

# Information environment and architecture of decision support system for nutrient reduction in the Baltic Sea

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## Introduction

The overall goal of a multidisciplinary research program MARE (Marine Research on Eutrophication: A Scientific Base for Cost-effective Measures for the Baltic Sea) is to develop a decision-support system (DSS) to be used as a tool for developing and testing cost-effective strategies of reducing eutrophication in the Baltic Sea (<http://www.mare.su.se>). Such a system has to have access to large amounts of diverse types of environmental data, be capable to run different kind of models, and provide users with an easy way to evaluate different scenarios. The system must be open to expand its capability by including other models, datasets and be available for public use. To achieve these goals the system is designed as a distributed web system. A client program – Nest – communicates with server based database(s) and application server(s) and analyzes the environmental data and modeling results on the client machine (Figure 1).

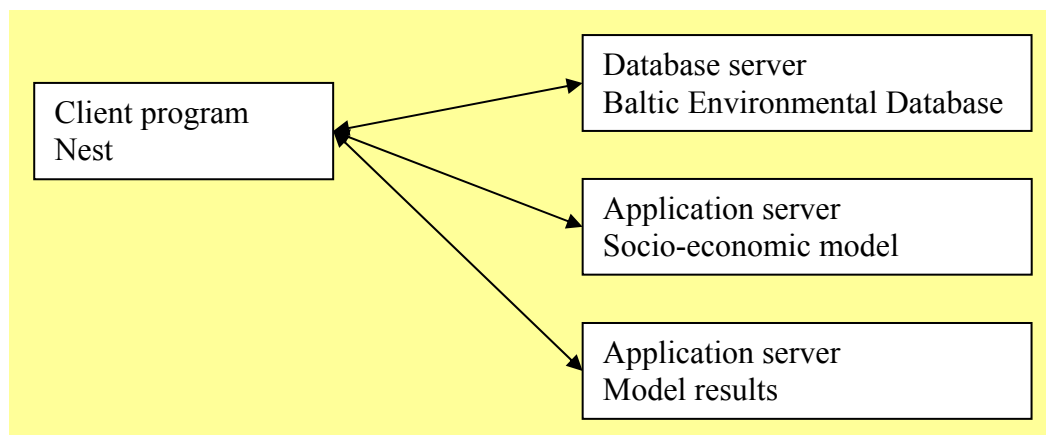


Figure 1. The client - server architecture of the system

The system is written using the Java™ 2 programming language (Campione et al 2000) which allows running a program on different platforms that support Java™ 2.

The Nest communicates with the servers using the Remote Method Invocation Application Programming Interface (RMI API) (Sun Corp, 2002a).

## Client – Server interactions

The decision support system (DSS) is designed as a system distributed on the Web and uses Java™ Web Start technology (Zukowski, 2002) for deploying the client program Nest via any browser, on any platform that support Java™ 2. Figure 2 presents a scheme of the client – server interactions. The client machine has to have only a web browser and Java™ 2 Virtual Machine (JVM) installed. Now the Java Web Start and the underlying Java Network Launch Protocol (JNLP) are a standard part of the Java 2 platform (as of version 1.4, see <http://java.sun.com/j2se>). The user accesses the HTTP server, downloads a small .jnlp file which tells the browser to start Java Web Start, outside the browser. Java Web Start then checks the version of a previously installed client program (if there is one), upgrades this program if necessary and starts it.

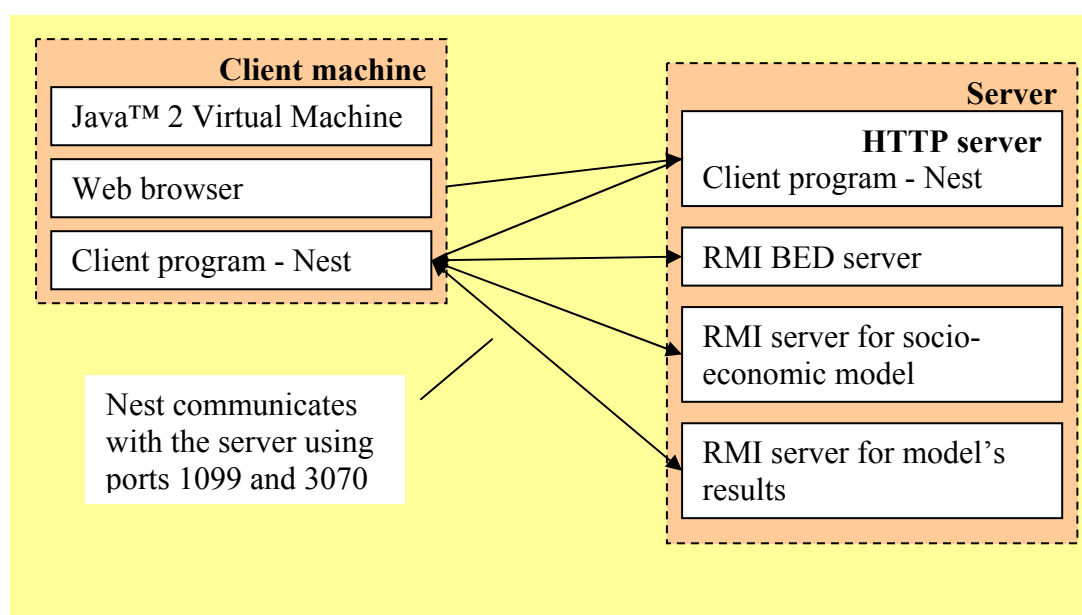


Figure 2. The scheme of client - server interactions

Usually a RMI client connects to a RMI server using port 1099 and then establishes a connection using a randomly chosen port. In order to avoid problems with firewalls the system explicitly specifies port 3070 to use and a firewall can then be easily configured to allow this.

Currently all RMI servers of the DSS (which is still a prototype) are installed on the same computer as the HTTP server. This is done to simplify further development of the system. Later RMI servers should be installed on different machines to increase security of the system and to more effectively use resources of the computers.

## **Server side software**

The server side of the system is a set of RMI servers registered on the host machine(s) and serve a client's requests like obtaining data from the database, send stored files with modeling results or run a model.

### **1.1 *Baltic Environmental Database and Database RMI server***

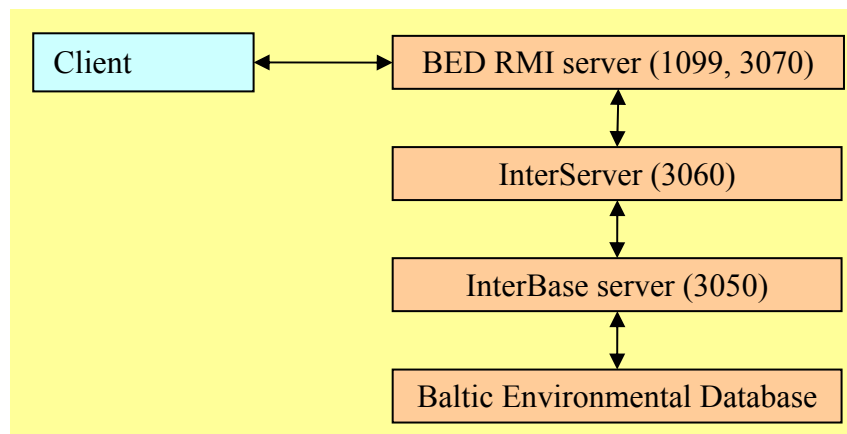
Creating of the Baltic Environmental Database – BED was originally initiated as part of a project "Large scale environmental effects and ecological processes in the Baltic Sea" under the responsibility of Fredrik Wulff in 1990 (Wulff & Rahm, 1991). The database is physically implemented at the Department of Systems Ecology, Stockholm University. BED is under constant development and updating and plays an important role for the groups in international research activities.

BED contains the following data:

- Hydrographic data – sampling data (Temperature, Salinity, Total oxygen, Phosphate, Phosphorus, Silicate, Nitrate, Nitrite, Nitrate + Nitrite, Ammonia, Total nitrogen, Chlorophyll) collected in the Baltic Sea from 1900 up to now by almost all major data makers around the Baltic Sea.

- River loads to the Baltic sea from monitored and unmonitored sources (Runoff, NH<sub>4</sub>N, NO<sub>2</sub>N, NO<sub>3</sub>N, TotN, PO<sub>4</sub>P, TotP, CODMn, CODCr, BOD<sub>5</sub>, BOD<sub>7</sub>, Si, COR) covering the time period from 1970 to 1990. These data were provided by Per Stålnake from Linköping University, Sweden.
- Loads from point sources (Flow, BOD<sub>5</sub>, BOD<sub>7</sub>, BOD<sub>21</sub>, TOC, CODCr, CODMn, TotP, TotN, NH<sub>4</sub>N, Hg, Cd, Cu, Cz, Pb) for 1990, provided by Per Stålnake from Linköping University, Sweden.
- Atmospheric nitrogen deposition (NO<sub>3</sub>N, NH<sub>4</sub>N, NO<sub>3</sub>N+ NH<sub>4</sub>N, HNO<sub>3</sub>+NO<sub>3</sub>-P, NH<sub>3</sub>+NH<sub>4</sub>-P, HNO<sub>3</sub>+NO<sub>3</sub>-P+NH<sub>3</sub>+NH<sub>4</sub>-P) to the Baltic Sea is gridded data with 1 by 1 degree resolution in space and one month step in time for the period from 1970 to 1992. These data were provided by Lennart Granat from the Department of Meteorology, Stockholm University, Sweden.

These data are stored in the database, managed by the InterBase SQL database management system (DBMS) (Borland Corp. 2002).



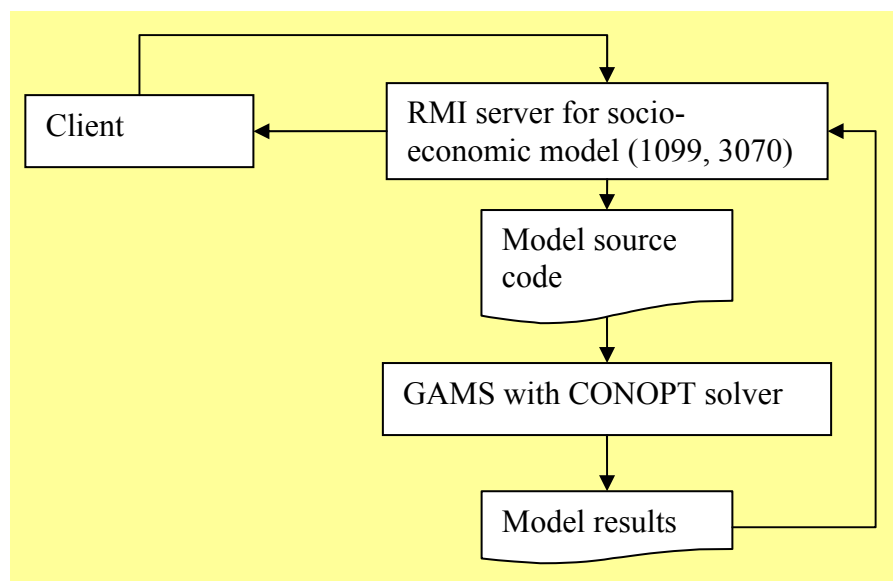
**Figure 3. The scheme of the database server**

Figure 3 shows the scheme of the database server interactions. BED RMI server is written in Java and uses the ports 1099 and 3070 to communicate with the client program. To access data in the database RMI server uses Java Database Connectivity Application Programming Interface (JDBC API) (Sun Corp, 2002b). InterBase

DBMS has a JDBC driver which is type 3 driver and consists of a driver itself and middleware (InterServer) that accepts JDBC requests using port 3060 and translates these to the InterBase API calls.

### **1.2 RMI server for running socio-economic model**

The socio-economic model for calculation of cost-effective reductions in the loads of nitrogen and phosphorus to the Baltic Sea has been developed by Ing-Marie Gren from the Beijer International Institute of Ecological Economics, Royal Swedish Academy of Sciences (RSAS). This nonlinear model has been developed in the general algebraic modeling system – GAMS (GAMS, 2002). To solve this model a nonlinear programming (NLP) algorithm CONOPT, developed by ARKI Consulting and Development in Denmark (CONOPT, 2002) is used.



**Figure 4. Running the GAMS model on the server**

Figure 4 shows the scheme of interactions between the client program and the RMI server in order to run the economic model. The client sends to the server a source code of the model with modified parameters according to the task to be solved, the server then saves this code and starts GAMS to solve the model using the CONOPT solver. When the calculation is finished, the RMI server reads the results and sends

them back to the client. In order to avoid conflicts when running several versions of the model concurrently, the RMI server generates unique names for each model code and modeling results.

### 1.3 RMI server for accessing precompiled model's results

A biogeochemical time-dependent model (Savchuk, 2002a) coupled with a physical transport model (Gustafsson, 2002), called BALTSEM, has been used in MARE to model biogeochemical cycle in the Baltic Sea. Simulations covering a long time period (20-30 years) are rather time consuming (several hours) and should not be run in interactive mode as a component of NEST. The model has therefore been run separately, with several different scenarios of nutrient loads on the Baltic Sea, and these results are available for the client to evaluate and analyze.

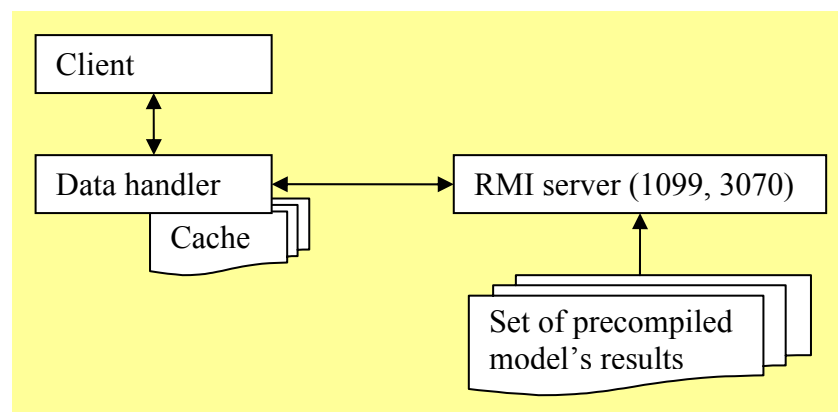


Figure 5. Client - RMI server interaction to work with large set of model's results

Figure 5 shows the scheme of the client – server interaction for BALTSEM. This is very similar to the structure of the RMI server for the socio-economic model, described earlier. The difference is that this time-dependent models produce very large amounts of data and the system should therefore pay special attention to reduce the time it takes to transfer data between server and client. To do so, the client uses a special Data handler, which caches previously obtained data locally (see Figure 5) and accesses the RMI server only if requested data has not been received in previous

requests. This server has been developed by Örjan Bodin at the Department of Systems Ecology, Stockholm University.

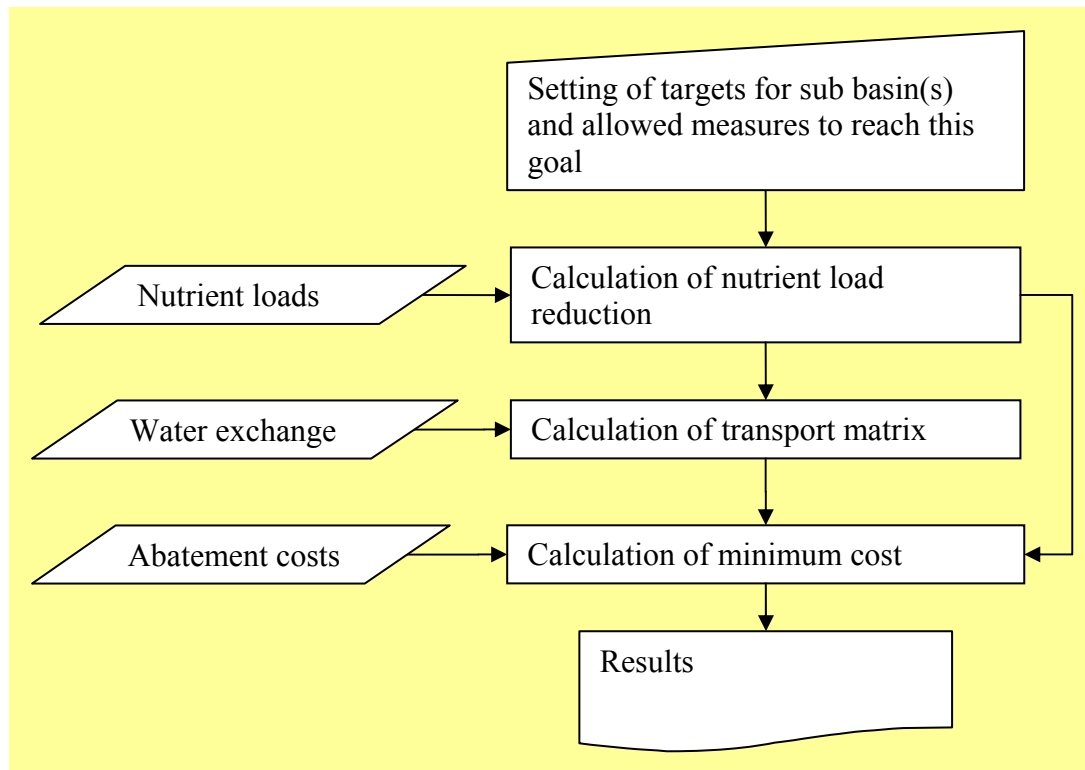
## **Client program - Nest**

Nest is a central part of the system; an integrated set of modules that performs different calculations, analyze data from the database, run models and jointly analyze results. It heavily uses a GIS package OpenMap™ (BBN Technologies, 2002) for graphical presentations and analyses of the results. Currently the Nest comprises four major modules:

- Cost Calculation – an interface to the socio – economic model of cost effective nutrient reductions;
- Nutrient Budgets – steady state nutrient budgets model;
- Loads – set of tools for data analysis;
- Model Results – an interface for graphical analysis of the modeling results.

### **1.4 Cost Calculation**

The **Cost Calculation** module of the Nest is the user interface to a model of cost effective nutrient reductions in the Baltic Sea. The Baltic is modeled as an input – output nutrient flow analysis (Kay & Graham, 1989), which is integrated with a programming model solving for cost effective solution, for further details see Appendix 2 and 3. The flow chart in Figure 6 illustrates a generalized scheme of the model.



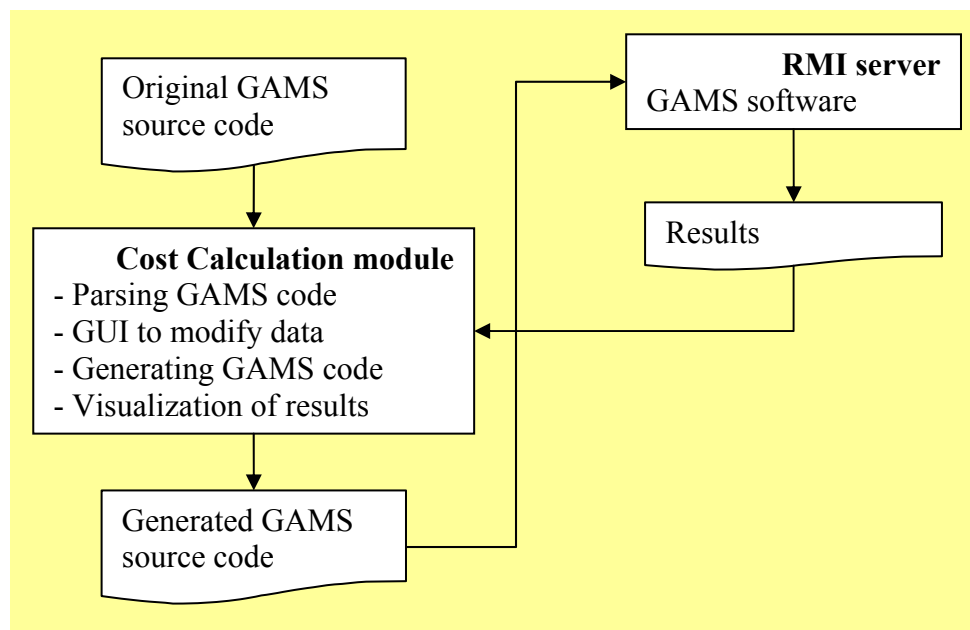
**Figure 6. The scheme of the economic model**

This module can work in “standard” and “expert” modes. In “standard” mode it allows a user to set targets (improvement of water transparency) for the seven major sub basins of the Baltic Sea and specify a set of possible measures for each country, which can be taken into consideration by the model. These measures are: Change of nitrogen spreading time, Land use, Livestock reduction, Sewage reduction, NOX reduction, Fertilizer use, and Wetland restoration. Abatement costs and other parameters of the model also can be changed in “expert” mode.

The model has been developed using the GAMS programming language and keeps all needed data (abatement costs, flow matrix etc) incorporated in the source code. The module parses the GAMS code and extracts all data from it to make the data available for user modifications using a Graphical User Interface (GUI). When the user requests to solve the model, the program converts these data to GAMS data format, inserts



these modified data into the GAMS model code and sends the code to the application server (Figure 7).



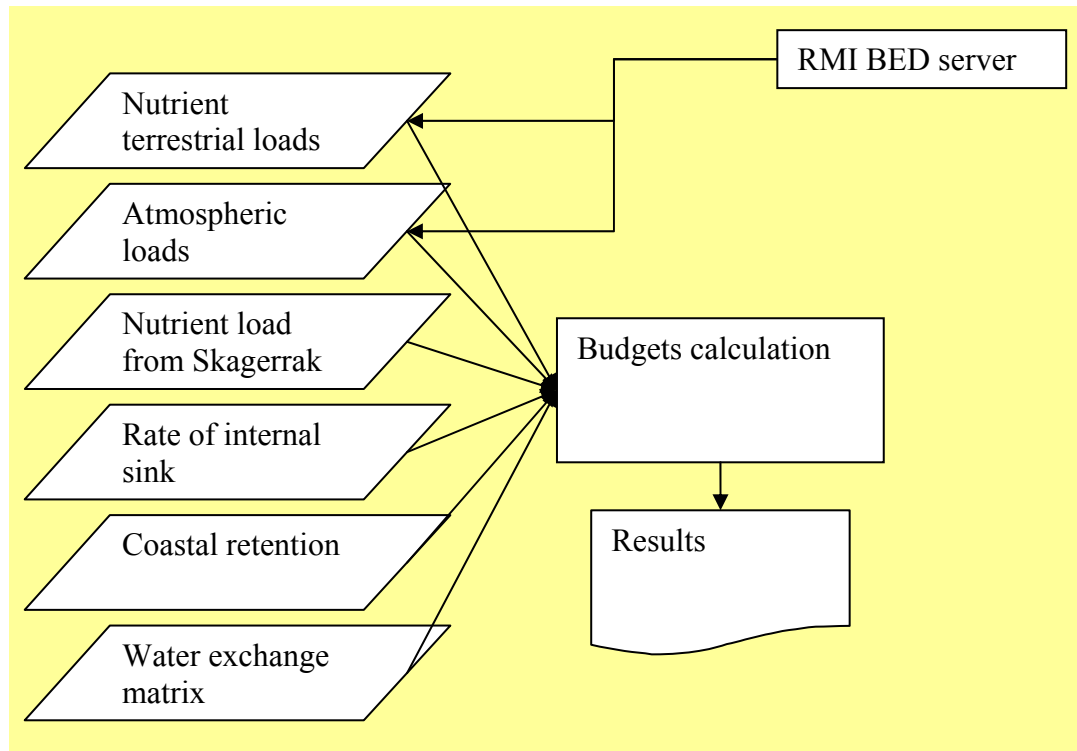
**Figure 7. Management of GAMS source code of the economic model**

The results, obtained from the server, can be then analyzed using GIS based visualization techniques and also can be saved as .csv file (Comma Separated Values) for later analysis with third party software tools (Microsoft Excel, for example).

### **1.5 Nutrient Budgets**

The **Nutrient Budgets** module is a front end to a nutrient budgets model, based on a flow matrix of water exchange between the major seven sub basins of the Baltic Sea (see Appendix 2). This model is a steady state, which use then limited computer resources and can therefore be used on the client machine in interactive mode. The flow chart in Figure 8 shows the main data flow used in the model. The main purpose of this simplistic steady – state model is to provide a fast, user friendly tool to study how this 7-basin sea reacts to a change of nutrient loads. This nutrient budgets module makes it easy to change terrestrial loads (in different countries/sub basins) and nutrient flow from the Skagerrak (boundary condition) and see the consequences in

term of nutrient concentrations in the all the basins. The module supports an “expert” mode in which the user can change atmospheric loads and internal parameters of the model as well (Coastal retention and Rate of internal sink). As default loads the model uses data from HELCOM PLC-3 (HELCOM, 1998). It is also possible to get data from the Baltic Environmental Database for a specified year.



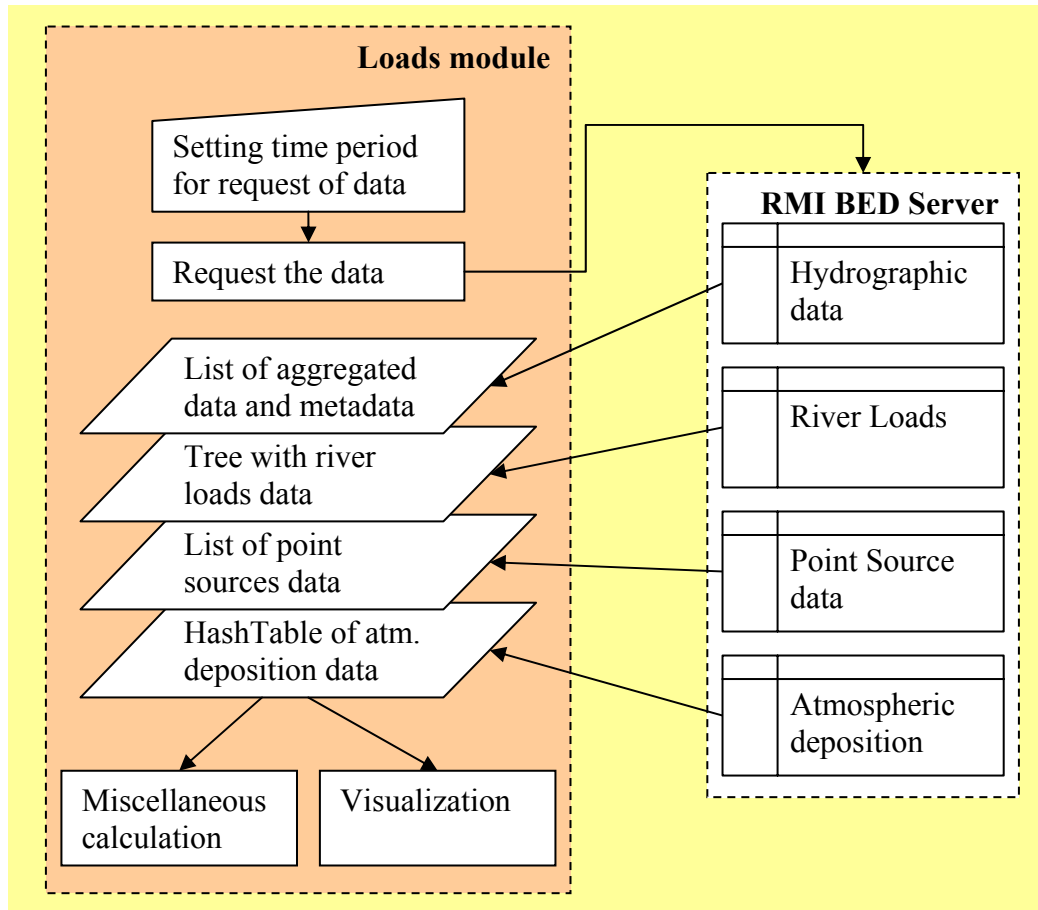
**Figure 8. Scheme of nutrient budgets model**

Results of the model calculations are presented in tables and in graphic form using GIS tools. Data and results can also be saved as .csv file (Comma Separated Values) for later analysis.

### **1.6 Loads**

The module **Loads** contains a set of tools to analyze data from the Baltic Environmental Database. The module provides means to obtain aggregated values of parameters for a chosen sub basin of the sea. The evaluating such kind of estimates, the users often need an easy way to inspect the raw data behind these. Thus, the system provides simple interfaces to both the aggregated and the raw data. Figure 9

shows the information flows and the scheme of the Loads module. Data, obtained from the database are stored in special data structures that make it possible to have an easy access to each piece of information.

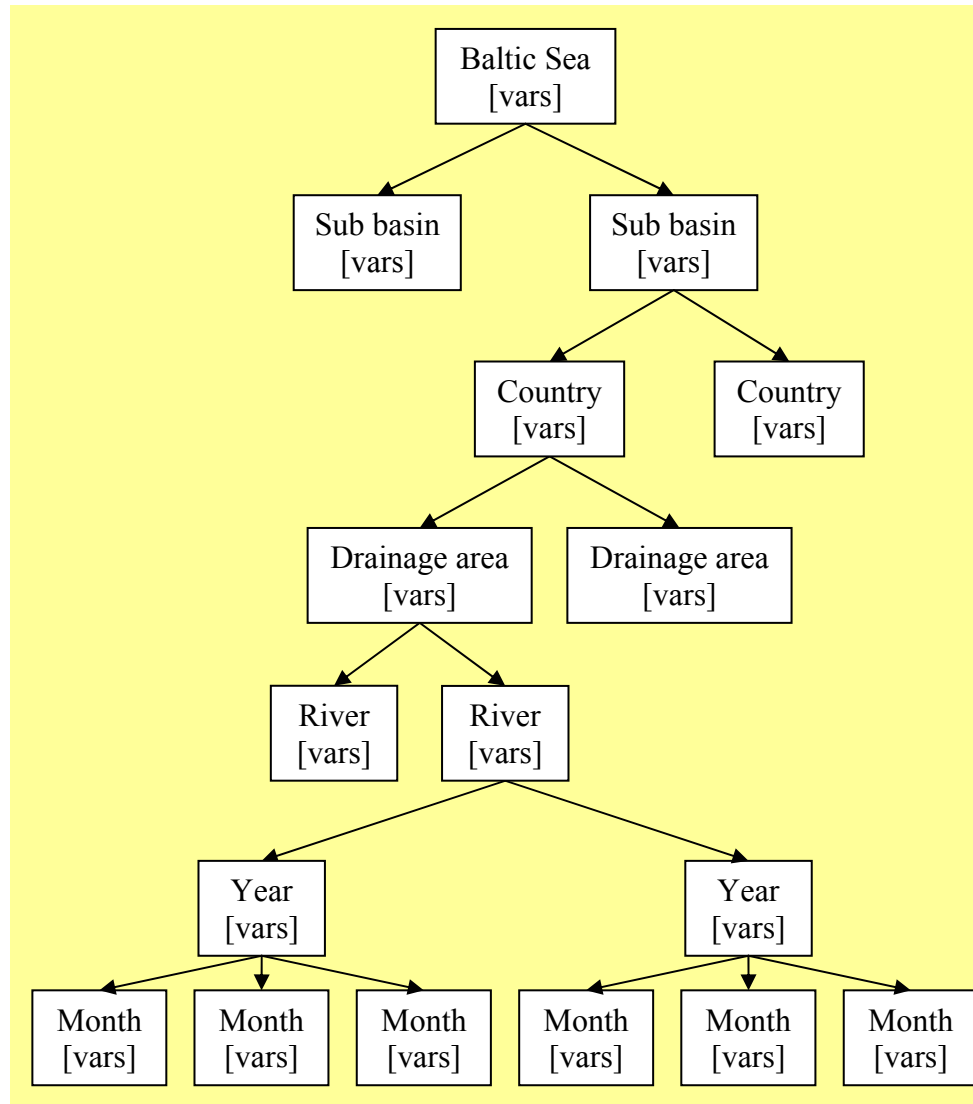


**Figure 9. Flow chart of module Loads and its interactions with the server**

Aggregation of the hydrographic data for each sub basin of the Baltic is performed on the server because of large amount of data being used. A list of stations used in these calculations is also prepared in order to provide a mechanism of retrieving raw data from the server. The information is then stored on the client machine for further analyses.

Data for river loads are relatively small and can be stored on the client machine in order to provide quick access. Users need to have a very flexible way to work with these data. It is very important to have the possibility to analyze load data with

different levels of aggregation (load to the whole Baltic Sea, load to a sub basin, load from particular country, etc). To allow such flexibility, the Loads module store the river loads data in a tree data structure, shown in Figure 10.



**Figure 10. Data structure of river loads data**

Each node of the tree contains an array of variables (Runoff, NH<sub>4</sub>N, NO<sub>2</sub>N, NO<sub>3</sub>N etc). Only leaves of the tree contain raw data in this array while data for all other nodes are calculated as a sum of their children's values with the exceptions of river and year level nodes, which are calculated as a means of their children's data in order to obtain mean monthly data. This data structure makes obtaining the data with any kind of aggregation an easy and quick task.

Data on point sources data and on atmospheric deposition are obtained from the server and stored locally in simple data structures (list and hash tables, respectively).

### **1.7 Model Results**

The **Model Results** module of the Nest program is a tool to query precompiled model results stored on a server and analyze time – dependent data with the graphical visualization technique used in the SwingStations (Sokolov & Wulff, 1999) and the NetStations programs (Sokolov, 2002). These results are obtained running BALTSEM. The four simulations that are currently included present time-depth dynamics of variables computed for 1971 – 1998 with the same initial and boundary conditions except the nutrient terrestrial loads.

### **Summary and concluding comments**

This distributed information system is a prototype of a decision support system that has been running since November, 2001. During this period it has proved to be stable and robust enough to serve the needs. It also clear that in real life use, the RMI servers should be truly distributed in order to increase security (we will run the HTTP server on a dedicated machine in order to avoid “hacker” attacks) and speed up the system’s response (the RMI server for the economic model needs more processor power while the RMI database server and the RMI server for model results compete for the Internet bandwidth sending large amount of data).

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