each facet we find a normal vector. We are choosing the direction of the facet with steepest downward vector. Tarboton are offering software that can be used to compute these values within ArcMap.

For all of these calculations it's a great concern regarding sinks. That means areas were the topography suggests that it should be a lake, but were we know that it isn't. In these situations we can conclude that the water are infiltrating and flowing with the groundwater. The approach to overcome these situations in our models is to fill the sink. That means that we are elevating every cell until we reach a threshold were we get a flow into neighbouring areas.

## **Accumulation**

When we have established the water flow directions we are ready to generate an accumulation map. This map will suggest the pattern of water flow within the area. There are different solutions for generating this map according to the approach used to get the directions, but the overall goal is to specify how many cells that contributes to water flow within each cell. Often we would express this as a physical variable by multiplying by the area of the grid cell.

In the basic approach each cell are directed to one of the neighbouring cells, and therefore the calculation is simply to find how many cells that are directed toward each cell. This is solved by finding every cell that doesn't have any inbound flow. These are given the value 1. The next step is to find every cell they are flowing toward and add up the contribution. This is repeated until every cell has been visited.

Tarboton (1997) suggests to give both of the neighbouring cells that constitutes the triangle facet with highest decent a fraction of the water flow. The fraction will be based on the water flow direction. This is also the method in models with diverging water flows, but the fraction would be the number of diverging cells.

The accumulation map could be used to see the pattern of drainage within the area, but can also be used to create a map of river network. This is done by specifying a threshold for river establishment. Each cell that has an accumulation value above this level is considered as a river. There exist some papers that look at the issues regarding how to specify the level of river foundation.

## How to use these models as input for Teotil

Our approach was somewhat different. We had the river network from Elvis, and wished to find the contributing area of each river-segment. These are specified as a line of points. Two or more segments are connected at a single point.

The solution we found was to use the same grid as in the DEM, and mark each cell that was interfered by a river segment by the identification of that segment. Since a grid can only hold one value for each cell this means that at the junctions only one of the river segment are represented. This doesn't seem to influence the final result.

From this grid we investigated every cell with a given id, and found those cells that had a main direction of flow toward the cell. These cells were given the same id as those they were flowing toward. This was repeated until there were no new cells. Unfortunately this wasn't coincident with every single cell having got an id. Our hope was that the grid should reflect the watersheds within the area, but our first result wasn't very reliable. Some of the watersheds were small in size, and many of them would only reflect one of the river sides.

This was the result of differences between the two sources: The Elvis network and the topographic grid. There is no guarantee that the river is mapped to the lowest part of the neighbourhood. Let us think of a valley floor with a little river. When we use a grid with a width of 25 m, the floor might constitute one or two cells and the river could as well hit one of the neighbouring cells. This would imply that only one of the valley sides is included within the watershed.

Steps to overcome these problems were as follows. First of all we lowered all the cells that constituted the river network by 50 meter. By doing this we ensured that all waterflow was directed toward the river network cells. Near the ocean we had a similar problem, and we introduced some new by lowering the river. To overcome these we used a topographic map of the oceans to lower these areas by 100 m. The same dataset would later be used to clip the final result to extract land area.

The next obstacle was in conjunction with the Regine data source. Some of the borders between basins didn't quite fit. Whether this was an error in Regine or the topographic model wasn't our problem. We used Regine as the true answer and made some corrections to the topographic model to avoid the problems. One of the problems was that some areas near the border weren't reach by our watersheds. This was corrected by raising all neighbouring Regine basins by 1000 meter. Another problem was that some areas seemed to flow out of the basin into the neighbouring. This was solved by clipping the final result with the Regine basin.

The final obstacle was connected to the behaviour at sea level. These cells will not flow in the direction of a river segment in Elvis, but will drain straight to the ocean. In Regine these areas are treated as sub-basins of one of the major river catchments whether it influences that river or not. We used these basins to model the areas that didn't end up in one of Elvis' watersheds. It's important not to forget these areas, because they often will have industry or other sources of interest for Teotil. This method could be error prone because the sub-catchments don't reflect the drainage of water. One sub-catchment could constitute both some mainland and an island, or it could be both sides of a river outlet.

This was the input for the Teotil model. For each river segment we would now find the area that drained through that segment. And we could find the area that runs straight to the ocean subjected to a Regine sub-basin.

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