

GIS based integrated system for ecological and economical management of water resources. Case study Bistrita River Basin - Romania

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1.Introduction

- This paper is part of the Life Diminish project (LIFE03 ENV/RO/000539: Development of an integrated basin management system in order to correlate water quantity and quality analysis with socio-economical analysis, using Open-GIS technology) having the main purpose to develop and implement an action program, able to forecast nutrient pollution using different approaches :
 - an on-line emission monitoring aimed at improving water quality in areas subject to nutrient pollution,
 - polluters have to be discouraged to maintain emissions regardless of the allowed maximum values;
 - public implication on the basin management plans must be increased before the adoption of final decisions concerning the environmental necessary measures.
- A completely integrated system, based on mathematical approach and Open-GIS technology has been elaborated, capable to inter-correlate information on long period of time and forecast the nutrient pollution in relation to human activities.

1.Introduction

- Economical methods for the monetary valuation of environmental costs have been developed and integrated into the system.
- Scenarios regarding the decrease of the pollution have been designed, such as the upgrade and the construction of sewage plants regarding point source pollution and rotation of crops or changes of land use concerning diffuse sources (according to the WFD).
- The consequences of the nutrient pollution are discussed from two points of view:
 - the effects of point and diffuse pollution for surface and groundwater, on the basis of the basin response to the changing pressures over the river catchments (industrial, rural, urban, agricultural changes),
 - the economical valuation of environmental costs and cost-effectiveness of the measures, that can be proposed from socio-economic scenarios, for reaching the “good ecological status” of this river.

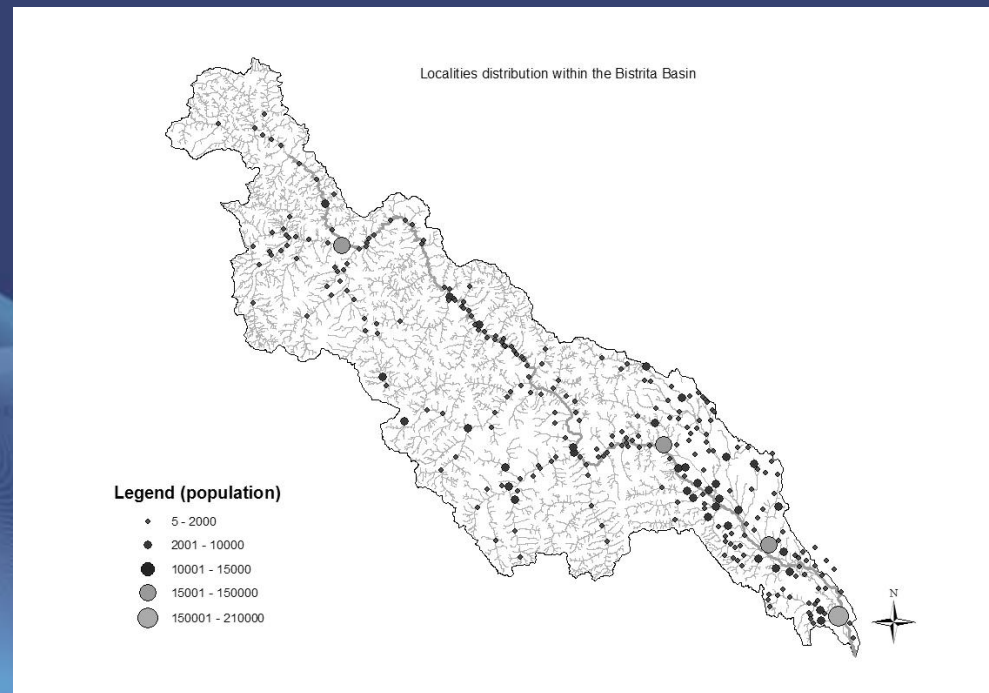
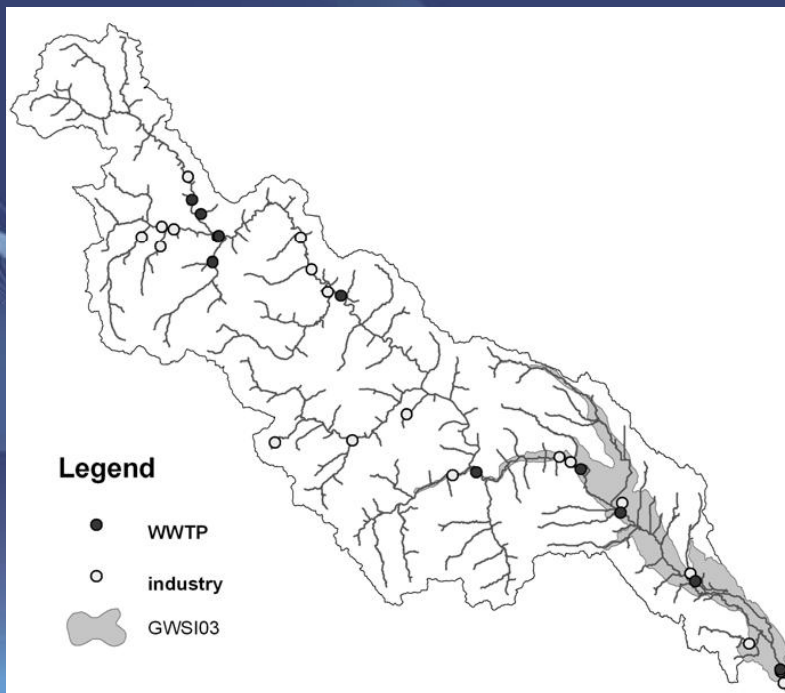
2. Study area

- The Bistrita River (283 km length) is one of the main tributaries of the Siret River, which is the second affluent of the Danube River in terms of discharge and basin surface. The Bistrita River Basin has an area of 7039 km² and its contribution to the Siret discharge represents more than 30% (65 m³/s). The mean altitude of the basin is 919 m.



2. Study area

- The Bistrita River Basin has a population about 550 000 inhabitants, from which some 55% live in urban areas.
- 43% are connected to the centralized water supply or sewage system.
- For nutrient balance calculations, the estimation of diffuse sources originated from the population is important, taking into account that only 10 agglomerations among a total of 375 localities have wastewater treatment plants.



2. Study area

- Environmental problems:
 - High concentrations of ammonium, organic matter, nitrates and suspended matter at the basin outlet.
 - Human activities, such as discharge of wastewater have disturbed the natural fluxes between the nitrogen and phosphorous, resulting in increased nutrient levels in surface waters.
 - A great percent of the total wastewater stations (> 50%) function improperly.
 - The groundwater quality is also affected by agriculture through water infiltrations from the surface waters.
 - The increase of the ammonium, nitrates, organic matter and phosphates concentrations especially in two areas: Bacau and Piatra Neamt cities, due to human activities.
 - An important consequence is the decrease of drinking water resources.

3. GIS Database

The on-line Diminish system allows the establishment of a complex database developed in the GIS environment and provides the possibility to bring together different types of information into the same reference system.

The structure of the dedicated GIS database has been planned for the study of the evaluation and management of information (related to water quality management), as well as for the assessment of damages produced by pollution effects.

Therefore, the database represented by the spatial geo-referenced information ensemble (satellite images, thematic maps, and series of the meteorological and hydrological parameters, other exogenous data) is structured as a set of file-distributed quantitative and qualitative data.

3. GIS Database

- The GIS database contains info-layers in a relational structure, that are: sub-basins and basin limits; land topography (15m cell size DEM); hydrographic and canal networks; transport network (roads, railways); localities; administrative boundaries; meteorological and hydrometrical gauge stations; points of interest (pollution sources, water quality control sections, wells, etc.); land cover/land use, updated from satellite images



3. GIS Database

- GIS database was created using different cartographic documents at the scales 1:25 000, 1:50 000, 1:200 000. Most of the thematic layers have been extracted from this classical mapping support.
- GIS database was updated on the basis of the recent satellite images (e.g. satellites: LANDSAT ETM+, TERRA/ASTER, SPOT 5 images: the hydrographic network, land cover/land use) or by field measurements (several measurement campaigns were organized using GPS technology, necessary to set up the points sources, wells location, etc.).
- data used for the modelling approaches, both to define the constraints of the system and to validate the simulations (e.g. discharge and water quality data, piezometric level or data on urban and industrial waste water).
- Complementary data were obtained from our own surveys carried out, in the control sections of the main axis. The determination of diffuse P, N sources is based on the distribution of the land types into percentages of forests, pasture, agricultural and arable land (Corine Land Cover database) and our own measurements made in areas of different geological units and land-use types, in the upstream and middle part of the basin, upstream of the localities and industrial sites.

3. GIS Database: Land topography (15 m DEM)



3. GIS Database: Geology



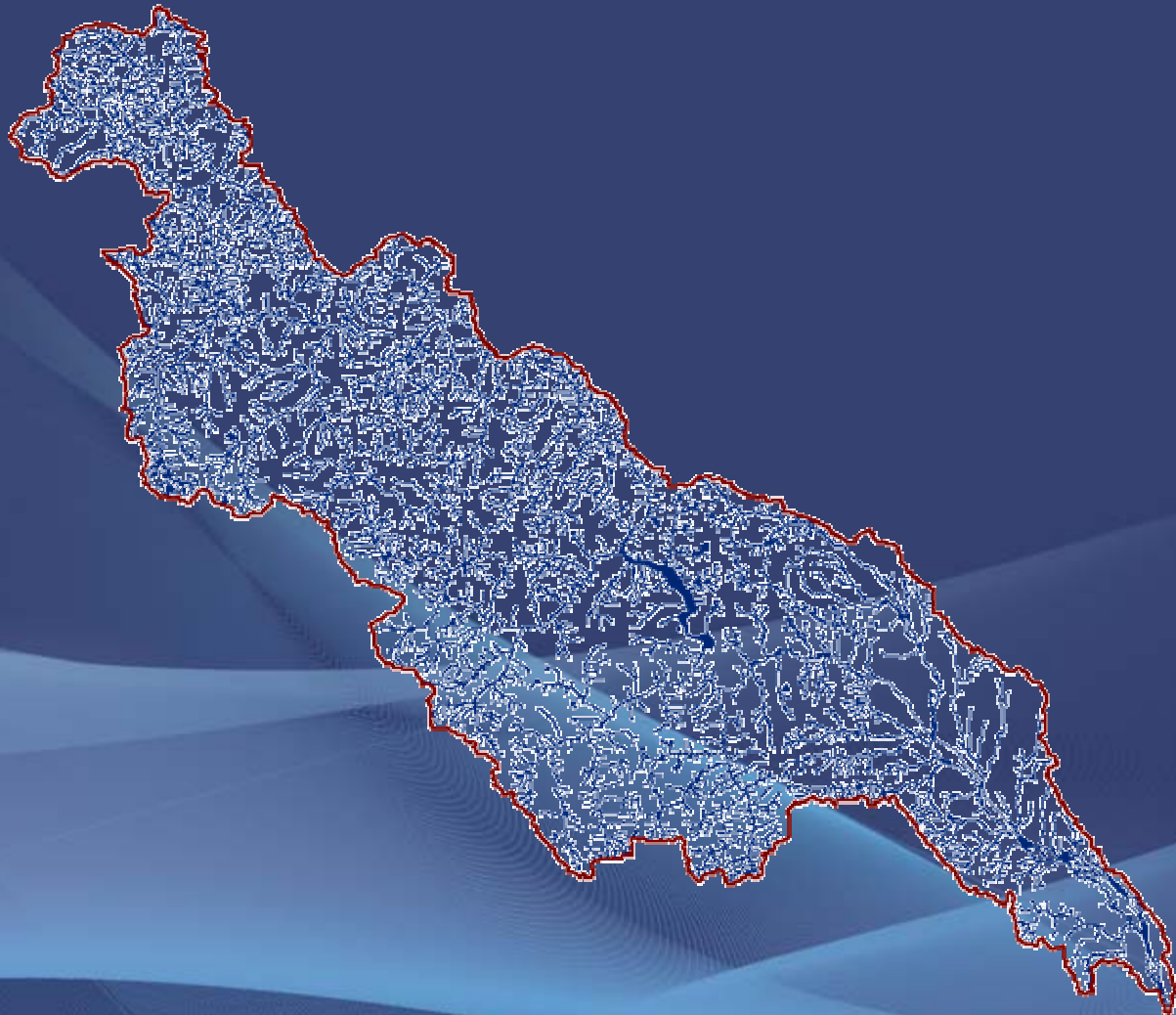
3. GIS Database: land cover/land use

7 classes:

- Forest
- Infield
- Pasture
- Urban, mine, industry
- Arable
- Water
- Wet land



3. GIS Database: Hydrographic network



3. GIS database: sub-basin and basin limits



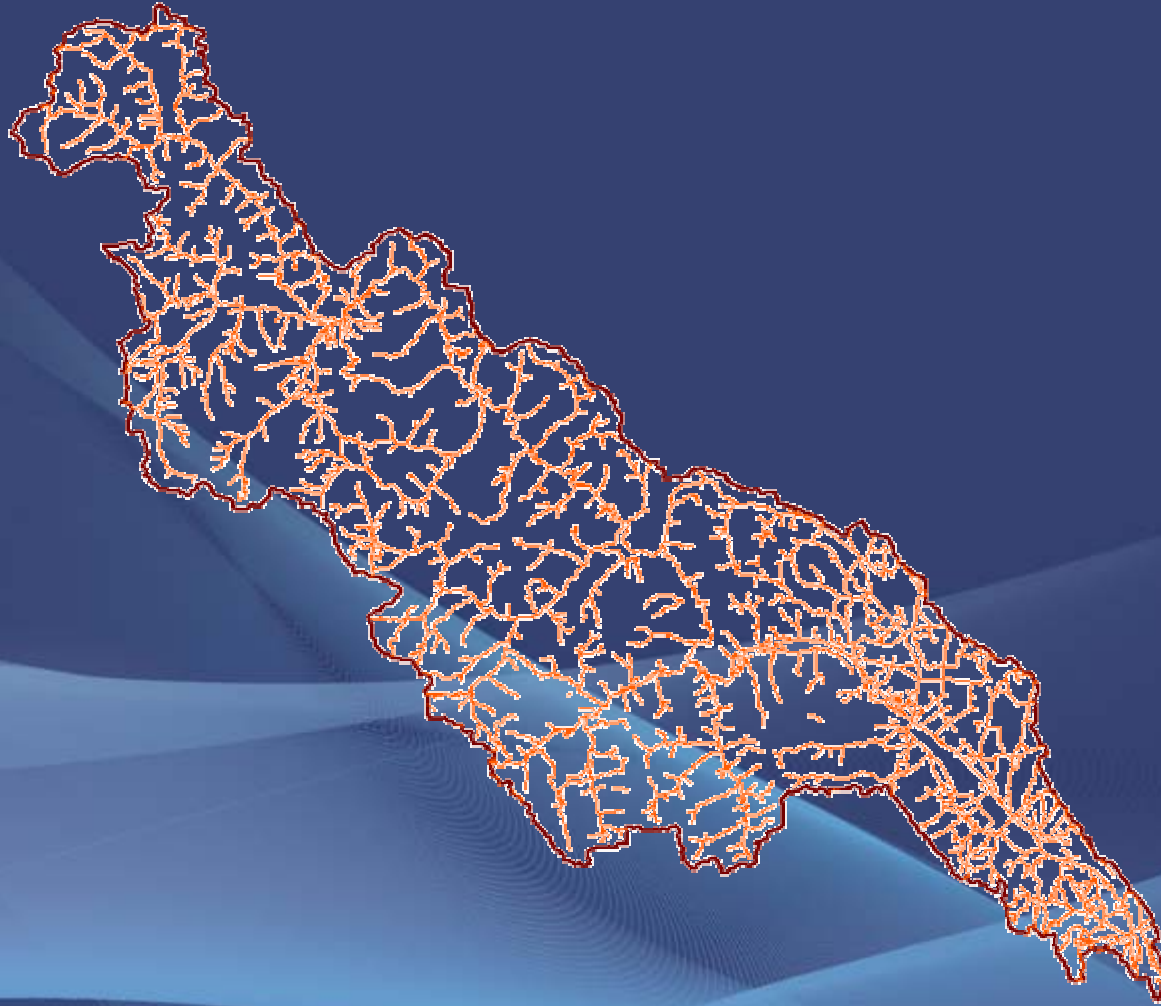
3. GIS Database: Administrative boundaries



3. GIS Database: Localities



3. GIS Database: communication ways network (roads, railways)



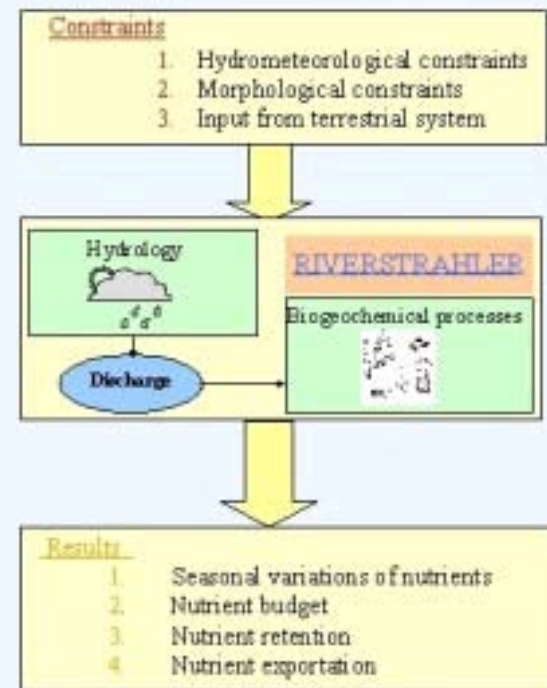
3. GIS Database: different point of interest (pollution sources, water quality control sections etc.)



4. Mathematics tools - surface water model

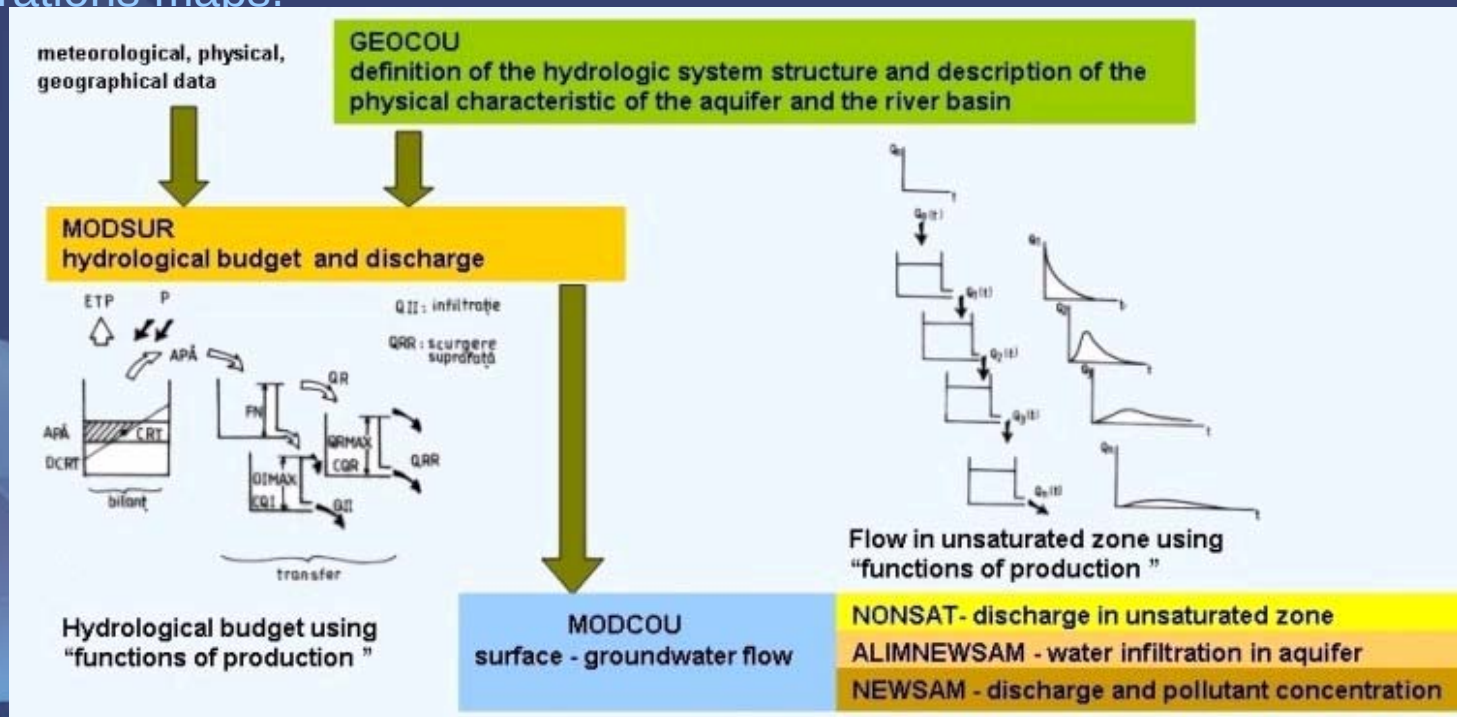
- The surface water model is one of the few available approach for modelling nutrient cycling and ecological functioning in the river catchments.
- The model consists in coupling a hydrological model (Hydrostrahler) with an ecological model (Rive).
- assumption fundamental of the modelling approach: the specific features of the ecological functioning of the river are the results rather of differences in the constraints (geomorphology, hydrology, climate and input of elements from diffuse and point sources) than of differences in the kinetics of the microbiological processes that are the same from headwaters to downstream sectors.

Structure of the RIVERSTRAHLER model
Hydrostrahler + Rive



4. Mathematics tools - groundwater coupled model

- Models have a modular structure in order to be used independently, in function of the analyzed problem.
- The input data in the groundwater model concerns: *monitoring wells database; geological database; hydrological database; hydrochemical database.*
- The outputs data of the groundwater model that could be used by the decision-makers are the piezometriques maps and the pollutants (nutrients) concentrations maps.



5. The cost-environment methodology

- Environmental costs methodology consists of the environmental damage costs of aquatic ecosystem degradation and depletion caused by a particular water use, such as the emission of pollutants (European Water Economics Working Group - Wateco, 2002).
- The role of environmental costs in the context of selecting a cost-effective program of measures (Article 11 and Annex III of WFD) is to signal to what extent existing or new environmental standards are met or not and what are the associated costs, including environmental damage costs and any costs arising as a result of an inefficient allocation of water and pollution rights.
- the costs of measures for reaching the good status are related to two important types of measures, applied to the chemical pressures:
 - costs for the urban and industrial sources, related to the wastewater treatment and sewage network;
 - costs for reducing pollution from agriculture.

5. The cost-environment methodology

- Concerning the point sources, the costs for applying the above mentioned measures were established on the base of the available categories of sewage and wastewater works, for each human agglomeration, according to the Complementary Position Paper of Romania (Annex 3 of the Document European Integration Department – Ministry of Environment and Water Management, Romania).
- The economical approach is based on the knowledge of the costs of investments, of the operation and maintenance of investments; these costs have been evaluated using unitary costs – Euro/population equivalent – obtained in Great Britain (Euroconsult EUROPEAID/114902/D/SV/RO) and taking into account the investment costs from ISPA projects.
- Concerning the diffuse pollution from agriculture, the economical approach is based on the identification of the available measures for reduction of uncontrolled outflow of nitrogen compounds such as: reconversion of the arable areas into intensive grasslands; applying the good agricultural practice concerning composting the animal manure from farming and modifying the location of the manure; creation of natural wastewater treatment in rural area (buffer areas).

5. The cost-environment methodology

- The corresponding costs have been evaluated on the basis of the french unitary cost and on the proportion of Gross Domestic Product (GDP) of agriculture between Romania and France.
- Classification of measures is needed as a basis for the selection of cost-effective combinations of measures.
- The cost/effectiveness analysis has the role to identify the most efficient measures from the cost/effect point of view.
- The effect of the measures is estimated by mathematical modelling like a difference between the nutrient loads simulated in both cases, before and after the implementation of the measure and on the basis of the user experience.
- The analyzed measure can be an individual measure or a combination of several individual measures.
- Taking into account the cumulated measure cost and the reduction of nutrient quantity, a rapport between cost and efficiency rapport is calculated (for each nutrient) for an automatically sort of the scenarios.

6. DIMINISH ON-LINE SYSTEM

- The DIMINISH on-line system is web-based with a distributed architecture and consists in a core server, which handles the interactions between the various modules, the end-users management, the display and manipulation of data.
- The web interface was designed to obtain a simple and friendly environment for spatial data management and scenario creation, taking into account the end-user needs:
 - process data for specific computations,
 - change the inputs for the mathematical models,
 - browse the mathematical models outputs in a GIS environment,
 - integrate the multisource processed information in order to better understand the impact of the pollution on humans and environment,
 - upgrade the result in a Decision-Analysis common access space of the GIS Server,
 - provide the right decisions at both short and long term.

6. DIMINISH ON-LINE SYSTEM: Web Interface

FUNCTIONS

acquisition, validation, storage, spatial analysis and data interpretation

management and exchange of raster and vector graphic information, and also of related attribute data for the water pollution monitoring activities

handling and preparation for a data rapid access

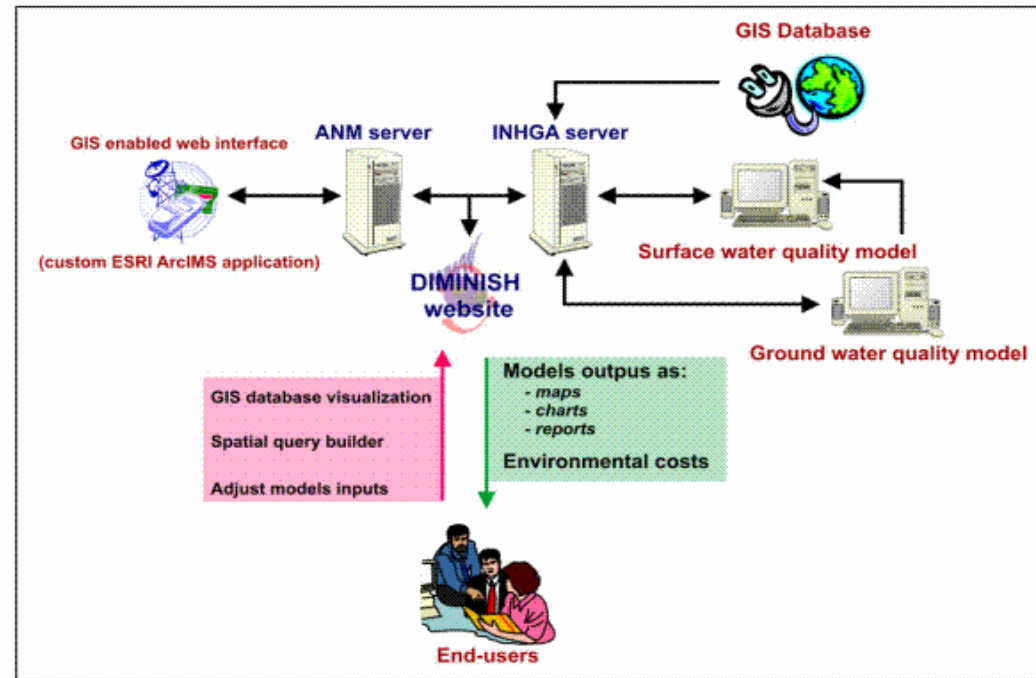
information updating (temporal modification)

data restoring, including the elaboration of thematic documents

generation of value-added information

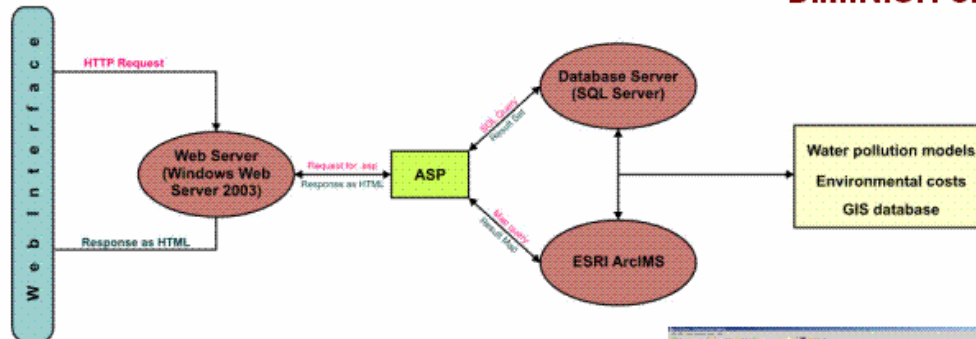
distribution of the derived products to the interested authorities, media, etc.

DIMINISH on-line GIS system flow-chart



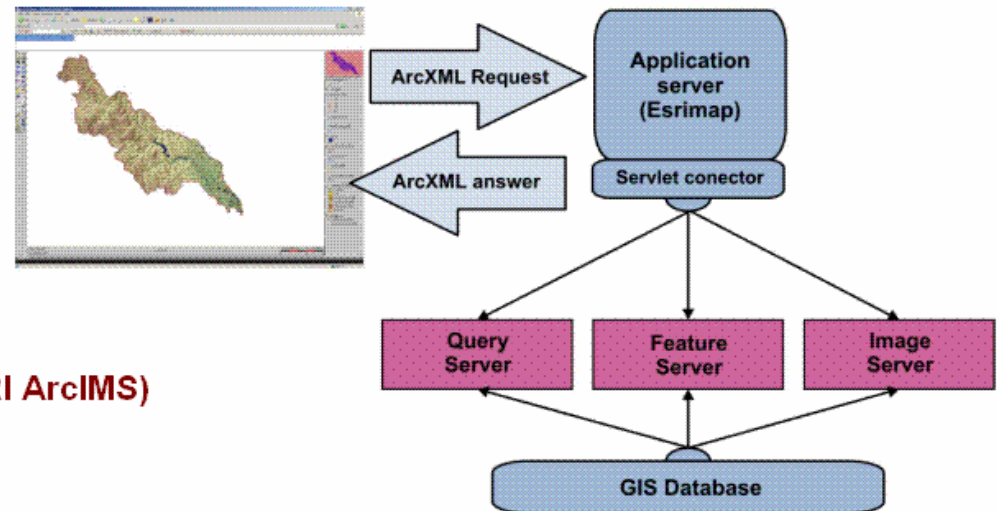
6. DIMINISH ON-LINE SYSTEM: Web Interface

DIMINISH on-line GIS system key components

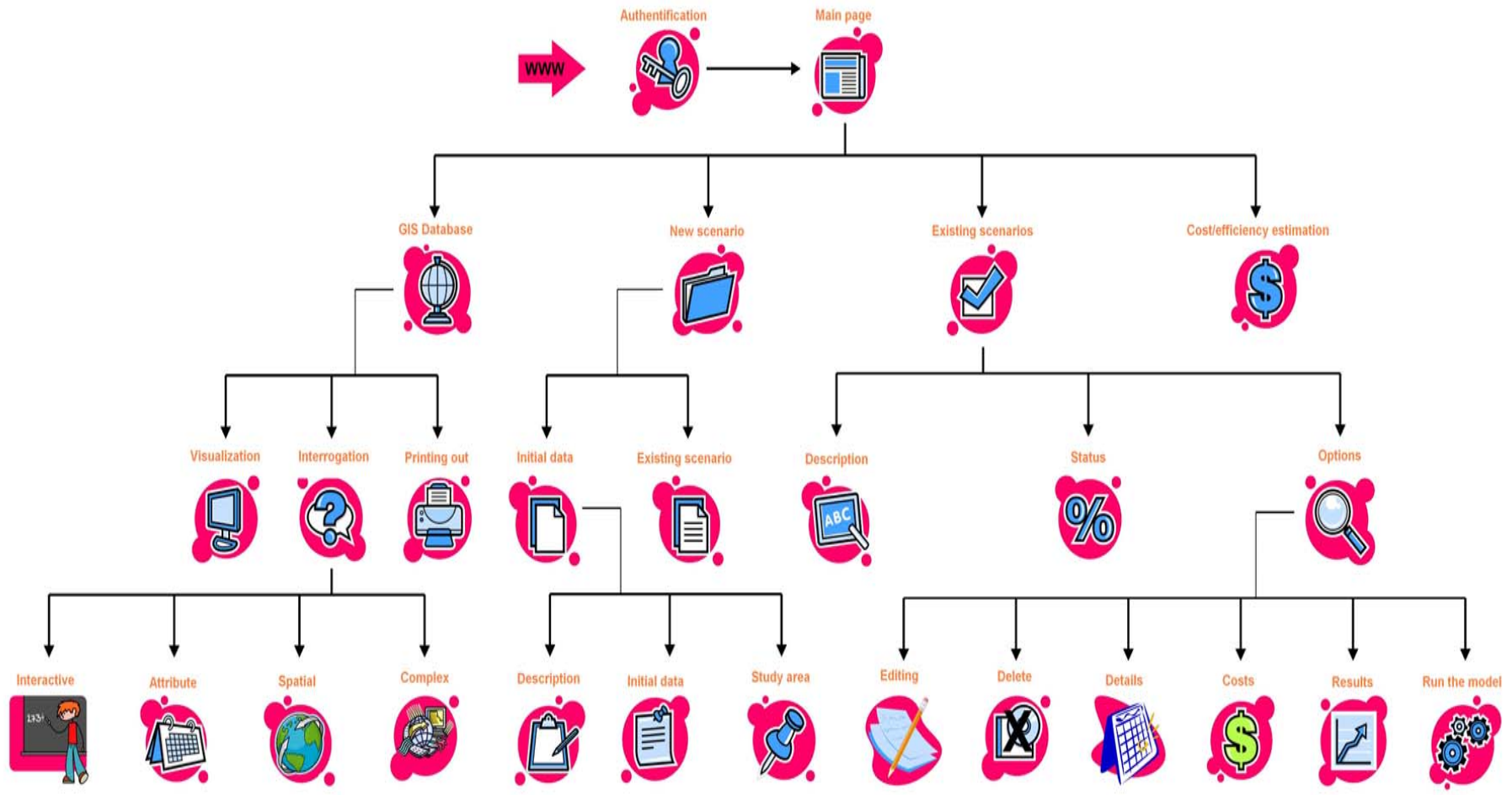


Core Server (webserver, database, server, mapserver), **GIS Database**, **Water Pollution Models**, **User Interface**

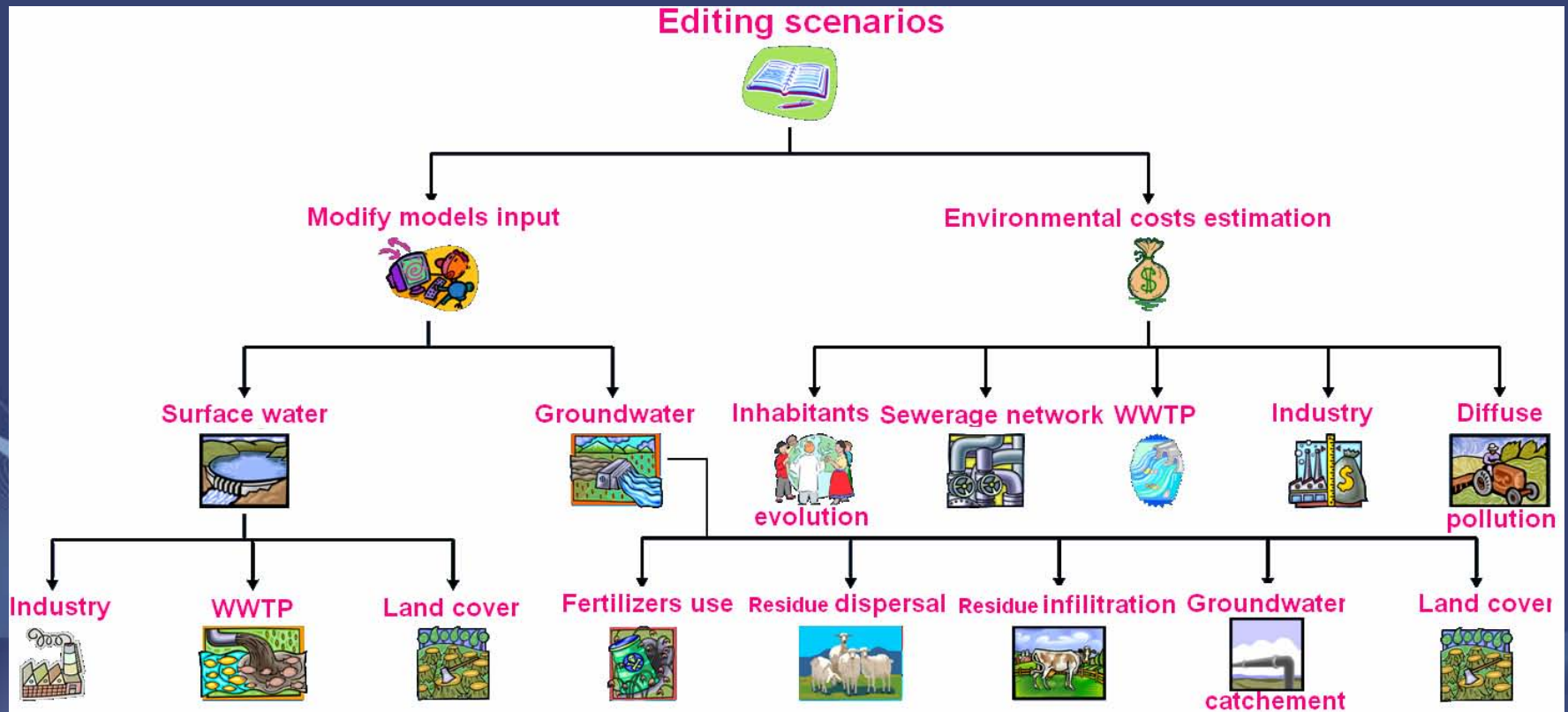
Mapserver application structure (ESRI ArcIMS)



5. DIMINISH System data flux dynamic - 1



5. DIMINISH System data flux dynamic - 2



6. Conclusions

- Our GIS system, focusing on nutrient management in the Bistrita river basin, is the first reported GIS on-line system which integrates a hydrological, geological, environmental land economical data base, by using an open web-based interrogation and analysis informatics tool, such that the basin management evaluation are made available to remote users.
- The study has proved that outputs of the developed system can be used for the assessment of ecological cause/effect relationships and ultimately for the selection of measures.
- Nutrient budget calculations and cost – effectiveness analysis have shown that the measures in the field of “upgrading the wastewater treatment plant” tend to be more cost intensive than measures that aimed at reducing nutrients from agriculture.
- Measures dedicated to reduce point source pollution could be generally supplemented by improving the structural quality of the hydro system, e.g. the creation of wetlands to reduce diffuse sources, which could increase with additional agriculture needs.
- Analysis and assessment of the most efficient combinations of measures constitute a basic step for the preparation of management programs for any river basin district, as part of the River Basin Management Plans. In this respect the nutrient trend within a basin, as it can be simulated and forecasted by the Diminish GIS system help to elaborate an argumentation guide for decision-makers.

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Thank you for your attention!

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