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ICREW First Semester Report



Improving costal
and recreational
waters for all

Melhorando águas
litorais e recreacionais
para todos

Amélioration des aux
côtières et récréationnelles
pour tout le monde

Mejorando la calidad de
las aguas costeras y de
recreo

	ICREW Semester Report		
	Semester Report nº1		
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ABSTRACT

A generic characterization for *ICREW* Portuguese study areas is given, with explanations of modeling efforts and future directions.

In Montargil, a reservoir with three main bathing areas, the implementation of SWAT (<http://www.brc.tamus.edu/swat/>) model in Sôr River watershed is explained, along with MOHID model in the reservoir. Conclusions are made on the importance of the Sôr river to bacterial contaminations of the beaches in the reservoir.

For the Zambujeira beach (costal bathing site), a compilations of existing data was made and the modeling strategy for this site was established.

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1 Foreword

The Portuguese sites for the *ICREW* project are an inland water site (Montargil reservoir) and a coastal site, Zambujeira beach. The problems that both sites face are quite different but represent a generic approach to the bathing water problem that inland and coastal areas face in Portugal.

Montargil reservoir suffers from cyanobacteria blooms (common to many reservoirs), while the ocean agitation makes this an unlikely scenario for the Zambujeira site. In Zambujeira a small stream reaches the ocean (which is typical for most coastal beaches in this area), this stream has a catchment area of 18 km² that crosses the natural reserve of the Southeast. During the dry season flow in this river is smaller than the Zambujeira wastewater treatment plant which is the only one on the selected watershed.

In both sites population increases during the summer months, when precipitation reaches its minimum values.

Montargil has a much larger catchment area (1 181 km²), fourteen urban wastewater treatment plants discharge to the Sôr river which is controlled at the Montargil dam creating the reservoir. A total of 37 point sources were identified in 1999 in the catchment, ranging from urban discharges to pig and cow farming. No inventory is available for the Zambujeira catchment.

Agriculture is present in both sites in the dryland cropping regime. In Montargil some irrigation cropping regime is present but has a minority of the agricultural areas. The agricultural uses of the water stored in the reservoir are downstream of the catchment area.

Both sites have registered non compliance values of bacterial indicator under the current directive as localized events, usually related to increasing population.

MARETEC is involved in several *ICREW* pilot actions; 2, 4, 5 and 7. In pilot action 4 the validation of existing modeling tools and creation of new modeling and data management tools is the priority task. These instruments usage should increase the understanding of the Diffuse Agric pollutions (PA2), and give a new insight to the problem of algae in reservoirs.

This technical paper resumes the modeling efforts occurred during the first six months of *ICREW*.

2 Montargil reservoir

2.1 Historical data

Montargil reservoir has a total volume of approximately 165 million m³ with the level of full storage fixed at 80m. This reservoir is feed by a watershed of 1 181 km² with 37 point sources identified in 1999.

The reservoir is exploited since 1958. Initially it was built for agricultural purposes, but the tourist potentialities of the location (close to Lisbon) are currently recognized in the reservoir ordinance plan (approved by the Portuguese minister council resolution n^o 94/2002). There are three bathing locations in the reservoir as in Figure 1.

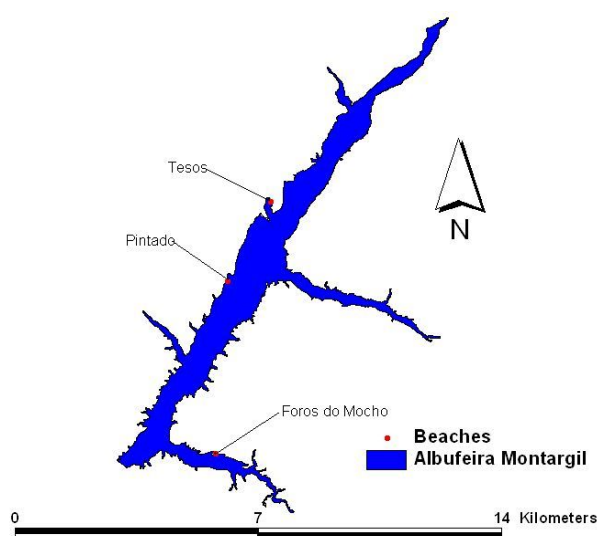


Figure 1 – Bathing location at the Montargil site

Pintado (close to a camping location) is classified as a bathing location according to the 76/160/CEE directive.

Tesos and Foros do Mocho, are present in CCDRA monitoring campaigns as potential bathing sites (under study according to Decreto-Lei n.º 236/98 de 1 de Agosto).

Historically water quality analyses are present since 2000. The official bathing site (Pintado) has failed to fulfill bathing water standards of the current directive (76/160) in that year, as did the remaining sites.

In 2001 bathing standards weren't achieved twice in Pintado, in May due to Fecal Coliforms and in September due to total Coliforms (data from Draot-A). Potential bathing sites Foros do Mocho and Tesos also shown poor water quality due to high pH values in Foros do Mocho and bacterial indicators in Tesos.

2001 was a particular bad year with complaints by bathers to the local authorities over bad water quality. The non governmental organization of Montargil reservoir users "Amigos da Barragem de Montargil" even got some media coverage in "Publico" with complaints that the water "looked like bleach" with active odors in some parts of the reservoir. High pH values were recorded all over the reservoir.

The year 2002 and 2003 have shown better water quality for all bathing sites. In 2002, "Foros do Mochos" monitoring by Draot-A stopped. "Pintado" only recorded two total Coliforms values over de recommended limit, in May and August. Tesos shown a tendency for high pH values and higher bacterial concentrations, all however within the mandatory values

2.2 Modeling strategy

The modeling approach for the prediction of bathing water quality in this type of reservoir must account for the impacts of diffuse pollution. Several studies have already shown that controlling point sources is not enough; diffuse pollution must be included. So, the use of watershed models is fundamental to try and establish nutrients and contaminants loads to the reservoir.

Once loads to the reservoir are known, the use of hydrodynamic models in the reservoir can simulate the dispersion and decay of bacterial indicators. Water quality models must also be tested to address the problem of algae with special incidence on cyanobacteria blooms. In conclusion the modeling strategy for Montargil reservoir is the use of watershed models coupled with a three dimensional flow and water quality model in the reservoir.

Currently MARETEC is developing MOHID Land, a watershed model that uses the MOHID programming philosophy (Miranda, R. et al. 2000). The specifications and development status of this model are present in Appendix II.

Because the development of this model is still underway, the BASINS system was used in the initial six months of *ICREW* to try to understand the mechanics of the Montargil watershed.

For the reservoir, MOHID (www.mohid.com) has been used in preliminary simulations to describe the flow in the reservoir. So far no coupling has been made on both models and only water flow has been simulated in both the watershed and the reservoir.

The next section explains with detail the modeling work done with both models and points to future directions.

2.3 Watershed Model

BASINS system was used to get a jump start on modeling the Montargil watershed. This system supplies a GIS interface that uses ESRI ArcView. This interface allows the user to organize input to several models:

- SWAT
- HSPF
- Qual2E
- Pload

So far only (USDA) SWAT has been used. This model is a river basin scale model developed to quantify the impact of land management practices in large, complex watersheds.

SWAT is a public domain model actively supported by the USDA Agricultural Research Service at the Grassland, Soil and Water Research Laboratory in Temple, Texas, USA (<http://www.brc.tamus.edu/swat/> for further details).

In brief the model components are: weather, surface runoff, return flow, percolation, evapotranspiration, transmission losses, pond & reservoir storage, crop growth & irrigation, groundwater flow, reach routing, nutrient & pesticide loading, and water transfer.

The basic inputs for such a model are:

- DEM – Digital elevation model
- Soil type
- Landuse
- Meteorological data

2.3.1 DEM:

Digital elevation models (DEM) are essential to watershed delineation and modeling because gravity drives water flow over land surfaces. A DEM is an array of elevation values for the ground at regularly spaced intervals (USGS, 1996). At this initial stage the existing DEM as reduced to a 200 meter cell resolution (Figure 2).

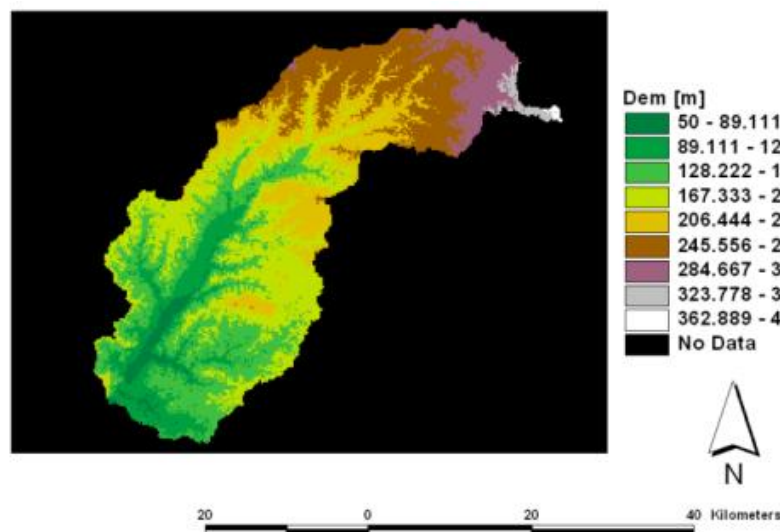


Figure 2 – DEM for the Montargil watershed

Because the DEM was supplied with no values outside the watershed, the delineation process originates a watershed smaller than the original. This must be corrected in future simulations.



Figure 3 – River delineation error

From the delineation another interesting aspect is that the values of the DEM close to the reservoir are probably inaccurate. This originates the straight river lines in Figure 3.

At this preliminary stage a point close to reservoir was selected as the watershed outlet. So for now only the main river (Sôr) will be modeled. Since an INAG hydrometric station (“Moinho Novo”) is present at this

location with flow values until 1990, calibration of river flow is possible for this smaller watershed that provides most of the water to the reservoir.

Figure 4 compares the generated river lines with the supplies lines obtained from military cartography.

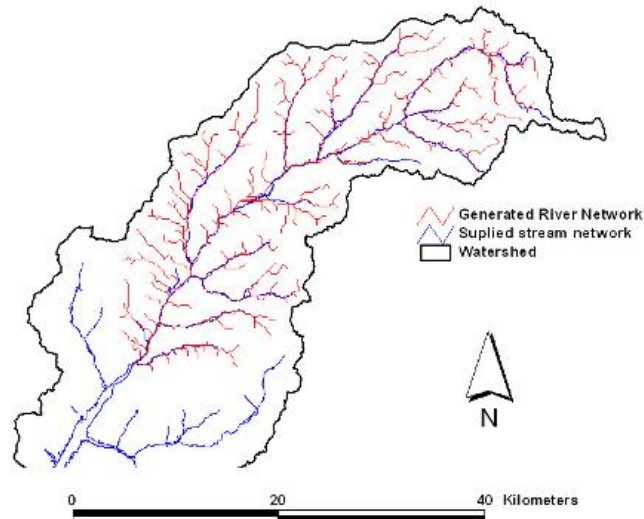


Figure 4 – River Networks Comparison

2.3.2 Soil

Soil and land use maps are fundamental for watershed modeling. It is the combination of soil type, land use and meteorology that determines the amount of precipitation converted into effective runoff. Soil maps used in these simulations are from FAO (<http://www.iambiente.pt/downloadall.htm>). Only three soil classes are defined for the entire watershed Figure 5.

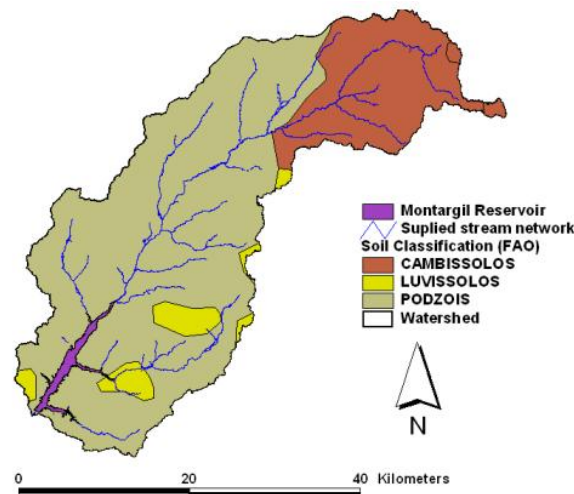


Figure 5 – FAO soil classifications

Portuguese soil cartography should reveal more soil classes, however hydraulic parameters are not easily available for many of these classes so for the initial runs only the three classes present in FAO cartography will be used.

For now the SCS¹ curve number methodology will be used to estimate surface runoff. The curve number is based on the area's hydrologic soil group, land use, treatment and hydrologic condition. As soil classification is only important to define one of 4 hydrologic groups to be used in the SCS curve.

Hydraulic parameters variations were one of the major sensitivity test performed.

2.3.3 Land Use

Corine land cover maps (1:100 000) were used to describe the watershed land use. The main reason for this was their availability (simple download on the internet <http://snig.igeo.pt/>). Unfortunately most of the data is probably outdated; satellite images on which the maps were made are from 1990. Satellite photographs from 1998 seem to prove that some changes have already occurred for land use.

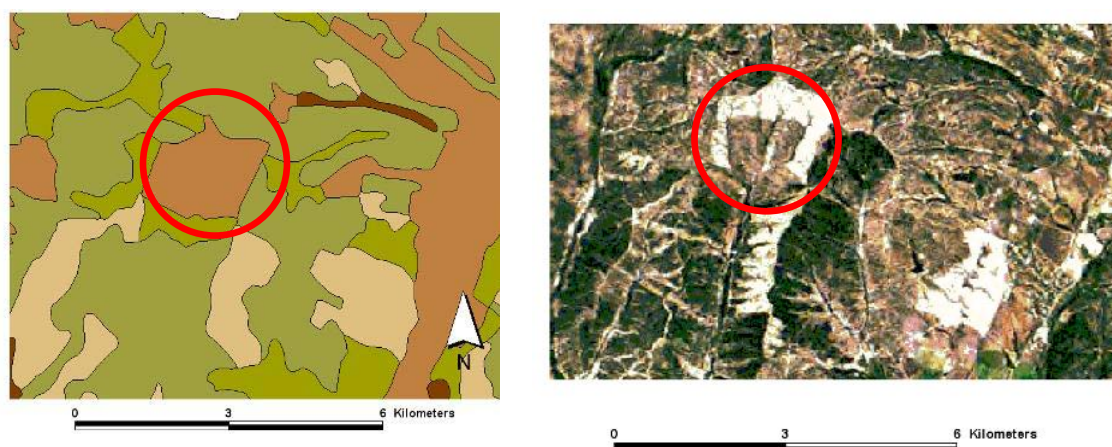


Figure 6 – Land use classification inconsistency. On the left Corine land cover clarification (1992), on the right satellite images from 1997.

However to reconstruct historical data recorded in Moinho Novo station (1980-1990), the land cover data will be considered adequate. Some revision will be needed for simulation of more recent events.

Another interesting aspect of land use classification is the correspondence between Corine land cover values and SWAT land use classification. When using SCS curve number for estimating runoff values the results are less sensitive to land use variations than a physical based approach like Green & Ampt infiltration method, where for instance canopy storage and evapotranspiration processes have a direct impact on water budget.

If more detailed simulations are to be performed using physical based models land use classification will become a decisive factor and revision will be needed.

Another important aspect of land use classification is the calculation of diffuse loadings to the stream network. For now and since water quality was not simulated, loadings to the stream network aren't critical which withdraws some importance on detailed land use classifications.

¹ US Soil Conservation Service

2.3.4 Meteorological data

The project partner INAG, operates several automatic weather stations in the area (Figure 7 – Automatic weather stations).

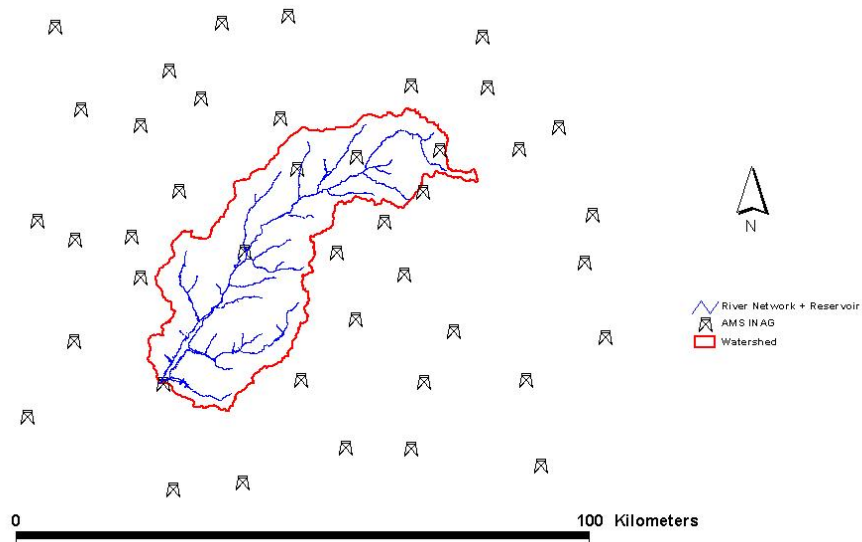


Figure 7 – Automatic weather stations

The available parameters for each station are listed in Appendix I. However since historical data is needed to calibrate the model with data from Moinho Novo hydrometric station, the following stations were used:

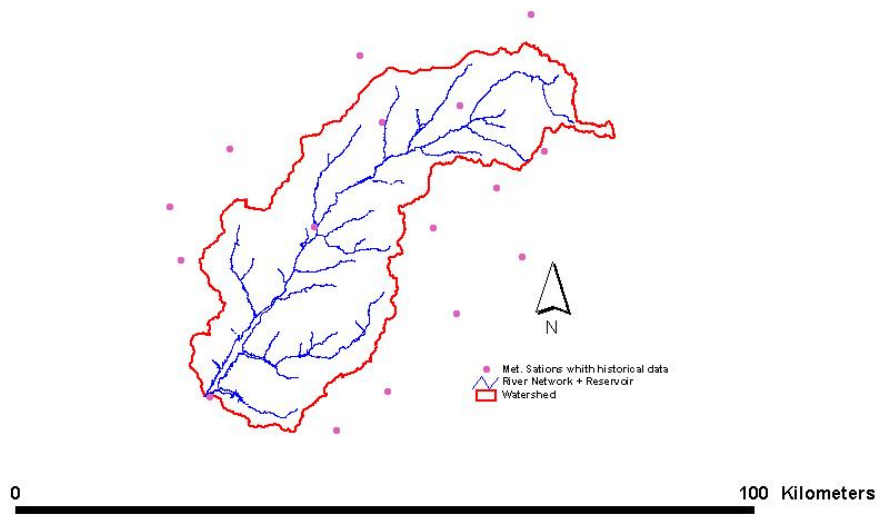


Figure 8 – Used weather stations (with historic data)

2.3.5 Results

The following results were obtained with CN curve protocol for surface runoff, Penman - Monteith evapotranspiration and variable storage routing method for channel flow.

Figure 9 - Model results using FAO soil data and Corine land cover charts shows water flow at “Moinho Novo” for a period between 1980 and 1985, using Corine land cover. In 13/12/1981 a single value close to 500 m³/s was recorded by the station. This value was neglected.

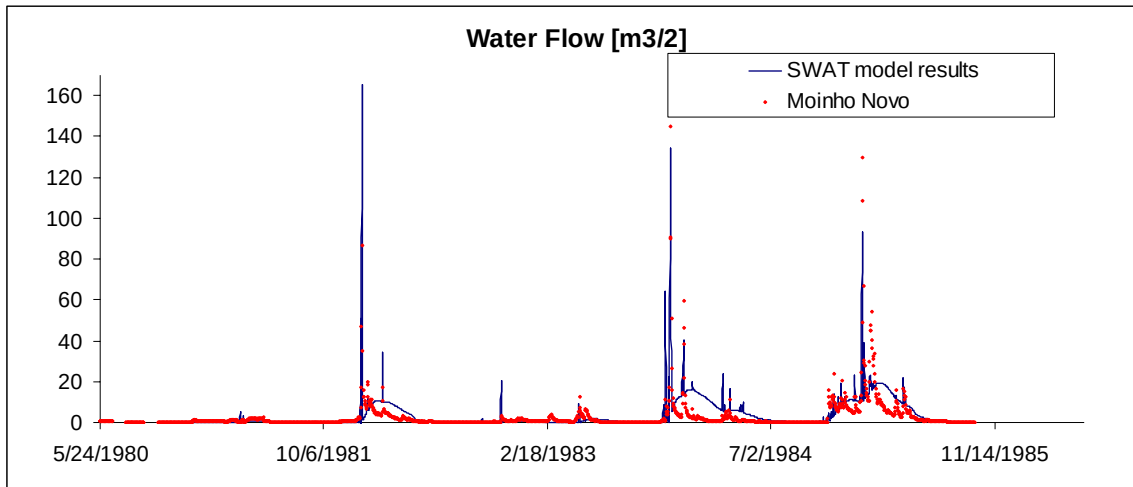


Figure 9 - Model results using FAO soil data and Corine land cover charts

Figure 10 shows model results with the same data as the previous simulation but with an impermeable soil covering the entire watershed.

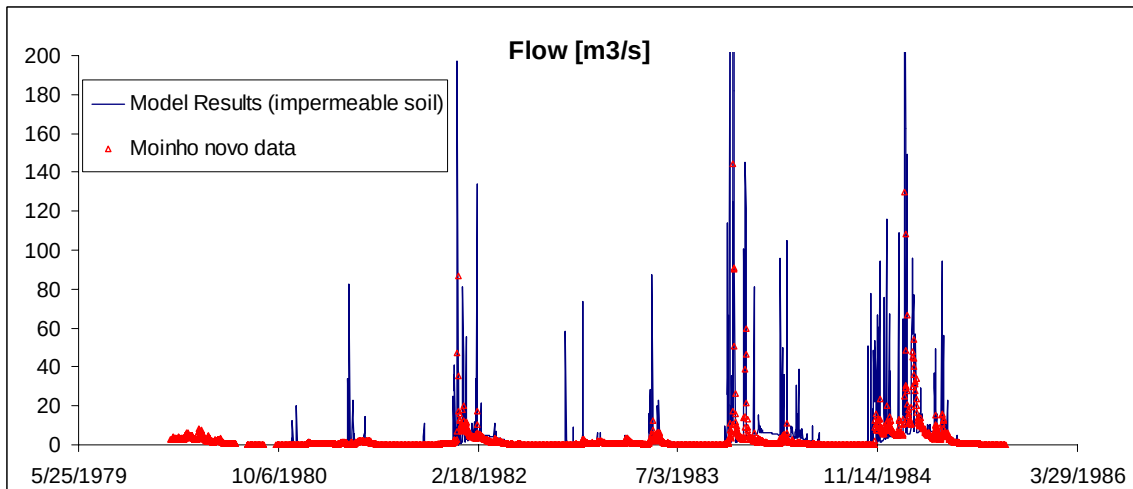


Figure 10 - Model results with impermeable soil

Figure 11 compares results when the model uses different soil formulations for ‘Podsoil’ (the soil class that is predominant in the watershed).

All the simulations have shown a wave like characteristic at the selected outlet (“Moinho Novo”), this behavior is not present in data recorded by the hydrometric

station. The explanation could be aquifer influences that are present in the model but do not exist.

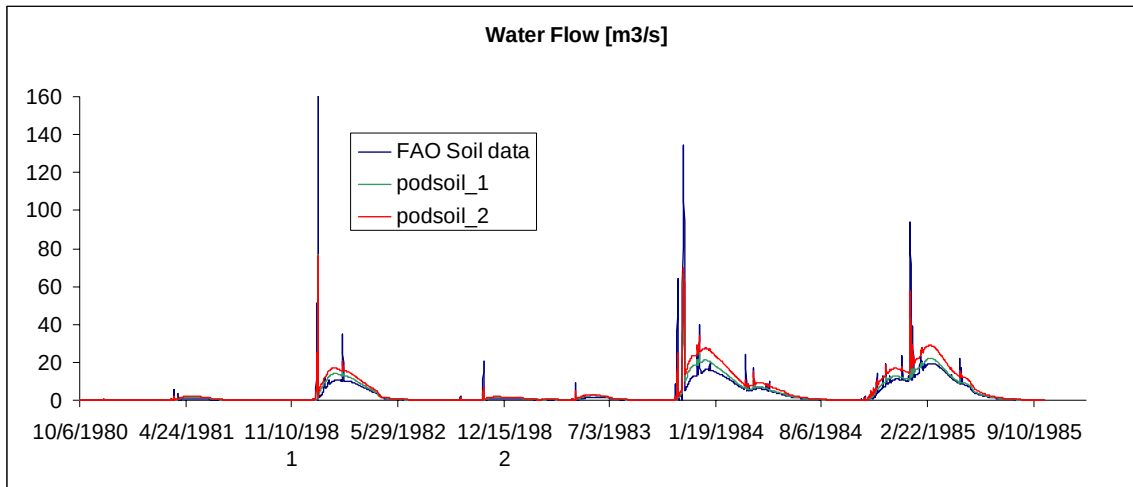


Figure 11 – Flow results [m3/s] with different soil types

2.3.6 Conclusion / Future directions

In all simulations water flow has been overestimated. The best results overestimate water entrances to the reservoir by 2% every year. This should point to either landuse or soil classification inconsistencies, precipitation mapping errors or shallow aquifer influences.

The high flow values recorded at 13/12/1981 of 500 m3/s by the hydrometric station were disregarded since such high values should correspond to a flooding situation, when the measuring capacities of the station are affected.

In order to obtain better results at the “Moinho Novo” station, more research has to be made into:

- Channel shape and rugosity variations
- Portuguese soil maps
- Better landuse resolution maps
- Green & Ampt infiltration method

Sufficient meteorological data can be supplied by the existing weather stations.

The river network created from the existing DEM should suffice for good results for Sôr River. No modeling attempts have been made on the remaining streams that flow to the reservoir, submodels for these streams are necessary and will require the use of higher resolution in the DEM. Modeling of these smaller watersheds is necessary to evaluate water quality at both Tesos and Foros do Mocho site. As seen from the reservoir hydrodynamic model, water at these locations suffers more influence in terms of bacterial

contaminations from these local rivers than from the main reservoir (see Reservoir Modeling results).

Swat water quality routines (inspired in Qual2E for the streams and WASP for reservoirs) should be the next modeling stage. The evaluation of the data quality supplied by “Moinho Novo” automatic station is a determinant step. Later the point sources discharge will be taken into account. Once point sources are correctly evaluated, diffuse pollution will be the main target.

Since no hydrometric stations are currently operating on most of the streams in the watershed, data campaigns have to be planned to validate future modeling attempts. Better modeling of the reservoir hydrodynamic should help establish the key streams that influence the selected sites.

SWAT has proven to provide reasonable results with a limited input dataset. Use of this model in the watershed will continue as a benchmark test, even when MOHID Land is available.

2.4 Reservoir modeling

For this study a preliminary hydrodynamic model of Montargil reservoir was created with MOHID software, a program developed by MARETEC (Marine and Environmental Technology Research Center) at the Instituto Superior Técnico (IST) in the Technical University of Lisbon.

MOHID Water’s versatility can easily be demonstrated by the range of applications carried out in the last couple of years: applications in the North Atlantic to study general circulation (Neves, *et al.*, 1998, Coelho, *et al.*, 2002), Oil Spills (Leitão, *et al.*, 2003), eutrophication and residence times in estuaries (Braunschweig, *et al.*, 2003), reservoirs (Braunschweig, 2001).

2.4.1 Bathymetry data for Montargil Reservoir

Unfortunately no bathymetric data is available for the reservoir. The DEM cannot be used since it contains no valid data in the reservoir.

In a first approach a schematic bathymetry was created based on:

- Topographic levels at the dam
- Contour line of the reservoir.

All point with elevation values inside the line that delimits the full reservoir were deleted. A straight line was created between the dam and the end of the reservoir. Elevation values for such points were obtained by simple linear interpolation. All points along the delimiting line were marked with the 80 m elevation. A three dimensional view of the resulting bathymetry can be seen in Figure 13

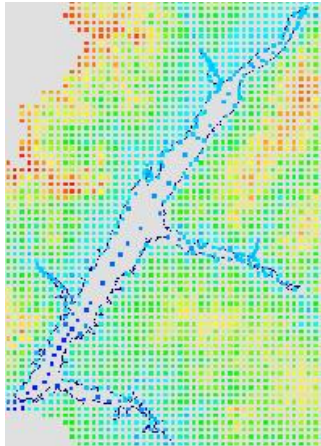


Figure 12 – Points used to create the reservoir bathymetry

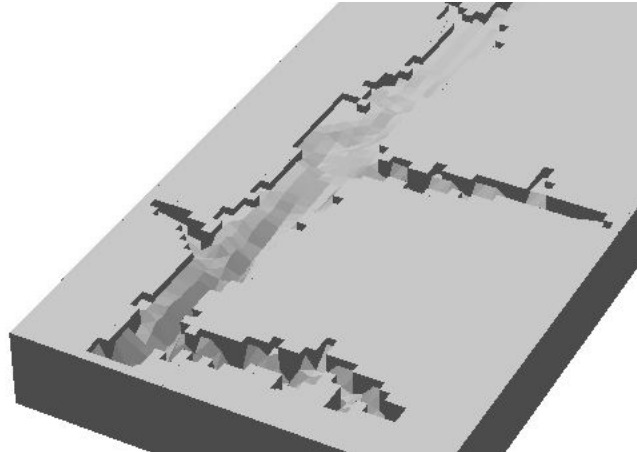


Figure 13 – Three dimensional view of the created bathymetry with a distorted vertical scale

2.4.2 Results

The reservoir simulations were carried out with two different input scenarios:

1. Steady 2.0m/s NE wind (typical winter situation), with baroclinic flow
2. No wind (typical summer situation), with baroclinic flow

A vertical harmonic discretization of 10 cells was used.

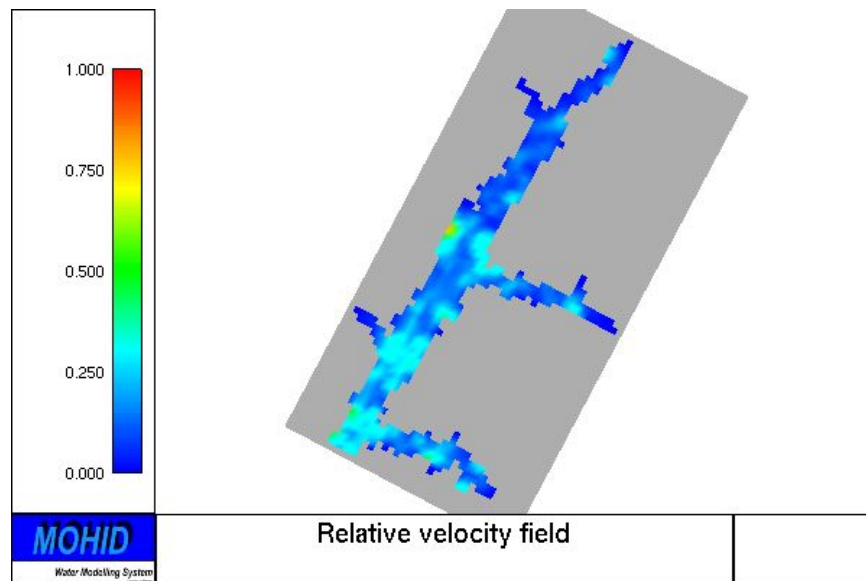


Figure 14 – Relative velocity field with no wind

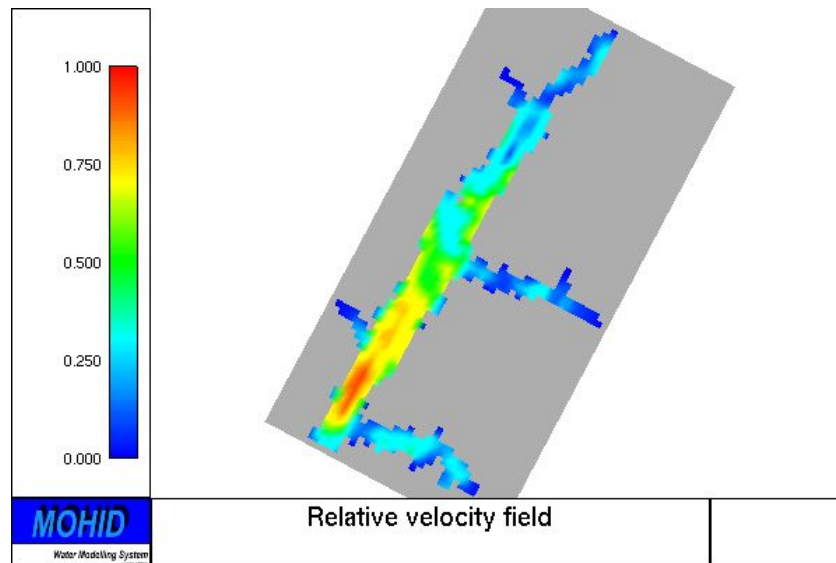


Figure 15 – Relative velocity field with typical winter wind

2.4.3 Conclusions / Future Directions

Water velocities in the reservoir are very low, 0.06 m/s under winter conditions and 0.02 in summer conditions. “Pintado” site shows relatively high velocities values when compared to both “Tesos” and “Foros do Mocho”. This seems to be the main advantage of that site allowing better performances for the bathing waters indicators.

“Foros do Mocho” is more influenced by the local effluent “Ribeira da Margem” than by the main reservoir and remaining rivers.

Since the velocities are so low in the reservoir, a particle would take the minimum time of 35 hours to travel from “Sôr river” to the zone of “Tesos”, which means that the main stream (Sôr river) may be the most important source for nutrients that affect water quality in the reservoir, but for bacterial contaminations, local streams (such as “Ribeira de Santa Margarida” or “Ribeira da Margem”) will have a higher importance. The use of watershed models at a smaller scale specifically for the streams that flow directly into the reservoir is fundamental to evaluate these sites.

In order to obtain more precise results and correctly model the reservoir level as a function of both river discharges and Dam management, a better bathymetry must be obtained. Also more research has to be made into the thermal stratification of the reservoir. This event can cause much higher velocities at the surface changing the previous conclusions.

3 Zambujeira Beach

3.1 Historical data

Zambujeira do Mar is a small beach on the southeast of Portugal, on the South border of Alentejo Region.

A small watershed of 18 km² discharges to the Zambujeira beach with a wastewater treatment plant located approximately 700 m upstream from the beach.

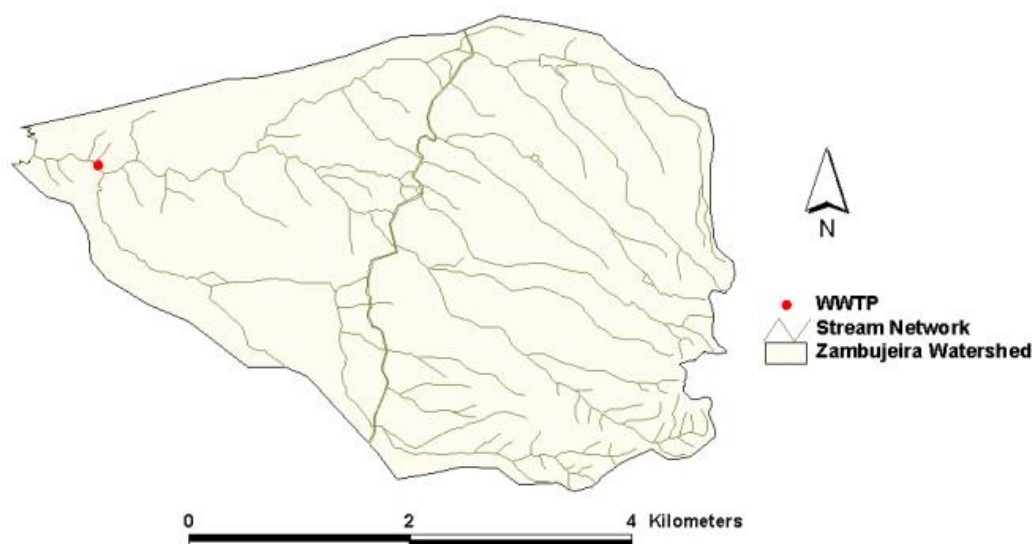


Figure 16 - Zambujeira Watershed

Historically water quality analyses are available since 1993 with non compliance values between 1998 and 1999. Since then until 2002 the beach has show better results, but with a tendency to high values in bacterial Coliform indicators.

3.2 Modeling strategy

A forecasting and observing system of hydrodynamic and biogeochemical properties has been built for the Tagus Estuary (<http://www.mohid.com/tejo-op/>), providing historical and real-time observations and daily predictions of several atmospheric and water conditions, including hydrodynamic and biogeochemical properties.

This tool merges several different sources of information stored in databases, and allows users to explore all available data via the internet. These sources of data comprise automatic data acquisition stations, field data campaigns, atmospheric and estuarine model predictions. One of the automatic data acquisition stations collects meteorological data, while the other station measures current meter data and several water properties (eg:

turbidity, temperature, salinity, chlorophyll) in the Tagus mouth. Both stations and their data acquisition are now automated.

The field data campaigns were included within the scope of an outfall monitoring program, financed by SANEST SA. This company is responsible for the Costa do Estoril wastewater system. A MapServer application (a spatially enabled Internet application – “WebGIS”) was built to provide user’s results obtained in these field campaigns.

The weather forecast prediction model included in this operational tool is operated by the Environmental Department of the Technical Superior Institute of Lisbon and provides daily results for final users, as well as establishes forcing conditions of the estuarine prediction model, like wind, heat fluxes exchange between the water column and the atmosphere, and radiation.

For the estuarine model predictions, MOHID modeling system is used. This system allows the simulation of costal hydrodynamic processes coupled with biogeochemical processes. In this case the hydrodynamic module was forced with tide, wind and density gradients. These gradients occur mainly due to fresh water input (Tagus River) and heat flux exchange between the water column and the atmosphere. A 3D model provides users with daily predictions of hydrodynamic properties, like water level, currents, temperature or salinity. The biogeochemical parameters modeled are oxygen, cohesive sediments, phytoplankton, zooplankton, nitrate, ammonia, PON² and DON³.

A nested model configuration methodology is applied - larger scale models supply boundary conditions to the smaller scale domains, the later with high resolution, and used to make small-scale predictions, helping outfall and beaches water quality monitoring. In the case of the outfall, a 3D submodel is run coupled with a Lagrangian 3D transport model. This model solves the near field using a jet integral model. This jet model computes initial dilution and plume location. These values are used as initial conditions for the Lagrangian tracers emitted to simulate the far field. High resolution ($dx = 20$ m) 2D nested models are also running along Costa do Estoril beaches to help explaining microbial field data results (Figure 17).

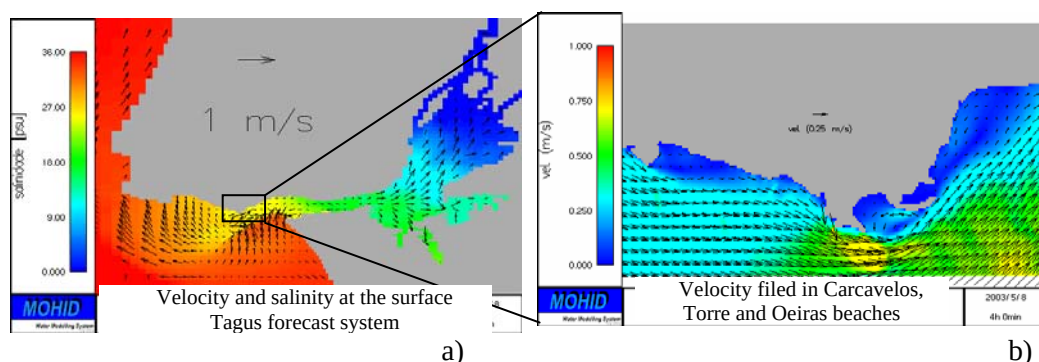


Figure 17 – a) Prediction at the estuary scale b) at the beach scale ($dx = 20$ m).

² Particulate Organic Nitrogen

³ Dissolved Organic Nitrogen

For the *ICREW* project a similar system will be implemented for the Zambujeira site, but integrating the watershed model to evaluate discharges to the beach.

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5 APPENDIX I – Automatic weather stations

CD	NOME	COORD_X (Portuguese military)	COORD_Y (Portuguese military)	Begin automatic data	Data Type
17H/01	ABRANTES	192689	275941	1/2/2002	Climatologic
18K/02	ALDEIA DA Mata	235300	259364	2/21/2001	Udumetric
18N/02	ALEGRETE	270085	252259	2/22/2001	Udumetric
17L/03	ALPALHÃO	244814	271596	-	-
18L/01	ALTER CHÃO	238748	250129	-	-
19N/01	ARRONCHES	273709	239307	2/21/2001	Udumetric
19J/03	AVIS	220708	231834	-	-
19H/02	BARRAGEM	196543	231190	3/2/2001	Climatologic
17M/03	BEIRÃ	265571	275629	-	-
17I/02	BEMPOSTA	199335	264527	-	-
20I/02	BROTAS	198415	212718	8/31/2001	Udumetric
18K/01	C. EXPE.	226932	253996	3/7/2002	Climatologic
19L/01	CABEÇO DE VIDE	247179	240368	-	-
16J/02	CARVOEIRO	218466	294928	10/24/2001	Udumetric
20K/02	CASA BRANCA	228518	219985	-	-
18G/01	CHOUTO	181212	256223	12/14/2001	Udumetric
16I/02	CHÃO DE CODES	206851	293767	10/24/2001	Udumetric
17K/01	COMENDA	230440	270416	-	-
17G/04	CONSTÂNCIA	182246	278641	10/25/2001	Udumetric
20G/01	ERRA	172836	225377	2/6/2002	Udumetric
19L/02	FRONTEIRA	241943	231425	-	-
17J/01	GAVIÃO	217002	277221	-	-
18I/01	LARANJAL	210819	254172	7/5/2001	Climatologic
19G/01	MACHUQUEI	181074	238645	2/23/2002	Udumetric
17J/02	MARGEM	219942	268254	2/27/2002	Udumetric
19M/01	MONFORTE	259856	231788	1/5/2001	Udumetric
16L/01	MONTALVÃO	252193	291381	4/19/2001	Udumetric
16I/03	MOURISCAS	203183	280626	10/24/2001	Udumetric
16L/03	NISA	239971	282857	2/22/2001	Udumetric
20I/01	PAVIA	210416	214051	3/21/2002	Udumetric

18H/02	POMBAS	192664	249727	4/19/2001	Udumetric
16L/04	PÓVOA MEA	253065	282504	-	Udumetric
20M/01	SANTO ALE	262355	216849	2/20/2001	Udumetric
16I/04	SARDOAL	197688	285530	10/24/2001	Udumetric
19K/01	SEDA	230118	242381	2/21/2001	Udumetric
20K/01	SOUSEL	239812	219942	2/20/2001	Udumetric
18N/01	SÃO JULIÃO	271329	260536	2/22/2001	Udumetric
18H/04	TOJEIRAS	191089	256822	2/26/2002	Udumetric
16G/01	TOMAR	177746	293148	10/3/2002	Udumetric
18G/02	ULME	174559	259572	2/26/2002	Udumetric
17L/02	VALE DO PESO	241839	264300	1/5/2002	Udumetric

6 APPENDIX II – MOHID Land specifications

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1 Context

This document describes some first ideas in how to implement MOHID LAND. Many parts of the text are based on a text initially written about the implementation of a mathematical model for hydrographic basins, following the strategy used by Mohid model for water bodies.

2 Introduction

Mathematical models for basin management are necessary to evaluate the contribution of diffuse pollution to water bodies. However some adaptations of existing models are necessary, for instance to model temporary waters. Instead of modifying all individual models, this document proposes a methodology focused on developing several modules which are needed for modeling basins. These modules will have two functionalities:

- they can be coupled to the existing models in order to fill existing lacks;
- all modules together can run as standalone model.

In this way the changes to existing models are minor and the implementations specific for temporary waters are common to all existing models.

The methodology here proposed has been successfully used in the last years during the development of the MOHID model (<http://www.mohid.com>).

Each module to be developed should contain the most common formulations and also the strong parts from all chosen models. **It is a crucial task to identify these strong parts among existing models.**

2.1 State of the Models

Existing models for basin management usually do not model the water cycle in an integrated approach. Models like SWAT, implement the most common formulations for basin management, related to surface runoff, erosion nutrient production, etc, but it lacks interaction between reservoirs, aquifers, and river hydrodynamics. For instance the SWAT model simulates the water quality dynamics in streams with some detail, but when it comes to water bodies the formulation is very poor (the question is why since the processes involved (e.g. nitrogen cycle) are the same)

3 New design of the Models – The modular approach

3.1 Overview

The MOHID model uses several object oriented features which can be implemented using ANSI Fortran 95. Instance creation of modules, encapsulation, polymorphism are feature of which are used in this module. The range of applications realized with this model (from a global tide preview, over estuaries, reservoirs to infiltration in soils) with this model proves that the methodology is a “good one”.

Using the above mentioned features, the coupling of new created modules to existing models will be easy.

Below follows an overview of the modules which are proposed to be developed.

3.2 Spatial scales

For basin modeling the development of four major modules is proposed. Each of these modules will be supported by several other modules:

- one module for the upper part of hydrographic basins, which permits to simulate the surface runoff, erosion, nutrient removal from soil and plant growth. This module will be called ModuleBasin;
- one module for river networks , which permits to model the transport and flow of the water through connected streams. This module will be called ModuleStreamNetwork;
- one module for Aquifers. This module should be able to simulate subsurface flow and transport and will be called ModuleAquifer;
- one module which integrates the different modules and handles communications among them. This module will be linked with an external executable file and communicate with each of the three executable files. In this way, reservoirs can be included in the basin management and estuaries can receive inputs directly from basins. This module will be called ModuleCommunication.

3.3 Time scales

The modules described in the previous paragraph have different time scales. For basin management proposes time scales in the order decades have to be considered. Water quality simulations in reservoirs are usually also object of long term (several years) simulations. On the other hand, to simulate first flush events (like for the tempQsim project <http://www.tempqsim.net/>), very detailed (temporal) simulations must be carried out. This difference between time scales should be kept in mind during model development.

3.4 Description of new modules to develop

This section describes new modules to develop. Information handled and exchanged by each module with other modules and the way the modules will be integrated into MOHID framework (and any other client model) are described.

3.4.1 Module Basin

ModuleBasin will be designed to simulate the catchment area. It will calculate the production of surface runoff and nutrient production from land areas it will route the water and its constitutions towards the river network until the water enters into one of the two following places:

- (i) a stream network modeled by the ModuleStreamNetwork or

- (ii) a water body simulated by a model able to simulate a surface water body (ex, CE-QUAL-W2, MOHID, etc).

The main inputs for Basin module are:

- (i) the digital terrain,
- (ii) the land use map and
- (iii) soil properties map. This module will work over a structured grid. The size of the grid cells should be able to variable in space. For different data, the possibility for different grid cell sizes should be foreseen.

This module will make use of different auxiliary modules which must be developed:

- surface runoff (cinematic wave (almost done))
- infiltration (SCS, Green-Ampt, Richardson (already done, etc),
- erosion (based on methodologies like USLE, MUSLE, other),
- nutrients "wash off" by surface runoff,
- Plant growth (including nutrient uptake).

For routing phase (until a stream reach simulated by ModuleStreamNetworks or until a water body), the flow and the constitutions should be simulated, following the cinematic wave equation.

Basin module should be able to manage inputs from local discharges (like WWTP's) or reservoirs and route this information downstream.

3.4.1.1 Interaction with other modules

Like mentioned above the ModuleBasin will act like a producer of flow and water dissolved or suspended constituents for downstream modules. Also, through infiltration, this module should be seen as a source for the Soil module and through this one for the Aquifer module. From the ModuleDischarges this module will receive discharge information (e.g. a WWTP discharge or the outflow of a reservoir). From the ModuleSurface, the ModuleBasin will receive atmospheric information (rain, wind, air temperature, etc.).

3.4.2 Module Stream Network

The ModuleStreamNetwork will be designed to simulate streams and rivers¹. This module should have the capability to be coupled to any model which simulates water bodies (e.g. CE-QUAL-W2, Mohid, etc), in order to simulate rivers and channels located close or inside water bodies (e.g. estuaries) or will run coupled to *MohidBasin* in order to simulate rivers in the catchments. In generic cases this module will link water bodies and

¹ On a first step this module will consider only 1D geometries, but it will be conceived to be extended to a 3D curvilinear module.

upstream catchments. To solve the evolution of hydrodynamic properties (water level, velocity) this module will solve the Saint Venant equation and for the transport this model will solve the advection/diffusion equation. The existing ModuleWaterQuality and ModuleSedimentProperties will be coupled to this new module to simulate sources & sinks and bottom exchanges.

The underlying grid of this module can be divided into two parts:

- (i) one part describes the network of rivers and
- (ii) the other part describes the sections of each river.

3.4.2.1 Interaction with other modules

This module will receive flow (as lateral discharges) from the ModuleBasin, and at each boundary the flow or water level either from linked rivers or from the water body model. Exchange with the surface model and the discharge module will also be implemented. Interaction with the bottom module (for sediments and benthic processes) should also be implemented.

3.4.3 Module Aquifer

The module aquifer will be designed to simulate subsurface saturated flow. The development of this module is still under investigation and it should be able to simulate the flow and transport processes. The grid of this module should be based on finite volumes, like the model MOHID model for water bodies.

3.4.3.1 Interaction with other modules

Module Aquifer will receive the water which infiltrates through the ModuleBasin (or module Soil) and can exchange water with the module StreamNetwork as a bottom boundary condition.

3.4.4 Module Communications

The ModuleCommunications should be built in a way that different MOHID framework programs are able to communicate among themselves. As an example, this module should be able to communicate results from the basin module to the water body module allowing flow and nutrients produced inside a basin to be used as boundary condition by that downstream module.

3.5 Description of existing modules of MOHID which can be useful

In this section the existing modules of the MOHID framework, which are useful for the basin management are described. For each module, the information that it handles, the information which it exchanges with other modules and the way the modules will be integrated into the MOHID framework is described. The necessary modification to each of these modules is discussed.

3.5.1 ModuleSurface

The ModuleSurface actually acts like a database and supplies the atmospheric conditions like air temperature, wind speed, solar radiation, heat fluxes, etc to the client modules. In order to use this module for long term simulation an automatic weather generator like the one which ships with the SWAT model should be included to the model.

3.5.1.1 Interaction with other modules

The ModuleSurface will be a supply meteorological conditions and air-water fluxes / air-land fluxes for the existing modules and for the ModuleBasin and for the ModuleStreamNetwork.

3.5.2 ModuleWaterQuality

Actually there are three zero-dimensional water quality modules within the MOHID framework which all include at least the nitrate, phosphorus and oxygen cycle. The most complex one simulates more than 60 state variables.

The integration of the ModuleWaterQuality as client module of the ModuleStreamNetwork should be easy, once it is designed as a zero dimensional module. New processes related to basin management, like the evolution of pesticides, CBOD and BOD must be included / improved.

3.5.2.1 Interaction with other modules

The ModuleWaterQuality will be used by the ModuleStreamNetwork (and any other module which needs water quality dynamics) to calculate the water quality processes inside rivers (or any water body).

3.5.3 ModuleSedimentQuality

To the ModuleSedimentQuality actually simulates the nitrogen and carbon cycle in soils. Like the water quality module it can be coupled to any module which needs to simulate the soil dynamics (in the Mohid framework this module is coupled to the Soil Module).

3.5.4 ModuleHDF

The ModuleHDF enables the storage of time and space varying structured grid data. A lot of post processing work is already done.

If on goal will be to handle triangular irregular networks (TINs) a way to store this kind of data in HDF (or any other format) must be implemented.

3.5.5 ModuleTriangulation

The ModuleTriangulation is useful for general interpolation (Grid generation, Weather stations, etc)

3.5.6 ModuleTimeSeries

This module is a general module to read and write time series.

3.5.7 ModuleDischarges

Useful to simulate any kind of water discharges (e.g. WWTP)

3.5.8 Module Soil

The module Soil solves the Richardson Equation for soils. It can be useful to estimate infiltration based on a physical model.

3.6 *Data management / Graphical User interface*

Data management is getting more and more important. Especially for basin management and many things have to be done (and many have been done). The data management in these areas cannot be solved without the use of a geographical information system. So it is desirable to find a common development strategy in this area. Possible options are to build modules which can be added to existing GIS software or build a system for our own needs from scratch. Every option has its advantages and its disadvantages.

Actually there are two major trends inside the Mohid developer group: (i) a system based on free GIS software (MapServer), able to represent spatial distributed data, which is stored in geo-referenced databases and (ii) a system which allows the model user to input data into the model (e.g. box definition, definition point location for time series outputting). A tool allowing both features over the some base layer (a geo-referenced database) is desirable. In this way data management would be much easier. A software project for the implementation of this project must be elaborated within the next months.