4 ESTABLISHMENT OF THE INTEGRATED MODELLING SYSTEM

4.1 Introduction

The Danubian Lowland between Bratislava and Komarno is an inland delta formed in the past by river sediments from the Danube. The entire area forms an alluvial aquifer, which throughout the year receives infiltration water from the Danube in the upper parts of the area and returns it into the Danube in the downstream part. The aquifer is an important water resource for municipal and agricultural water supply.

Various human activities have gradually changed the hydrological regime and affected the ground water quality within the study area. This study mainly concentrates on the man induced impacts on:

- ground water regime
- ground water quality
- surface water regime
- surface water quality
- sediment transport
- agriculture, and
- flood plain ecology

The Gabçikovo hydro power scheme is the largest of the man induced impacts within the study area, and hence it plays a central role in this project.

The immediate project objective is to develop, test and transfer an integrated mathematical modelling system including the most important aspects for water resources management in the Danubian Lowland. The ultimate project objective is that the transferred modelling system be used as the technical/scientific basis for future management decisions.

4.2 Equipment

The core of the computer system is two Hewlett Packard work stations (HP Apollo 9000/735). Via a local area network these work stations have been interconnected to a number of personal computers and X-terminals providing a total number of 11 work places.

In addition various field- and laboratory equipment and a project car have been procured. Table 4.1 provides an overview of the equipment procured under this project.

Table 4.1 Status of Project Equipment by January 1995.

Supply No	Description	Supplier	Price ECU	Status
Minor supplies				
MS 01	Copy machine + telefax	CZ & CZ	9,200	Delivered, April 1993
MS 02	PC equipment	BSP	26,130	Delivered, July 1992
MS 03	PC equipment	Zecco	6,360	Delivered, July 1992
MS 04	PC equipment	APS	12,600	Delivered, July 1992
MS 05	MODFLOW (software)	Scientific Software group	1,200	Delivered, May 1993
MS 06	Car	Kama	10,400	Delivered, Feb. 1994
MS 07	Field equipment - tensiometers and cer. cups for sampling of NO_3 leaching	Eijkelkamp	9,123	Delivered, April 1993
MS 08	Field equipment - measurements of chemical parameters directly in obs.wells	Venika	19,700	Delivered, August 1993
MS 10	GPS	Gravquick	46,900	Delivered, May 1993
MS 11	Laboratory equipment - retention curves and gulph hydraulic conductivity	Eijkelkamp	7,801	Delivered, July 1993
MS 12	Laboratory equipment - measurements of N-components in soil, water and plants.	Skalar	40,725	Delivered, August 1993
MS 13	2 X-terminals	DIGIS	10,000	Delivered, August 1994
MS 14	2 X-terminals, Computer memory upgrade, additional hard disk,UPS	DIGIS	30,630	Delivered April-May 1995
MS 15	Arc/Info upgrade, UPS	ArcGEO	12,370	Delivered March 1995
International tender - major computer supply				
Lot 1	Modelling computer	DIGIS	64,246	Delivered, Apr. 1994
Lot 2	Info server system	ARC data	239,198	Delivered, Dec. 1993
Lot 4	A1 elstat plotter	MATRA	45,541	Delivered, Oct. 1993
Lot 6	Local area network	EDICO	3,816	Delivered and installed, April 1994
GRAND TOTAL			595.940	

4.3 Danubian Lowland Information System

The Danubian Lowland Information System (DLIS) has been developed, providing a central database and Geographical Information System (GIS) with facilities for data storage, maintenance, processing and presentation. In addition, data can be imported and exported in file formats readable for the applied modelling system.

DLIS is based on two software resources, the Informix relational database and the Arc/Info GIS. All non-spatial data is stored in Informix and all spatial data in Arc/Info.

The non-spatial data that is stored in Informix may be any kind of data that is related to a certain location. For instance time series of measurements ground water levels, concentration of oxygen in rivers, river discharge etc. It may also be information on soil horizons in a soil profile in terms of water retention curves and hydraulic conductivities. For all kind of information some additional information may also be stored. It could for instance be a description of soil horizons or name and address of the organisation that owns a certain observation well for ground water observations.

Spatial data stored in Arc/Info (GIS) could for instance be surface topography, geological layer boundaries, cropping and land use, river geometry etc. Spatial data may be displayed together with other spatial data (e.g. cities, roads, rivers etc.) or with point information like location of water supply production wells etc. Some examples on different types of spatial data are given in Fig. 4.1.

An interface between DLIS and MIKE SHE has been developed enabling exchange and presentation of data in MIKE SHE file format. In that way MIKE SHE results may be displayed together with any other data stored in the DLIS. An interface enabling storage of river cross-sections in MIKE 11 file formats has also been developed. A direct interface to the remaining modelling systems has not been implemented. However, data can easily be transferred from MIKE SHE file formats to any other of the relevant modelling systems.

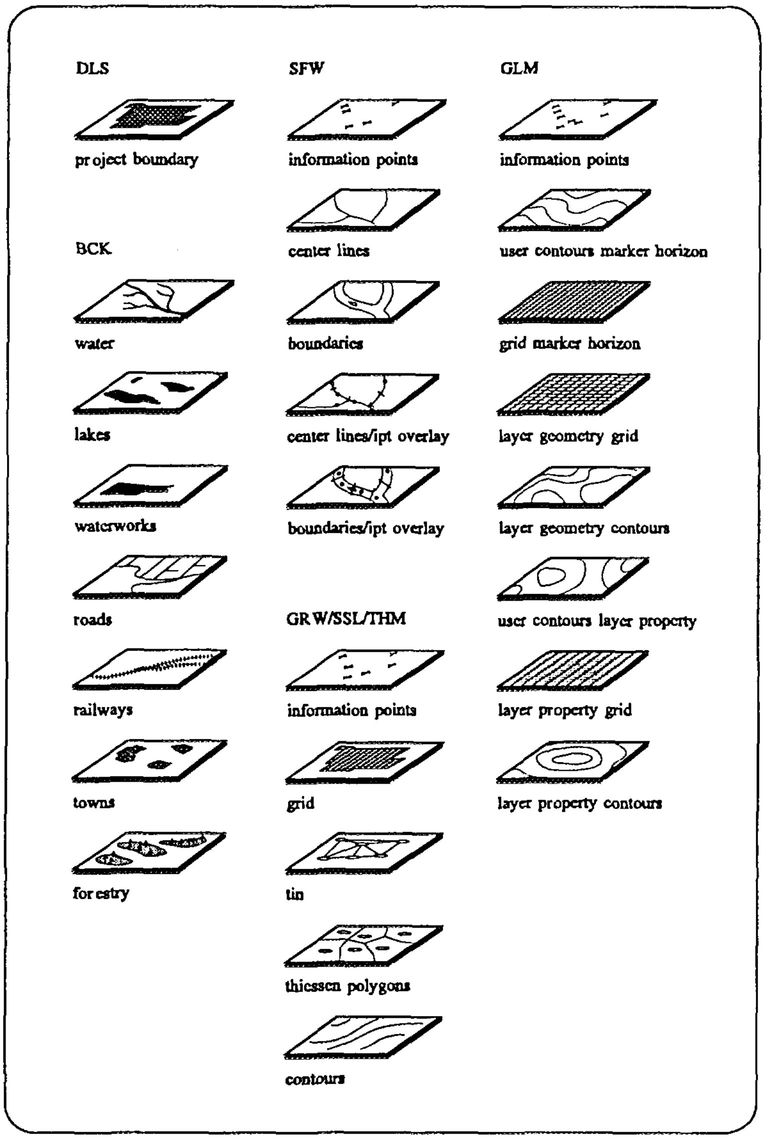


Fig. 4.1 Different spatial data stored in Arc/Info.

4.4 Modelling Approach

A number of individual modelling systems have been applied within this study:

- **MIKE 11** which is a one dimensional river modelling system used for hydraulics, sediment transport and morphology and water quality.

- **MIKE 21** which is a two dimensional modelling system used for reservoir modelling, including hydrodynamics, sediment transport and water quality.

- **MIKE SHE** which simulates the major flow and transport processes of the hydrological cycle. MIKE SHE comprises the following main components which are fully coupled allowing for feedbacks and interactions between the components:

  - 1D flow and transport in the unsaturated zone
  - 3D flow and transport in the ground water zone
  - 2D flow and transport on the ground surface
  - 1D flow and transport in rivers.

- **DAISY** which is a one-dimensional root zone model for simulation of soil water dynamics and nitrogen transport and transformation.

4.4.1 Further development of modelling systems

Although the above mentioned models are generalized tools with comprehensive applicability ranges, some model modifications were needed in order to accommodate the very special conditions in the area. The following model modifications have been made as part of the project:

Daisy

A new crop growth and nitrogen module for maize has been developed.

Coupling of MIKE SHE and MIKE 11

A fully dynamic coupling of MIKE SHE with the hydraulic module of MIKE 11 has been developed. The two modelling systems are running simultaneously exchanging data in the computer memory.

Geochemical Model

A geochemical model describing chemical/microbiological processes related to transformations of nitrogen species, organic matter, oxygen and manganese. This model is linked to the solute transport module of MIKE SHE.

Simplified Unsaturated Zone Description in MIKE SHE

A simplified unsaturated zone description only accounting for gravity flow has been implemented in MIKE SHE.

4.4.2 The integrated modelling system

The integrated modelling system is formed by the exchange of data and the feed-backs between the individual modelling systems. The structure of the integrated modelling system and the exchange of data between the various modelling systems are illustrated in Fig. 4.2.

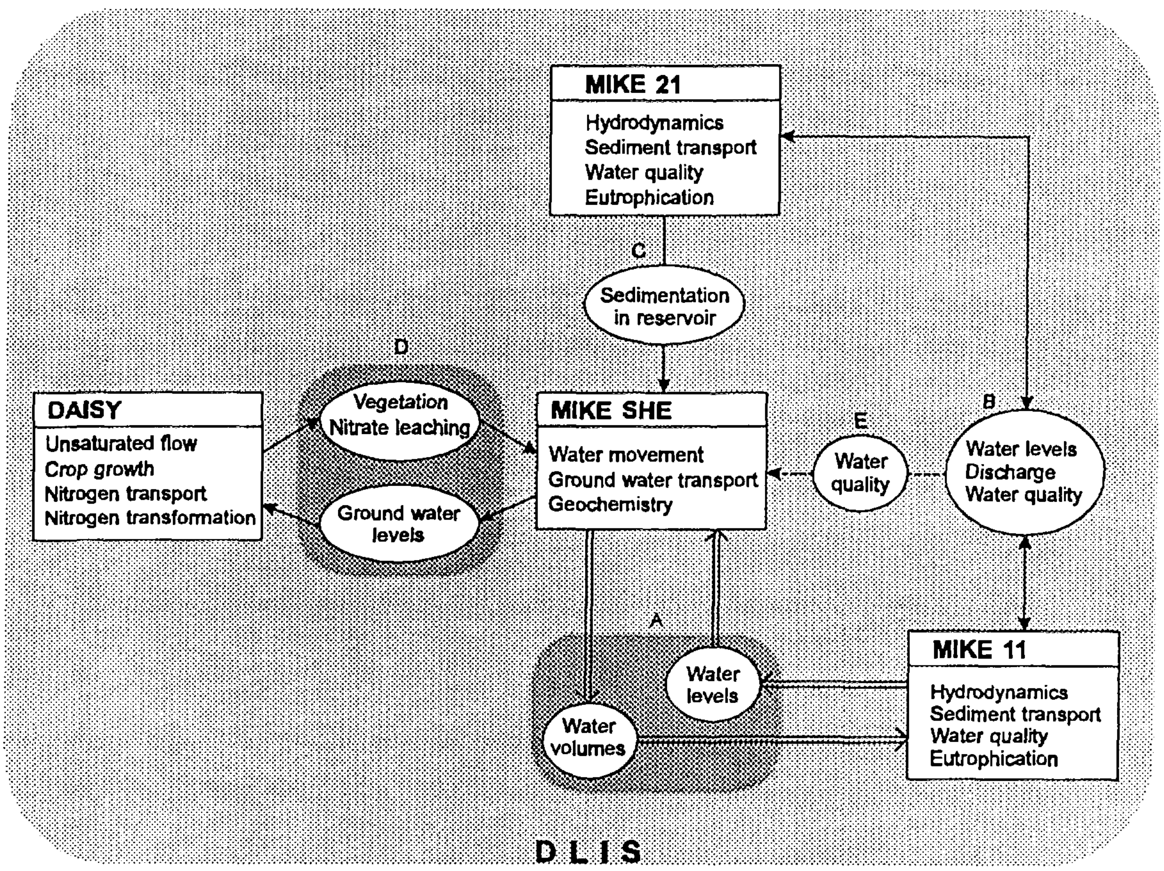


Fig. 4.2 Structure of the integrated modelling system.

The interfaces A-E between the various models are briefly described below:

A) MIKE SHE forms the core of the integrated modelling system having interfaces to all the individual modelling systems. The coupling of MIKE SHE and MIKE 11 is a fully dynamic coupling where data is exchanged after each computational time step.

The remaining modelling systems are coupled in a more simple manner involving a sequential execution of various models and subsequently a transfer of boundary conditions from one model to another. Some examples are listed below.

B) Results of eutrophication simulations with MIKE 21 in the reservoir are used to estimate the concentration of various water quality parameters in the water that enters the Danube downstream of the reservoir to be used for water quality simulations for the Danube using MIKE 11.

C) Sediment transport simulations in the reservoir with MIKE 21 provide information on the amount of fine sediment on the bottom of the reservoir. This information is used to calculate leakage coefficients which are used in ground water modelling with MIKE SHE.

D) The DAISY model calculates vegetation parameters which are used in MIKE SHE to calculate the actual evapotranspiration. Ground water levels calculated with MIKE SHE act as lower boundary conditions for DAISY unsaturated zone simulations. Consequently, this process is iterative and requires a few model simulations.

E) Results from water quality simulations with MIKE 11 and MIKE 21 are used to estimate the concentration of various species in the water that infiltrates to the aquifer from the Danube and the reservoir. This is being used in the ground water quality simulations (Geochemistry) with MIKE SHE.

4.4.3 Approach of model application

The procedure that has been applied in the model applications involves three steps:

1) **Model setup**; involves that the geometry of the system and some physical characteristics are implemented in the model. For instance river cross-sections, surface topography, soil physical parameters, land use, vegetation parameters and hydraulic conductivities in the ground water zone.

2) **Model calibration**; involves that a number of model simulations is carried out and model results are compared with measured data, until a satisfactory correspondence is obtained. All the applied modelling systems are physically-based implying that all input data can be assessed directly from field data. Thus, the model calibration has been limited to adjustment of a few physical parameters within narrow ranges.

3) **Model validation**; involves that the model demonstrates the ability to reproduce measured data outside the calibration period.

4.5 Ground Water Modelling

Ground water modelling has been carried out at different scales with different objectives. Thus, the following ground water models have been established:

- a regional ground water model for pre-dam conditions,
- a regional ground water model for post-dam conditions,
- a local ground water model for an area surrounding the reservoir
- a local ground water model for the river branch system, and
- a cross-sectional (vertical profile) model near Kalinkovo.

The regional model area covers about 3000 km^2 but the main area of interest is the Žitný Ostrov which is the area between the Danube, the Little Danube and the Vah. The model area is shown in Fig. 4.3 for the regional model as well as for the local models.

The main objectives of the regional ground water modelling are to study the impacts of the damming of the Danube on the hydrological regime within the project area, in particular in terms of ground water levels and dynamics, and to provide reliable boundary conditions for local ground water models.

The objectives of the local ground water model around the reservoir are to provide more accurate results for this area than can be done with the more coarse regional model and to provide boundary conditions for the cross-sectional model.

The objective of the local model for the river branch system area is to provide more accurate results for this area than can be done with the more coarse regional model.

The objective of the cross-sectional model near Kalinkovo is to provide the hydraulic basis for geochemical modelling of the area where comprehensive project field investigations were carried out.

The applied modelling systems are MIKE SHE, MIKE 11 and the coupled version of the two. All the modules of MIKE SHE have been applied implying that the major flow processes in the hydrological cycle are described.

The model setup is based on information on location of river systems and cross-sectional geometry, surface topography, climatology, land use and cropping pattern, soil physical properties and hydrogeology. The setup for the two regional models reflecting pre- and post-dam conditions is basically the same. The only difference is that the post-dam model includes the Hrusov reservoir and related hydraulic structures and canals.

The ground water flow regime on Žitný Ostrov is to a large extent controlled by the water level dynamics of the river. Time series of ground water levels measured at locations close to the Danube show a high degree of correlation with the water level fluctuations in the Danube. In zones further away from the river the ground water level dynamics is also significantly affected by precipitation.

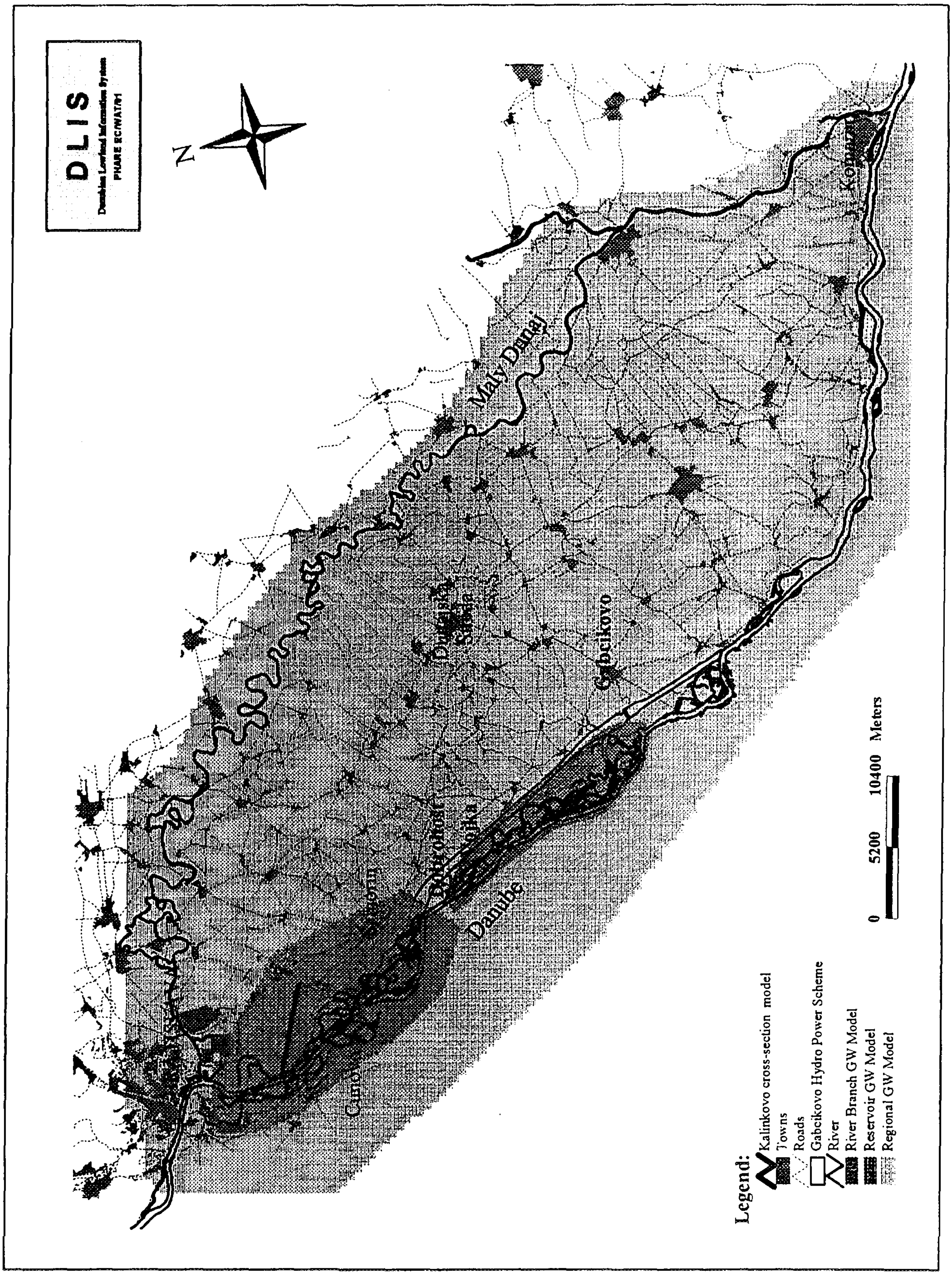


Fig. 4.3 Extent of the regional model area, and indication of local modelling scales.

In order to model the ground water flow regime within the model area it is therefore of the utmost importance that the river models are simulating the water level dynamics in the Danube correctly. The river model that is used in the ground water modelling is identical to the MIKE 11 river model of the Danube, which has been successfully validated.

The regional ground water models apply a horizontal discretization of 500 m and in the vertical the aquifer has been divided into four geologically determined computational layers.

The pre-dam model was calibrated against measured ground water levels, discharge and water levels for the five year period from 1986 to 1991, and validated by demonstrating the ability to reproduce ground water levels measured after the damming of the Danube.

In general the model reproduces measured ground water levels and dynamics quite well. Figs. 4.4 and 4.5 show comparison of measured and simulated ground water levels for the calibration period and the validation period respectively. As seen the ground water dynamics as well as the levels have been changed significantly due to the damming.

The ground water model for the reservoir area is a sub-model of the regional model and the parameter values of the local model are identical to the ones in the regional model with the only change that the local model applies a horizontal discretization of 250 m, and a finer vertical discretization with 7 computational layers.

Similarly, the local model for the river branch area is a sub-model of the regional model. This local model has a horizontal discretization of 100 m.

The local models receive time varying ground water levels from the regional models as boundary conditions.

4.6 Pollution Status of Reservoir Sediments

The data collected and analysed within the present project are not sufficient to provide firm conclusions regarding the status of organic contaminants and heavy metals in floodplain sediments. From the existing data no general pollution has been detected. However, some samples from the flood plain along the Danube river showed relatively high contents of some PAH's, which can be attributed to local pollution. In respect to other processes affecting the migration of contaminants (mixing, sorption, decay, etc.), the identified local contents of PAH's in sediments are not likely to pose significant threats for deterioration of ground water quality. As the heavy metals origin in sulphides, which are rich on heavy metals, and are characteristic and common for the Alpino-Carpathian geologic situation, the relatively high contents for Ni, Cu and Fe might be explained by higher background contents in Slovakia. A significant portion of metals may be associated with non-reactive minerals. Potential release of metals follows probably destruction of reactive minerals like Fe-oxides, but other processes may be important as well.

4.7 Ground Water Quality

4.7.1 Geochemical field investigations at Kalinkovo

A geochemical field investigation has been carried out in a cross-section north of the reservoir near Kalinkovo (see Fig. 4.3). This investigation was directed towards the development of ground water quality during infiltration of the Danube river water into the aquifer. It has been suggested that a change in ground water quality may happen after damming the Danube due to enhanced infiltration of dissolved organic matter in the gravel aquifer.

Eleven multi-screen wells were installed forming a 7.5 km long cross-section close to the water supply wells at Kalinkovo. The multi-screen wells have been sampled frequently to investigate the ongoing (bio)geochemical processes during infiltration of the Danube river water into the aquifer.

A seasonal fluctuation in the concentrations of various species with a delay compared to the fluctuation of the Danube river water was observed for the screens that are close to the Danube. Interpretation of collected data indicates slow denitrification by both solid and dissolved organic matter and reductive dissolution of Mn-oxides, possibly manganite. It is not known whether or not the two redox processes interact.

4.7.2 Ground water quality model

A mathematical model has been developed that includes kinetic denitrification by solid organic matter coupled to reductive dissolution of Mn-oxides. The model consists of three components:

1) advective/dispersive transport of all chemical components
2) kinetically-controlled denitrification, and
3) (pseudo) equilibrium-controlled speciation and equilibrium-controlled inorganic chemistry.

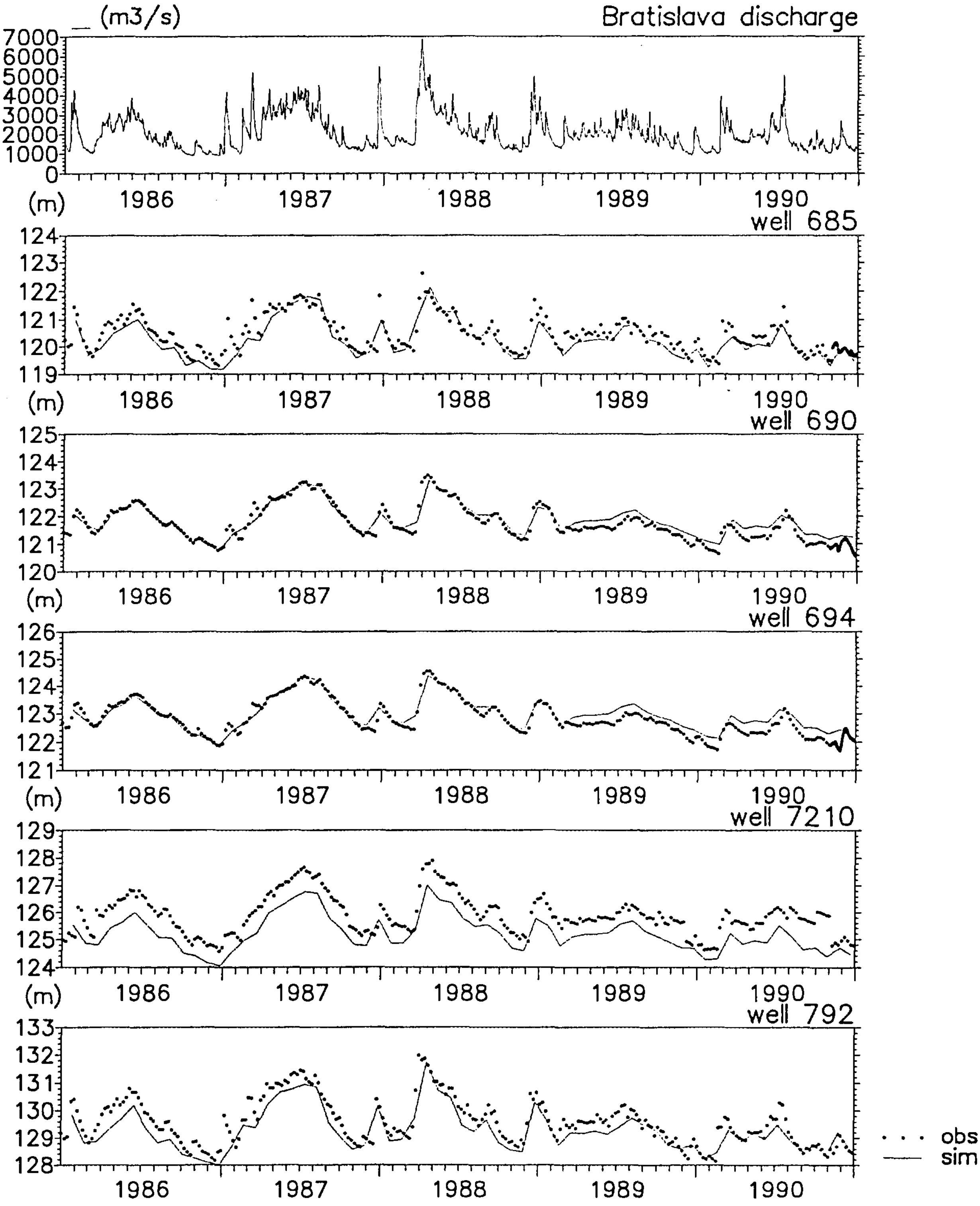


Fig. 4.4 Simulated and observed ground water levels in some wells on Žitný Ostrov (calibration period).

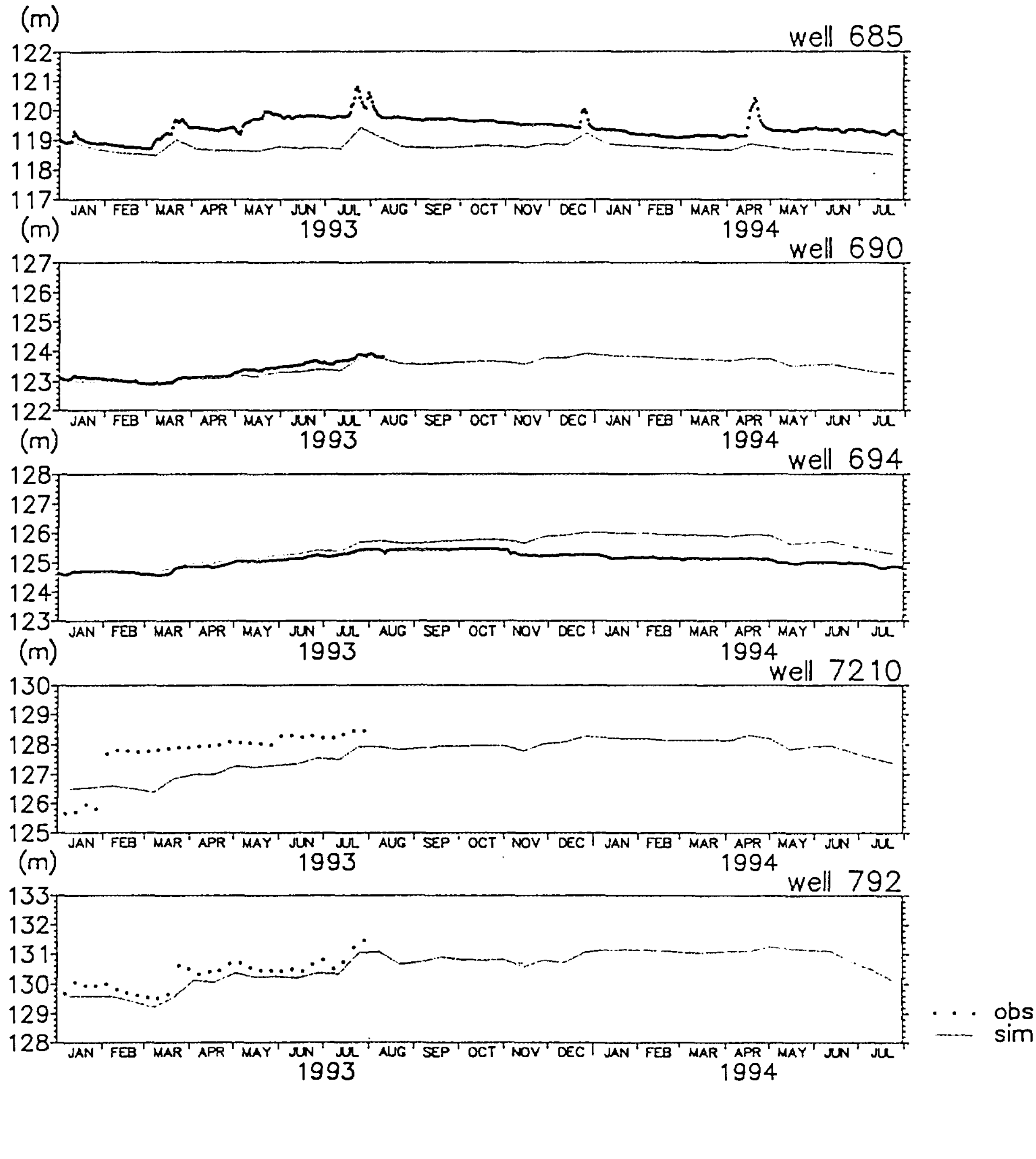


Fig. 4.5 Simulated and observed ground water levels in some wells on Žitný Ostrov (validation period).

The denitrification module is a simple, empirical first-order denitrification model, having two parameters. These parameters are a rate parameter and an apparent equilibrium constant for the redox couple NO_3/NO_2. The rate parameter determines the rate of denitrification and the equilibrium constant determines the occurrence of NO_2 as intermediate denitrification product. The denitrification model includes also a more complex description where denitrification takes place under consumption of dissolved organic carbon in addition to consumption of solid organic matter.

The model has been tested for a geohydrological system based on geochemical data from Kalinkovo. These tests have shown that the geochemical model behaves qualitatively correct.

Conservative transport of ^{18}O in the Kalinkovo cross-section and reactive transport has been modelled. The setup of a cross-sectional ground water flow model was based on detailed measurement on the cross-section. An example of a model simulation is given in Fig. 4.6 which shows simulated distribution of $\delta^{18}O$ in the Kalinkovo cross-section in April 1994 and a comparison of measured and simulated $\delta^{18}O$ in one of the wells at Kalinkovo.

4.8 Unsaturated Zone and Agricultural Modelling

The objectives of the agricultural studies were to evaluate the impact on agricultural potential and nitrate leaching risk on Žitný Ostrov, due to the damming of the Danube.

The applied modelling system is the DAISY model which simulates crop growth, water flow in the unsaturated zone and nitrogen transport and turnover. The model was calibrated on the basis of data from field experiments carried out during the years 1981-1987 at the experimental station in Most near Bratislava. During this process the crop parameters used in the model were adjusted to Slovak conditions.

After the initial setup and calibration, the model performance was evaluated through preliminary simulations using data from a number of plots located on an experimental field site at Lehnice. On the basis of comparisons between measured and simulated values of nitrogen uptake, dry matter yield and nitrate concentration in soil moisture, the model performance under Slovak conditions was considered satisfactory.

Modelling of the pre-dam and post-dam conditions regarding agricultural potential and nitrate leaching risk was carried out using a representative selection of soil units, cropping pattern and meteorological data covering the area of Žitný Ostrov.

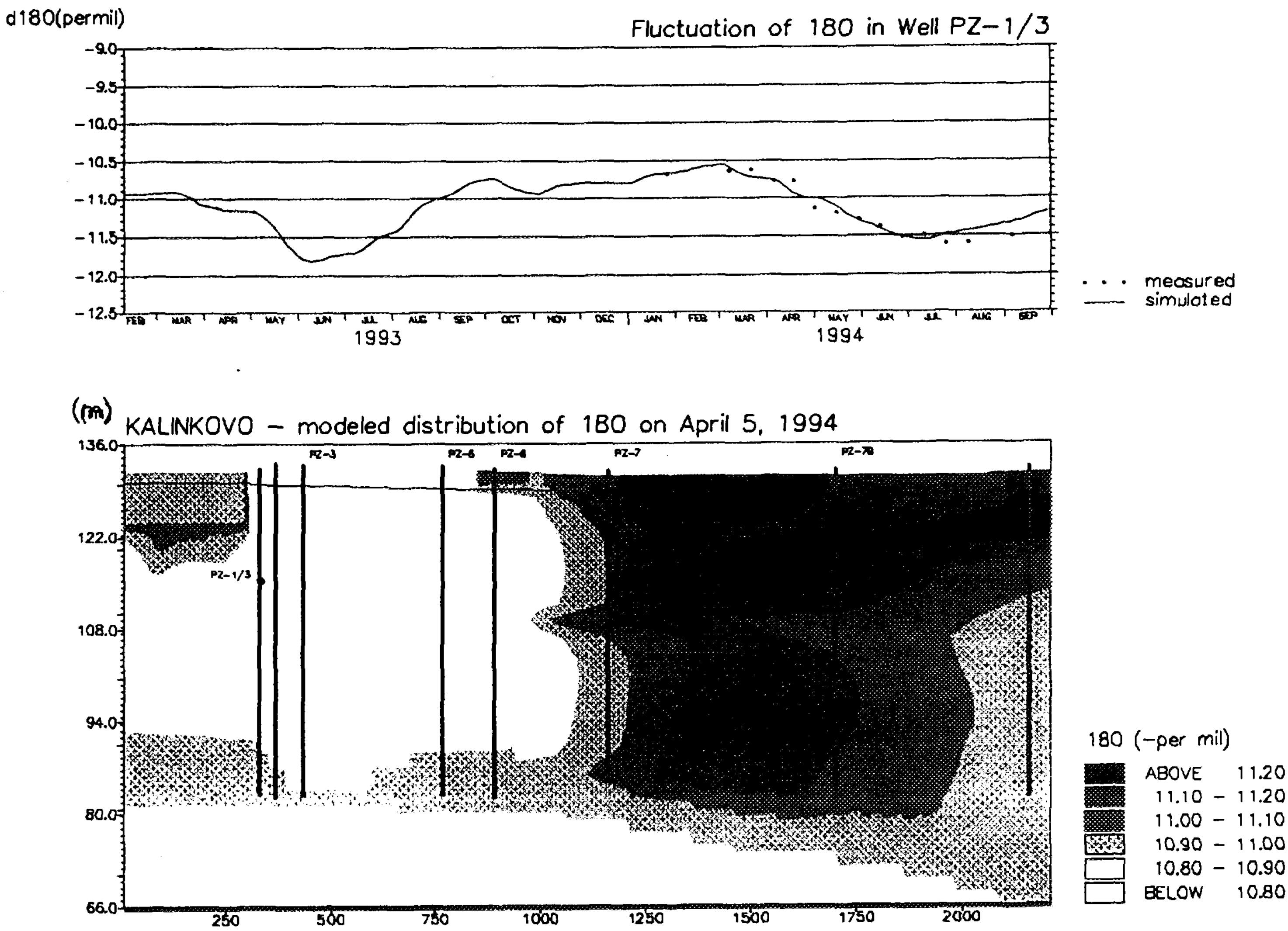


Fig. 4.6 Model results from the Kalinkovo cross-section. a) Modelled distribution of $\delta^{18}O$ in April 1994 and b) Comparison between measured and modelled $\delta^{18}O$ in one of the wells in the cross-section.

The simulations were carried out for the period 1986-1991.

The DAISY model uses time varying ground water levels simulated with the regional MIKE SHE ground water model as lower boundary condition, for the unsaturated flow simulations.

Cropping pattern and fertilizer application is included in the model based on measurements and statistical data from the Žitný Ostrov.

4.9 River and Reservoir Hydrodynamic Modelling

The main objectives for the hydrodynamic modelling are to provide calibrated and validated flow models to be used in relation to water quality, eutrophication and sediment transport modelling. Furthermore, water depths and flow velocities are important factors for ecological predictions.

The applied modelling systems are the hydrodynamic module of MIKE 11 and MIKE 21.

The following models have been setup, calibrated and validated:

- one-dimensional MIKE 11 model for the Danube from Bratislava to Komarno
- one-dimensional MIKE 11 model for the river branch system at the Slovak floodplain.
- two-dimensional MIKE 21 model for the Hrusov reservoir.

The MIKE 11 models have been established in two versions reflecting post- and pre-dam conditions, respectively.

MIKE 11 on the Danube

The setup of the MIKE 11 model for the Danube is based on river cross-sections measured in 1989 and 1991.

The applied boundary conditions were measured daily discharge at Bratislava (upstream) and a Q-h relation at Komarno (downstream).

The model was initially calibrated for two steady state situations reflecting a low flow situation (905 m^3/s) and a flow situation close to the long term average (2390 m^3/s), respectively. Subsequently, the model was calibrated against water levels and discharges measured at Bratislava, Medvedov and Komarno in 1991.

The model was finally validated by demonstrating the ability to reproduce measured data from 1990. Fig. 4.7 shows the results of the model validation from Medvedov.

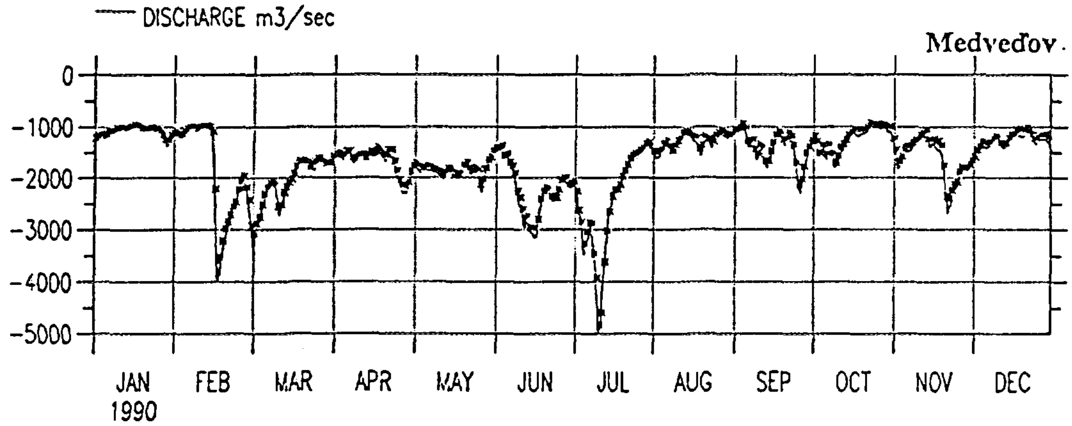


Fig. 4.7 Validation of MIKE 11 model for the Danube for pre-dam conditions.

For the post-dam model some river reaches were updated with cross-sections measured in 1993. In addition the reservoir and related hydraulic structures and canals were included. As the conditions after damming of the Danube have changed significantly, recalibration for the post-dam model was carried out for the period April 1993 - July 1993. Subsequently, the model was validated against measured data for the period November 1992 - March 1993.

MIKE 11 on river branch system

The Slovak and Hungarian floodplain are at many locations characterized by a complex system of river branches. The area referred to as the river branch system covers about 20 km of the Slovak flood plain between the Old Danube and the hydro power canal. A layout of the river branch system is shown in Fig. 4.8.

This area is of major ecological interest and is one of the key areas for the ecological studies in this project (cf. Section 4.12).

The cross-sections in the river branch system were measured during the 1960's and 1970's.

The pre-dam model was calibrated against data from the 1965 flood.

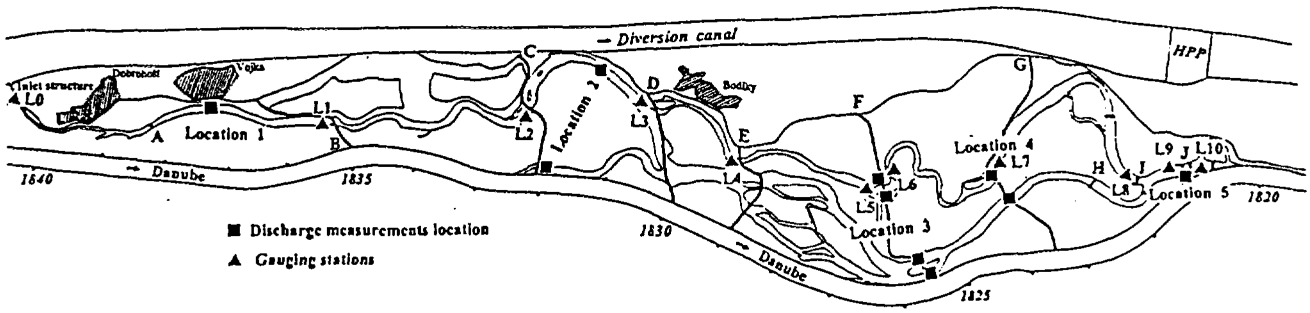


Fig. 4.8 Layout of the river branch system.

In the post-dam situation the branch system is fed by an inlet structure with water from the hydro power canal (on the figure denoted diversion canal). The system consists of a number of compartments separated by small dikes (lines B-I). On each of these dikes combined structures of culverts and spillways are located enabling some control of the water flows in the system.

Only very scarce and not very reliable data on flow and water levels in the river branch system was available. Therefore, a programme comprising measurements of discharges and water levels at a number of locations was carried under this project during the summer 1994. Fig. 4.9 shows results of the model calibration against these data.

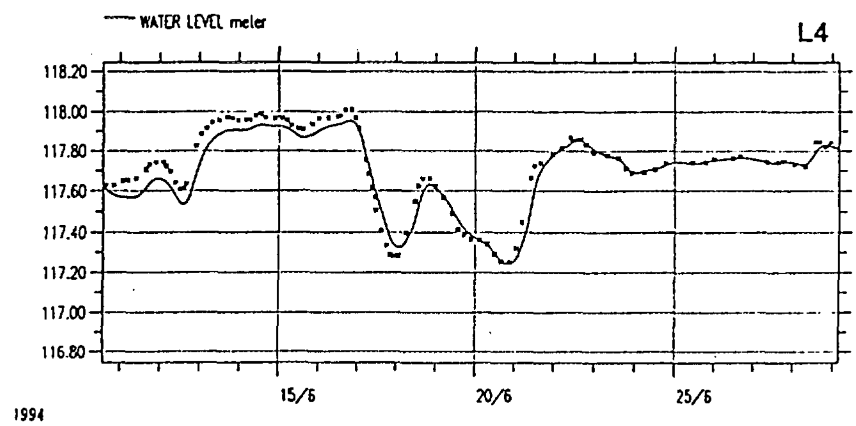


Fig. 4.9 Comparison of measured and simulated water levels with in the calibration period, at one location in the river branch system.

MIKE 21 on the reservoir

A MIKE 21 hydrodynamic model for the Hrusov reservoir has been established based on a reservoir bathymetry measured in 1994.

The model was calibrated against flow velocities measured in the reservoir in the autumn of 1994. The results of the calibration are illustrated in Fig. 4.10.

4.10 River and Reservoir Sediment Transport Modelling

The sediment transport modelling was based on the use of existing data on the sediment transport processes prevailing in the Danube river. Few additional measurements were carried out to complement these data. Different sediment transport models covering both the fine suspended sediment (cohesive sediment and fine sand) and the bed load sediment (coarse sand and gravel) were established.

Measurements of concentration of suspended sediment at different cross-sections showed that the suspended load has decreased significantly from the 50'ties to the 90'ties due to construction of new reservoirs and treatment plants upstream of Bratislava.

Based on these measurements and established sediment rating curves, both one-dimensional and two-dimensional sediment transport models of transport of fine (suspended) sediment were established for the Danube river, the reservoir and for the river branch system on the Slovak flood plain between the hydro power canal and the Old Danube. The period from November 1992, when the reservoir was taken into operation, to August 1993 was simulated in the two-dimensional MIKE 21 model. Sedimentation rates in the correct order of magnitude (approximately 10 cm in the sedimentation areas) was simulated.

Various grain sizes were included in the mathematical model enabling prediction of the grain size distribution of the new sediment deposits in the reservoir. This information was used together with the simulated thickness of the deposited sediment layer to calculate leakage coefficients for modelling water exchange between the surface water in the reservoir and the ground water beneath it. Sediment rating curves were estimated at different cross-sections based on the simulated sediment transport rates. Siltation as function of upstream discharge was subsequently derived. From November 1992 to August 1993, the simulated siltation rate (kg/day) was 42% of the total suspended load at Bratislava. Simulated sedimentation in the reservoir during November 1992 to August 1993 is shown in Fig. 4.11.

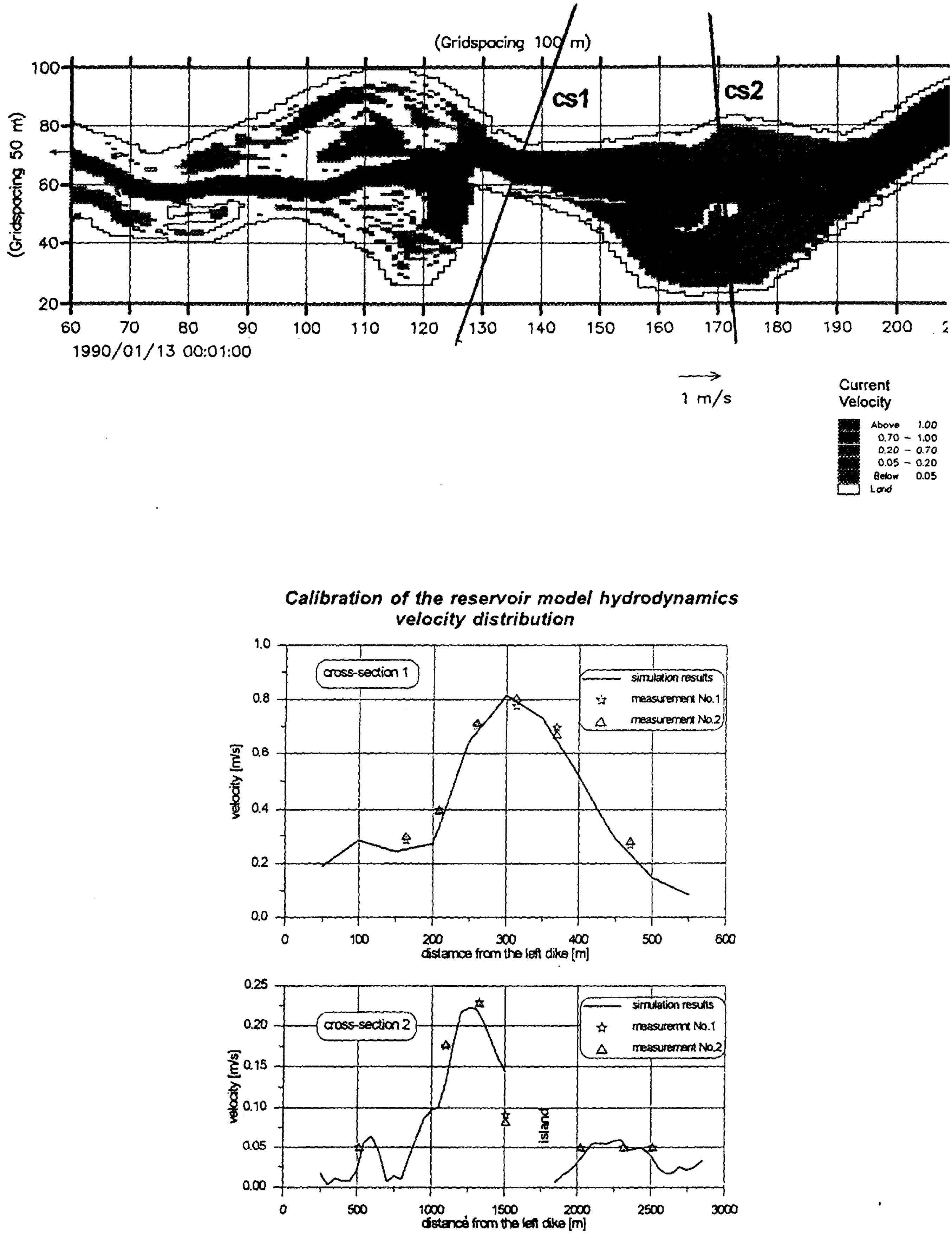


Fig. 4.10 Comparison of measured and simulated flow velocities in two cross-sections in the reservoir.

Alluvial channel bed material was investigated with respect to grain sizes and exhibited significant scatter due to the natural grading of the sediment inside the cross-sections with bars, pools etc. In order to avoid difficulties in determining accurate mean grain sizes for the mathematical model, the change in mean water level over a decade rather than changes in bed elevations was compared between observations and simulations. By using such an approach, perturbations in bed levels from one cross-section to another did not destroy the picture of the overall trends in aggradation and degradation of the river bed. The morphological model predicted the observed erosion downstream Bratislava during the last decades to a very satisfactory degree.

The reach between rkm 1820 and rkm 1840 (the Danube) is, under pre-dam conditions, characterized by a very complex flow pattern because the Danube interacts with the river branch system. These interactions are not properly described in the hydrodynamic model and consequently the simulated morphological development is less accurate in this reach.

Simulated and measured erosion of the river bed is shown in Fig. 4.12 which also illustrates the effects of dredging.

Subsequently, the morphological model was used to evaluate the effect of the dredging which has been going on over the years. Also the effect of the Gabçikovo Dam was investigated with respect to changes in bottom elevations and mean water levels in the new course of the river as well as in the Old Danube.

4.11 Surface Water Quality Modelling

The goal of the surface water quality modelling was to establish models describing the water quality in the main stream of the Old Danube before and after damming, in the reservoir, and in the river branches, respectively.

A BOD-DO model (MIKE 11 WQ) has been used to describe the water quality in the main stream of the Danube in the pre-dam situation and in the main stream of the old Danube in the post-dam situation. This model describes oxygen concentration (DO) as a function of the decay of organic matter (BOD), transformation of nitrogen components, re-aeration, oxygen consumption by the bottom and oxygen production and respiration by living organisms.

The river branches were simulated with a eutrophication model (MIKE 11 EU), in which the algae production is the driving force. The algae growth in this model is described as a function of incoming light, transparency of the water, temperature, sedimentation and growth rate of the algae and of the available inorganic nutrients.

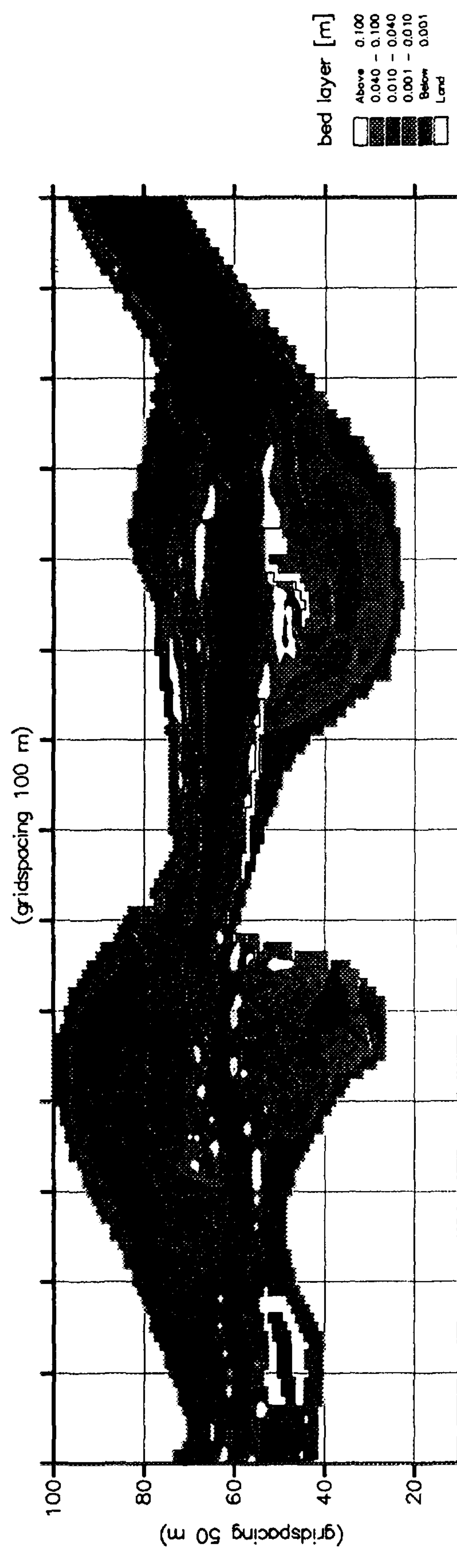


Fig. 4.11 Simulated sedimentation in the reservoir from November 1992 to August 1993.

In the reservoir the driving force is also the algae growth and hence a eutrophication model (MIKE 21 EU) was applied. This model is, in principle, the same as the MIKE 11 EU, but operates in two-dimensional (horizontally) whereas the MIKE 11 EU operates in one-dimensional.

To provide the basis for the modelling existing field data on water quality have been evaluated.

The field measurements show no significant changes in oxygen level in the Danube river from Bratislava to Komarno. The measurement has shown differences in oxygen concentration of up to 1 - 2 mg O_2/l in the river. This difference can be ascribed to the diurnal variation created by oxygen production and respiration of the algae in the river water. Oxygen concentration in the outlet canal from the reservoir have been observed to be 4 mg O_2/l higher than in the upstream river. This may also be due to oxygen production of the algae.

No vertical stratification of the water masses in the reservoir was observed during August and September 1994. The measured data do not indicate increases in BOD-level through the reservoir.

The BOD-DO model (MIKE 11 WQ) has been calibrated and validated to a satisfactory level both for pre-dam and post-dam condition. The model furthermore describes the diurnal variation satisfactorily. A comparison of simulated and measured oxygen concentrations in the Danube is shown in Fig. 4.13.

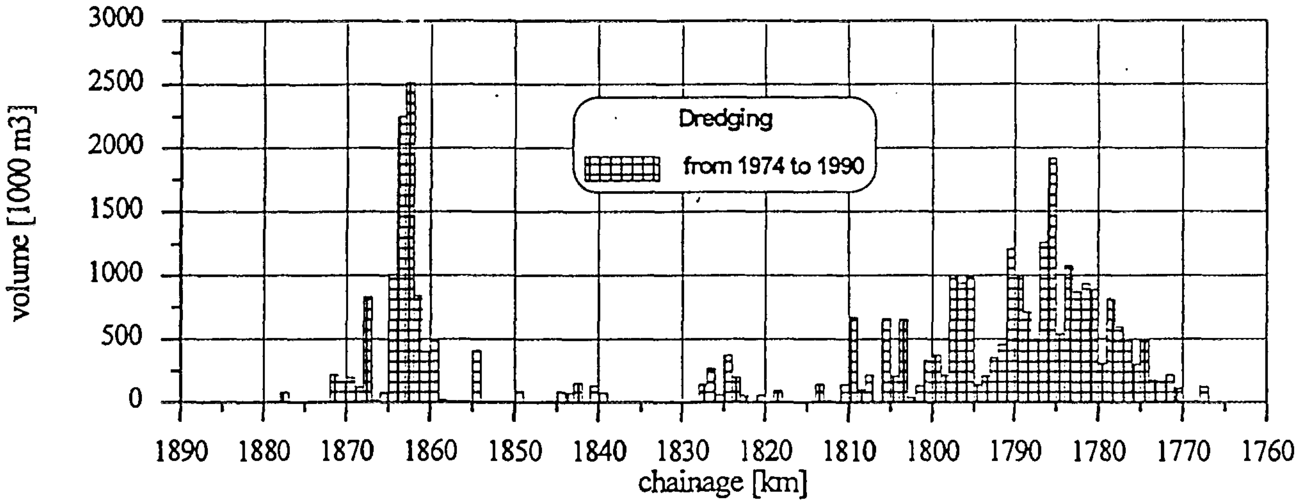
The conditions from pre-dam to post-dam have changed significantly, and hence a recalibration of the pre-dam model was necessary to obtain a well calibrated model for the post-dam situation. The pre-dam model was calibrated against data from October 1991 and validated against data from April and August/September 1991 The post-dam situation was calibrated against data from May 1993 and validated against data from June 1993.

Results from the eutrophication model for the river branch system against data from June-August 1993 (MIKE 11 EU) is shown in Fig. 4.14.

The simulated phytoplankton production is at the same level as the measured one and algae concentrations have been simulated correct within a difference of few micrograms chlorophyll. A little to high nutrient concentrations are at the moment simulated. Smaller adjustment through a continued short calibration procedure in the first quarter of 1995 is expected to bring this model to a stage where it is ready to use for simulation of different scenarios.

The EU model for the reservoir has also been satisfactory calibrated.

a)



b)

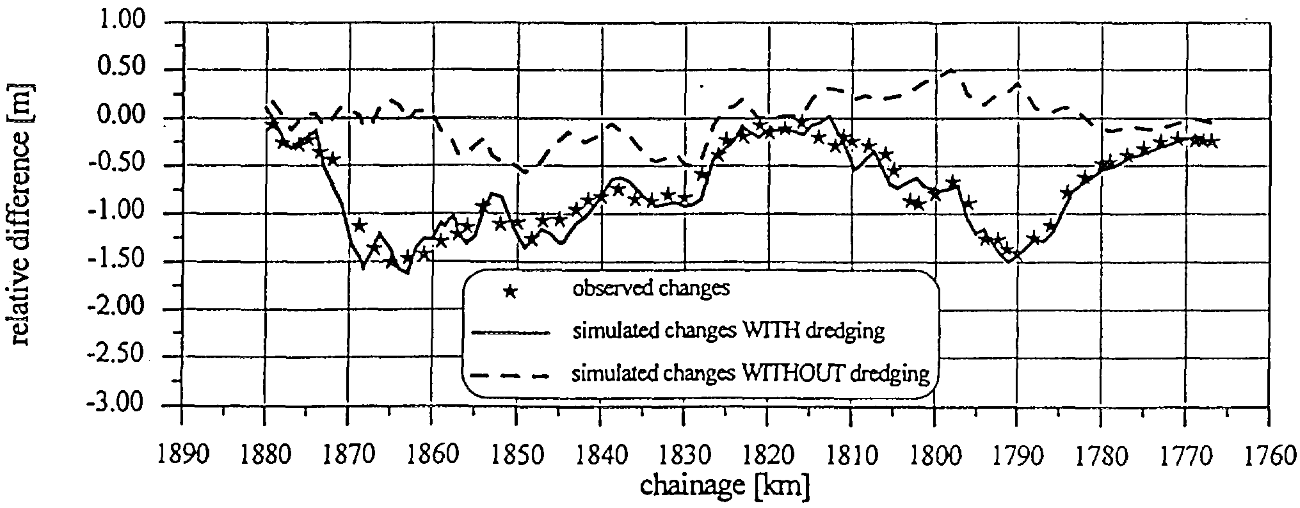


Fig. 4.12 Amount of dredging (a) and the effect of dredging for the morphological development of the river bed (b).

4.12 Flood Plain Ecology and Modelling

The ecological studies mainly put focus on the Hrusov reservoir, the Danube river and the river branch system on the Slovak floodplain between the hydropower canal and the Old Danube.

An ecological management tool has been developed. It is based on output from the established integrated modelling system and a number of criteria that links model results to a number of different ecotopes.

The integrated modelling system provides data regarding:

- water quality and eutrophication
- sedimentation regime
- surface water flow regime, and
- subsurface flow regime

The ecological criteria are directly comparable with processed model results. The criteria are, for instance, expressed in terms of:

- frequency, duration and depth of floodings
- average depth to ground water table
- variations in ground water table
- flow velocities in rivers
- primary production

A detailed model of the river branch system on the Slovak floodplain has been established. This model is based on the coupled version of MIKE 11 and MIKE SHE and describes the complex network of river branches, their interactions with the subsurface flow regime and the Old Danube.

The model setup is based on the MIKE 11 model for the river branch system and the MIKE SHE regional ground water models. The model was setup in a network of 100 m grid squares, and reflect pre- as well as post-dam conditions.

The model has been calibrated against measured discharges in the river branch system. Large amounts of water is lost as infiltration to the ground water on its way through the river branches. Hence, a successful calibration of flow in the branches require that exchange of water between surface- and subsurface flow regimes are simulated correctly.

An example of model results is given in Fig. 4.15 which shows the extent and depth of flooding in the river branch system in July 1993.

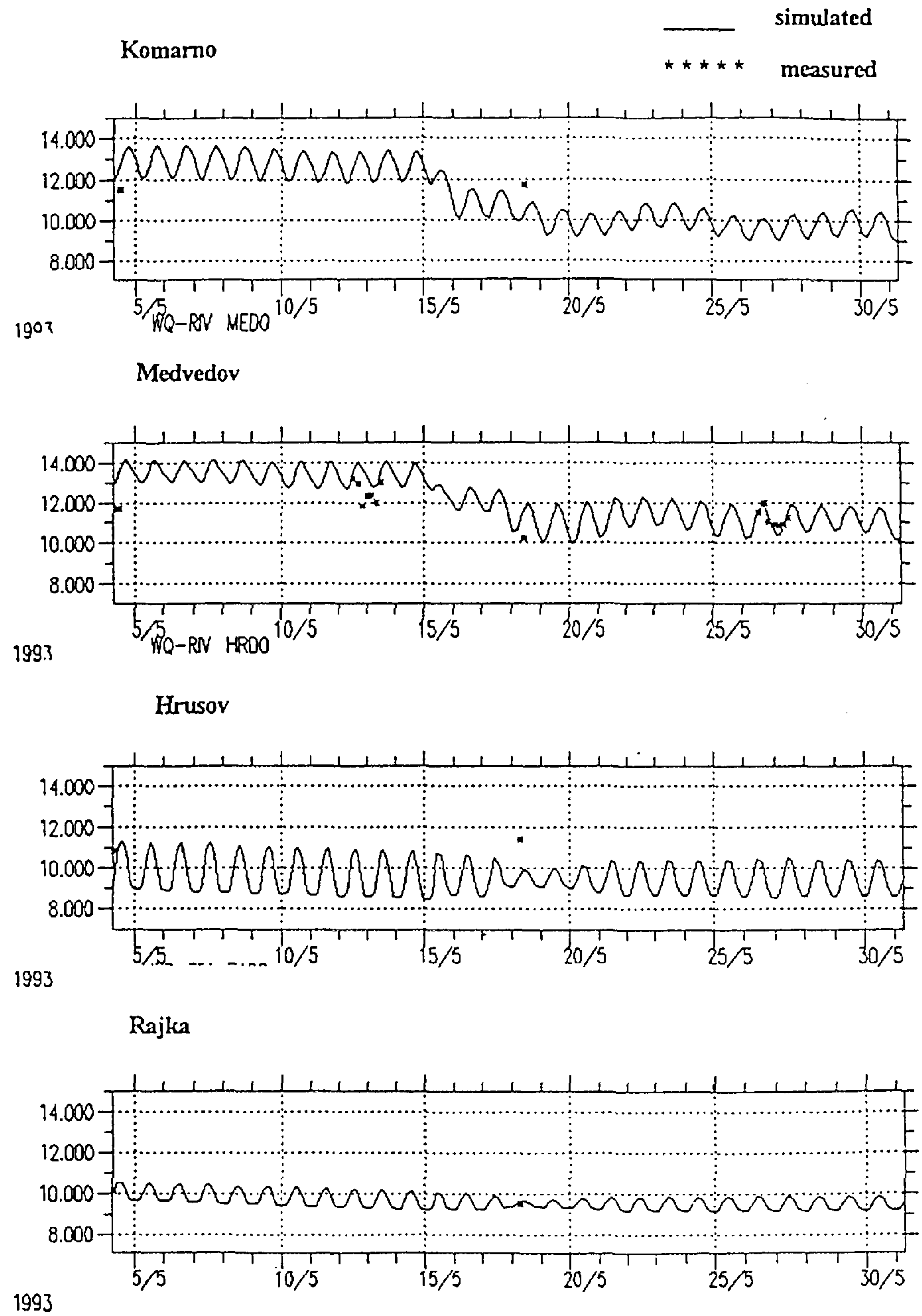
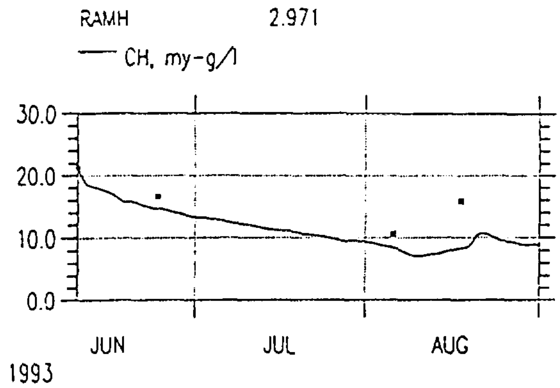
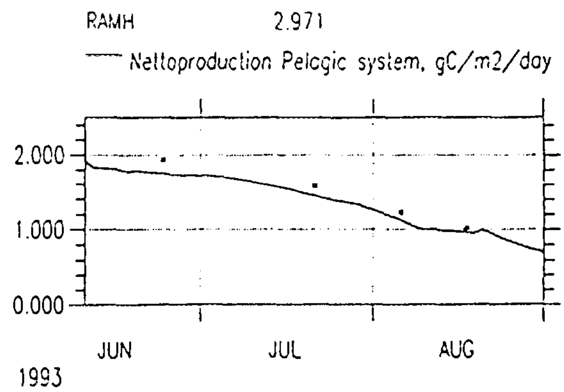


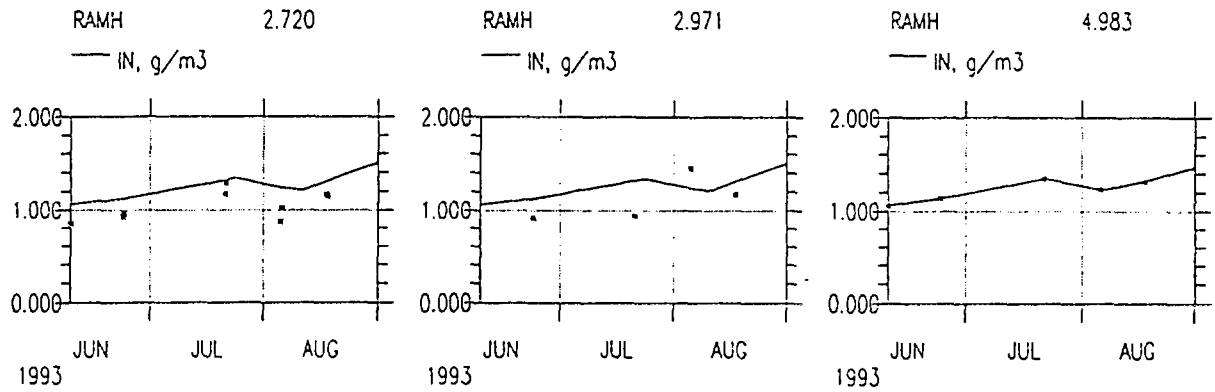
Fig. 4.13 Comparison of simulated and measured oxygen concentrations in the Danube. Post-dam situation. Calibration.



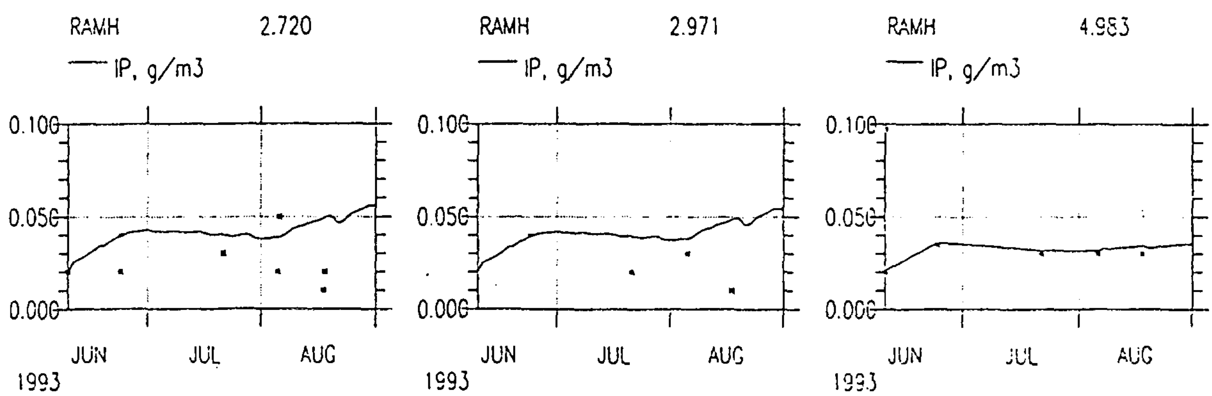
Chlorophyll a



Net Production



Inorganic Nitrogen



Inorganic Phosphorus

Fig. 4.14 Comparison of simulated and measured water quality data for the river branch system, (Baka branch).

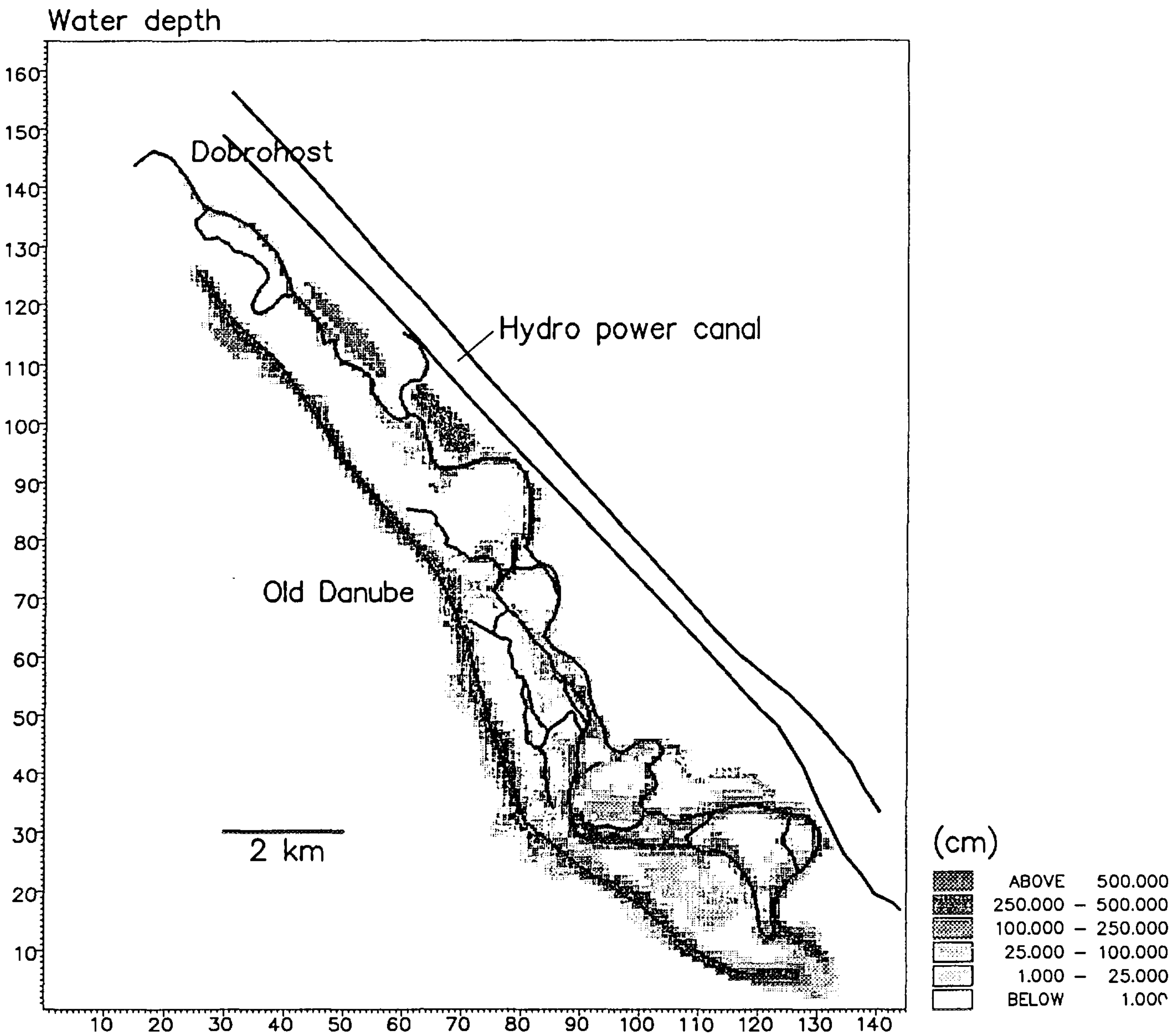


Fig. 4.15 Simulated areal extent and depth of flooding on 25 July 1993.