ARSGISIP - Applied Remote Sensing for Sediment and Solute Transport Modeling in European Catchments

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Abstract The overall objective of the ARSGISIP project is to promote the application of remote sensing techniques and GIS integration for the parameterization of hydrological, erosion, and solute transport models. Activities of the first project stage are presented, emphazising the common environmental problem of nutrient leaching within four representative European catchments located in Germany, Austria, Italy, and Sweden. The scientific approach concentrates on deriving physical parameters describing soil and vegetation cover by means of land use classifications using Landsat-5 TM, IRS-1C LISS/PAN, and ERS-2 SAR data. The preliminary results obtained in ARSGISIP confirm the benefits expected from the use of EO data for parameterization. It is shown that land cover information, in particular agricultural crops and mediterranean vegetation, can be classified with optical and radar data, and that distributed parameter information from the test catchments Vegetation – Soil – Topography - Interfaces (VSTIs) can be derived.

1 INTRODUCTION

The overall objective of the EU project "Applied Remote Sensing and GIS Integration for Model Parameterization" (ARSGISIP) is to apply Earth Observations (EO) for model parameterizations, and to identify source areas which generate runoff, erosion, and nutrient leaching. Such information is needed for environmental simulation models. ARSGISIP started in January 1998 and is carried out in transnational collaboration by seven Research End User Teams (RETs) from research organizations and management agencies. They apply standard remote sensing techniques using optical and microwave data, and results obtained will contribute to a methodological remote sensing pool comprised in the Idealized European Catchment (IEC) as described by Flügel and Müschen [1998].

This paper focuses on the aspect of nutrient leaching into surface waters as rivers, reservoirs, lakes, and the sea and consequent eutrophication. Research from Flügel [1995] has shown that overland flow, erosion, and nutrient leaching are generated from source areas distributed over a heterogeneous Vegetation – Soil – Topography – Interface (VSTI) within the catchment. Factors controlling their hydrological dynamics are represented in physically based simulation models which make use of process algorithms and parameterizations related to the VSTI. Due to a lack of information at present, such parameterizations can only be achieved with low spatial and time resolution. Exploiting the potential classification techniques offered by remote sensing integrated into a Geographic Information System (GIS), the resolution and quantification of such parameterizations can be improved.

2 OBJECTIVES

The objectives of the ARSGISIP project are addressing the following research subjects: (i) exploite the synergetic potential of remote sensing and GIS integration for parameterizing regional water, sediment and solute transport models; (ii) developing and applying such techniques in test catchments of major European climatic zones (humid-temperate, mediterranean, cold boreal); (iii) evaluate their cost/benefit ratio in comparison to standard field methods.

3 METHODS

The selected test catchments differ in climate and scale but have serious impacts from diffuse nutrient leaching from agriculture and grazing land in common. Additionally, untreated sewage water from point sources and erosion during floods is aggravating the nutrient transport.

The model input data can to a large extent be supplied by existing and future Earth Observation (EO) techniques and can be grouped as follows:

(i) mapping the spatial-temporal distribution of land cover,

Figure 1: Selected test catchments, marked in white dots from North to South: Lagan, Sweden; Weida-Zeulenroda, Germany; Innbach, Austria; Flumendosa, Italy.

(ii) mapping of land use, vegetation/agricultural crop pattern, surface roughness and surface water characteristics,

(iii) derived information from EO data combined with standard surveys and/or expert knowledge such as seasonal management practices and evapotranspiration.

The first two points can be derived directly from EO applying digital image processing techniques. The last point typically will be handled in a GIS or in models combining input information derived from different sources.

The physically based simulation models WASMOD, PRMS, and SOIL-N, together with HBV-N were selected for the German, Austrian, Italian, and Swedish catchments. A preliminary review of these models revealed that they parameterize similar physiographic catchment properties controlling their hydrological and solute transport dynamics. Such properties are land use (i.e. land cover and management), topography, geology, and soils comprising the VSTI. The latter in turn can be described and quantified by parameters such as slope gradient, aspect, soil moisture, surface roughness, or leaf area index.
A systems analysis was carried out within the four catchments to identify their major hydrological subsystems, physiographic properties, and management practices controlling their interlinked water and solute transfer dynamics. From this exercise, key model parameters and variables were identified, which are directly related to the VSTI and can be quantified spatially by means of image processing.

Modelling of spatial processes is strongly dependent on the availability of consistent spatial data. EO data are the basis for simultaneous information about land cover for the whole area at well defined dates (Figure 2). By combination with data from ground survey and expert knowledge land cover data are transformed to model parameters. Under consideration of the end user requirements the transformation methods are focused on the identification of spatio-temporal land use states, critical for erosion or surface water quality. To fulfil these requirements the land use activities within a one year period have to be modelled under consideration of regional land use practices. A second focus of parameterisation is the derivation of vegetation characteristics, relevant for evapotranspiration, from land cover data. Especially in agricultural areas these factors are influenced by land use practices, therefore it is necessary to combine land use information with ecophysiological parameters of the vegetation. These methods are still under development.

Standard remote sensing techniques as well as GIS analyses were applied to derive the above mentioned key parameters by classifying source areas for nutrient leaching within the catchments. The classifications included canopy development, forestry types, land degradation by erosion, chlorophyll, and sediment distribution of reservoirs and lakes. For the supervised classifications, ground truth data were collected by means of field mapping and field measurements. The challenge for ARSGISIP is to develop a methodology to map land use and crop distribution routinely with a minimum of ground information.

4 DESCRIPTION OF CATCHMENTS

The **Weida-Zeulenroda** reservoir (V = 40 mill. m^3) in Thuringia, Germany is managed by the Thüringer Talsperren – Verwaltung (TTV). Reservoir eutrophication due to nitrate leaching and drainage from agricultural fields and pastures is causing severe problems for the water supply and high costs for removing chlorophyll when preparing potable water. The Weida River (A = 163 km^2) supplies the reservoir and is also the major contributor of nutrients to the reservoir. The land use of the catchment is characterized by intensive agriculture and grazing in about 60% of

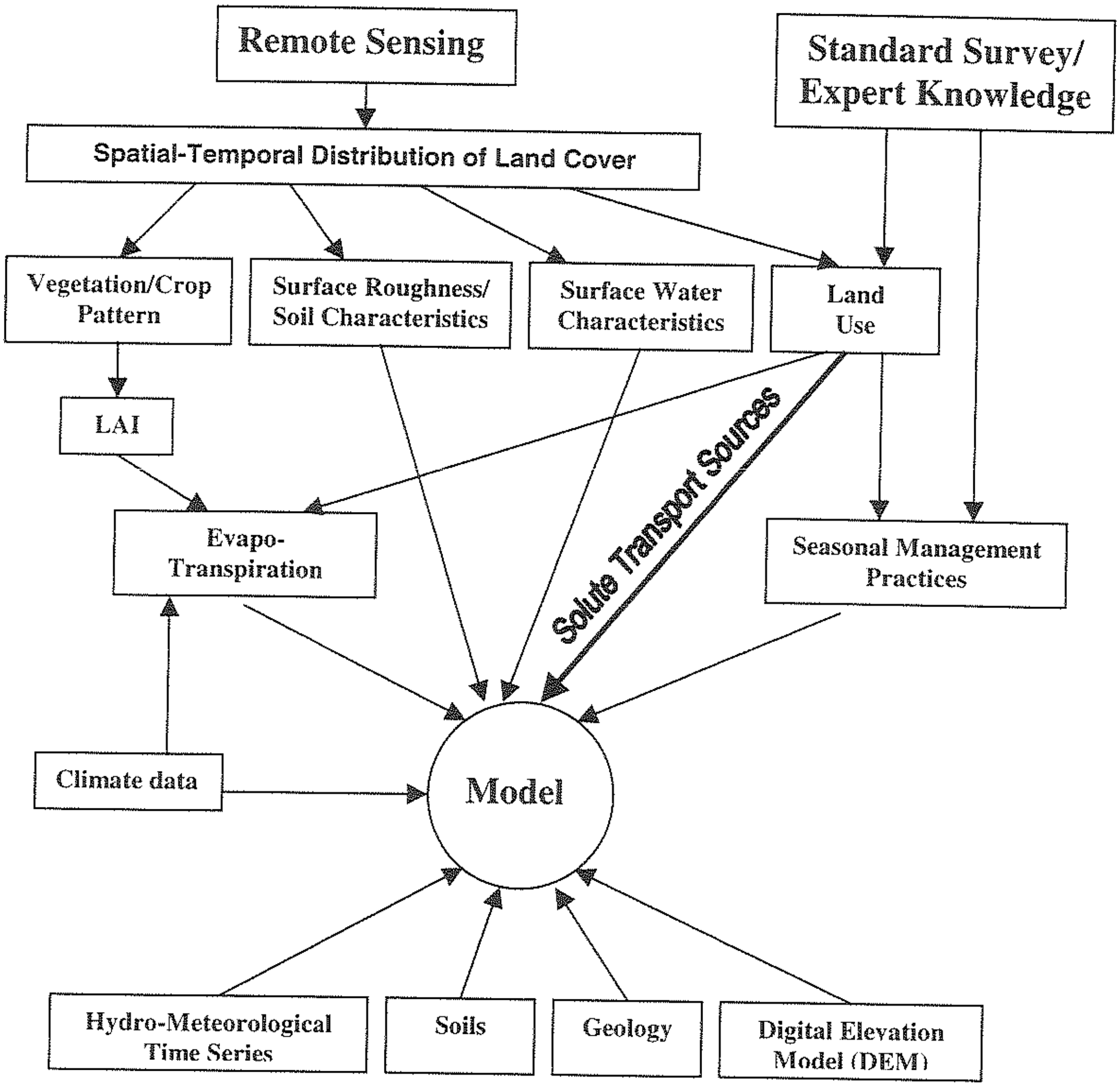

Figure 2: Basic principle of parameterization by EO and ground survey data.

the catchment's area. The remaining area is covered by forests and predominantly rural settlements. The climate is humid-temperate with mean annual precipitation of about 620 mm. Interflow from the hillslopes is a major hydrological component transporting nitrates via the groundwater system into the river. Additional input of phosphorus into the reservoir is caused by untreated sewage water from rural deposition ponds.

The **Innbach** River catchment covers an area of 385.6 km². The catchment is under investigation by the Department of Environmental Protection, Government of Upper Austria, because of its land use characteristics which is typical for catchments of rivers polluted by non – point sources. The Innbach catchment area is dominated by agricultural landuse.

Two general types of agriculture with different system characteristics can be distinguished in the area, an intensive industrial vegetable production in the flat northern part and conventional agricultural production in the rest of the catchment area. The vegetable production is characterized by short rotation periods on the plots, determined by vegetation cycles of the vegetables. Intensive application of mineral fertilizers influences primarily the groundwater quality because of the relatively flat terrain. Methods of soil cultivation and the management of fertilizer application is strongly depending on the needs of the actual culture.

In the area with conventional agriculture intensive cattle breeding and the resulting output of manure is strongly influencing the mix of organic and mineral fertilizer, and the management of fertilizer application under consideration of the needs of crops and grassland. Methods of soil cultivation, which is of substantial influence on surface runoff, are depending on the geometry of the plots in relation to the hill slopes and on the equipment and practical experience of the farmers. These factors are of high importance on soil erosion and fertilizer exports on uncovered soils and under crops with intensive throughfall (e.g. maize). Surface water eutrophication in this area is probably a result of imports from surface runoff and of some drainage effects from organic fertilizer dumps.

The **Flumendosa** (V = 347 mill. m^3) and the **Mulargia** reservoirs (V = 316 mill. m^3) in Sardinia, Italy are managed by the Ente Autonomo del Flumendosa (EAF). The Flumendosa River and Mulargia Torrent feeding these reservoirs are collecting runoff from the southeastern regions of Sardinia. In this central-eastern part of Sardinia, both natural and human made landscapes are characterized by great variability in time and space, and are subject to rapid changes. Recently, both reservoirs showed a serious algae bloom caused by a high degree of eutrophication. Nutrients are leached through the poorly buffered soils and are washed in by overland flow and erosion. The upper part (A = 1826 km^2) of the Flumendosa River catchment has been selected as representative for the total system. The catchment's climate is mediterranean, with a dry weather period in summer and a rainy season in winter. Mean annual precipitation of about 750 mm varies with elevation and falls within a time span of about 45 days during the winter. Heavy storms contribute vast amounts of eroded sediments and solutes into the fluvial system. Except for the highest regions and some north-facing slopes, soils are generally shallow with frequent rock outcrops, and subject to a "xeric" moisture regime. Land use is characterized by grazing of sheep and goats and areas covered by mediterranean Macchia vegetation.

The **Lagan** River drainage catchment (A = 6454 km^2) located in Sweden delivers considerable amounts of nutrients from agricultural areas into the North Sea and the Baltic Sea. The problem is under investigation by the Swedish Environmental Protection Agency (NV) for southern Sweden. Major nutrient sources are agricultural areas in a 10-15 km wide coastal strip covered by Quaternary sandy soils having high leaching rates. Beyond this strip hilly Precambrian outcrops of bedrock and moraines are covered by forests, bogs, and swamps. Ponds and lakes are abundant, ranging in size from a few hundred square meters to about 200 km^2. In the first stage of the project the study catchments of the Fylleån River (A = 223 km^2) and the Genevadsån River (A = 395 $km^{2)}$ have been selected. Larger parts of the Lagan catchment will be incorporated into the research in a later stage of ARSGISP. The climate is cold-boreal and annual precipitation ranges from 600 mm in the coastal strip to 1200 mm in the western part of the highlands with elevations around 150 m.

5 DESCRIPTION OF MODELS

The **WASMOD** water and solute transport model is applied at the Weida-Zeulenroda catchment in Germany. It is a distributed model simulating water balance and nitrate leaching from soil on a catchment scale and was developed by the University of Kiel, Germany [Reiche, 1991]. The model is uses physically based process algorithms to simulate soil water movement and the dynamics of nitrification and denitrification. The spatial distribution is realized by identifying modeling entities of "smallest geometry" which correspond to the HRU- and CHRU-approach described by Flügel [1995]. Routing of water and nutrient transport between the modeling entities is carried out using GIS analyses.

The Precipitation-Runoff Modeling System (**PRMS**) is applied at the catchments of the Innbach River in Upper Austria and the Flumendosa River in Sardinia. It is a modular-designed, physically based, distributed modeling system developed by the USGS-Denver, USA [Leavesley et al., 1983]. Catchment response to rainfall input is simulated to evaluate the dynamics of discharge components, flood peaks and volumes, soilwater distributions, sediment yields, and groundwater recharge. By means of GIS analyses, the catchments were divided into Hydrological Response Units (HRUs) which are used as distributed modeling entities [Flügel, 1995]. Their delineation is carried out by means of GIS analyses and is based on the findings of hydrological systems analyses considering distributed basin characteristics such as slope, aspect, elevation, vegetation type, soils, land use, and local climatology.

The two models **SOIL-N** and **HBV-N** were applied by the Swedish partner. SOIL-N, developed at the Swedish Agricultural University, simulates nitrate leaching that takes place during harvest under normal climatic conditions. Input data comprise, among others, crop type, climatic data, and the use of manure and chemical fertilizers [Johansson and Hoffmann, 1997]. The HBV-N model, developed at the Swedish Meteorological and Hydrological Institute, simulates the retention of nitrogen (immobilization and transformation) during its transport through the catchment towards the sea [Naturvårdsverket, 1997]. Both models have been applied in the past to estimate the input of nitrogen from southern Sweden to the Baltic Sea, the Kattegat and Skagerak. It is intended to improve and extend them to include the catchment's phosphorus dynamics as well.

6 LAND USE CLASSIFICATIONS

6.1 Data Processing

Except for the adaptive filtering, the processing of microwave data is similar to methods used for optical data. Both data were processed as follows: (i) adaptive filtering to reduce speckle (only microwave images), (ii) registration of the individual scenes to a common reference system, (iii) visual assessment of land use, crops, regional patterns and specific features, (iv) unsupervised and (v) supervised classification, and (vi) post processing of classification results.

6.2 Data acquisition

For the **Weida-Zeulenroda** catchment, optical data from Landsat TM (30 m) acquired March, May and August 1998 and ERS-2 SAR data (25 m) acquired July, September and October 1998 have been processed. Four ground campaigns have been carried out during summer 1998 to map crop types and to collect soil samples. From the latter gravimetric soil moisture was found to be correlated with corresponding radar backscatter.

Two Landsat TM scenes acquired in May and August 1998 and a panchromatic image from the Indian Remote Sensing Satellite IRS-1C were applied for land use classification of the **Innbach** River catchment. A ground campaign carried out during July 1998 provided reference information on different crop types and land use practices in the area.

For the **Flumendosa River** catchment, one IRS-1C LISS image (23 m) acquired July 1997 and three Landsat-5 TM scenes acquired April 1998, August 1998 and April 1999 have been processed.

Optical data from the Indian LISS and WiFS (180 m) instruments from May 1998 and ERS-2 data from six dates between March and September 1998 are under evaluation for the **Lagan River** catchment.

6.3 Preliminary Results

For the **Weida-Zeulenroda** catchment, five dominant land cover classes: water, settlement, forest, grassland/pasture, and farmland (with nine sub-classes) could be classified from three Landsat-5 TM images acquired 1998 (Figure 3). Due to the pixel size (30 m x 30 m) of Landsat TM images, rural sewage ponds which are point sources for considerable phosphorus discharge can only be identified if they are sufficiently large.

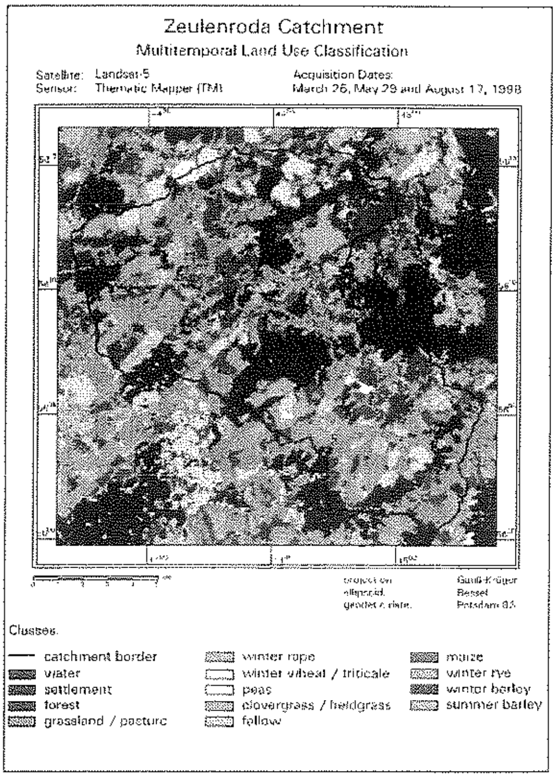

Figure 3: Multitemporal land use classification of the Zeulenroda catchment.

For the **Innbach River** catchment a multiresolution / multitemporal classification approach was applied. After geocoding of all image scenes to the national projection system (Gauß-Krüger M31) the multispectral Landsat TM images were fused with the panchromatic image in order to improve their spatial resolution using an adaptive fusion algorithm [Steinnocher, 1999]. In the second step the seasonal variation of the cover types was analyzed in order to recognize the different crop types. For the non-agricultural areas a standard land cover classification was performed. The resulting land use data base has a resolution of 5 m and distinguishes between 8 crop types and 6 remaining land cover types (grassland, forest, water bodies, artificial surfaces, sparse vegetation, bare soil).

For the **Flumendosa River** catchment seven dominant land cover classes were distinguished using multitemporal Landsat-5 TM images (Figure 4): water, settlement, forest, shrubs, pasture, farmland (with two sub-classes) and burnt areas. Due to illumination and shadow effects, the spectral appearance of the different vegetation types in mountainous regions is strongly influenced by the elevation of the sun and its zenith angle.

In the **Lagan River** catchment four dominant land cover classes water, built up areas, forest (with two

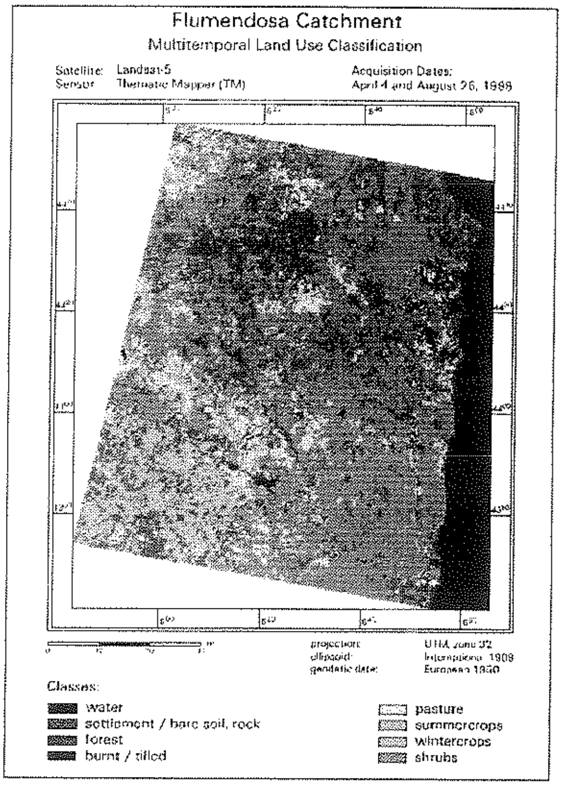

Figure 4: Multitemporal land use classification of the Flumendosa River catchment.

two sub-classes), and agriculture were classified with both optical and multitemporal radar data. Problems were encountered with the separation of specific agricultural crops, e.g. certain types of wheat and pasture. It is expected that further ground truthing in the growing season will improve the classification accuracy significantly. The radar data show additional brightness differences not only related to land use and crop types. Only in some areas are agricultural fields large enough to be identified in the WiFS data which has a 180 m resolution. Common agricultural management practices such as planting sugar beets or potatoes in the central part of the field surrounded by a strip of grain 10 m in width, or very small and irregular fields in the hilly areas cause additional problems for the classification.

7 CONCLUSION AND FUTURE

The preliminary results obtained in ARSGISIP confirm the benefits expected from the use of EO data for parameterization. It was shown that land cover information, in particular agricultural crops and mediterranean vegetation, can be classified with optical and radar data, and that distributed parameter information from the test catchments VSTIs can be derived. However, the cause for local and regional differences in the spectral characteristics of crops and forests require further attention. Future research in ARSGISIP will also focus on the combination of optical and radar data for improving the obtained classifications. This study will be the basis for the intended cost-benefit evaluation, which is demanded by the end users of the respective national RETs.

8 ACKNOWLEDGEMENT

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