Integrated Watershed modeling

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1.   Abstract

Integrated systems that bring together EO data, local measurements and modeling tools, are a fundamental instrument to help decision making in watershed and land use management.
The BASINS system (EPA http://www.epa.gov/OST/BASINS/) follows this philosophy, merging data from local measurement with modeling tools (HSPF, SWAT, PLOAD, QUAL2E). However, remote sensed data is still used in a very static way (usually to define land cover, see corine land cover project).
This approach is being replaced with operational methods that use EO data (such as land surface temperature, vegetation state, soil moisture, surface roughness) for both inputs and validation.
The development of integrated watershed models that dynamically interact with remote sensed data opens interesting prospective to the validation and improvement of such models.
This paper describes the possible data contribution of remote sensing to the needs associated with state of the art watershed models, including well know systems (such as SWAT or HSPF) and a system still under development (MOHID LAND). Application of such models is shown at two pilot sites, which were selected under EU projects, TempQsim and Interreg II B - ICRW.

2.   Introduction

Watershed models face a challenging task, they must accurately describe the land phase of the hydrologic cycle. This includes modeling surface runoff, plant uptake, vadoze zone flow, etc... The number of uncertainty parameters associated with this task can make physical based models seem quite inadequate. However, over the last few years several tools that face this problem have been developed. Mike SHE (DHI), solves the full Richards equation for vadoze zone flow coupled with a three dimensional groundwater model and a diffuse wave approach for runoff flow. SWAT uses the Green & Ampt method for water infiltration or SCS curve number protocol.
Plant growth models are also a common place nowadays, usually related to the head units theory for growth. Evapotranspiration theory and models are also easily available. Nutrient cycling models such as RZWQM or DAISY simulate carbon and Nitrogen transformation in unsaturated soil according to agricultural practices.

However, all any of these approaches huger for data, especially for land use and soil type. Land use can clearly become a problem since anthropogenic intervention is only considered in such models for repetitive chores. The change of agricultural fields to urban occupation cannot be predicted, and agricultural practices are hard to verify.

EO has helped to soften this problem providing landuse data that is now widely available, (although outdated) thought the Corine Land cover project CLC90 that shows European land cover data from the late 80's and is now being updated in CLC2000 (still not available in Portugal). Remote data contribution is clearly far from its full potential, not only as input data for an integrated and operational system, but also as validation data [8]. A fully integrated operational model for watersheds would integrate local measurements with remote data and computational models that would assimilate both as input or validation data.

3. Problem Overview

When accessing water quality in rivers, reservoirs or estuaries there are two types of pollution sources that can load external properties to the system: point sources and diffuse sources.
An example of a point source is a wastewater treatment plant, if enough data is available this can be regarded a simple input to any model. Diffuse source are quite more difficult to account for, agricultural nitrate and pesticides are not unloaded to the nearby rivers by a pipe. Instead water flows over or underground in a diffuse way unloading these properties to water mass.
In order to account for this type of pollution watershed models are necessary, these types of models usually divide water flow and processes into two distinct phases, a land phase and a routing phase.

The use of watershed models requires three fundamentals data sets:

- DEM – Digital Elevation Model
- Landuse charts
- Soil type

Currently the DEM is easily accessed in Portugal (even thought it is no free), with 8m meter resolution. On the other hand Soil types is one of the most difficult data to obtain, since most of the existing data is either incomplete or lacks the parameters that are necessary to run more detailed models.
Landuse have been the main contribution of remote sensing for these models, charts are easily available from the 1990 corine land cover project that for Portuguese soils offers a total of 4 levels and 56 classes. Even thought the CLC 2000 project is on the way, land cover data is quite static for inputs of models that tend to be operational. Both SWAT and HSPF or MIKE SHE have vegetation covers that change in time, season and accordingly to agricultural practices. The usage pf remote data could not only act has input parameters, but could also validate the models predictions (for instance, vegetation state, soil moisture, evapotranspiration, etc). Because of its narrower bands and improved radiometry, MERIS may be suited to supply this sort of data, especially if supported with products from by ASAR and AATSR. This integration could clearly improve watershed models in both accuracy and reliability.

4. Modeling tools

A modeling tool that supports such an integrated system should allow the simulation physical processes and biogeochemical cycles.
The MOHID modeling system (www.mohid.com) (originally a coastal environment model) has been developed over the last 20 years by MARETEC a team from Instituto Superior Técnico (www.ist.utl.pt) in Lisbon, with contributions from the permanent research team and from a large number of Ph.D students on Environmental and Mechanical Engineering and from IST master course on Modelling of the Marine Environment. Contributions from other research groups have also been very important for the development of the model. The whole model is programmed in ANSI FORTRAN 95, using the objected orientated philosophy.

On the last few years and thanks to the object oriented philosophy that was imported to the system a MOHID framework has been developed that supports both MOHID water and MOHID LAND. A full description of MOHID water is out of the scope, but several studies have been performed with this model including the main Portuguese estuaries (Minho, Lima,

Douro, Mondego, Tejo, Sado, Mira, Arade and Guadiana) , some European estuaries have also been modeled - Western Scheldt , The Netherlands, Gironde, France[2] and Carlingford, Ireland [4].

MOHID land is still under development and its first applications are the sites defined in this paper. At the current status of model development, three dimensional unsaturated groundwater flow [6] and the cinematic approach to channel flow have been implemented. Evapotranspiration modules are already present as integrated carbon / Nitrogen cycling in unsaturated soil [3].
The modeling tools that where selected as benchmarks or guides, and that along with MOHID land will be used in projects where MARETEC is involved are:

SWAT, the acronym for Soil and Water Assessment Tool, a river basin, or watershed, scale model developed by Dr. Jeff Arnold for the USDA Agricultural Research Service. SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time. The models includes several submodels that account for different processes, for instance a QUAL2E module simulates in stream water quality, a WASP like module does the same for reservoirs (no stratification is considered). EPIC model like modules take care of plant growth and management practices.

HSPF stands for Hydrological Simulation Program—Fortran, also a watershed models developed in and simulates for extended periods of time the hydrologic, and associated water quality, processes on pervious and impervious land surfaces and in streams and well-mixed impoundments.
Both these models are included in BASINS, a multipurpose environmental analysis system that integrated GIS management of point data and several modeling tools (besides SWAT and HSPF, PLOAND and QUAL2E are included).

Several international studies have been produced over the years with both models (HSPF as initially developed in the early 60's) that are subject of continuous development efforts, which turns them into reference software in watershed modeling.

5.   Study sites

MARETEC is currently a member in two European projects in the watershed modeling area, TempQsim and Interreg II B – Improving Coastal and recreational waters (ICRW).

TemQsim is a research project supported by the European Commission and the Swiss Government under the Fifth Framework Program, contributing to the implementation of the Key Action 1 "Sustainable management and quality of water" within the Energy, Environment and Sustainable Development (Contract no: EVK1-CT2002-00112).
The project goal is to Evaluate and improve water quality models for application to temporary waters in Southern European catchments. In this project both existing watershed models (SWAT and HSPF), and MARETEC developed models (MOHID Land) will be applied to a temporary River. Pilot action IV of this project includes software development.

ICRW, is a project for reducing pollution and improving water quality in both inland and costal waters under the shade of the revised bathing water directive. This reflects on the study sites, a $160E^{06}$ m3 reservoir in Sôr River that is used for both agricultural and recreational proposes and the Zambujeira beach were small river meets the ocean.

Diffuse pollutions plays a center roll in the overall goals of both projects. The evaluation of the importance of agricultural phosphorus and nitrate in water quality is one of the primary tasks, which enhances the importance of land use data in the process.
Integrated watershed models such as SWAT, HSPF and MOHID land, along with three-dimensional hydrodynamic models (for reservoirs and the marine environment, MOHID WATER) will be used to achieve these goals

6.   Development status

The BASINS management system has been implemented in both sites with the available data (CORINE land cover data). This allows the usage of both SWAT and HSPFH. Hydrodynamic results are being calibrated and sensitivity analyses are being performed on the land cover data to access its influence on hydrodynamic and water quality.

The development of MOHID Land as been carried out with recent IT issues in concern, such as GUI development, database management and WebGIS applications. The MARETEC team as previous experience with the MERIS/(A)ATSR Toolbox (BEAM), and interface software is being developed to integrate BEAM libraries on MOHID modeling system. Hopefully this will create a versatile system where data integration of both remote and local sensing can interact with modeling tools. The recent AO proposal from MARETEC would facilitate this integration but isn't considered a limiting factor.

7. Conclusions

When it comes to interaction with environmental modeling of watersheds, remote sensing is far from its potential. The traditional approach, where remote data is used only as inputs for such models, is being replaced with operational methods that use such data for both inputs and validation. The development of integrated watershed models that dynamically interact with remote sensed data opens interesting prospective to the validation and improvement of such models.

MARETEC currently has 4 PhD students working on the area of watershed modeling. This, together with two ongoing European projects in this area creates a suitable environment for cooperation with other research teams specialized on both subjects (modeling and remote sensing).

8. References

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