Summary

A case study for simulation of nitrate transport in groundwater was carried out, in order to investigate methods and tools for prediction of pumped groundwater quality at drinking water wells. The case study concerns Pumping Station Roosteren, in Limburg Province.
Construction of the flow model and simulation of chloride transport are described in *Technical Report* 1 and 2 of this project.

Observed nitrate concentrations
Within 5 m. distance to the groundwater table, observed nitrate concentrations are relatively high, up to 80 mg/l. Variability of nitrate concentrations in time and space is high (<0.5 – 80 mg/l) in these shallow sub-soil sections. Nitrate concentrations in groundwater decrease in downward direction, resulting in values of less than 5 mg/l in sections below 20 m. below surface. The average of observed nitrate concentrations in the Meuse at Keizersveer is 3.7 mg N /l (ca. 16 mg NO3/l) (1970-1990). Pumped groundwater at P.S. Roosteren contained on average 17 mg NO3/l. Only 4 observations are available (1991 – 1997). Close to P.S. Roosteren, average nitrate concentrations are high in comparison with the rest of the study area. No clear trend in observed nitrate concentrations over time can be distinguished.

Model results
Simulation of nitrate transport was carried out for the period 1983 –1996. Transport through saturated and unsaturated zones was simulated separately. Unsaturated nitrate transport was simulated by means of the REGIONIT model (Beekman, 1997). Results of the REGIONIT simulations were used as input for simulation of nitrate transport in the saturated zone by means of MT3D (Papadopoulos, 1990; Zheng et al. 1998). Alternatively, top layer boundary conditions for simulations with the MT3D model were based on interpolation of observed nitrate concentrations. Both simulation approaches resulted in too high nitrate concentrations. Best results were those where the top layer conditions were based upon interpolation of observed nitrate concentrations. Apparently, the REGIONIT model required further calibration.
Calibration of the REGIONIT model was not carried out for two reasons:

- calibration cannot be evaluated directly, as no observations on nitrate fluxes into the saturated zone are available.
- quantitative data on denitrification in the unsaturated zone are not available;

Therefore, top layer boundary conditions were based on annual averages of observed nitrate concentrations.
Transport simulations by means of MT3d, where nitrate was treated as a conservative species, resulted in systematic overestimation of nitrate concentrations. The overestimations were probably due to biodegradation of nitrate. Therefore, non-conservative transport simulations were carried out, where biodegradation was simulated as a first order decay reaction. This approach lead to an improvement of general performance of the model. The rate of denitrification was determined by analyses of the nitrate-chloride ratio in analysed samples. The gradient of the nitrate-chloride ratio along pathlines formed the basis for the calculation of the local rate of denitrification.
Absolute differences between observed and simulated chloride concentrations according to the different approaches are enumerated in table 1.

Top boundary condition	**Type of transport approach**	**Average error (layer 2 – 8) mg/l**	**Average absolute error (layer 2 – 8) mg/l**
REGIONIT	Conservative	10.7	11.8
OBSERVED	Conservative	7.3	8.7
OBSERVED	Non-conservative	-0.15	5.2

Simulation of nitrate concentrations in pumped groundwater at P.S. Roosteren became less accurate by introducing biodegradation of nitrate into the model. No significant relation between soil type and biodegradation could be found.

General Project Data

Project title: PRESYS-GQ:
Demonstration of a Groundwater Quality Prediction System for Impact Assessment of Landuse Development on Sustainable Drinking Water Production
LIFE96ENV/NL/230

Project location: Pumping Station Roosteren
Region/country: Limburg Province, The Netherlands

Beneficiary's full name and address:

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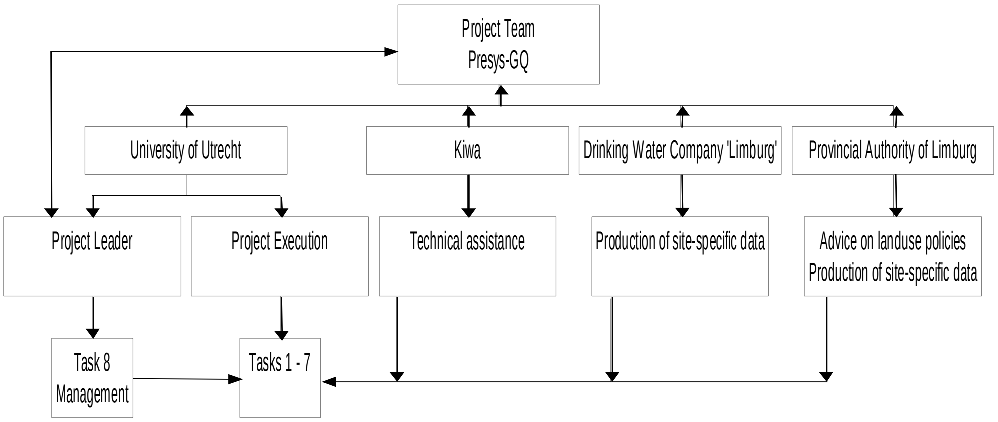
Project manager: Dr. Paul P. Schot

Duration: 1-6-1997 - 1-6-2001 (48 months)

Total costs: 425,053.04 Ecu
Contribution by LIFE: 212,526.51 Ecu

Presys-GQ Organisation Chart



Organisational Structure

Figure 1: Organisation chart PRESYS-GQ Project.

Participants of the project:	**Tasks:**
- University of Utrecht	all main tasks;
- Kiwa	technical assistance, development of software modules;
- Drinking Water Company Limburg	production of site-specific data;
- Provincial Authority Limburg	advice on landuse policies, production of site-specific data.

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1. Introduction

1.1. Background

This report forms part of the PRESYS-GQ project, which is focussed on the development of a groundwater quality prediction system. The project is carried out by Utrecht University. Other project participants are Drinking Water Company Limburg (WML), Provincial Authorities of Limburg Province and Kiwa Onderzoek en Advies.

In the European Union, groundwater quality is deteriorating, thus threatening the drinking water supply of tens of millions of people. One of the reasons groundwater contamination is still continuing, is the fact that local authorities (provincial and municipal) acting as land use planners, lack insight in the relation between different types of land use and their effects on groundwater quality. Therefore, local authorities generally disregard the need for sustainable (non-polluting) forms of land use in areas where groundwater contamination may lead to severe problems in drinking water wells.

On the other hand, drinking water companies generally lack insight in the future quality development of their primary source, i.e. groundwater. When a groundwater contamination is detected in water samples from monitoring or production wells, often rather ad-hoc decisions are made to invest either in purification facilities or in reallocation of wells, both of which are very costly. However, the long-term efficiency of these investments is unclear due to inadequate insight in future groundwater quality development.

In the light of the above there is an obvious need for a groundwater quality prediction system which can be used by the above mentioned actors relevant for the drinking water supply and which can facilitate an integrated decision making. This system should be accessible for experts as well as non-experts.

The prediction system will consist of an existing groundwater modelling package, which will be integrated with several new package modules. These new package modules will enable simulation of chemical processes in groundwater and soil, relevant to the production of drinking water. In this way, effects of different landuse policies on groundwater quality can be demonstrated. Simulation results will be presented by means of state-of-the-art computer visualisation techniques.

To demonstrate the feasibility of the prediction system a case study will be worked out for an area from the Province of Limburg, the Netherlands. Nonetheless, the prediction system will be designed for general purpose and will be applicable throughout the Community.

1.2. Objectives and project phases

General objective of the PRESYS-GQ Project is the development of a groundwater quality prediction system which can be used by actors relevant for the drinking water supply and which can facilitate an integrated decision making. This system should be accessible for experts as well as non-experts.

The project consists of three phases. The relation between phases and tasks is described in the following paragraph.

A. Standard Model Construction
  - tasks 1, 2, 3
  - task 6 partly

B. Advanced model Construction
  - tasks 4, 5
  - task 6 partly

C. Dissemination
  - task 7
  - task 6 partly

In phase A the following tasks are distinguished:

1. Construction of a groundwater flow model (MODFLOW)
2. Construction of a conservative transport model for chloride (MT3D-Cl)
3. Standard non-conservative transport model (MT3D-decay)

This report pertains to the results of the aforementioned task 3: Construction of a non-conservative transport model for simulation of nitrate transport. The preceding tasks were reported in Technical report 1 and 2. The tasks are concisely described in the following paragraphs.

Figure 2: Location of the study area

1.3. Description of task 1 (Technical report 1)

Aim:
Construction of a groundwater flow model of the selected case-area.
Method:
Groundwater modelling software code MODFLOW.
Activities:
0.Selection of a representative case-area.
1.Collection of site-specific data as input for MODFLOW.
2.Simulation of groundwater levels.
3.Calibration of model by comparing simulated water levels with observed water levels in monitoring wells.
4.Calculation of streamlines and delineation of the groundwater recharge area.
5.Technical report T1.

1.4. Description of task 2 (Technical report 2)

Aim:
Simulation of conservative transport of chloride in the case-area.
Method:
1. Simulation of groundwater fluxes in the case area by means of the groundwater modelling software code MODFLOW.
2. Simulation of chloride transport in the case area by means of the groundwater transport software code MT3D96.
3. Chemical analyses of water samples.

Activities:
1. Collection of site-specific data on chloride deposition over time.
2. Collection of water samples for chemical analyses.
3. Simulation of groundwater fluxes over time after refining the groundwater model, which has been constructed during the execution of task 1. (MODFLOW).
4. Simulation of transport of chloride in the saturated zone over time (MT3D96).
5. Calibration of chloride transport by comparison of simulated with observed chloride concentrations.
6. Writing technical report T2.

Relation to other tasks:
The construction of the flow model during task 1 forms the basis for flow simulations of task 2.
The adapted flow model constitutes input for tasks 3,4,5 and 6.

1.5. Description of task 3 (this report)

Aim:
Simulation of non-conservative transport of nitrate in the case-area, using the flow model from task 2.

Method:
1.KIWA-code for leaching of contaminants from unsaturated zone.
2.Groundwater transport software code MT3D using a decay factor to account for denitrification.

Activities:
1. Collection of site-specific data on nitrate input over time in relation to landuse.
2. Simulation of leaching of nitrate ions from unsaturated zone over time.
3. Simulation of transport of nitrate in the saturated groundwater zone using decay factor in MT3D.
4. Calibration of nitrate transport by comparison of simulated with observed nitrate concentrations in production or observation wells.
5. Technical report T3.

Relation to other tasks:
Results constitute input for tasks 6 and 7.

1.6. Contents of the Report

A general description of the PRESYS-GQ project and of the tasks related to this report is described in Chapter 1 of this report. Chapter 2 contains is about observed nitrate concentrations in the study area. In Chapter 3, modelling of nitrate leaching from the unsaturated zone by means of the REGIONIT model is described. Chapter 4 is about transport of nitrate in the saturated zone.

2. Observed Nitrate Concentrations in the Model Area

2.1. River Meuse

Sources of data

Observed nitrate concentrations in the Meuse originate from Riza (1992).

Data availability

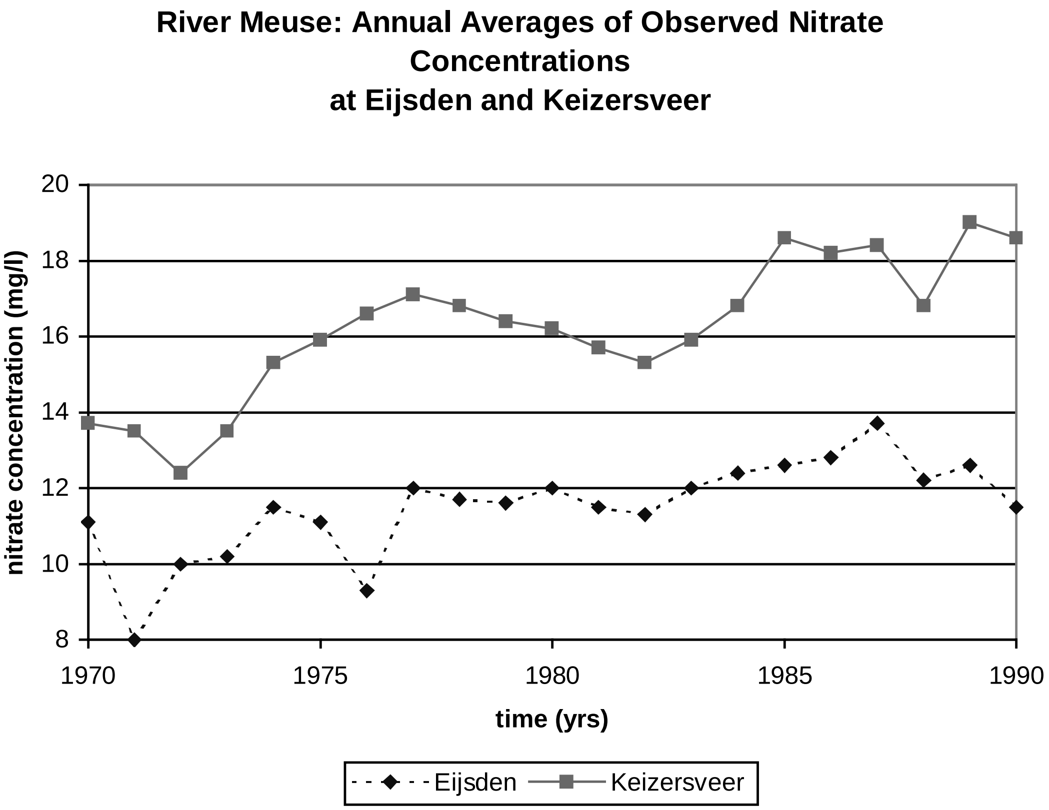
Data were measured at river monitoring stations near Eijsden and Keizersveer. Available data concern annual averages from 1970 to 1990.

Description

Eijsden is located in the southern part of Limburg Province, within 10 km. distance from the Belgium frontier. Keizersveer is located at 50 km. from the mouth of the River Meuse. The model area is located in between these locations.

At Keizersveer, observed nitrate concentrations between 1983 and 1990 vary between 16-19 mg/l (see Figure 3). Over the considered period, a slight increase of nitrate concentrations can be observed. Since the annual variability of nitrate concentrations over the simulation period does not exceed 5 mg NO3/l, river cells in the numerical model were allocated a constant value throughout the whole period. In the model area, average concentrations between 1983 and 1996 are estimated at ca. 20 mg NO3/l.

Figure 3: Average observed nitrate concentration in the River Meuse.



2.2. Groundwater

Sources of data

Observations on nitrate concentrations in groundwater have been supplied by Waterleiding Maatschappij Limburg (WML) and the Rijks Instituut voor Volksgezondheid en Milieu (RIVM). An overview of these data is supplied by Olde Wolbers (1998).

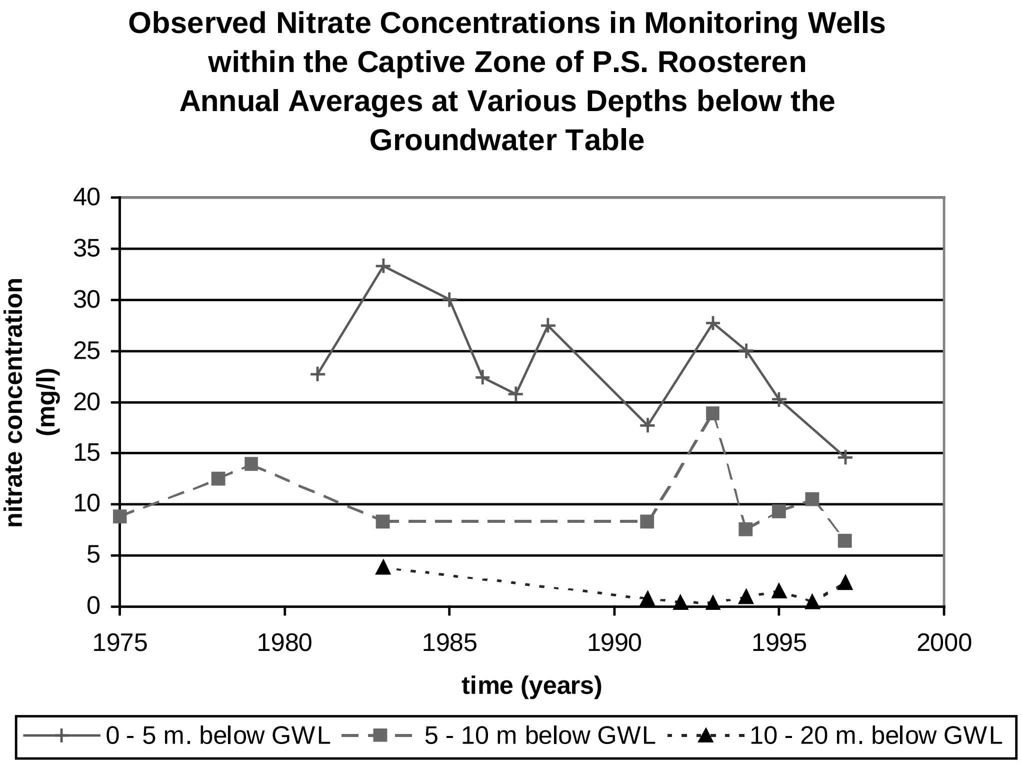


Figure 4: Average nitrate concentrations over time at various depths.

Data availability

The major part of the available data stems from the western part of the model area (see Map 1). All available data were sampled at locations in the Netherlands. The total number of analyses is 662, measured between 1969 and 1998, at 199 different screens. From these, 580 samples have been taken at locations within the model area. Long series of data at any location are scarce. Many screens have been analysed once or twice only: the average number of analyses per screen is ca. 3. 8 observations are available on nitrate concentrations in pumped groundwater at P.S. Roosteren, sampled during the simulation period (1983-1996).

Description

Observed nitrate concentrations in groundwater within the model area vary from 0 (i.e. < detection limit) to 80 mg/l. Highest nitrate concentrations occur in the NW part of the model area. In the SE section of the model area, concentrations are lower. The observed difference is probably related to the kind and intensity of local agricultural production and presence of urban zones.

With respect to the vertical distribution, nitrate concentrations generally decrease with increasing sample depth. An interpolated surface of observations on nitrate concentration at variable depths is presented in Map 2 to Map 5. Highest concentrations occur close to the watertable. Below 20 m. under the water table, no significant presence of nitrate has been found. High concentrations occur near the watertable and originate from young groundwater, polluted by human activities. Spatial variability is also highest near the watertable.

Figure 4 illustrates the variability over time within the model area. Only averages of more than 3 observations are displayed in the graph. Variability is highest in shallow groundwater. At greater depth below the groundwater table, temporal and spatial variation is dampened by the nature of the groundwater transport process. Average concentrations over time seem to undergo a modest decrease since the beginning of the eighties. However, interpretations concerning the trend within these observations should be treated with reserve, as the number of available observations is quite limited.

3. Assessment of Nitrate Quantities that Enter the Saturated Zone

3.1. Introduction

Nitrates enter the saturated zone by leaching out of the unsaturated zone. The MODFLOW/ MT3D models concern transport through the saturated zone. Nitrate fluxes that enter the saturated zone need therefore to be determined separately, as they form a major boundary condition to the transport model. During task 2, transport of chloride ions over time was simulated. In order to assess the quantities of chloride that enter the saturated zone, simulation of chloride transport through the unsaturated zone was initially assessed by means of application of the REGIONIT model (Beekman, 1997). Results of the simulation of chloride leaching by means of REGIONIT (Otte, 1998) turned out to be too inaccurate, which could clearly be distinguished by the frequent occurrence of (erroneous) negative quantities of chloride entering the saturated zone. The reason of the observed inaccuracy originates from the adopted simulation approach, where chloride quantities that enter the saturated zone are calculated as the difference of total quantities of chloride that enter the soil (manure, fertiliser, road salts) and the quantities that leave the land in harvest products. The results of these balance calculations are inaccurate because the uncertainties of both these quantities are relatively large in comparison with the difference, calculated between the two quantities. Therefore, a different approach was adopted for the definition of the boundary conditions of the top layer of the transport model. In Technical Report 2, chloride concentrations in the top model layer were based upon average observed chloride concentrations in the top layer of the model.

Within the framework of this study, the REGIO_NIT model was applied again, this time for nitrate (Beekman, Kiwa Environmental Consultants). Inside the REGIONIT model, transport simulation of nitrate transport through the unsaturated zone is approached differently from chloride transport. In stead of an exclusive mass balance approach, as is applied for chloride transport, leaching of nitrate is also based upon empirical relations of relevant process variables and conditions, such as the soil type, organic matter and agricultural production (Beekman 1997).

3.2. Modeling approach

Results of the simulation of transport of nitrate through the unsaturated zone by means of REGIONIT consist of calculated annual nitrate loads that enter the saturated zone, expressed in mass per unit area per unit time. In order to translate these results into nitrate concentrations of the groundwater, it should be divided by the recharge volume over the relevant period. Recharge fluxes are not precisely known and resulting nitrate concentrations are quite sensitive to the magnitude of the recharge flux. An evaluation of the reliability and accuracy of the simulation results cannot be carried out directly therefore, as no direct observations are available on the mass flux of nitrates into the saturated zone, nor on the nitrate concentrations of soil moisture leaching out of the unsaturated zone. Results based on the REGIO_NIT approach were evaluated by comparison of simulation results of transport in the saturated zone, by means of MT3d. Two approaches with respect to top layer boundary conditions were compared (see figure 3):

- top layer boundary conditions based upon observed nitrate concentrations;
- top layer boundary conditions based upon REGIO_NIT model results.

The first approach was carried out by allocation of constant annual concentrations to the top layer of the MT3d model, based upon spatial linear inverse distance interpolation of observed values. The second approach, using the REGIONIT model, was carried out by allocation of constant annual concentrations to the top layer of the MT3D model, based upon the ratio of annual mass fluxes of nitrate as generated by the REGIONIT simulation, and average volumes of recharge (calculation of recharge is described in T2).

Simulated nitrate concentrations by both approaches were compared with observed nitrate concentrations.

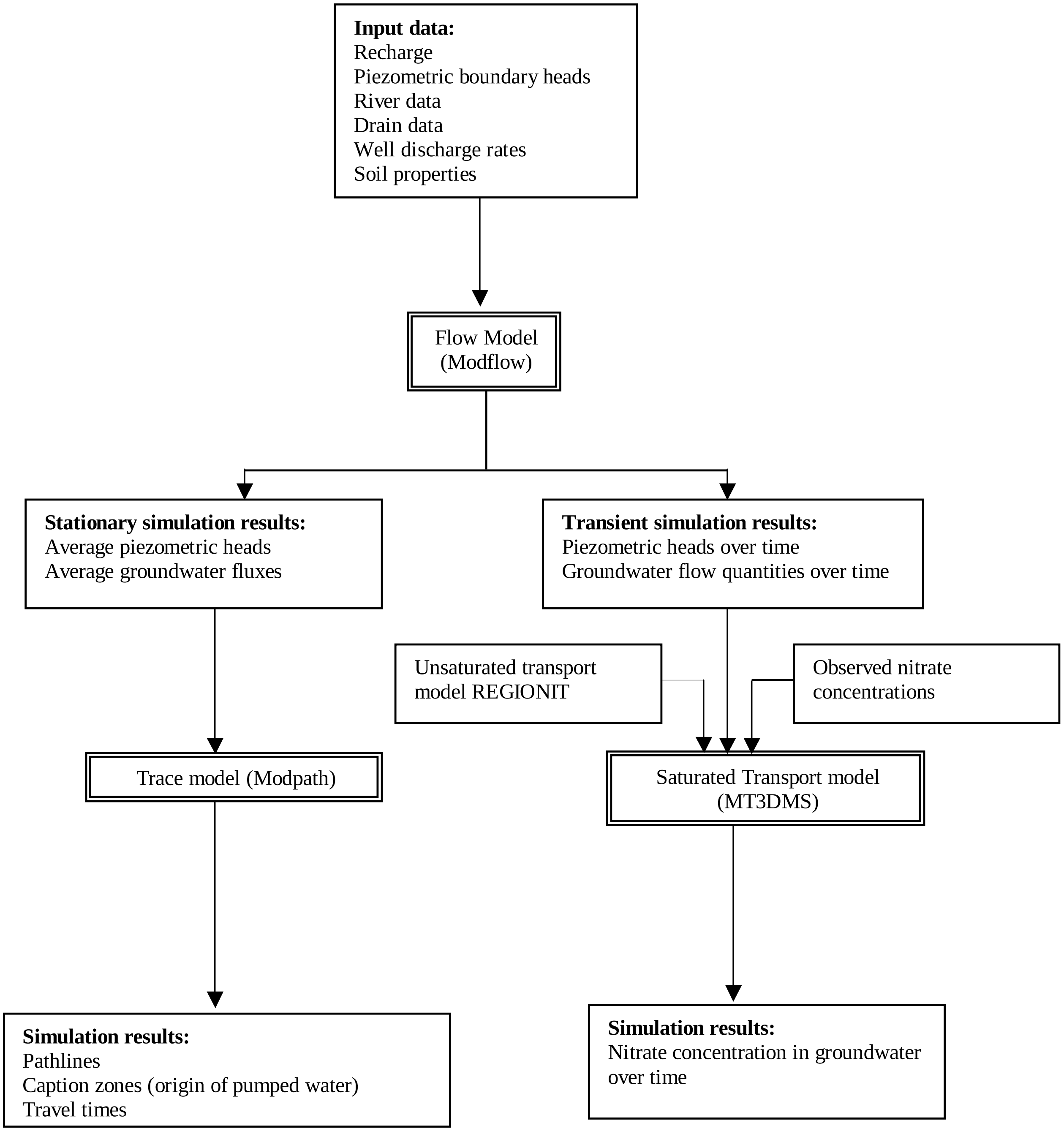


Figure 5: Schematic presentation of modelling approach

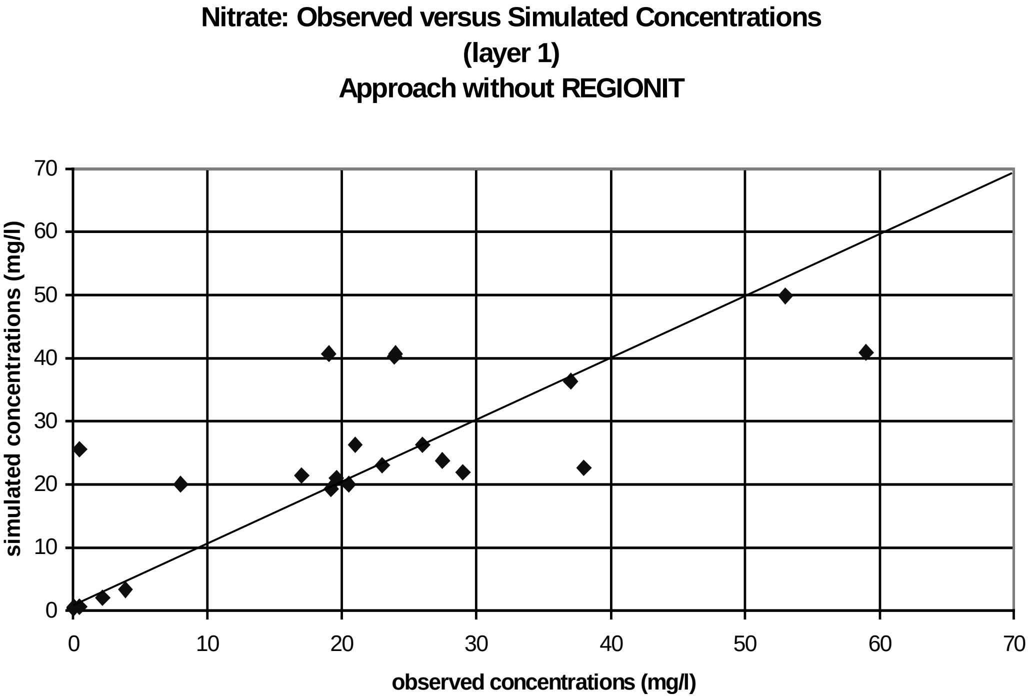


Figure 6: Observed versus simulated concentrations (layer 1); approach without REGIONIT.

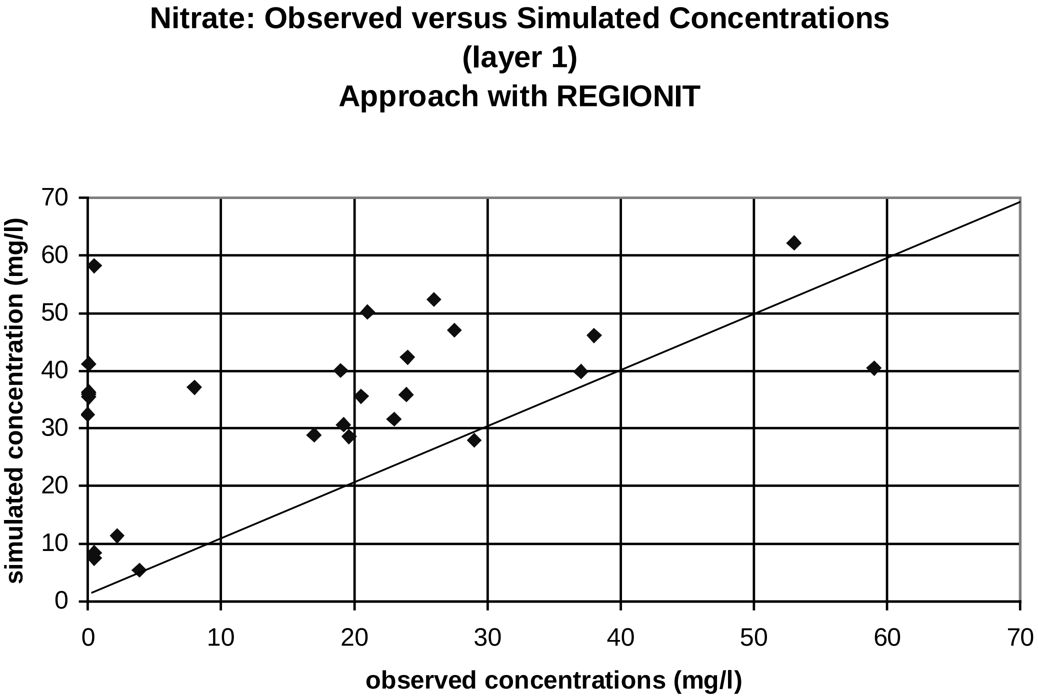


Figure 7: Observed versus simulated concentrations (layer 1); approach with REGIONIT.

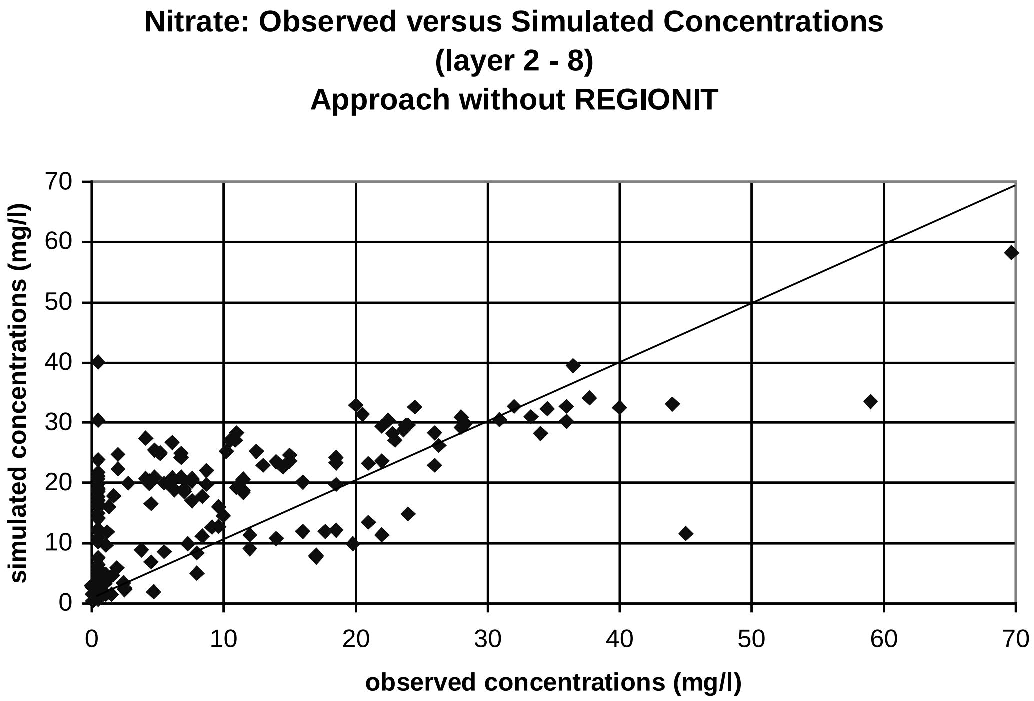


Figure 8: Observed versus simulated concentrations (layer 2-8); approach without REGIONIT.

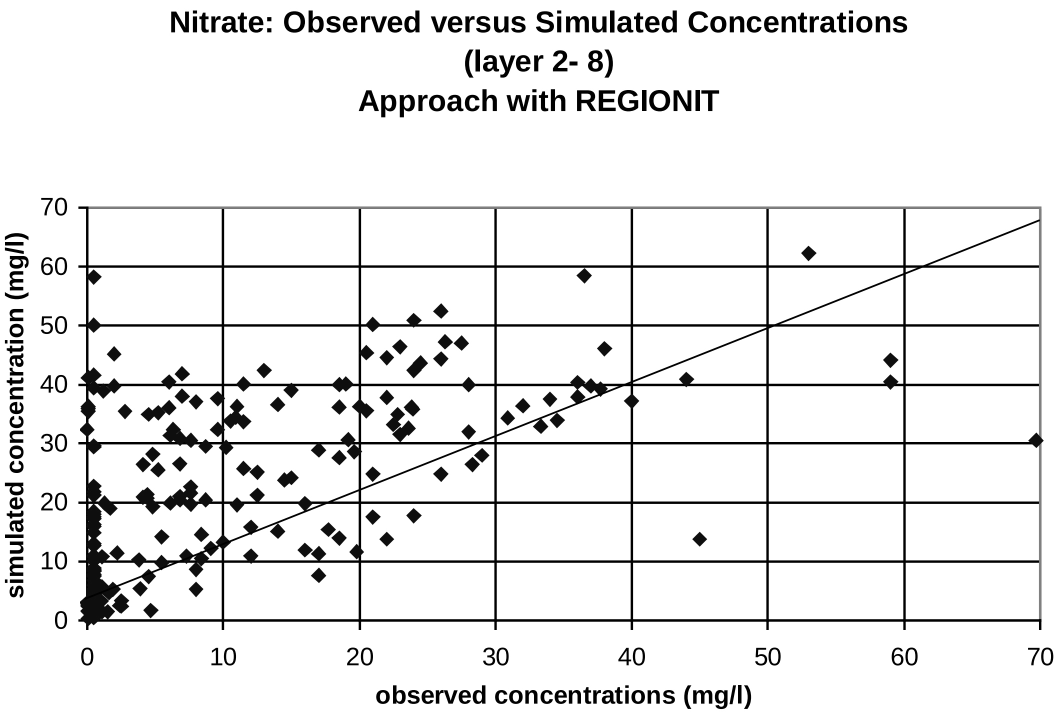


Figure 9: Observed versus simulated concentrations (layer 2-8); approach with REGIONIT.

3.3. Simulation results

Results of the simulations according to the two approaches are presented in Figure 6 to Figure 9. The simulation that involved data generated by REGIONIT resulted in a pronounced general over-estimation of nitrate concentrations in the groundwater. Simulations where boundary conditions for the top layer were based on interpolation of observed nitrate concentrations resulted in a better correspondence with observed data, although this approach also resulted in too high concentrations on average. In both simulations, no biodegradation of nitrate was simulated. Differences in simulated nitrate concentrations according to both approaches were negligible in layers that represent depth below 12.5 m. NAP. Apparently, no significant groundwater quantities from the top of the watertable reached these depths within the simulation period (1983 - 1996).
The comparison between the two approaches and observed concentrations points out the need for calibration of the REGIONIT model.

3.4. Discussion

The approach within the REGIONIT model contains a number of advantages as compared to the definition of top layer boundary conditions on a basis of interpolated field data:

- a process-model approach (such as REGIONIT) is more comprehensive and enables to relate the leaching of nitrate to relatively well known process factors such as soil type and agricultural production, as compared to the assessment of quantities of nitrate based on a 'black box' interpolation of observed concentrations;
- evaluation of the impact of scenarios for changes in landuse or water management is possible.

The REGIONIT approach may therefore result in a potentially better assessment of nitrate quantities entering the saturated zone, than interpolation of sparse observations in monitoring wells.

MT3d simulations based upon data that were generated by the REGIONIT approach resulted in general over-estimations of nitrate concentrations. Apparently, the REGIONIT model needs to be calibrated. However, calibration of the REGIONIT model is only possible if a comprehensive pattern in deviations of the model results can be discovered. Serious set backs with respect to the calibration consists in:

- the virtually unknown local influence of biodegradation of nitrate;
- the fact that the results generated by the model cannot be compared directly to observed values, as they are generally unavailable, which obliges to a 'lumped calibration' with recharge and saturated transport models.

If biodegradation of nitrate would occur homogeneously, it might be possible to identify how major process factors such as landuse, soil type, or thickness of the unsaturated zone are related to model errors. However, due to the pronounced heterogeneity of soil composition (see Map 6) and hydrologic conditions, it is highly unlikely that denitrification rates are homogeneous over the model area. Thus, calibration of the REGIONIT model for conditions in the current model area seems only promising if biodegradation of nitrate in the unsaturated zone can be assessed with a sufficient degree of precision, which is unfortunately not the case.

Since the current study does not involve the evaluation of scenarios of different land use policies and calibration of the REGIONIT model would demand extensive further research, it was decided that top layer boundary conditions would be based on observed nitrate concentrations, as these produced better results. Top layer boundary conditions for all transport simulations that are described in the remaining chapters of this report were therefore based upon interpolation of observed nitrate concentrations.

4. Simulation of Nitrate Transport in the Saturated Zone

4.1. Introduction

Results of the MODFLOW model that was constructed during task 2 (see Technical report 2) consist of both stationary and transient groundwater fluxes. The output that was generated by means of the MODFLOW code, was used as input to the MT3dMS transport model (Papadopoulos, 1990; Zheng et al. 1998). The transport simulations were based upon transient flow simulations that were generated by the MODFLOW model, representing the period from 1983 to 1996. By simulating the past, performance of the model can be assessed by comparison of simulated with observed concentrations. It is assumed that a satisfactory simulation of nitrate transport implies that the related processes and variables are sufficiently implemented in the model. Thus, simulations by means of the developed models can contribute to a better understanding of the relevant processes and to evaluation of management scenarios for the future.

4.2. Conservative transport

At the first stage of the transport simulations, nitrate transport was simulated in a conservative manner. The simulations were carried out analogous to the approach adopted for the chloride simulations (T2). Contrary to the good model results for chloride, simulated nitrate concentrations were systematically too high, as compared to observations. A probable explanation may be the biodegradation of nitrate within the model area. If this hypothesis can be confirmed, and indeed biodegradation of nitrates forms the reason of the over-estimated nitrate concentrations, then conservative transport results can be used to indicate the locations of areas where biodegradation of nitrates occurs.

4.3. Non-Conservative transport

A first order irreversible reaction was added to the simulations, in order to account for biodegradation of nitrate. The reaction type forms a standard option of the MT3D code and is defined as:

$$C(t) = C0*0.5\text{\textasciicircum}(t/L) \qquad (1)$$

Where:
t: time (T)
C(t): concentration at time t (ML^{-3})
C0: initial concentration (ML^{-3})
L: half-life (T)

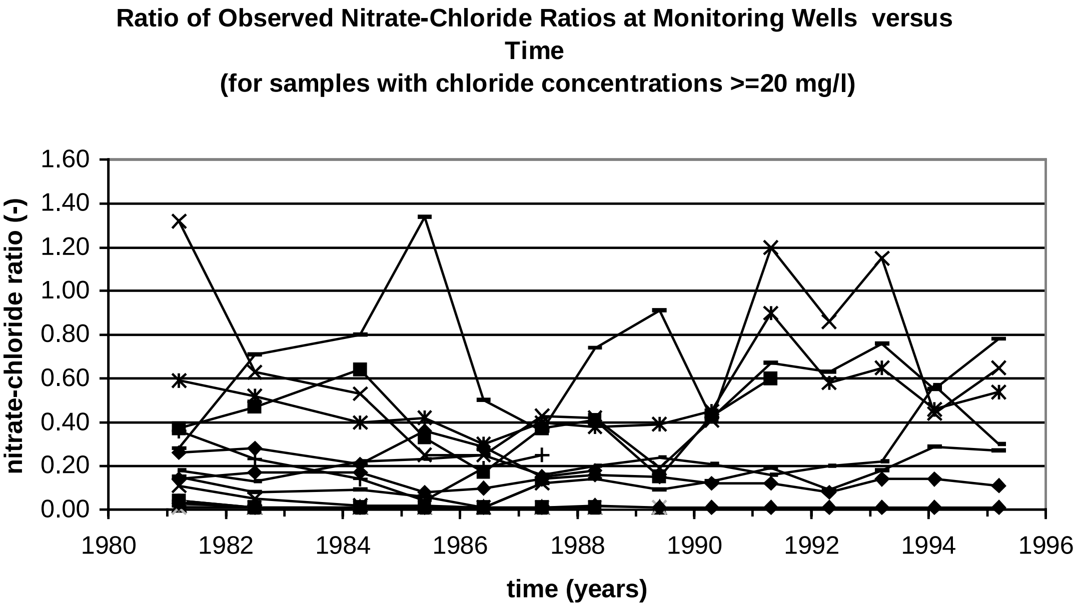
In this approach, the value of L represents the rate of denitrification. A quantification of the spatial distribution of reaction rates could in principle be based upon the degree of over-estimation of nitrate concentrations by the conservative transport simulations, but such an approach would not distinguish between over-estimations due to biodegradation and the impact of possible model errors. Thus, the introduced process model of biodegradation would form a compensation for both ‘true’ biodegradation and possible model errors. An alternative method, by which biodegradation of nitrate could be determined independently of simulation results, would offer a better confirmation of the conservative transport simulations. Therefore, the rate of biodegradation of nitrate was assessed by analyses of the ratio of observed nitrate and chloride concentrations within the model area. Thus, assessment of reaction rates of denitrification could be determined independently of the conservative transport simulations. The reaction rate was determined by calculation of the gradient of nitrate-chloride ratios along pathlines of the flow model, calculated with MODPATH. Samples with chloride concentrations less than 20 mg/l were considered unpolluted and left out of the analysis.
The approach was based upon the following reasoning:

1. Over the past 15 years, no pronounced trend of the nitrate-chloride ratio can be distinguished in any of the monitoring wells. This is illustrated by Figure 10, which displays the nitrate-chloride ratio over time, at a number of observation wells at different depths. Although variation in time of the nitrate-chloride ratio occurs frequently - particularly in screens that are located within 5 m. vertical distance of the groundwater table - no clear trend over time can be observed. It is therefore assumed that the average ratio of nitrate-chloride concentrations at fixed locations in the groundwater has not changed significantly.

2. According to pathline calculations, vertical flow velocities of groundwater in the study area are 0.5 - 1 m per year in the upper 15 m. of the saturated zone. Assuming that no biodegradation of nitrate occurs, the absence of a clear trend in nitrate-chloride ratios over the last 15 years would imply that, between 0 and 15 meter below groundwater level, no clear vertical stratification of the nitrate-chloride ratio would exist.
3. However, in general a clear vertical stratification of the nitrate-chloride ratio exists (
4. Figure 11). The average nitrate-chloride ratio of groundwater apparently becomes reduced during the flow process. This points towards the occurrence of biodegradation of nitrate. Not all samples show a significant reduction of nitrate-chloride ratio as compared to elevations closer to the groundwater table. Apparently, no substantive biodegradation of nitrate occurred near these monitoring wells.
5. According to the assumptions and observations stated here above (1-3), the nitrate-chloride ratio can be used for quantification of rates of biodegradation of nitrate, provided that no pronounced mixing of groundwaters with very different origin occurs. The half-life of first-order decay of nitrate can thus be defined as:

$$L=dt* \log10(0.5)/\log10(dratio) \qquad (2)$$

Where:
dt: travel time of water particles between two locations (T)
dratio: change of nitrate-chloride ratio two locations (-)



Ratio of Observed Nitrate-Chloride Ratios at Monitoring Wells versus Time
(for samples with chloride concentrations >=20 mg/l)

Figure 10: Nitrate-chloride ratio over time at specific locations

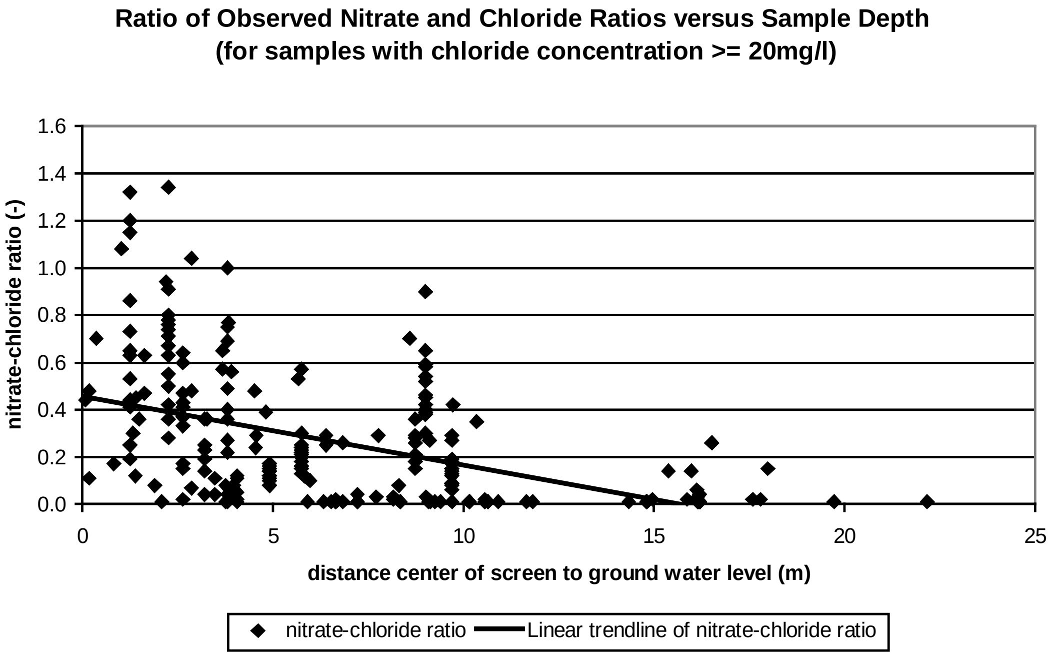


Figure 11: Nitrate-chloride ratio versus sample depth

In Map 7 to Map 10, locations with probable biodegradation of nitrates are indicated. The identification of sites was based on two approaches:

- Over-estimation of nitrate concentrations by conservative transport simulations;
- A nitrate-chloride ratio < 0.2, with simultaneously chloride concentrations > 20 mg.

The results of the quantification of rates of biodegradation according to the nitrate-chloride ratio approach is presented in Map 11 to Map 13. Below 15 m. NAP, no significant changes in nitrate-chloride ratios along pathlines were found.

4.4. Simulation results

Results of the non-conservative transport simulations of nitrate showed a significantly better correspondence with observed values, as compared to conservative simulations (Figure 12). At some locations, no significant biodegradation of nitrate could be observed, according to the adopted approach. In general however, the results indicate that biodegradation of nitrate plays an important role in the model area. Map 14 to Map 27 display simulation results and relevant field data for two cross-sections. The simulation run without biodegradation of nitrate displays a gradual increase over time of nitrate concentrations in the lower sections of the subsoil. The simulations with biodegradation of nitrate do not show such a gradual increase, on the contrary, average nitrate concentrations decrease over time. Rates of biodegradation seem to be somewhat too high, if simulated concentrations are compared to averages of observed values over the relevant periods. Near P.S. Roosteren, groundwater that originates from the river Meuse and both deep and shallow soil sections comes together; this probably reduces the reliability of the adopted approach. A comparison between indicative predictions of nitrate concentrations for the year 2060 according to both conservative and non-conservative modelling results, illustrate the importance of biodegradation of nitrate in the model area. (See Map 28 to Map 31). Although non-conservative transport simulation of nitrates generally performed considerably better than conservative simulations in this study, this was not the case for simulated concentrations in pumped groundwater. The average nitrate concentration in pumped groundwater is ca. 16 mg/l., whereas simulated concentrations by the non-conservative model result in average concentrations of ca. 6 mg/l. The reason why such pronounced differences occur is most probably related to the scarce availability of observations of nitrate concentrations at some distance of the pumping well. Very few observations are available from the part of the captive zone where travel times to the pumping station exceed 5 years. Therefore, initial concentrations in those parts of the captive zone could not be allocated with sufficient precision.

Determination of the rate of biodegradation in the vicinity of the pumping well is also prone to errors, as pathlines are highly dependent on pumping rates. Determination of the rates of biodegradation was based on average stationary flow patterns and flow velocities, whereas real flow conditions have been variable

due to the variable pumping rates. As different types of groundwater come together near the screens of the pumping well, the mixing effects that are invoked by pumping, introduce errors in the determination of the rate of biodegradation.
Further calibration of the model by adjusting start-concentrations and or rates of denitrification could reduce diffrences between observed and simulated nitrate concentrations. However, without additional field data, it cannot be determined in which degree either denitrification or initial nitrate concentrations are not represented correctly within the model. Considering the absence of empirical data on the biodegradation of nitrate and the scarce availability of other relevant field data, it was decided that no additional calibration would be carried out. Additional gathering of field data, particularly with respect to observed nitrate concentrations, is thought to be a better strategy for the solution of inaccurate model results in the vicinity of the pumping well.

4.5. Relation of nitrate concentrations to landuse

Particles that pass screens of monitoring wells were traced by application of MODPATH, in order to determine the dominant land use class of the origin of pathlines, at the surface. Transport through the unsaturated zone was assumed vertical. Average observed nitrate concentrations in monitoring wells along the calculated itinerary were compared to the dominant land use classes at the start of the pathlines (see Figure 14). The presented relations should be interpreted with some reserve, as only few observations per landuse class were available. However, the general image of the relations between average observed nitrate concentrations and the land use class at the origin of the pathline are not in contradiction with theory.

4.6. Relation of rates of biodegradation to subsoil composition

The reconstructed pathlines of particles that pass monitoring wells were also analysed with respect to the sub-soil composition along the pathlines. Analyses of available borehole descriptions in conjunction with the reconstructed pathlines, resulted in a description of cumulative time and distance that groundwater particles have passed in different soil types before arrival in the screen of a monitoring well. These quantitative descriptions of the subsoil along the pathline of particles were compared with nitrate-chloride ratios based upon observed concentrations in the relevant screens of monitoring wells. No significant correlation was found between the average nitrate-chloride ratio in screens and the composition of the sub-soil along pathlines that preceded arrival at the screens (see Figure 15). A significant negative correlation between travelled distance of a particle and the average nitrate-chloride ratio was found, indicating a positive correlation between travelled distance and cumulative biodegradation.

Absence of a clear correlation between cumulative denitrification and sub-soil composition is thought to be liable to the following reasons:

- The subsoil composition in the study area is very heterogeneous; all types of soil occur virtually everywhere;
- relatively few data on soil descriptions and nitrate-chloride ratio are available; occurrence of soil types and nitrate concentrations cannot be localised very precisely for the whole model area.

Since only manifest degradation could be identified, only locations where nitrate concentrations were relatively high at the starting point of a pathline formed part of the group of potential spots with high biodegradable capacities. Thus, especially in the NE part of the model area, many soils probably do have a high capacity for degradation of nitrate, but as there is nothing to degrade, no correlation between sub-soil types and biodegrading capacities can be found.

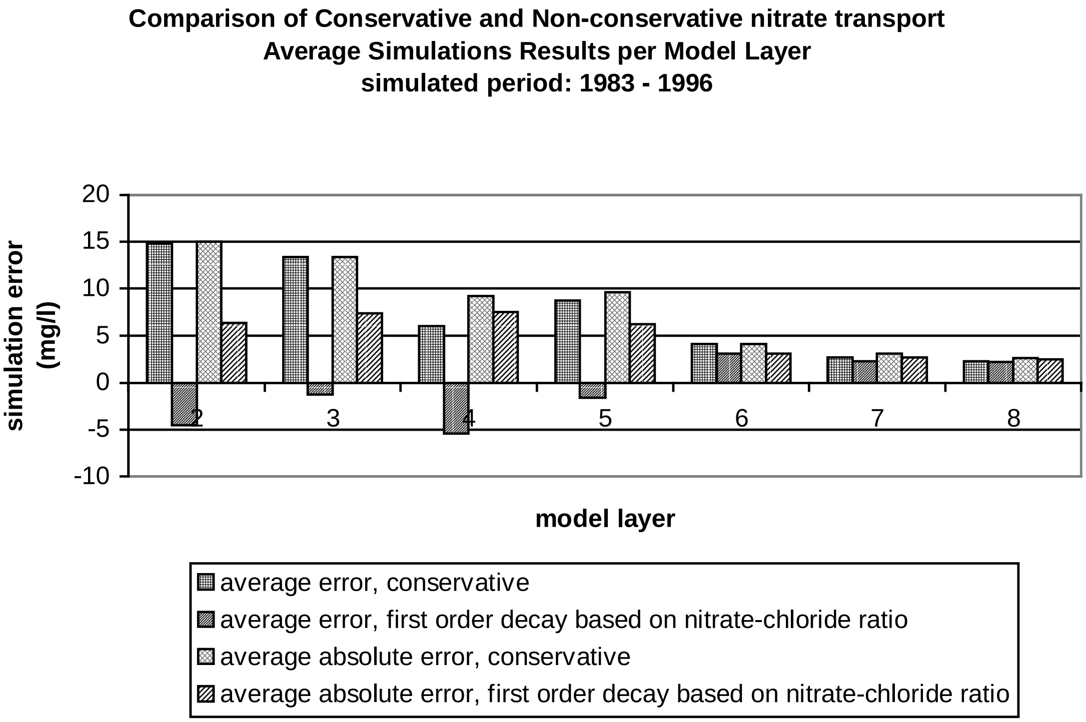


Figure 12: Differences between simulated and observed nitrate concentrations –conservative and non-conservative (nitrate-chloride) approach

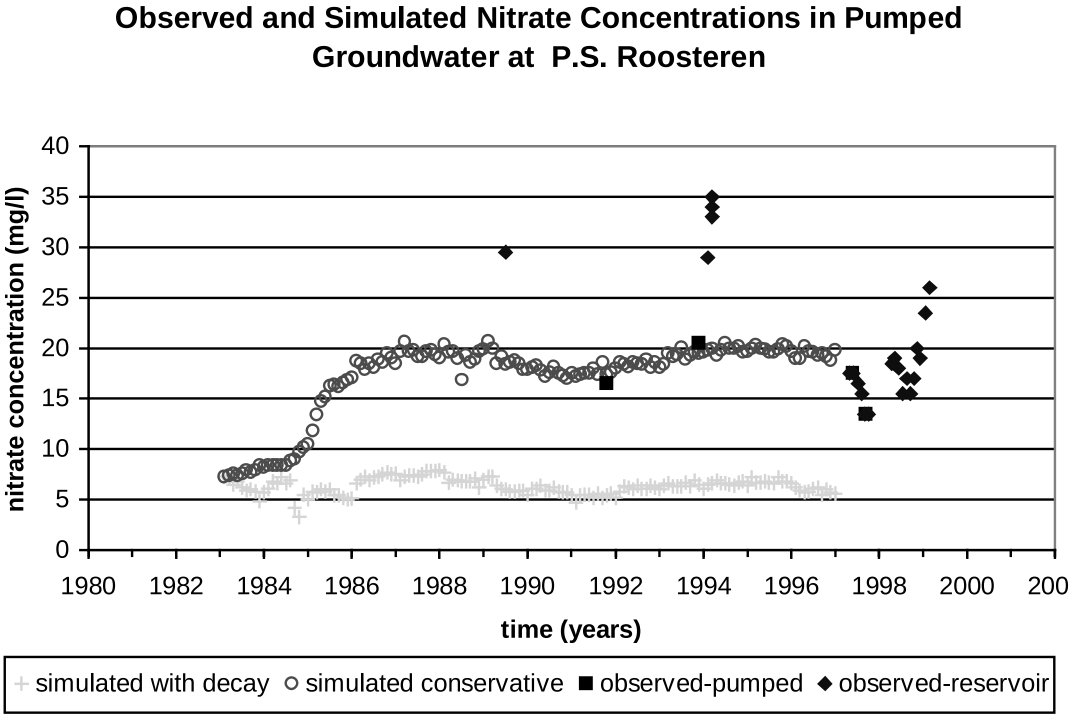


Figure 13: Simulated and observed nitrate concentrations in pumped groundwater at P.S. Roosteren

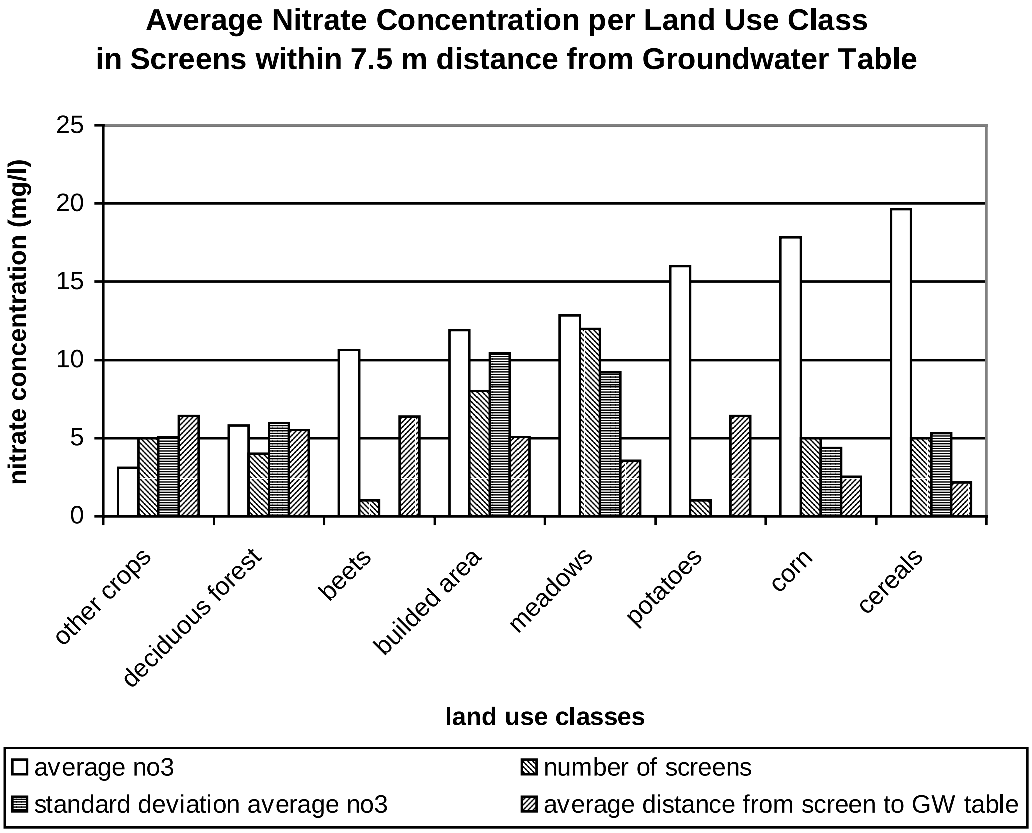


Figure 14: Average Nitrate Concentration per Land Use Class

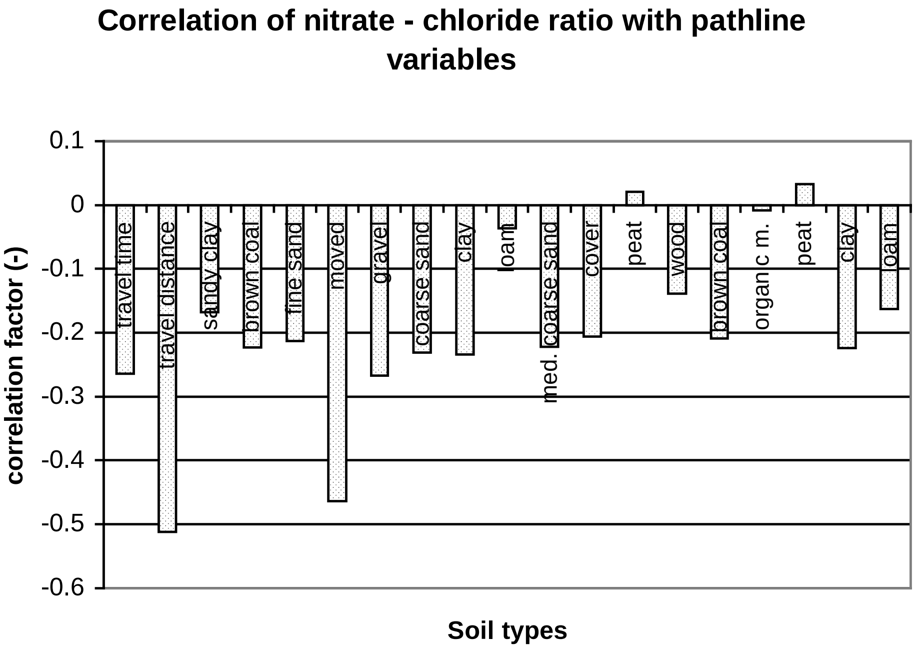


Figure 15: Correlation of nitrate - chloride ratio with soil composition along pathlines

4.7. Conclusions

General performance of the transport simulations indicated that significant biodegradation of nitrate occurs in the model area. Most of the biodegradation is thought to occur in shallow groundwater. No significant correlation of average nitrate-chloride ratios and soil composition could be found.
Rates of denitrification were based on the change of the ratio of observed nitrate and chloride concentrations along pathlines. In general, the non-conservative simulations resulted in smaller differences between observed and simulated concentrations than conservative transport simulations (see Figure 12). However, with respect to the nitrate concentration in pumped groundwater at P.S. Roosteren, the conservative approach lead to better results than the non-conservative approach. Poor data availability on nitrate concentrations in sections of the captive zone at groundwater travel times of more than 5 years form the well are thought to be the most probable cause for this anomaly, but inappropriate assessment of rates of denitrification might as well be the main source of model errors. Further adjustment of the model was not carried out, since it could not be determined which model-input variable should be adjusted for a better simulation of nitrate concentrations in pumped groundwater. Given the poor availability of data on observed nitrate concentrations and rates of denitrification in important parts of the captive zone, it is thought that additional gathering of field data should precede further calibration of the transport model. The assessed widespread occurrence of biodegradation of nitrate in the model area and the high spatial variability of soils and observed nitrate concentrations, imply that a reliable simulation of non-conservative nitrate transport towards P.S. Roosteren needs extensive and detailed field data.

4.8. General Evaluation

Hydrological models for simulation of groundwater flow and computer programs for visualisation and analyses of spatial information have become increasingly sophisticated over the past years. The performance of personal computers simultaneously has shown a steep increase. Ever greater quantities of data can be handled per unit of time.
If full advantage is to be taken of these strongly improved instruments, availability of field data should be improved proportionally. However, quantity and quality of field data has not yet shown such a strong improvement over time. Hopefully, new remote sensing techniques and instruments for cheap automatic registration of piezometric heads and groundwater quality parameters will improve the availability of relevant field data in the near future. The success of simulation of advective transport of nitrate within this project was limited, due to the pronounced spatial and temporal heterogeneity of parameters that determine the relevant processes, in combination with poor data availability on sections of the captive zone that exceed the 5 years travel time boundary.

Due to the complexity of present-day hydrological modelling studies, numerical simulations require far more assumptions on hydrological processes, interpretations of field data, interpolation and other data processing than in classical 'analytical' hydrology. Consequently, the impact of these assumptions and interpretations on final simulation results becomes vague, and hard to assess. Adjustment of model input variables in order to improve simulation results is often technically possible, but solutions are rarely unique. In those cases, it cannot be determined analytically which variable should be modified. This identification problem in model calibration increases with the increasing complexity of models. Although a number of techniques has been developed in order to estimate parameter values and assess reliability and accuracy of simulation results (e.g. te Stroet 1995 and Hill 1992), general practical application is not yet feasible for large and complex model studies. For simulation of large models at regular personal computers, required calculation time for these techniques is still too long for practical applications. In the near future, it can be expected that assessment of reliability and accuracy will attain practical applicability, mainly thanks to further improvement of the performance of personal computers.

Achievable precision of forecasts of pumped groundwater quality is not only dependent on data availability, but also on the variability of system parameters. Variability of groundwater quality parameters is highest in the unsaturated zone. In the saturated zone, temporal and spatial changes in chemical composition of groundwater are less pronounced than in the unsaturated zone, which improves the opportunities for accurate simulation results. In the model area, spatial and temporal variations in groundwater composition reduced exponentially with depth below the watertable. At depths below 20 m. under the water table, predictions of groundwater quality are much more reliable than at smaller depths. Relatively shallow groundwater is being pumped at P.S. Roosteren, which implies high data requirements for precise simulations.

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Appendix 1 Time Table

Appendix 2 Observed Nitrate Concentrations in Groundwater

Monitoring well	bottom screen elev. (m NAP)	top screen elev. (m NAP)	Year	month	day	nitrate conc. (mg/l)
"EINI 394 1"	39.00	41.00	88	11	30	32.3
"EINI 394 1"	39.00	41.00	89	6	23	26.8
"EINI 394 1"	39.00	41.00	90	5	8	28.8
"EINI 394 1"	39.00	41.00	91	6	14	28.5
"EINI 394 1"	39.00	41.00	92	4	9	27.6
"EINI 394 1"	39.00	41.00	94	4	27	30.5
"EINI 394 1"	39.00	41.00	95	6	27	25.8
"EINI 394 1"	39.00	41.00	96	4	11	26.5
"EINI 394 2"	29.00	34.00	88	12	14	12.4
"EINI 394 2"	29.00	34.00	89	6	23	28.2
"EINI 394 2"	29.00	34.00	90	5	8	25.8
"EINI 394 2"	29.00	34.00	91	6	14	27.5
"EINI 394 2"	29.00	34.00	92	4	9	27.5
"EINI 394 2"	29.00	34.00	94	4	27	28.4
"EINI 394 2"	29.00	34.00	95	6	27	27.5
"EINI 394 2"	29.00	34.00	96	4	11	26.9
"NSTD 260 1"	20.00	22.00	81	3	18	<0.5
"NSTD 260 1"	20.00	22.00	82	6	14	<0.2
"NSTD 260 1"	20.00	22.00	84	4	4	<0.5
"NSTD 260 1"	20.00	22.00	85	5	29	<0.5
"NSTD 260 1"	20.00	22.00	86	5	27	<0.5
"NSTD 260 1"	20.00	22.00	87	5	20	<0.5
"NSTD 260 1"	20.00	22.00	88	4	29	<0.5
"NSTD 260 1"	20.00	22.00	89	6	7	<0.5
"NSTD 260 1"	20.00	22.00	90	5	7	<0.5
"NSTD 260 1"	20.00	22.00	91	5	6	<0.5
"NSTD 260 1"	20.00	22.00	92	5	6	0.03
"NSTD 260 1"	20.00	22.00	93	3	30	0.14
"NSTD 260 1"	20.00	22.00	94	2	9	0.06
"NSTD 260 1"	20.00	22.00	95	3	7	0.05
"NSTD 260 1"	20.00	22.00	96	4	10	0.06
"NSTD 260 2"	16.00	18.00	81	3	18	<0.5
"NSTD 260 2"	16.00	18.00	90	5	7	<0.5
"NSTD 260 2"	16.00	18.00	91	5	6	<0.5
"NSTD 260 2"	16.00	18.00	92	5	6	<0.5
"NSTD 260 2"	16.00	18.00	93	3	30	<0.5
"NSTD 260 2"	16.00	18.00	94	2	9	<0.5
"NSTD 260 2"	16.00	18.00	95	3	7	<0.5
"NSTD 260 2"	16.00	18.00	96	4	10	<0.5
"NSTD 260 3"	6.00	8.00	81	3	18	<0.5
"NSTD 260 3"	6.00	8.00	82	6	14	<0.5
"NSTD 260 3"	6.00	8.00	84	4	4	<0.5
"NSTD 260 3"	6.00	8.00	85	5	29	<0.5
"NSTD 260 3"	6.00	8.00	86	5	27	<0.5
"NSTD 260 3"	6.00	8.00	87	5	20	<0.5
"NSTD 260 3"	6.00	8.00	88	4	29	<0.5
"NSTD 260 3"	6.00	8.00	89	6	7	<0.5
"NSTD 260 3"	6.00	8.00	90	5	7	<0.5
"NSTD 260 3"	6.00	8.00	91	5	6	0.09
"NSTD 260 3"	6.00	8.00	92	5	6	<0.5
"NSTD 260 3"	6.00	8.00	93	3	30	0.05
"NSTD 260 3"	6.00	8.00	94	2	9	0.03
"NSTD 260 3"	6.00	8.00	95	3	7	0.06
"NSTD 260 3"	6.00	8.00	96	4	10	0.07
"PEY 259 1"	26.00	27.00	81	3	17	18.0
"PEY 259 1"	26.00	27.00	82	6	14	16.0
"PEY 259 1"	26.00	27.00	84	4	3	21.0
"PEY 259 1"	26.00	27.00	85	5	29	29.2
"PEY 259 1"	26.00	27.00	86	5	28	43.5
"PEY 259 1"	26.00	27.00	87	6	12	23.1
"PEY 259 1"	26.00	27.00	88	4	26	18.0
"PEY 259 1"	26.00	27.00	89	5	31	12.4
"PEY 259 1"	26.00	27.00	90	5	7	24.2
"PEY 259 1"	26.00	27.00	91	5	7	58.2
"PEY 259 1"	26.00	27.00	92	5	5	67.5

"PEY 259 1"	26.00	27.00	93	3	31	0.7
"PEY 259 1"	26.00	27.00	94	2	9	20.8
"PEY 259 1"	26.00	27.00	95	3	8	1.0
"PEY 259 1"	26.00	27.00	96	4	9	24.7
"PEY 259 2"	16.00	18.00	81	3	17	2.5
"PEY 259 2"	16.00	18.00	90	5	7	<0.5
"PEY 259 2"	16.00	18.00	91	5	7	<0.5
"PEY 259 2"	16.00	18.00	92	5	5	<0.5
"PEY 259 2"	16.00	18.00	93	3	31	<0.5
"PEY 259 2"	16.00	18.00	94	2	9	<0.5
"PEY 259 2"	16.00	18.00	95	3	8	<0.5
"PEY 259 2"	16.00	18.00	96	4	9	<0.5
"PEY 259 3"	7.00	9.00	81	3	17	<0.5
"PEY 259 3"	7.00	9.00	82	6	14	0.6
"PEY 259 3"	7.00	9.00	84	4	3	1.4
"PEY 259 3"	7.00	9.00	85	5	29	1.3
"PEY 259 3"	7.00	9.00	86	5	28	1.2
"PEY 259 3"	7.00	9.00	87	6	12	1.4
"PEY 259 3"	7.00	9.00	88	4	26	1.05
"PEY 259 3"	7.00	9.00	89	5	31	<0.5
"PEY 259 3"	7.00	9.00	90	5	7	0.86
"PEY 259 3"	7.00	9.00	91	5	7	0.29
"PEY 259 3"	7.00	9.00	92	5	5	<0.5
"PEY 259 3"	7.00	9.00	93	3	31	0.04
"PEY 259 3"	7.00	9.00	94	2	9	0.13
"PEY 259 3"	7.00	9.00	95	3	8	0.11
"PEY 259 3"	7.00	9.00	96	4	9	0.34
"PEY PP IA 0"	-162.75	-139.70	93	5	13	<0.5
"PEY PP IA 0"	-162.75	-139.70	94	5	11	0.7
"PEY PP IA 0"	-162.75	-139.70	95	5	11	<0.5
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"PEY PP IV 0"	-79.32	-57.32	93	5	6	6.5
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"PEY PP IX 0"	-66.00	-52.12	93	5	13	<0.5
"PEY PP IX 0"	-66.00	-52.12	94	5	11	<0.5
"PEY PP IX 0"	-66.00	-52.12	95	5	11	<0.5
"PEY PP V 0"	-81.37	-56.37	93	5	6	<0.5
"PEY PP V 0"	-81.37	-56.37	94	5	4	<0.5
"PEY PP V 0"	-81.37	-56.37	96	5	2	<0.5
"PEY PP VI 0"	-81.80	-56.80	93	5	6	<0.5
"PEY PP VIA 0"	-78.97	-56.97	94	5	4	<0.5
"PEY PP VIA 0"	-78.97	-56.97	96	5	2	<0.5
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"PEY PP VII 0"	-82.42	-69.85	94	5	4	<0.5
"PEY PP VII 0"	-82.42	-69.85	96	5	2	<0.5
"PEY PP VIII 0"	-83.30	-55.30	93	5	6	<0.5
"PEY PP VIII 0"	-83.30	-55.30	94	5	4	<0.5
"PEY PP VIII 0"	-83.30	-55.30	96	5	2	<0.5
"PEY PP X 0"	-63.83	-52.83	93	5	13	<0.5
"PEY PP X 0"	-63.83	-52.83	94	5	11	<0.5
"PEY PP X 0"	-63.83	-52.83	95	5	11	<0.5
"PEY PP XI 0"	-128.77	-107.85	93	5	13	<0.5
"PEY PP XI 0"	-128.77	-107.85	94	5	11	<0.5
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"PEY PP XII 0"	-58.00	-43.06	94	5	11	<0.5
"PEY PP XII 0"	-58.00	-43.06	95	5	11	<0.5
"PEY WP 11 1"	20.15	25.15	92	7	10	<0.5
"PEY WP 11 1"	20.15	25.15	93	1	14	<0.5
"PEY WP 11 1"	20.15	25.15	93	4	15	<0.5
"PEY WP 11 1"	20.15	25.15	93	7	13	<0.5
"PEY WP 11 1"	20.15	25.15	93	10	14	<0.5
"PEY WP 11 1"	20.15	25.15	94	7	14	0.7
"PEY WP 11 2"	-39.82	-34.82	92	7	10	<0.5
"PEY WP 11 2"	-39.82	-34.82	93	1	14	<0.5

"PEY WP 11 2"	-39.82	-34.82	93	4	15	0.6
"PEY WP 11 2"	-39.82	-34.82	93	7	13	<0.5
"PEY WP 11 2"	-39.82	-34.82	93	10	14	<0.5
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"PEY WP 11 3"	-66.79	-61.79	92	7	10	<0.5
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"PEY WP 11 3"	-66.79	-61.79	93	4	15	<0.5
"PEY WP 11 3"	-66.79	-61.79	93	7	13	<0.5
"PEY WP 11 3"	-66.79	-61.79	93	10	14	<0.5
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"PEY WP 11 4"	-151.75	-146.75	93	1	14	<0.5
"PEY WP 11 4"	-151.75	-146.75	93	4	15	<0.5
"PEY WP 11 4"	-151.75	-146.75	93	7	13	<0.5
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"PEY WP 11 4"	-151.75	-146.75	94	7	14	<0.5
"PEY WP 11 5"	-208.72	-203.72	92	7	10	<0.5
"PEY WP 11 5"	-208.72	-203.72	93	1	14	<0.5
"PEY WP 11 5"	-208.72	-203.72	93	4	15	<0.5
"PEY WP 11 5"	-208.72	-203.72	93	7	13	<0.5
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"PEY WP 11 5"	-208.72	-203.72	94	7	14	<0.5
"REUT WP 1 4"	-151.01	-149.01	92	11	10	<0.5
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"ROOS 261 1"	17.00	19.00	81	3	18	9.5
"ROOS 261 1"	17.00	19.00	82	6	15	9.2
"ROOS 261 1"	17.00	19.00	84	4	4	8.4
"ROOS 261 1"	17.00	19.00	85	5	29	2.8
"ROOS 261 1"	17.00	19.00	86	5	28	4.4
"ROOS 261 1"	17.00	19.00	87	5	20	6.8
"ROOS 261 1"	17.00	19.00	88	4	29	7.6
"ROOS 261 1"	17.00	19.00	89	6	7	7.6
"ROOS 261 1"	17.00	19.00	90	5	7	6.8
"ROOS 261 1"	17.00	19.00	91	5	6	5.2
"ROOS 261 1"	17.00	19.00	92	5	6	4.8
"ROOS 261 1"	17.00	19.00	93	3	30	8.7
"ROOS 261 1"	17.00	19.00	94	2	9	6.1
"ROOS 261 1"	17.00	19.00	95	3	8	4.1
"ROOS 261 2"	11.00	13.00	81	3	18	0.4
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"ROOS 261 2"	11.00	13.00	91	5	6	<0.5
"ROOS 261 2"	11.00	13.00	92	5	6	<0.5
"ROOS 261 2"	11.00	13.00	93	3	30	<0.5
"ROOS 261 2"	11.00	13.00	94	2	9	<0.5
"ROOS 261 2"	11.00	13.00	95	3	8	<0.5
"ROOS 261 3"	5.00	7.00	81	3	18	<0.2
"ROOS 261 3"	5.00	7.00	82	6	15	<0.5
"ROOS 261 3"	5.00	7.00	84	4	4	0.1
"ROOS 261 3"	5.00	7.00	85	5	29	<0.5
"ROOS 261 3"	5.00	7.00	86	5	28	<0.5
"ROOS 261 3"	5.00	7.00	87	5	20	<0.5
"ROOS 261 3"	5.00	7.00	88	4	29	<0.5
"ROOS 261 3"	5.00	7.00	89	6	7	<0.5
"ROOS 261 3"	5.00	7.00	90	5	7	<0.5
"ROOS 261 3"	5.00	7.00	91	5	6	1.1
"ROOS 261 3"	5.00	7.00	92	5	6	0.06
"ROOS 261 3"	5.00	7.00	93	3	30	0.05
"ROOS 261 3"	5.00	7.00	94	2	9	0.3
"ROOS 261 3"	5.00	7.00	95	3	8	0.11
"ROOS PP I 1"	16.83	17.83	75	9	22	8.5
"ROOS PP I 1"	16.83	17.83	75	9	29	9.5
"ROOS PP I 1"	16.83	17.83	75	10	6	8.7
"ROOS PP I 1"	16.83	17.83	75	10	13	8.3
"ROOS PP I 1"	16.83	17.83	76	5	1	7.9
"ROOS PP I 1"	16.83	17.83	76	7	1	5.9
"ROOS PP I 1"	16.83	17.83	76	9	1	5.0
"ROOS PP I 1"	16.83	17.83	76	11	1	5.3
"ROOS PP I 1"	16.83	17.83	77	1	1	5.0
"ROOS PP I 1"	16.83	17.83	77	10	1	4.5
"ROOS PP I 1"	16.83	17.83	77	11	1	4.5
"ROOS PP I 1"	16.83	17.83	77	12	1	9.0
"ROOS PP I 1"	16.83	17.83	78	4	17	11.5

"ROOS PP I 1"	16.83	17.83	78	5	22	12.5
"ROOS PP I 1"	16.83	17.83	78	6	12	10.0
"ROOS PP I 1"	16.83	17.83	78	7	24	16.4
"ROOS PP I 1"	16.83	17.83	78	8	21	13.0
"ROOS PP I 1"	16.83	17.83	78	9	25	12.0
"ROOS PP I 1"	16.83	17.83	78	10	23	13.5
"ROOS PP I 1"	16.83	17.83	78	11	27	11.0
"ROOS PP I 1"	16.83	17.83	78	12	18	12.5
"ROOS PP I 1"	16.83	17.83	79	1	1	12.5
"ROOS PP I 1"	16.83	17.83	79	3	1	10.5
"ROOS PP I 1"	16.83	17.83	79	5	1	17.5
"ROOS PP I 1"	16.83	17.83	79	8	1	14.5
"ROOS PP I 1"	16.83	17.83	79	9	1	14.5
"ROOS PP I 1"	16.83	17.83	80	6	1	17.0
"ROOS PP I 1"	16.83	17.83	80	7	1	17.0
"ROOS PP II 1"	20.17	21.17	75	10	27	10.0
"ROOS PP II 1"	20.17	21.17	76	5	1	8.2
"ROOS PP II 1"	20.17	21.17	76	6	1	9.0
"ROOS PP II 1"	20.17	21.17	87	3	19	19.2
"ROOS PP IVA 0"	9.59	18.99	91	11	8	1.7
"ROOS PP IX 0"	13.50	20.00	95	9	11	20.5
"ROOS PP IX 0"	13.50	20.00	97	5	29	12.0
"ROOS PP V 0"	12.20	19.20	95	9	21	<0.5
"ROOS PP V 0"	12.20	19.20	97	5	29	<0.5
"ROOS PP VI 0"	11.00	23.50	95	9	27	<0.5
"ROOS PP VI 0"	11.00	23.50	97	5	29	<0.5
"ROOS PP VI 1"	1.80	2.80	97	10	16	<0.5
"ROOS PP VII 0"	8.50	21.50	97	5	29	2.8
"ROOS PP VII 1"	-0.66	0.34	97	10	16	<0.5
"ROOS PP VIII 0"	3.30	17.00	95	9	25	12.5
"ROOS PP VIII 0"	3.30	17.00	97	5	29	7.5
"ROOS PP VIII 1"	5.65	6.65	97	10	16	7.5
"ROOS PP X 0"	11.30	22.00	95	5	3	27.0
"ROOS PP X 0"	11.30	22.00	98	1	15	14.0
"ROOS PP X 0"	11.30	22.00	98	2	4	14.5
"ROOS PP X 0"	11.30	22.00	98	2	26	15.0
"ROOS WP 11 1"	18.32	20.32	83	9	19	24.0
"ROOS WP 11 1"	18.32	20.32	85	3	6	6.3
"ROOS WP 11 1"	18.32	20.32	98	3	12	24.0
"ROOS WP 11 2"	11.67	13.67	83	9	19	2.5
"ROOS WP 11 2"	11.67	13.67	98	3	12	13.5
"ROOS WP 11 3"	3.71	5.71	83	9	19	1.5
"ROOS WP 11 3"	3.71	5.71	98	3	12	<0.5
"ROOS WP 12 1"	20.37	22.37	83	9	27	37.0
"ROOS WP 12 1"	20.37	22.37	98	3	11	23.0
"ROOS WP 12 2"	12.89	14.89	83	9	27	17.0
"ROOS WP 12 2"	12.89	14.89	98	3	11	12.5
"ROOS WP 12 3"	5.48	7.48	83	9	27	16.0
"ROOS WP 12 3"	5.48	7.48	98	3	11	11.5
"ROOS WP 14 1"	20.00	21.00	91	3	5	16.8
"ROOS WP 14 1"	20.00	21.00	91	4	26	21.0
"ROOS WP 14 1"	20.00	21.00	91	6	4	30.0
"ROOS WP 14 1"	20.00	21.00	91	9	3	15.0
"ROOS WP 14 1"	20.00	21.00	91	12	3	15.0
"ROOS WP 14 1"	20.00	21.00	92	3	6	20.5
"ROOS WP 14 1"	20.00	21.00	92	6	2	21.5
"ROOS WP 14 1"	20.00	21.00	92	9	1	10.5
"ROOS WP 14 1"	20.00	21.00	92	12	1	15.5
"ROOS WP 14 1"	20.00	21.00	93	3	9	29.0
"ROOS WP 15 1"	15.65	17.65	83	9	26	16.0
"ROOS WP 15 2"	6.70	8.70	83	9	26	8.0
"ROOS WP 16 1"	17.66	19.66	83	9	19	40.0
"ROOS WP 16 1"	17.66	19.66	85	3	6	<0.5
"ROOS WP 16 2"	13.19	15.19	83	9	19	4.5
"ROOS WP 16 3"	8.21	10.21	83	9	19	<0.5
"ROOS WP 17 1"	16.64	18.64	83	9	26	1.0
"ROOS WP 17 1"	16.64	18.64	91	4	25	<0.5
"ROOS WP 17 1"	16.64	18.64	92	2	27	<0.5
"ROOS WP 17 1"	16.64	18.64	94	3	10	<0.5
"ROOS WP 17 1"	16.64	18.64	95	3	8	<0.5
"ROOS WP 17 1"	16.64	18.64	96	3	8	<0.5
"ROOS WP 17 1"	16.64	18.64	97	3	4	<0.5

"ROOS WP 17 1"	16.64	18.64	98	3	5	<0.5
"ROOS WP 17 2"	8.49	10.49	83	9	26	<0.5
"ROOS WP 17 2"	8.49	10.49	91	4	25	<0.5
"ROOS WP 17 2"	8.49	10.49	92	2	27	<0.5
"ROOS WP 17 2"	8.49	10.49	94	3	10	<0.5
"ROOS WP 17 2"	8.49	10.49	95	3	8	<0.5
"ROOS WP 17 2"	8.49	10.49	96	3	8	<0.5
"ROOS WP 17 2"	8.49	10.49	97	3	4	<0.5
"ROOS WP 17 2"	8.49	10.49	98	3	5	<0.5
"ROOS WP 18 1"	15.19	17.19	83	9	26	<0.5
"ROOS WP 18 1"	15.19	17.19	91	4	25	<0.5
"ROOS WP 18 1"	15.19	17.19	98	3	12	<0.5
"ROOS WP 19 1"	16.23	18.23	83	10	3	1.6
"ROOS WP 19 1"	16.23	18.23	91	4	25	<0.5
"ROOS WP 19 1"	16.23	18.23	94	3	10	<0.5
"ROOS WP 19 1"	16.23	18.23	95	3	8	<0.5
"ROOS WP 19 1"	16.23	18.23	96	3	19	<0.5
"ROOS WP 19 1"	16.23	18.23	97	3	4	<0.5
"ROOS WP 19 1"	16.23	18.23	98	3	5	<0.5
"ROOS WP 20 1"	14.31	16.31	83	9	28	1.0
"ROOS WP 20 1"	14.31	16.31	91	4	25	<0.5
"ROOS WP 20 1"	14.31	16.31	92	2	25	<0.5
"ROOS WP 20 1"	14.31	16.31	98	3	11	<0.5
"ROOS WP 21 1"	23.51	25.51	83	9	28	80.0
"ROOS WP 21 2"	15.55	17.55	83	9	28	23.0
"ROOS WP 22 1"	17.04	19.04	83	9	19	10.0
"ROOS WP 22 1"	17.04	19.04	91	3	5	6.9
"ROOS WP 22 1"	17.04	19.04	91	4	26	11.0
"ROOS WP 22 1"	17.04	19.04	91	6	4	11.5
"ROOS WP 22 1"	17.04	19.04	91	9	3	13.0
"ROOS WP 22 1"	17.04	19.04	91	12	3	8.5
"ROOS WP 22 1"	17.04	19.04	92	3	6	10.5
"ROOS WP 22 1"	17.04	19.04	92	6	2	12.0
"ROOS WP 22 1"	17.04	19.04	92	9	1	12.0
"ROOS WP 22 1"	17.04	19.04	92	12	1	9.0
"ROOS WP 22 1"	17.04	19.04	93	3	11	10.5
"ROOS WP 22 1"	17.04	19.04	94	3	10	11.0
"ROOS WP 22 1"	17.04	19.04	95	3	8	26.0
"ROOS WP 22 1"	17.04	19.04	96	3	8	13.0
"ROOS WP 22 1"	17.04	19.04	97	3	5	7.0
"ROOS WP 22 1"	17.04	19.04	98	3	5	11.5
"ROOS WP 22 2"	13.09	15.09	83	9	19	8.0
"ROOS WP 22 2"	13.09	15.09	91	3	5	3.7
"ROOS WP 22 2"	13.09	15.09	91	4	25	4.9
"ROOS WP 22 2"	13.09	15.09	91	6	4	3.2
"ROOS WP 22 2"	13.09	15.09	91	9	3	0.7
"ROOS WP 22 2"	13.09	15.09	91	12	3	6.5
"ROOS WP 22 2"	13.09	15.09	92	3	6	7.0
"ROOS WP 22 2"	13.09	15.09	92	6	2	5.0
"ROOS WP 22 2"	13.09	15.09	92	9	1	7.0
"ROOS WP 22 2"	13.09	15.09	92	12	1	10.0
"ROOS WP 22 2"	13.09	15.09	93	3	11	5.5
"ROOS WP 22 2"	13.09	15.09	94	3	10	9.1
"ROOS WP 22 2"	13.09	15.09	95	3	8	14.0
"ROOS WP 22 2"	13.09	15.09	96	3	8	12.0
"ROOS WP 22 2"	13.09	15.09	97	3	5	7.0
"ROOS WP 22 2"	13.09	15.09	98	3	5	8.5
"ROOS WP 22 3"	6.64	8.64	83	9	19	0.7
"ROOS WP 22 3"	6.64	8.64	91	3	5	1.1
"ROOS WP 22 3"	6.64	8.64	91	4	25	<0.5
"ROOS WP 22 3"	6.64	8.64	91	6	4	<0.5
"ROOS WP 22 3"	6.64	8.64	91	9	3	<0.5
"ROOS WP 22 3"	6.64	8.64	91	12	3	<0.5
"ROOS WP 22 3"	6.64	8.64	92	3	6	<0.5
"ROOS WP 22 3"	6.64	8.64	92	6	2	<0.5
"ROOS WP 22 3"	6.64	8.64	92	9	1	<0.5
"ROOS WP 22 3"	6.64	8.64	92	12	1	<0.5
"ROOS WP 22 3"	6.64	8.64	93	3	11	<0.5
"ROOS WP 22 3"	6.64	8.64	94	3	10	<0.5
"ROOS WP 22 3"	6.64	8.64	95	3	9	<0.5
"ROOS WP 22 3"	6.64	8.64	96	3	8	<0.5
"ROOS WP 22 3"	6.64	8.64	97	3	5	<0.5

"ROOS WP 22 3"	6.64	8.64	98	3	5	<0.5
"ROOS WP 23 1"	27.94	29.94	83	9	29	5.6
"ROOS WP 23 1"	27.94	29.94	92	3	10	20.5
"ROOS WP 23 2"	19.96	21.96	83	9	29	1.4
"ROOS WP 23 2"	19.96	21.96	92	3	10	<0.5
"ROOS WP 23 2"	19.96	21.96	98	3	11	<0.5
"ROOS WP 28 1"	21.64	24.64	98	3	11	7.0
"ROOS WP 29 1"	25.17	26.17	91	1	17	57.0
"ROOS WP 29 1"	25.17	26.17	92	12	1	23.0
"ROOS WP 29 1"	25.17	26.17	97	3	5	24.0
"ROOS WP 29 2"	20.70	23.20	91	1	17	33.0
"ROOS WP 29 2"	20.70	23.20	91	4	26	27.0
"ROOS WP 29 2"	20.70	23.20	91	6	4	24.0
"ROOS WP 29 2"	20.70	23.20	91	9	3	15.5
"ROOS WP 29 2"	20.70	23.20	91	12	3	20.0
"ROOS WP 29 2"	20.70	23.20	92	3	6	24.0
"ROOS WP 29 2"	20.70	23.20	92	6	4	22.0
"ROOS WP 29 2"	20.70	23.20	92	9	1	13.5
"ROOS WP 29 2"	20.70	23.20	92	12	1	16.5
"ROOS WP 29 2"	20.70	23.20	93	3	11	59.0
"ROOS WP 29 2"	20.70	23.20	94	3	11	24.0
"ROOS WP 29 2"	20.70	23.20	95	3	15	27.5
"ROOS WP 29 2"	20.70	23.20	96	3	19	21.0
"ROOS WP 29 2"	20.70	23.20	97	3	5	20.0
"ROOS WP 29 2"	20.70	23.20	98	3	5	19.0
"ROOS WP 29 3"	13.21	15.21	91	1	17	16.0
"ROOS WP 29 3"	13.21	15.21	91	4	26	22.5
"ROOS WP 29 3"	13.21	15.21	91	6	4	16.5
"ROOS WP 29 3"	13.21	15.21	91	9	3	17.5
"ROOS WP 29 3"	13.21	15.21	91	12	3	16.0
"ROOS WP 29 3"	13.21	15.21	92	3	6	21.5
"ROOS WP 29 3"	13.21	15.21	92	6	4	18.0
"ROOS WP 29 3"	13.21	15.21	92	9	1	19.5
"ROOS WP 29 3"	13.21	15.21	92	12	1	20.0
"ROOS WP 29 3"	13.21	15.21	93	3	11	45.0
"ROOS WP 29 3"	13.21	15.21	94	3	11	18.5
"ROOS WP 29 3"	13.21	15.21	95	3	15	17.0
"ROOS WP 29 3"	13.21	15.21	96	3	19	22.0
"ROOS WP 29 3"	13.21	15.21	97	3	5	20.0
"ROOS WP 29 3"	13.21	15.21	98	3	5	20.5
"ROOS WP 29 4"	4.24	5.24	91	1	17	<0.5
"ROOS WP 29 4"	4.24	5.24	91	4	26	<0.5
"ROOS WP 29 4"	4.24	5.24	91	6	4	2.4
"ROOS WP 29 4"	4.24	5.24	91	9	3	<0.5
"ROOS WP 29 4"	4.24	5.24	91	12	3	<0.5
"ROOS WP 29 4"	4.24	5.24	92	3	6	<0.5
"ROOS WP 29 4"	4.24	5.24	92	6	4	<0.5
"ROOS WP 29 4"	4.24	5.24	92	9	1	<0.5
"ROOS WP 29 4"	4.24	5.24	92	12	1	<0.5
"ROOS WP 29 4"	4.24	5.24	93	3	11	<0.5
"ROOS WP 29 4"	4.24	5.24	94	3	11	<0.5
"ROOS WP 29 4"	4.24	5.24	95	3	15	<0.5
"ROOS WP 29 4"	4.24	5.24	96	3	19	<0.5
"ROOS WP 29 4"	4.24	5.24	97	3	5	1.3
"ROOS WP 29 4"	4.24	5.24	98	3	5	<0.5
"ROOS WP 3 1"	16.29	18.29	98	12	3	14.5
"ROOS WP 30 1"	10.65	25.35	81	6	23	43.0
"ROOS WP 30 1"	10.65	25.35	81	6	29	28.0
"ROOS WP 30 1"	10.65	25.35	85	2	6	43.8
"ROOS WP 30 1"	10.65	25.35	85	3	5	52.5
"ROOS WP 30 1"	10.65	25.35	85	4	15	33.8
"ROOS WP 30 1"	10.65	25.35	85	5	13	36.8
"ROOS WP 30 1"	10.65	25.35	85	9	2	21.6
"ROOS WP 30 1"	10.65	25.35	86	6	24	20.0
"ROOS WP 30 1"	10.65	25.35	87	3	19	19.2
"ROOS WP 30 1"	10.65	25.35	87	6	1	25.7
"ROOS WP 30 1"	10.65	25.35	88	6	28	32.0
"ROOS WP 31 1"	11.74	25.04	81	6	29	16.0
"ROOS WP 31 1"	11.74	25.04	85	2	6	43.8
"ROOS WP 31 1"	11.74	25.04	85	3	5	41.9
"ROOS WP 31 1"	11.74	25.04	85	4	15	35.7
"ROOS WP 31 1"	11.74	25.04	85	5	13	31.3

"ROOS WP 31 1"	11.74	25.04	85	9	2	19.6
"ROOS WP 31 1"	11.74	25.04	86	6	24	33.3
"ROOS WP 31 1"	11.74	25.04	87	3	19	17.1
"ROOS WP 31 1"	11.74	25.04	87	6	1	30.5
"ROOS WP 31 1"	11.74	25.04	88	6	28	28.0
"ROOS WP 32 1"	10.69	26.59	81	6	23	22.0
"ROOS WP 32 1"	10.69	26.59	83	12	27	21.0
"ROOS WP 32 1"	10.69	26.59	85	2	6	44.0
"ROOS WP 32 1"	10.69	26.59	85	3	5	38.5
"ROOS WP 32 1"	10.69	26.59	85	4	15	32.6
"ROOS WP 32 1"	10.69	26.59	85	5	13	12.2
"ROOS WP 32 1"	10.69	26.59	85	9	2	14.2
"ROOS WP 32 1"	10.69	26.59	86	6	24	30.9
"ROOS WP 32 1"	10.69	26.59	87	3	19	16.4
"ROOS WP 32 1"	10.69	26.59	87	6	1	27.5
"ROOS WP 32 1"	10.69	26.59	88	6	28	36.0
"ROOS WP 33 1"	13.03	26.83	81	6	29	18.0
"ROOS WP 33 1"	13.03	26.83	83	12	27	26.0
"ROOS WP 33 1"	13.03	26.83	85	2	6	25.0
"ROOS WP 33 1"	13.03	26.83	85	3	5	41.2
"ROOS WP 33 1"	13.03	26.83	85	4	15	25.2
"ROOS WP 33 1"	13.03	26.83	85	5	13	30.2
"ROOS WP 33 1"	13.03	26.83	85	9	2	18.2
"ROOS WP 33 1"	13.03	26.83	86	6	24	23.6
"ROOS WP 33 1"	13.03	26.83	87	3	19	19.2
"ROOS WP 33 1"	13.03	26.83	87	6	1	26.4
"ROOS WP 33 1"	13.03	26.83	88	6	28	34.0
"ROOS WP 34 1"	21.90	23.90	94	3	25	38.0
"ROOS WP 34 1"	21.90	23.90	95	3	17	26.0
"ROOS WP 34 1"	21.90	23.90	97	3	6	17.0
"ROOS WP 34 2"	17.95	19.95	91	4	25	16.5
"ROOS WP 34 2"	17.95	19.95	94	3	25	11.5
"ROOS WP 34 2"	17.95	19.95	95	3	17	7.0
"ROOS WP 34 2"	17.95	19.95	96	3	20	2.0
"ROOS WP 34 2"	17.95	19.95	97	3	6	8.5
"ROOS WP 34 2"	17.95	19.95	98	3	3	13.0
"ROOS WP 34 3"	11.00	13.00	91	4	25	<0.5
"ROOS WP 34 3"	11.00	13.00	94	3	25	<0.5
"ROOS WP 34 3"	11.00	13.00	95	3	17	<0.5
"ROOS WP 34 3"	11.00	13.00	96	3	20	<0.5
"ROOS WP 34 3"	11.00	13.00	97	3	6	<0.5
"ROOS WP 34 3"	11.00	13.00	98	3	3	<0.5
"ROOS WP 34 4"	5.54	7.04	91	4	25	<0.5
"ROOS WP 35 1"	17.67	19.67	91	11	7	2.7
"ROOS WP 35 1"	17.67	19.67	93	5	11	6.0
"ROOS WP 35 2"	10.52	12.52	91	11	7	<0.5
"ROOS WP 35 2"	10.52	12.52	93	5	11	<0.5
"ROOS WP 35 3"	3.77	5.37	91	11	7	<0.5
"ROOS WP 35 3"	3.77	5.37	93	5	11	<0.5
"ROOS WP 36 1"	17.31	19.31	91	10	31	1.4
"ROOS WP 36 2"	9.34	11.34	91	10	31	<0.5
"ROOS WP 36 3"	3.36	5.36	91	10	31	<0.5
"ROOS WP 37 2"	19.39	21.39	91	11	1	4.5
"ROOS WP 37 3"	9.64	11.64	91	11	1	<0.5
"ROOS WP 37 4"	5.16	7.16	91	11	1	2.5
"ROOS WP 39 1"	18.45	20.45	91	10	31	1.2
"ROOS WP 39 2"	12.00	14.00	91	10	31	<0.5
"ROOS WP 39 3"	6.13	8.13	91	10	31	<0.5
"ROOS WP 40 1"	19.18	21.18	91	11	14	15.0
"ROOS WP 40 1"	19.18	21.18	93	5	12	36.0
"ROOS WP 40 1"	19.18	21.18	94	3	24	44.0
"ROOS WP 40 1"	19.18	21.18	95	3	15	59.0
"ROOS WP 40 1"	19.18	21.18	96	3	20	24.5
"ROOS WP 40 1"	19.18	21.18	97	3	7	17.5
"ROOS WP 40 1"	19.18	21.18	98	1	22	18.5
"ROOS WP 40 1"	19.18	21.18	98	1	27	21.0
"ROOS WP 40 1"	19.18	21.18	98	2	3	15.0
"ROOS WP 40 1"	19.18	21.18	98	2	12	20.0
"ROOS WP 40 1"	19.18	21.18	98	2	17	21.5
"ROOS WP 40 1"	19.18	21.18	98	2	26	23.5
"ROOS WP 40 1"	19.18	21.18	98	3	5	18.0
"ROOS WP 40 1"	19.18	21.18	98	3	10	25.0

"ROOS WP 40 2"	12.70	14.70	91	11	14	12.5
"ROOS WP 40 2"	12.70	14.70	93	5	12	14.5
"ROOS WP 40 2"	12.70	14.70	94	3	24	11.5
"ROOS WP 40 2"	12.70	14.70	95	3	15	18.5
"ROOS WP 40 2"	12.70	14.70	96	3	20	15.0
"ROOS WP 40 2"	12.70	14.70	97	3	7	7.5
"ROOS WP 40 2"	12.70	14.70	98	3	3	9.5
"ROOS WP 40 3"	5.24	7.24	91	11	14	1.9
"ROOS WP 40 3"	5.24	7.24	93	5	12	<0.5
"ROOS WP 40 3"	5.24	7.24	94	3	24	<0.5
"ROOS WP 40 3"	5.24	7.24	95	3	15	<0.5
"ROOS WP 40 3"	5.24	7.24	96	3	20	<0.5
"ROOS WP 40 3"	5.24	7.24	97	3	7	<0.5
"ROOS WP 40 3"	5.24	7.24	98	3	3	<0.5
"ROOS WP 41 1"	20.57	21.57	95	1	11	8.0
"ROOS WP 41 2"	17.59	18.59	95	1	11	<0.5
"ROOS WP 41 2"	17.59	18.59	98	1	15	1.4
"ROOS WP 41 2"	17.59	18.59	98	1	22	18.5
"ROOS WP 41 2"	17.59	18.59	98	1	27	21.0
"ROOS WP 41 2"	17.59	18.59	98	2	3	8.5
"ROOS WP 41 2"	17.59	18.59	98	2	12	9.0
"ROOS WP 41 2"	17.59	18.59	98	2	17	14.5
"ROOS WP 41 2"	17.59	18.59	98	2	26	17.0
"ROOS WP 41 2"	17.59	18.59	98	3	5	12.5
"ROOS WP 41 2"	17.59	18.59	98	3	10	24.0
"ROOS WP 41 3"	14.62	16.12	95	1	11	<0.5
"ROOS WP 41 4"	7.46	9.46	95	1	11	<0.5
"ROOS WP 42 1"	19.37	20.37	95	1	16	<0.5
"ROOS WP 42 2"	17.40	18.40	98	2	3	5.0
"ROOS WP 42 2"	17.40	18.40	98	2	12	2.2
"ROOS WP 42 2"	17.40	18.40	98	2	17	1.0
"ROOS WP 42 2"	17.40	18.40	98	2	26	0.7
"ROOS WP 42 2"	17.40	18.40	98	3	5	<0.5
"ROOS WP 42 2"	17.40	18.40	98	3	10	4.5
"ROOS WP 42 3"	14.13	16.13	95	1	16	<0.5
"ROOS WP 43 1"	21.09	22.09	94	12	20	35.0
"ROOS WP 43 2"	18.61	19.61	94	12	20	23.0
"ROOS WP 43 2"	18.61	19.61	98	2	12	2.8
"ROOS WP 43 3"	16.64	17.64	94	12	20	18.5
"ROOS WP 43 4"	13.76	14.76	94	12	20	1.5
"ROOS WP 43 5"	2.99	4.99	94	12	20	4.7
"ROOS WP 44 1"	19.08	21.08	95	1	10	46.0
"ROOS WP 44 2"	16.11	17.11	95	1	10	26.0
"ROOS WP 44 3"	11.56	13.56	95	1	10	21.0
"ROOS WP 45 1"	20.52	21.52	95	1	24	53.0
"ROOS WP 45 2"	17.03	18.03	95	1	24	24.0
"ROOS WP 45 3"	13.28	15.28	95	1	24	14.0
"ROOS WP 45 4"	0.71	2.71	95	1	24	2.4
"ROOS WP 46 1"	20.83	21.83	95	4	26	20.5
"ROOS WP 46 2"	16.36	17.36	95	4	26	12.0
"ROOS WP 46 3"	11.40	13.40	95	4	26	1.1
"ROOS WP 46 4"	5.41	7.41	95	4	26	<0.5
"ROOS WP 46 5"	-0.46	1.54	95	4	26	<0.5
"ROOS WP 47 1"	19.65	20.65	95	4	27	18.5
"ROOS WP 47 2"	15.17	16.17	95	4	27	5.5
"ROOS WP 47 3"	11.38	13.38	95	4	27	<0.5
"ROOS WP 48 1"	19.30	21.30	95	4	27	15.5
"ROOS WP 48 2"	14.80	15.80	95	4	27	<0.5
"ROOS WP 48 3"	11.75	13.25	95	4	27	<0.5
"ROOS WP 49 1"	19.90	20.90	95	4	26	22.0
"ROOS WP 49 2"	15.41	16.41	95	4	26	<0.5
"ROOS WP 49 3"	11.42	13.42	95	4	26	<0.5
"ROOS WP 49 4"	6.48	8.48	95	4	26	<0.5
"ROOS WP 49 5"	0.45	1.45	95	4	26	<0.5
"ROOS WP 6 1"	13.92	25.47	77	8	1	18.5
"ROOS WP 7 1"	16.68	22.68	77	8	1	11.6
"ROOS WP 74 1"	-27.38	-25.38	77	12	27	<0.5
"ROOS WP 74 2"	-66.88	-64.88	77	12	27	<0.5
"ROOS WP 74 3"	-159.88	-157.88	77	12	27	<0.5
"ROOS WP 74 4"	-193.88	-191.88	77	12	27	<0.5
"ROOS WP 74 5"	-240.88	-238.88	77	12	27	<0.5
"ROOS WP 76 1"	15.36	17.36	85	3	6	<0.5

"ROOS WP 8 1"	10.40	17.90	69	6	25	12.2
"ROOS WP 8 1"	10.40	17.90	69	6	26	10.0
"ROOS WP 9 1"	19.18	20.18	85	3	6	69.7
"ROOS WP 95 1"	18.12	19.12	98	3	12	22.0
"ROOS WP 9A 1"	21.28	24.28	91	1	17	23.0
"ROOS WP 9A 2"	16.81	18.81	91	1	17	11.0
"ROOS WP 9A 3"	4.84	7.84	91	1	17	<0.5
"SCHI 268 1"	39.00	41.00	83	6	22	6.8
"SCHI 268 1"	39.00	41.00	84	4	10	6.9
"SCHI 268 1"	39.00	41.00	85	5	23	7.1
"SCHI 268 1"	39.00	41.00	87	5	21	6.8
"SCHI 268 1"	39.00	41.00	88	4	28	6.9
"SCHI 268 1"	39.00	41.00	89	6	1	7.3
"SCHI 268 1"	39.00	41.00	90	5	4	7.0
"SCHI 268 1"	39.00	41.00	91	11	12	8.5
"SCHI 268 1"	39.00	41.00	92	12	16	10.6
"SCHI 268 2"	5.00	7.00	83	6	22	<0.5
"SCHI 268 2"	5.00	7.00	85	5	23	<0.5
"SCHI 268 2"	5.00	7.00	89	6	1	<0.5
"SCHI 268 2"	5.00	7.00	91	11	12	<0.5
"SCHI 268 2"	5.00	7.00	92	12	16	0.01
"SCHI 268 3"	-21.00	-19.00	83	6	22	0.1
"SCHI 268 3"	-21.00	-19.00	84	4	10	0.1
"SCHI 268 3"	-21.00	-19.00	85	5	23	<0.5
"SCHI 268 3"	-21.00	-19.00	86	5	28	<0.5
"SCHI 268 3"	-21.00	-19.00	87	5	21	<0.5
"SCHI 268 3"	-21.00	-19.00	88	4	28	<0.5
"SCHI 268 3"	-21.00	-19.00	89	6	1	<0.5
"SCHI 268 3"	-21.00	-19.00	90	5	4	<0.5
"SCHI 268 3"	-21.00	-19.00	91	11	12	0.13
"SCHI 268 3"	-21.00	-19.00	92	12	16	<0.5
"SCHI 418 1"	41.00	43.00	94	6	2	11.2
"SCHI 418 1"	41.00	43.00	95	6	28	11.2
"SCHI 418 1"	41.00	43.00	96	12	4	12.0
"SCHI 418 2"	6.00	8.00	94	6	2	0.07
"SCHI 418 2"	6.00	8.00	95	6	28	<0.5
"SCHI 418 2"	6.00	8.00	96	12	4	<0.5
"SCHI PP IVA 0"	-3.81	14.89	93	6	15	<0.5
"SCHI PP IVA 0"	-3.81	14.89	94	6	14	<0.5
"SCHI PP IVA 0"	-3.81	14.89	95	6	13	<0.5
"SCHI PP VA 0"	-8.22	-0.44	93	6	15	<0.5
"SCHI PP VA 0"	-8.22	-0.44	94	6	14	<0.5
"SCHI PP VA 0"	-8.22	-0.44	95	6	13	<0.5
"SCHI PP XII 0"	-26.59	-15.59	93	6	29	<0.5
"SCHI PP XII 0"	-26.59	-15.59	94	6	28	<0.5
"SCHI PP XII 0"	-26.59	-15.59	95	6	27	<0.5
"SCHI PP XIII 0"	-26.46	-13.44	93	6	29	<0.5
"SCHI PP XIII 0"	-26.46	-13.44	94	6	28	<0.5
"SCHI PP XIII 0"	-26.46	-13.44	95	6	27	<0.5
"SCHI PP XIV 0"	-30.42	-14.53	93	6	29	<0.5
"SCHI PP XIV 0"	-30.42	-14.53	94	6	28	<0.5
"SCHI PP XIV 0"	-30.42	-14.53	95	6	27	<0.5
"SCHI PP XV 0"	-138.75	-97.55	93	6	29	<0.5
"SCHI PP XV 0"	-138.75	-97.55	94	6	28	<0.5
"SCHI PP XV 0"	-138.75	-97.55	95	6	27	<0.5
"SCHI PP XVI 0"	-131.40	-104.62	93	6	29	<0.5
"SCHI PP XVI 0"	-131.40	-104.62	94	6	21	<0.5
"SCHI PP XVI 0"	-131.40	-104.62	94	6	28	<0.5
"SCHI PP XVI 0"	-131.40	-104.62	95	6	27	<0.5
"SCHI WP 13 1"	50.55	52.55	92	5	21	10.0
"SCHI WP 13 2"	31.55	33.55	92	5	21	<0.5
"SCHI WP 13 3"	-6.44	-4.44	92	5	21	<0.5
"SCHI WP 13 4"	-26.42	-24.42	92	5	21	0.9
"SCHI WP 13 5"	-65.00	-63.00	92	5	21	<0.5
"SITT 262 1"	37.00	42.00	90	5	9	34.2
"SITT 262 1"	37.00	42.00	91	6	13	19.0
"SITT 262 1"	37.00	42.00	92	4	9	22.4
"SITT 262 1"	37.00	42.00	94	4	28	27.4
"SITT 262 1"	37.00	42.00	95	10	17	34.5
"SITT 262 1"	37.00	42.00	96	4	11	35.0
"SUST PP I 0"	-91.19	-81.69	93	4	13	<0.5
"SUST PP I 0"	-91.19	-81.69	94	4	12	<0.5

"SUST PP I 0"	-91.19	-81.69	95	4	11	<0.5
"SUST PP I 0"	-91.19	-81.69	96	4	9	0.7
"SUST PP II 0"	-92.90	-77.35	93	4	13	<0.5
"SUST PP II 0"	-92.90	-77.35	94	3	2	<0.5
"SUST PP II 0"	-92.90	-77.35	94	4	12	<0.5
"SUST PP II 0"	-92.90	-77.35	95	4	11	<0.5
"SUST PP II 0"	-92.90	-77.35	96	4	9	<0.5
"SUST PP III 0"	-100.83	-81.58	93	4	13	<0.5
"SUST PP III 0"	-100.83	-81.58	94	4	12	<0.5
"SUST PP III 0"	-100.83	-81.58	95	4	11	<0.5
"SUST PP III 0"	-100.83	-81.58	96	4	9	<0.5
"SUST PP IV 0"	-89.44	-68.44	93	4	13	<0.5
"SUST PP IV 0"	-89.44	-68.44	94	4	12	<0.5
"SUST PP IV 0"	-89.44	-68.44	95	4	11	<0.5
"SUST PP IV 0"	-89.44	-68.44	96	4	9	<0.5
"SUST PP IX 0"	-159.12	-134.12	93	4	27	<0.5
"SUST PP IX 0"	-159.12	-134.12	94	4	26	<0.5
"SUST PP IX 0"	-159.12	-134.12	95	4	25	<0.5
"SUST PP IX 0"	-159.12	-134.12	96	4	23	<0.5
"SUST PP V 0"	-87.24	-67.44	93	4	20	<0.5
"SUST PP V 0"	-87.24	-67.44	94	4	19	<0.5
"SUST PP V 0"	-87.24	-67.44	96	4	16	<0.5
"SUST PP VI 0"	-95.22	-76.88	93	4	20	<0.5
"SUST PP VI 0"	-95.22	-76.88	94	4	19	<0.5
"SUST PP VI 0"	-95.22	-76.88	96	4	16	<0.5
"SUST PP VII 0"	-84.99	-67.74	93	4	20	0.7
"SUST PP VII 0"	-84.99	-67.74	94	4	19	<0.5
"SUST PP VII 0"	-84.99	-67.74	96	4	16	<0.5
"SUST PP VIII 0"	-152.14	-127.14	93	4	20	0.7
"SUST PP VIII 0"	-152.14	-127.14	94	4	19	<0.5
"SUST PP VIII 0"	-152.14	-127.14	96	4	16	<0.5
"SUST PP X 0"	-167.44	-138.64	93	4	27	<0.5
"SUST PP X 0"	-167.44	-138.64	94	4	26	<0.5
"SUST PP X 0"	-167.44	-138.64	95	4	25	<0.5
"SUST PP X 0"	-167.44	-138.64	96	4	23	<0.5
"SUST PP XI 0"	-150.45	-126.54	93	4	27	<0.5
"SUST PP XI 0"	-150.45	-126.54	94	4	26	<0.5
"SUST PP XI 0"	-150.45	-126.54	95	4	25	<0.5
"SUST PP XI 0"	-150.45	-126.54	96	4	23	<0.5
"SUST PP XII 0"	-163.66	-125.07	93	4	27	<0.5
"SUST PP XII 0"	-163.66	-125.07	94	4	26	<0.5
"SUST PP XII 0"	-163.66	-125.07	95	4	25	<0.5
"SUST PP XII 0"	-163.66	-125.07	96	4	23	<0.5
"SUST WP 4 1"	20.59	22.59	84	12	5	<0.5
"SUST WP 4 1"	20.59	22.59	98	3	11	7.5
"SUST WP 4 2"	-41.30	-39.30	84	11	21	<0.5
"SUST WP 5 1"	25.01	27.01	84	6	25	2.2
"SUST WP 5 1"	25.01	27.01	98	11	3	35.0
"SUST WP 5 2"	-89.98	-87.98	84	6	20	0.8
"SUST WP 5 3"	-125.96	-123.96	84	6	18	<0.5
"SUST WP 5 4"	-143.90	-141.90	84	6	18	<0.5
"SUST WP 6 1"	26.19	28.19	84	7	10	<0.5
"SUST WP 6 1"	26.19	28.19	98	11	3	1.8
"SUST WP 6 2"	-77.72	-75.72	84	7	5	<0.5
"SUST WP 6 3"	-118.70	-116.70	84	7	5	<0.5
"SUST WP 6 4"	-141.66	-139.66	84	7	5	<0.5
"SUST WP 7 1"	24.79	26.79	84	12	5	3.9
"SUST WP 7 1"	24.79	26.79	98	3	12	<0.5
"SUST WP 7 2"	-45.62	-43.62	84	11	28	<0.5
"SUST WP 7 3"	-94.53	-92.53	84	11	26	<0.5
"SUST WP 7 4"	-166.45	-164.45	84	11	26	<0.5

Appendix 3 **Observed and Simulated Nitrate Concentrations over Time**

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Maps

GENERAL

Map 1: Location of Monitoring Wells with Observed Nitrate Concentrations

Map 2: Averages of Observed Nitrate Concentrations (0 - 5 m. below GWL)

Map 3: Averages of Observed Nitrate Concentrations (5 -10 m. below GWL)

Map 4: Averages of Observed Nitrate Concentrations (10 - 20 m. below GWL)

Map 5: Averages of Observed Nitrate Concentrations (> 20 m. below GWL)

Map 6: Sub-soil Composition along Cross Section A - A'

Quantification of biodegradation

Map 7: Locations with Probable Biodegradation of Nitrate (0 - 5 m. below GWL)

Map 8: Locations with Probable Biodegradation of Nitrate (5 - 10 m. below GWL)

Map 9: Locations with Probable Biodegradation of Nitrate (10 - 15 m. below GWL)

Map 10: Locations with Probable Biodegradation of Nitrate (15 - 20 m. below GWL)

Map 11: Calculated Rates of Denitrification in layer 2 (19 - 20 m. NAP)

Map 12: Calculated Rates of Denitrification in layer 3 (17 - 19 m. NAP)

Map 13: Calculated Rates of Denitrification in layer 4 (15 - 17 m. NAP)

VALIDATION I
CROSS SECTIONS- CONSERVATIVE TRANSPORT SIMULATION RESULTS AND OBSERVATIONS

Map 14: Averages of Observed and Simulated Nitrate Concentrations 1983-1984 Cross section A-A', Conservative Simulation

Map 15: Averages of Observed and Simulated Nitrate Concentrations 1991-1993 Cross section A-A', Conservative Simulation

Map 16: Averages of Observed and Simulated Nitrate Concentrations 1994-1996 Cross section A-A', Conservative Simulation

Map 17: Averages of Observed Nitrate Concentrations 1997-1998 Cross section A-A'

Map 18: Averages of Observed and Simulated Nitrate Concentrations 1983-1984 Cross section B-B', Conservative Simulation

Map 19: Averages of Observed and Simulated Nitrate Concentrations 1991-1993 Cross section B-B', Conservative Simulation

Map 20: Averages of Observed and Simulated Nitrate Concentrations 1994-1996 Cross section B-B', Conservative Simulation

Map 21: Averages of Observed Nitrate Concentrations 1997-1998 Cross section B-B'

VALIDATION II
CROSS SECTIONS: NON-CONSERVATIVE TRANSPORT SIMULATION RESULTS AND OBSERVATIONS

Map 22: Averages of Observed and Simulated Nitrate Concentrations 1983-1984 Cross section A-A', Non-Conservative Simulation

Map 23: Averages of Observed and Simulated Nitrate Concentrations 1991-1993 Cross section A-A', Non-Conservative Simulation

Map 24: Averages of Observed and Simulated Nitrate Concentrations 1994-1996 Cross section A-A', Non-Conservative Simulation

Map 25: Averages of Observed and Simulated Nitrate Concentrations 1983-1984 Cross section B-B', Non-Conservative Simulation

Map 26: Averages of Observed and Simulated Nitrate Concentrations 1991-1993 Cross section B-B', Non-Conservative Simulation

Map 27: Averages of Observed and Simulated Nitrate Concentrations 1994-1996 Cross section B-B', Non-Conservative Simulation

ILLUSTRATIVE PREDICTION

Map 28: Illustrative Prediction of Nitrate Concentrations in 2060 Cross section A-A', Conservative Simulation

Map 29: Illustrative Prediction of Nitrate Concentrations in 2060 Cross section A-A', Non-Conservative Simulation

Map 30: Illustrative Prediction of Nitrate Concentrations in 2060 Cross section B-B', Conservative Simulation

Map 31: Illustrative Prediction of Nitrate Concentrations in 2060 Cross section B-B', Non-Conservative Simulation