Modeling floods in Enxoé watershed

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Abstract

Enxoé reservoir was built in 1998. Enxoé is a temporary river with tendency to flushy regime and the flood dynamics, that may impact reservoir state, was characterized using the following approach:

- Collect data in the, until then, ungauged watershed (2010-2011);
- Implement MOHID Land model and validate the hydrology against existing data, and
- With the model validated, quantify flood role on annual loads and depict flood dynamics.

It was observed that soil loss of permeability in Enxoé is an important factor to accurately predict first floods or first peaks of consecutive floods and cumulative load results with orders similar to urbanized watersheds reinforced this fact. First floods in the year had a lower weight in terms of annual volume and annual nutrient load to the reservoir (less than 3% and 7% respectively) that floods in winter (between 10%-20% each). However, first floods in the year transported particulates concentrations that were 5 to 50 times the low waters value (and most of the transported occurred in the first minutes of flood, before flow peak, from deposited material in river bed and in neighbor land areas), while in winter, concentration remained almost constant during flood. Further work should link watershed models to a reservoir model in order to depict the flood impact in the reservoir and test management strategies to reduce trophic state. (David Brito, Ramiro Neves).

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1st Chapter. Introduction

From a strict hydrological sense, **flood** is defined as a rise, usually brief, in the water level in a stream to a peak from which the water level recedes at a slower rate (UNESCO-WMO 1974).

Flood is a natural phenomenon that occurs when the volume of water flowing in a system exceeds its total water holding capacity.

The natural phenomenon can have several sources as: prolonged rain with considerable intensity, dam or dike break, river blockages, storm surges.

In recent history, floods are becoming more frequent and severe and some organizations even counted it as the most damaging natural disaster in a region. In Europe, flooding, is the most common natural disaster and the most costly in economic terms. The Emergency Disasters Data Base (EM-DAT) has recorded a total of 238 flood events in European region from 1975 to 2001.

The frequency of occurrence and the intensity of damages and losses of lives resulting from floods made it known all over the world that flood is a great treat to humanity. However, since serious floods occur in a certain location with a return period of years or decades, the lessons learned from previous flood may have been forgotten (Miller, 1997).

The direct effects of floods includes: losses of lives, damage to property, disruption of transportations, communications, health and community services, crop and livestock damages and interruptions and losses in business.

The consequence of floods has called for the growing attention because of the need to prevent or control flood damages in our society. Mitigating flood damages can be drawn in two possible ways: structural measures and non-structural measures. Structural measures include the building of dikes, dams and reservoirs and channel improvements designed to reduce the incidence or extent of flooding. Structural mitigation measures are methods designed to divert flood water away from people. This type of mitigation measures are proven effective but most often expensive.

The non – structural method of mitigating flood damages place people away from the flood.

The aim of this work was flood modeling in Enxoé watershed. The primary objectives of the study are:

- To determine the flood behavior including design flood levels;
- To provide a model that can establish the effects on flood behavior of future development.
- To simulate watershed and reservoir dynamics and to represent the actual situation and test management.

2nd Chapter. Literature survey

2.1 Hydrologic cycle at catchment scale

At a catchment scale, considerations of hydrological cycle include the processes that take place in the atmosphere, land surface and subsurface. The precipitation falls from the atmosphere but before it reaches the ground, part of it is intercepted by vegetation and evaporates back into the atmosphere. The precipitation that reaches the land surface will either infiltrate to the subsurface or will become Horton overland flow or rill flow. As the rill flow accumulates, it becomes a stream flow then channel flow. Channel flow also has some contribution from the groundwater flow in the form of baseflow; it becomes the catchment runoff when it flows out from the catchment.

Rainwater that infiltrates will contribute to unsaturated flow, macro pore flow and perched flow. Unsaturated flow will recharge the groundwater through the process of percolation. Water that passes through macro pore and perched flow will either contribute to the groundwater flow or to the exfiltration process depending on the soil moisture condition. When rainwater reaches the groundwater through percolation, part of it will join the channel flow as baseflow and again evaporation will take place. Majority of the groundwater will remain as groundwater recharge or groundwater storage. The total evaporation is the summation of the canopy evaporation, transpiration and soil evaporation and evaporation from open water. The catchment runoff is the accumulation of the channel flow and the contribution from the groundwater.

2.2 Runoff processes

The concept that surface runoff is generated where and when the rainfall intensity exceeds the rate at which water can enter the soil, most hydrologists considered that all storm runoff was generated by this mechanism.

Infiltration. The passage of water through the soil surface into the soil is termed infiltration. Although a distinction is made between infiltration and percolation, the gravity flow water within the soil, the two phenomena are closely related since infiltration cannot continue unimpeded unless percolation removes infiltrated water from the surface soil. The soil is permeated by non-capillary channels through which gravity water flows downward toward the groundwater, following the path of least resistance. Capillary forces continuously divert gravity water into capillary-pore spaces, so that the quantity of gravity water passing successively lower horizons is steadily diminished. This leads to increasing resistance to gravity flow in the surface layer and a decreasing rate of infiltration as a storm progresses. The rate of infiltration in the early phases of a storm is less if the capillary pores are filled from a previous storm.

The maximum rate at which water can enter the soil at a particular point under a given set of conditions is called the *infiltration capacity*. Infiltration capacity depends on many factors such as soil type, moisture content, organic matter, vegetative cover and season. Of the soil characteristics affecting the infiltration, non-capillary porosity is perhaps the most important. Porosity determines storage capacity and also affects resistance to flow. Thus infiltration tends to increase with porosity.

Saturation overland flow. Rain falling on the stream surfaces constitutes an effective mechanism for flow generation even though it is not usually a major factor. Overland flow also tends to occur if water is forced to the surface where the surface layer is saturated. Saturation overland flow occurs primarily at the base of slopes marginal to stream channels, in topographic hollows where flow lines converge, and in localized areas with thin soils underlain by relatively impervious strata.

The distinction between Hortonian and saturation overland flow is perhaps somewhat academic since the uppermost minute layer of the soil must be saturated at any point where overland flow is present, and saturation of a surface layer does not preclude infiltration. It has been proposed that the distinction be clarified by specifying that overland flow is the result of a rising shallow water table or lateral subsurface storm inflow (e.g. “surface saturation from below”). Academic or not there are catchments for which the principal mechanism of surface runoff is not entirely in accord with the concepts of Horton or Betson. Rainfall intensity over some forested upland catchments seldom exceeds the infiltration capacity, except for small characteristic areas in valley bottoms and hollows. The variable source concept postulates that these contributing (saturated) areas shrink and expand, depending on antecedent conditions and storm rainfall.

Sub-surface storm flow. For subsurface storm flow (interflow) to provide a major contribution to the total storm runoff requires the existence of a shallow layer of high permeability at the surface. Even then, the effectiveness of the mechanism has been questioned.

2.3 Hydrologic modeling

The concept of watershed modeling is embedded in the interrelationships of soil, water, climate and land use and is represented by means of mathematical abstractions. The behavior of each process is different and controlled by its own characteristics and its interaction with other processes within a given catchment. Rainfall is one of the predominant hydrologic processes, in addition to interception, evapotranspiration, infiltration, surface runoff, percolation and subsurface flow. Various mathematical models have been formulated during the last four decades. The developed models vary from empirical models for the evaluation of flood events to simple ones containing a certain degree of physicality, to stochastic models of different kinds and finally to the distributed models (Gosain and Mani, 2009).

The original mathematical models were mainly developed to estimate the maximum flow for design purposes. The rational formula is one of the earliest and simplest hydrologic models (Mulvaney, 1851). The method was based on the concept of the time of concentration and assumed that when the duration of the storm equals the time of concentration all parts of the watershed are contributing simultaneously to the discharge at the outlet. The method was modified when applied to large and homogeneous basins to include the effect of non-uniform rainfall distribution and spatial variation of watershed characteristics. Later, it was introduced the unit hydrograph. The unit hydrograph represents direct runoff at the outlet of a basin resulting from one unit of precipitation excess over the basin. The excess occurs at a constant intensity over a specified duration. Assumptions associated with application of a unit hydrograph are the following:

a) Precipitation excess and losses can be treated as basin-average (lumped) quantities.
b) The ordinates of a direct runoff hydrograph corresponding to precipitation excess of a given duration are directly proportional to the volume of excess (assumption of linearity).
c) The direct runoff hydrograph resulting from a given increment of precipitation excess is independent of the time of occurrence of the excess (assumption of time invariance).

For complex dynamic systems, a system approach has been involved. The response function was obtained from the analysis of input and output data. The subsequent development of these techniques was satisfactory from a mathematical point of view, but lost its connection with the real hydrologic system. Although these techniques helped to obtain the unit hydrograph they failed to incorporate many other processes and subsystems active in the rainfall-runoff processes. The flow volumes were estimated either based on statistical analysis of data records or by using an empirical rainfall-runoff relationship.

During the 1960s continuous hydrologic simulation was introduced through conceptual models. The models are continuously accounting volumes, based on water balances. The models have proven to be useful for studying the catchment response over time to a wide variety of weather sequences. The basic functioning of these models is controlled by parameters, which represent the processes of the drainage system. These models may not be useful for ungauged catchments since long-term data for calibration are not available (Gosain and Mani, 2009).

Hydrological modeling of ungauged catchments has focused on obtaining reliable estimates of runoff, it was achieved by linking parameter values to catchment characteristics. Some parameters that have a physical significance can indeed be measured from field experiments. A major difficulty with this is caused by the catchment heterogeneity. Runoff generating processes vary spatially in a pattern determined by many physical and topographic features. This phenomenon of spatial heterogeneity has been taken care of by distributed models (Gosain and Mani, 2009).

Based on the parameters representation, conceptual models are classified as lumped models, which are represented by spatially averaged watershed characteristics, and distributed models that incorporate the spatial variability. A semi-distributed model may adopt a lumped representation for individual sub-catchments (Gosain and Mani, 2009; Wheater, 2005).

2.3.1 Lumped conceptual models

A lumped model is one in which the spatial variations of watershed characteristics are generally ignored. Precipitation is considered spatially uniform throughout the watershed. Average values of watershed characteristics are utilized. The lumped catchment models are applied widely in water resource assessment and water resources management including real time forecasting.

The first attempt of modeling arid regions by means of a lumped model has been performed by Boughton in 1966. The model uses daily rainfall and evaporation data. It distinguishes three zones in the soil moisture storage: upper, temporary and subsoil zones. Infiltration takes place between upper soil and subsoil zones and is evaluated using the modified Horton equation. Runoff is produced when moisture supply is in excess of the three soil moisture storages. Pathak, 1989, used a modified soil conservation service SCS runoff model for simulating runoff in small catchments in semi-arid areas. The soil-water-retention parameter is estimated based on the curve number method. The model represents the soil characteristics which in turn have a strong influence on the runoff.

Lumped conceptual models have some limitations that can be summarized as follows:

- Average values of the catchment's characteristics are utilized to represent the various processes of the hydrologic cycle and thus the processes are averaged. Due to the non-linearity and the existence of threshold values, this can lead to significant errors that affect the simulation accuracy.

- The calibration is based on historical records, data errors may transfer to the set of optimized parameter values, which restricts the applicability of the model to other catchments.
- Model parameters are optimized for some rainfall-runoff events over a given watershed and the optimized values at the best represent the watershed only for the events used in the optimization.
- The parameters in most of the lumped models have some degree of dependency. Thus, the parameter values attained through the optimization are not necessarily the best estimates of the physical values.

2.3.2 **Distributed conceptual models**

Distributed models take the spatial variability of the watershed properties into account. The underlying principle in these models is to discretize the watershed into a number of zones that are hydrologically similar. The discretization can be made by:

- Representative Elementary Areas (REA), which is equivalent to the representative elementary volume concept (Freeze and Cherry, 1979).
- Hydrological Response Units (HRU), in which the HRU is considered homogeneous based on a distinct hydrological response such as vegetative cover, soil type, slope etc.
- Grouped Response Units (GRU), in which regions in a watershed that can be grouped based on zones of uniform meteorology or grid cells that is convenient for integrating with map coordinates and remotely sensed data (Gosain and Mani, 2009).

The runoff generation processes such as infiltration and surface runoff are modeled separately for each unit, hence a separate set of parameter values are required. The computed yield is then routed through one unit to another to obtain the total catchment yield.

Distributed models are well suited for evaluating the effects of land-use change within a watershed and the effects of spatially variable inputs and outputs; they are useful in simulating the water quality and sediment yield on a watershed basis. The major problems that have been involved in using the distributed models can be summarized as follows:

- They require a large amount of input data, which often render them inefficient for operational hydrology.
- Lack of insufficient available information about the physical characteristics of the basin (Loague and Freeze, 1985).
- Insufficient understanding of the processes of runoff generation at the catchment scale for building accurately models.
- Some studies have demonstrated that simple models are as successful as complex models (Gosain and Mani, 2009; Loague and Freeze, 1985; Pilgrim and McDermott, 1982).

2.3.3 Semi-distributed conceptual models

Semi-distributed models are developed in order to overcome the difficulties being faced with the distributed models; they are a compromise between lumped models and fully distributed models (Arnold et al., 1993; Williams et al., 1985). These models have simple algorithms. The spatial heterogeneity is represented by observable physical characteristics of the basin such as land use, soils and topography. It has been reported that semi-distributed approach is better than the lumped approach. The major advantage is that relating the parameter values to land use characteristics provides a method of investigating the impact of land use changes and allows the model to be more easily transferred to other basins.

Beven and Kirkby (1979) have taken into account the spatial variability in hydrological processes, particularly those that give rise to rapid runoff during and immediately following rain. First, it combined the distributed effects of contributing areas within the model and subsequently the model parameters are estimated from measurements taken in the field. Kite and Kouwen (1992) applied a hydrological model separately for each land use class in each sub-basin and routed the resulting hydrographs to the outlet and subsequently through lower sub-basins.

2.4 Existing Models

SWAT

SWAT is 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 (ARS). SWAT was developed to predict the impact of land management practices of water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time. To satisfy this objective, the model:

- Is physically based. Rather than incorporating regression equations to describe the relationship between input and output variables, SWAT requires specific information about weather, soil properties, topography, vegetation and land management practices occurring in the watershed. The physical processes associated with water movement, sediment movement, crop growth, nutrient cycling etc. are directly modeled by SWAT using this input data.
  Benefits of this approach are:
  - Watersheds with no monitoring data (e.g. stream gage data) can be modeled;
  - The relative impact of alternative input data (e.g. changes in management practices, climate, vegetation, etc.) on water quality or other variables of interest can be quantified
- Uses readily available inputs. While SWAT can be used to study more specialized processes such as bacteria transport, the minimum data required to make a run are commonly available from government agencies.
- Enable users to study long-term impacts.

- Is computationally efficient. Simulation of very large basins or a variety of management strategies can be performed without excessive investment of time or money.

SWAT is a continuous time model, a long-term yield model. The model is not designed to simulate detailed, single-event flood routing.

SWAT allows a number of different physical processes to be simulated in a watershed.

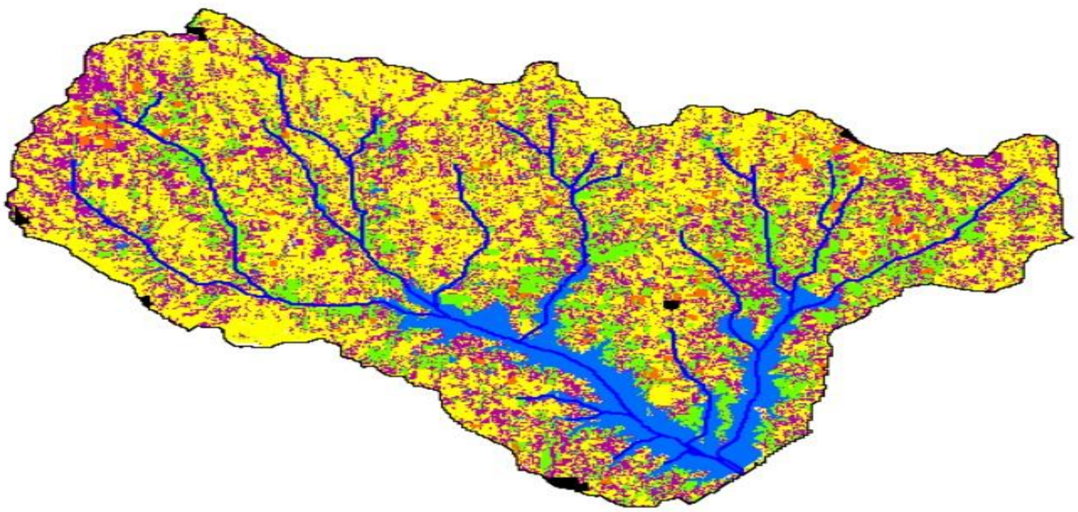


Figure 2.1 Map of the Lake Fork Watershed in Northeast Texas showing the land use distribution and stream network

For modeling purposes, a watershed may be partitioned into a number of sub-watersheds or sub-basins. The use of sub-basins in a simulation is particularly beneficial when different areas of the watershed are dominated by land uses or soils dissimilar enough in properties to impact hydrology. By partitioning the watershed into sub-basins, the user is able to reference different areas of the watershed to one another spatially.

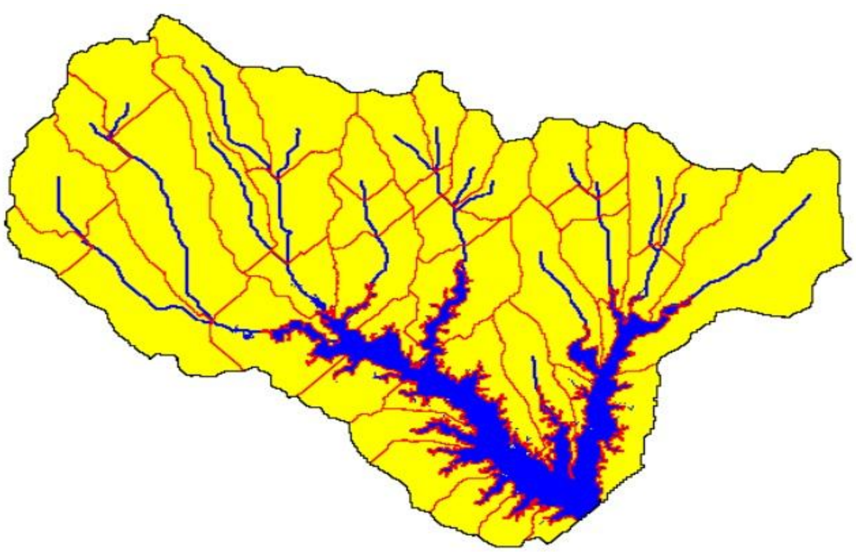


Figure 2.2 Sub-basin delineation of the Lake Fork watershed

Input information for each sub-basin is grouped or organized into the following categories: climate, hydrologic response units or HRUs; ponds/wetlands; groundwater; and the main channel, or reach, draining the sub-basin. Hydrologic response units are lumped land areas within the sub-basin that are comprised of unique land cover, soil, and management combinations.

No matter what type of problem studied with SWAT, water balance is the driving force behind everything that happens in the watershed. To accurately predict the movement of pesticides, sediments or nutrients, the hydrologic cycle as simulated by the model must conform to what is happening in the watershed. Simulation of the hydrology of a watershed can be separated into two major divisions. The first division is the land phase of the hydrologic cycle, depicted in Figure 2.3. The land phase of the hydrologic cycle controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each sub-basin. The second division is the water or routing phase of the hydrologic cycle which can be defined as the movement of water, sediments, etc. through the channel network of the watershed to the outlet.

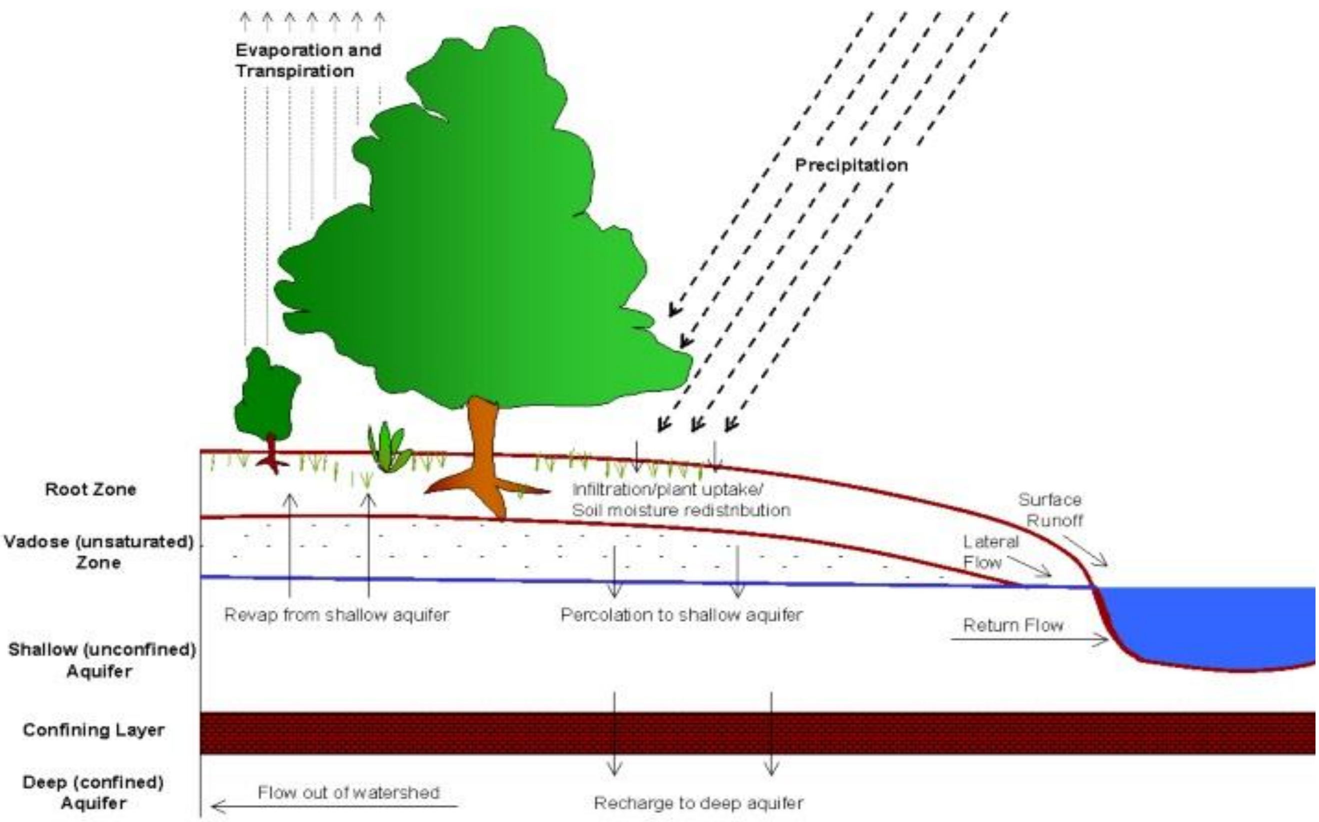


Figure 2.3 Schematic representation of the hydrologic cycle

HEC-RAS

HEC-RAS is a computer program that models the hydraulics of water flow through natural rivers and other channels. The program is one-dimensional, meaning that there is no direct modeling of the hydraulic effect of cross section shape changes, bends, and other two- and three-dimensional aspects of flow. The program was developed by the US Department of Defense, Army Corps of Engineers in order to manage the rivers, harbors, and other public works under their jurisdiction; it has found wide acceptance by many others since its public release in 1995.

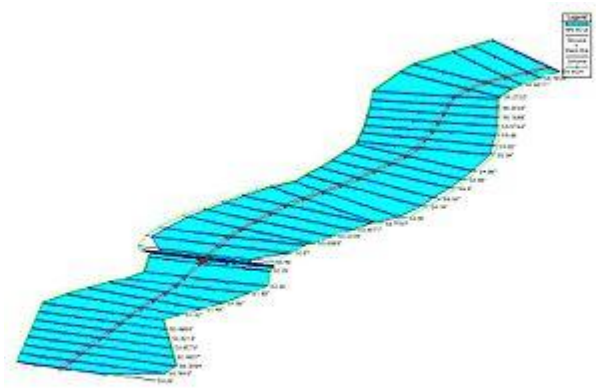


Figure 2.4: 3D view

The Hydrologic Engineering Center (HEC) in Davis, California developed the River Analysis System (RAS) to aid hydraulic engineers in channel flow analysis and floodplain determination. It includes numerous data entry capabilities, hydraulic analysis components, data storage and management capabilities, and graphing and reporting capabilities.

WMS

The Watershed Modeling System (WMS) is a comprehensive graphical modeling environment for all phases of watershed hydrology and hydraulics. WMS includes powerful tools to automate modeling processes such as automated basin delineation, geometric parameter calculations, GIS overlay computations (CN, rainfall depth, roughness coefficients, etc.), cross-section extraction from terrain data, and many more.

The full process of flood modeling and mapping has been integrated into a seamless process in WMS. Perform a simulation with any hydrologic model (HEC-1 or HMS, TR-20, TR-55, Rational Method, MODRAT, NFF) and link the peak flow or complete hydrograph to a HEC-RAS model of the river channel in your watershed. Complete the set up of HEC-RAS with cross-section cutting, area attribute mapping (roughness values assigned by polygons), and automated assignment of thalweg and bank locations and downstream distances. Once a HEC-RAS simulation is completed, you can import the W.S.E. results directly from the HEC-RAS project files and use them to determine the flooding extents and depths on the terrain model in WMS.

2D (Distributed) Hydrology

After many years of research and development, a 2D surface/groundwater hydrologic model is now available in WMS! The GSSHA model is the perfect solution for studies which require analysis of 2D surface flow and groundwater/surface water interaction. The model uses a 2D finite-difference grid to analyze surface runoff, 1D channel hydraulics, and groundwater interaction in a comprehensive hydrologic cycle model. Water quality and sediment transport processes may also be modeled with GSSHA. The model is capable of single event or long term rainfall simulation; radar rainfall data is supported in either case.

Typical applications of this model are:

- Flood forecasting (depth and velocity over entire 2D domain)
- Thunderstorm (localized rainfall) flood analysis
- Surface ponding and infiltration analysis

- Groundwater/surface water interaction modeling

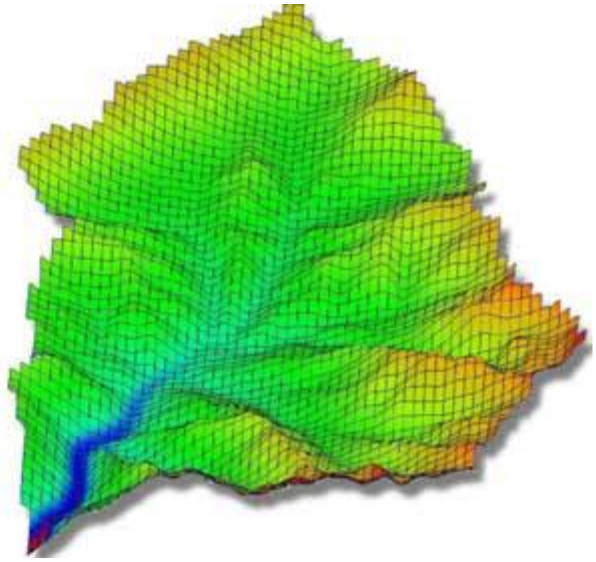


Figure 2.5: WMS view

MIKE 11 is the most popular river modelling system among professionals dealing with surface water problems in the world. It includes more than 20 years of built-in experience and continuous development. It is a versatile one-dimensional hydrodynamic software package including a full solution of the St. Venant equations, plus many process modules for advection-dispersion, water quality and ecology, sediment transport, rainfall-runoff, flood forecasting, real-time operations, and dam break modelling.

MIKE FLOOD - Flood Modeling Software

MIKE FLOOD is an integrated tool for detailed floodplain studies. It combines the two numerical hydrodynamic models MIKE 11 (1-D) and MIKE 21 (2-D) with a unified user interface and gives you the best of both worlds: Detailed spatial modelling where needed, plus the speed of 1-D calculations where appropriate. MIKE FLOOD is ideal for many types of analyses such as flooding, storm surge, dam break, embankment failure, and more.

MIKE FLOOD is a comprehensive modelling package covering all the major aspects of flood modelling. MIKE FLOOD integrates flood plains, streets, rivers and sewer/storm water systems into one package. Using this integrated approach enables the best engineering and numerical practices to be used where appropriate.

MIKE FLOOD integrates three of the most widely used hydrodynamic models namely MIKE 21, MIKE 11 and MIKE URBAN into one package. The philosophy being that the appropriate spatial resolution is applied where needed e.g. pipes and narrow rivers are modelled using one-dimensional solvers whereas the overland flow is modelled using two spatial dimensions.

MIKE FLOOD offers the following advantages as compared to traditional flood modelling techniques:

- Coupled 1D/2D
- Integration of hydraulic structures in 2D grids
- Effective, stable and locally/globally mass conserving flooding/drying routine

- Applied for riverine, urban and coastal flood mapping
- Accurate and physically based simulation of flow splits
- Extensive user support and documentation.

MIKE FLOOD relieves the modeller of the burden of having to choose between the number of horizontal dimensions and the often-prohibitive resolution requirements of modeling in a detailed 2D grid. With MIKE FLOOD it is not an either or. Since MIKE FLOOD consists of both 1D and 2D solvers the modeller can combine these as they see fit.

Typically the 1D model may be used

1. to represent flow in channels that may not be resolved in the 2D grid,
2. to model underlying pipe and sewer networks
3. to simulate hydraulic structures such as culverts, bridges, weirs etc. and
4. to simulate dam or levee failures
5. to route flow in longer river reaches for which a 2D models would be computationally heavy.

Whereas the 2D model is normally used

1. to represent over bank flows, an application where 1D modeling may be insufficient. A 2D model has the advantage of being able to accurately represent the floodplain geometry, so that discharge, storage, and attenuation in the floodplain can be accurately simulated.
2. to relieve the modeller of the burden of having to pre-define the flow paths, the 2D model will simulate flow splits based on the input topography.
3. to describe the complex network of streets and path ways found in urban areas.

TUFLOW

TUFLOW is a powerful computational engine that provides one-dimensional (1D) and two-dimensional (2D) solutions of the free-surface flow equations to simulate flood and tidal wave propagation. TUFLOW also leads the way in 2D/1D flood modelling with unparalleled 1D/2D linking, flexibility, robustness and a range of features no other product provides.

Applicability

- River flooding
- Urban flooding
- Pipe network modelling
- Storm tide and tsunami inundation
- Estuarine and coastal tidal hydraulics

TUFLOW is ideally suited to modelling:

- flooding of rivers and creeks with complex flow patterns
- overland and piped flows through urban areas
- estuarine and coastal tide hydraulics
- inundation from storm tides and tsunamis

TUFLOW offers unparalleled 1D/2D and 1D/1D dynamic linking capabilities with other products.

The TUFLOW engine interfaces with GIS software such as MapInfo, ArcGIS or SAGA and/or via the Aquaveo SMS GUI. 12D Solutions are developing a customized TUFLOW interface and WaterRIDE displays, animates and post-processes TUFLOW output.

TUFLOW is the dominant 2D flood modeling software in the UK, and is the most widely used 1D/2D flood modelling software in Australia. In 2010, TUFLOW and XP-2D were given FEMA approval in the USA.

Figure 2.6: Estuarine application

SOBEK, an one and two dimensional integrated modelling framework for integral water solutions

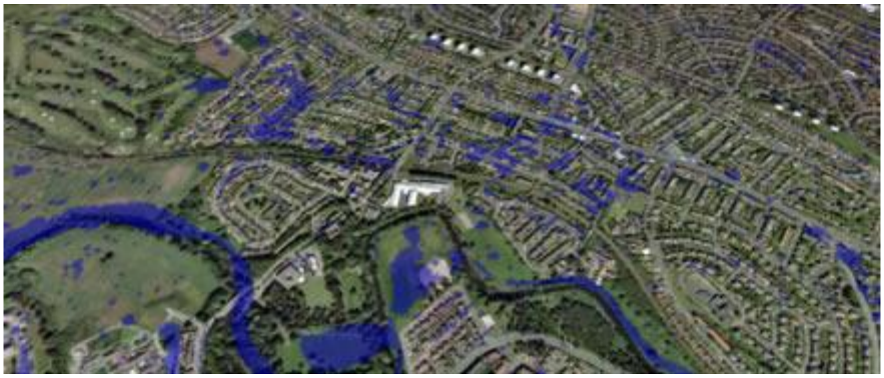
SOBEK is a powerful modelling framework for flood forecasting, optimization of drainage systems, control of irrigation systems, sewer overflow design, river morphology, salt intrusion and surface water quality. The components within the SOBEK modelling framework simulate the complex flows and the water related processes in almost any system. The components represent phenomena and physical processes in an accurate way in one dimensional (1D) network systems and on two dimensional (2D) horizontal grids.

SOBEK offers one software environment for the simulation of all management problems in the areas of river and estuarine systems, drainage and irrigation systems and wastewater and storm water systems. This allows for combinations of flow in closed conduits, open channels, rivers overland flows, as well as a variety of hydraulic, hydrological and environmental processes.

ISIS FAST

ISIS FAST is an innovative flood inundation modelling tool designed to allow quick assessment of flooding using simplified hydraulics. It provides results in seconds or minutes as opposed to hours or days, which is up to 1,000 times faster than traditional two-dimensional models.

The software works by first identifying depressions on the floodplain then routing water through these depressions. Water depths in the depressions are determined by the volume of water flowing into each one, the level at which water can spill into neighboring depressions and the water level in the neighboring depressions. ISIS FAST is able to do this by adopting new and innovative ways of resolving the detailed hydraulics.



ISIS FAST allows modellers to rapidly estimate flood extents and depths from multiple sources of water, including tide, surge and fluvial overtopping or breaching of defences, surface water and sewer flooding. The speed with which it can calculate water depths gives modellers the flexibility to explore uncertainty. Event magnitude and the interactions and dependency between flood sources were previously unpractical or economical.

The application of ISIS FAST includes near real-time flood inundation prediction on the Tidal Thames in London through to prediction of areas susceptible to pluvial flooding for the whole of Scotland.

Key features of ISIS FAST:

- rapidly estimates flood extents and depths from many sources of flooding, including coastal, fluvial, surface water and sewer flooding
- pluvial flood mapping and risk assessments at local, regional and national scales
- real-time flood mapping when linked to forecast rainfall
- used in conjunction with more detailed modelling software, such as ISIS Professional and ISIS 2D
- can remove the cost of some detailed modelling by identifying the flood risk hot spots where detailed analysis is needed
- can be used in probabilistic analysis frameworks
- can test solutions that protect people, property, critical infrastructure and the urban environment.

3rd Chapter . MOHID Land. Model description

MOHID Land is an integrated model with four compartments or mediums (atmosphere, porous media, soil surface and river network) and water moves through the mediums based on mass and momentum balances. The atmosphere is not explicitly simulated but provides data necessary for imposing surface boundary conditions to the model (precipitation, solar radiation, wind etc.) that may be space and time variant. Surface land is described by a 2D horizontal grid that can have variable spatial step. The porous media is a 3D domain with the same horizontal grid as surface, adding a vertical grid, also allowing variable layer thickness. The river network is a 1D domain defined from DTM by reaches linking surface cell centers. (fig 3.1) .

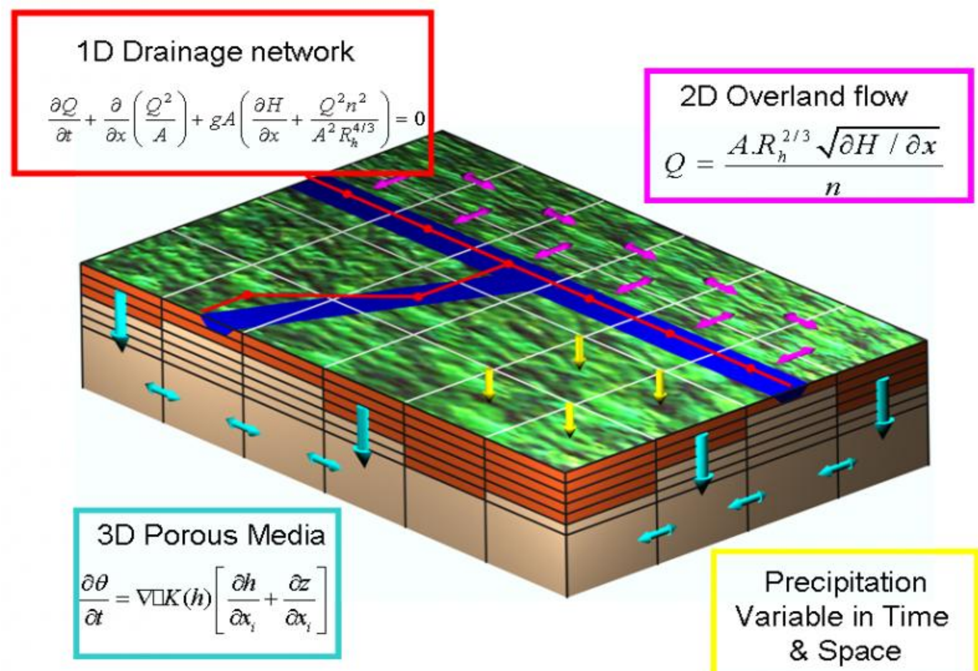


Figure 3.1: MOHID Land equations

The main processes solved are:

- 3D Porous Media solving Richard's Equations.
- 1D Drainage Network solving Kinematic Wave, DiffusionWave or complete St. Venant equations (dynamic wave)
- 2D Overland Flow (solving Diffusion Wave)
- Evapotranspiration using Penman Motheith and water availability in soil
- Plant growth and agricultural practices (planting, harvest, kill, fertilization, pesticide application, etc.) including dormancy and SWAT crop database
- Porous Media interaction with Runoff in Infiltration using continuity (Richard's equation with Head gradient)

- Porous Media and Runoff interaction with Drainage Network using continuity (surface gradient between Runoff and Drainage Network. Richard's equation with level gradient between Porous Media and Drainage Network)
- Property transport in all mediums and transformation in soil and river (water quality models can be coupled)
- Biological and chemical reactions in soil as mineralization, nitrification, denitrification, immobilization, chemical equilibrium, property decay, and processes in river as primary production, nutrient assimilation, property decay, etc.
- Linkage to MOHID Water by Module Discharges
- Floods.

Mohid Land model uses a finite volume approach (control volume) for computing state variables and fluxes. Each grid cell is a control volume, being the state variables computed in their centers and the fluxes (and related variables) on the faces. Mohid Land uses a variable time step approach decreasing it for high fluxes (e.g. high rain intensities and floods) and increasing it during dry season, making it suitable for flood simulation and yearly basis in a continuous way. Mohid Land processes are based in mass conservation equation, momentum equation (derived from Newton's second law) and continuity equation (derived from mass conservation when water is the property transported).

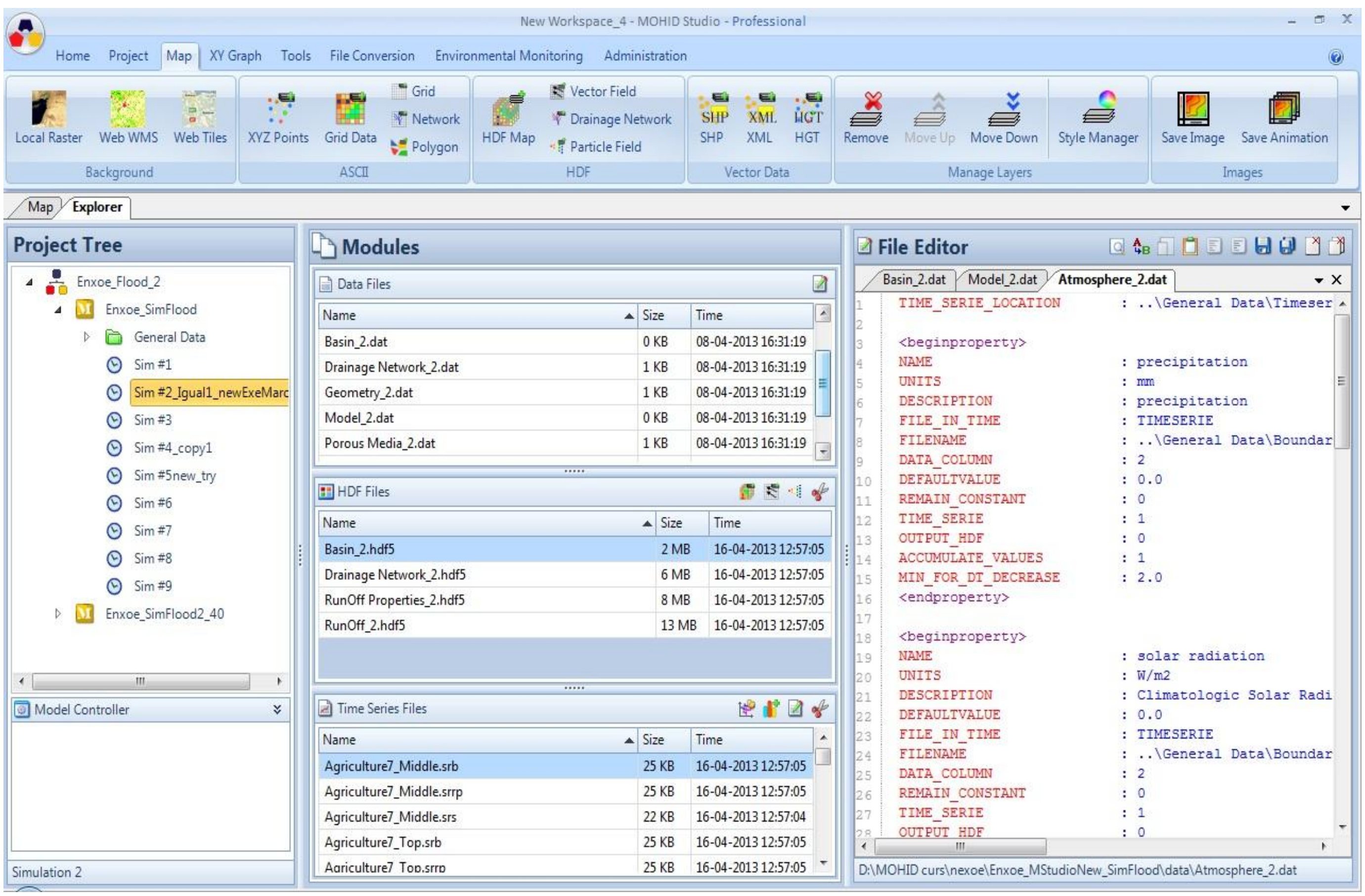


Fig. 3. MOHID Land interface

MOHID Land Modules

Some modules developed are related with specific processes which occur inside a watershed and on a specific medium, creating thus a modular structure. For user first approach and advanced use, processes solved, equations, input data files examples are presented below for each MOHID Land module:

- Module PorousMedia which calculates infiltration, unsaturated and saturated water movement
- Module PorousMediaProperties which calculates property transport and transformation in soil.
- Module SedimentQuality which calculates property transformation in soil driven by microorgansims (mineralization, nitrification, denitrification, etc.).
- Module PREEQC which calculates property transformation in soil through chemical equilibrium.
- Module Runoff which calculates overland runoff;
- Module RunoffProperties which calculates property transport in runoff.
- Module DrainageNetwork which handles water and property routing and property transformation inside rivers.
- Module Vegetation which handles vegetation growth and agricultural practices.
- Module Basin which handles information between modules and computes interface forcing fluxes between atmosphere and soil (e.g. throughfall, potential evapotranspiration, etc.).

MOHID Land also uses all the modules for data pre-processing, computation and post-processing that are common to MOHID Water (e.g. data file read, geometry handling, results writing in HDF and time serie, etc.) See below how you can see module source code.

Module Runoff

Module Runoff allows the calculation of the overland surface runoff over a grid as function of the water column slopes between adjacent cells (dynamic wave). The water column, namely the water located above the terrain, is given by the Module Basin after considering the precipitation input and the losses due to the evaporation and the infiltration. Overland flow is evaluated by the Manning’s equation.

Main Processes

Manning Equation

The overland surface runoff flow (m3/s) is calculated at the cell faces and it is obtained by applying the Manning's equation <ref>Gauckler, P. (1867), Etudes Théoriques et Pratiques sur l'Ecoulement et le Mouvement des Eaux, Comptes Rendues de l'Académie des Sciences, Paris, France, Tome 64, pp. 818–822</ref> :

$$Q = \frac{1}{n} \cdot A \cdot R_h^{2/3} \cdot s^{1/2}$$

where:

Q is the overland flow (m^3/s)

A is the area of the cross-section (m^2)
n is the Manning coefficient ($s/m^{1/3}$)
R_h is the hydraulic radius (m)
S is the slope of the water surface (m/m)

In order to apply the Manning's equation each grid cell is considered as an open channel as shown in the scheme below.

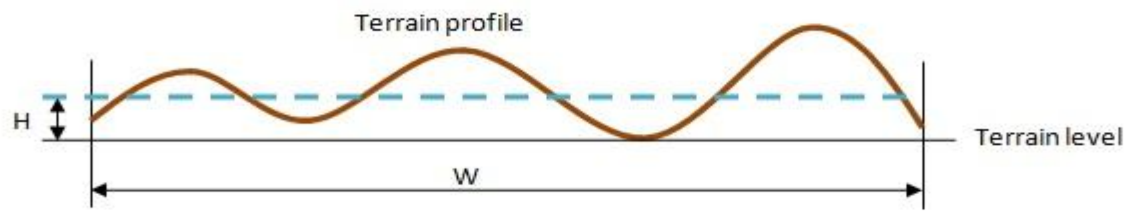


Figure 3.2: Cell scheme

where:

h is the water column (m)
w is the cell width (m)

Hydraulics radius

In rectangular channels, the hydraulic radius is evaluated by the formula:

$$R_h = \frac{w \cdot h}{w + 2 \cdot h} \quad (1.2)$$

But in runoff the lateral cell face is open boundary (to the next cell) not exerting friction in a surface as the bottom boundary, and so hydraulic radius can be rewritten:

$$R_h = \frac{w \cdot h}{w} \quad (1.2)$$

and the hydraulic radius is R_h=h. Therefore the Manning's equation can be rewritten as:

$$Q = \frac{1}{n} \cdot w \cdot h^{5/3} \cdot s^{1/2} \quad (1.3)$$

Slope

The slope (s) is calculated by the difference of the water levels (H) at the extremities of the considered cell:

$$H(i,j) = h(i,j) + T(i,j) \quad (1.4)$$

where:

H is the water level (m)
h(i,j) is the water column (m)
T(i,j) is the Topography (m)
j is X direction
i is Y direction

$$s_x = \frac{H(i,j-1) - H(i,j)}{DZX} \quad (1.5)$$

where:
s_x is the slope in the X direction (m)
H(i,j-1) is the water column at the left face of the cell (m)
H(i,j) is the water column at the right face of the cell (m)
DZX is width of the cell in the X direction (m)

$$s_y = \frac{H(i-1,j) - \mathrm{H(i,j)}}{DZY} \quad (1.6)$$

where:

s_y is the slope in the Y direction (m)
H(i-1,j) is the water column at the left face of the cell (m)
H(i,j) is the water column at the right face of the cell (m)
DZY is width of the cell in the X direction (m)

In order to take in account the limitation given by the Manning's equation (1.1) that tends to overestimate the flow velocity when slope > 0.04, the slope value obtained by the formulas (1.5) and (1.6) it is subsequently adjusted by the following function: Slope correction given by City of Albuquerque, 1997, p.22-26

$$s = 0.05247 + 0.06363 \cdot s - 0.182 \cdot e^{(-62.38 \cdot s)} \quad (1.7)$$

where:

s is the slope (m)

Manning coefficient

The Manning coefficient is derived from the land use map. Indeed by using a GIS program it is possible to associate at each cell a land use class in order to obtain, by the support of an abacus or table, a Manning coefficient value.

Calculated Flows

The flows obtained by the equation (1.3) are divided into flows in X direction and Y direction according with the Figure 3.3.

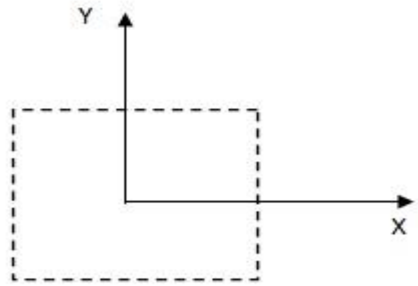


Figure 3.3: Flow directions

In the eventuality presence of a river in the basin analyzed it is possible to obtain two different configurations:

- Flow to the river when the water level of the river is lower that soil one

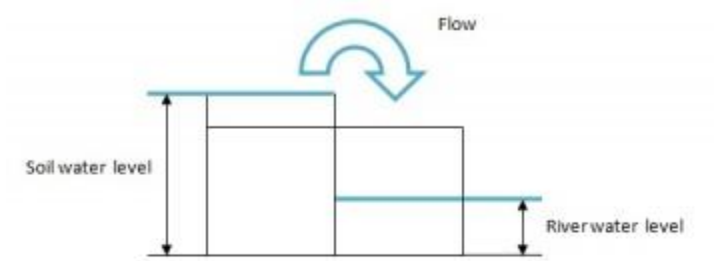


Figure 3.4: Flow to the river

- Flow from the river when the water level is higher than the soil one

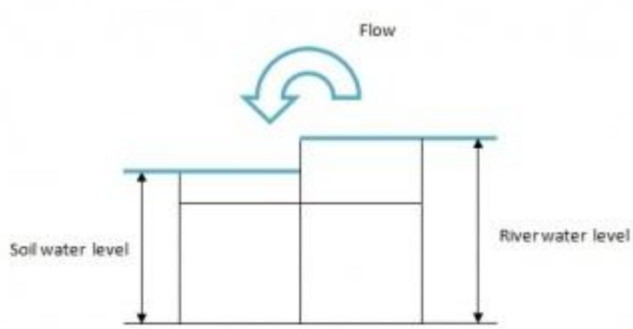


Figure 3.5: Flow from the river

The flow between river and runoff is computed using the same formulation as in runoff cells using the surface gradient between runoff and river.

Porous Media Geometry

Porous Media is a 3D domain delimited in its upper limit by topography and lower limit by soil bottom (defined by user). In terms of soil definition it can be defined vertical horizons to correspond to real soil horizons with different hydraulic characteristics. See the picture below for information.

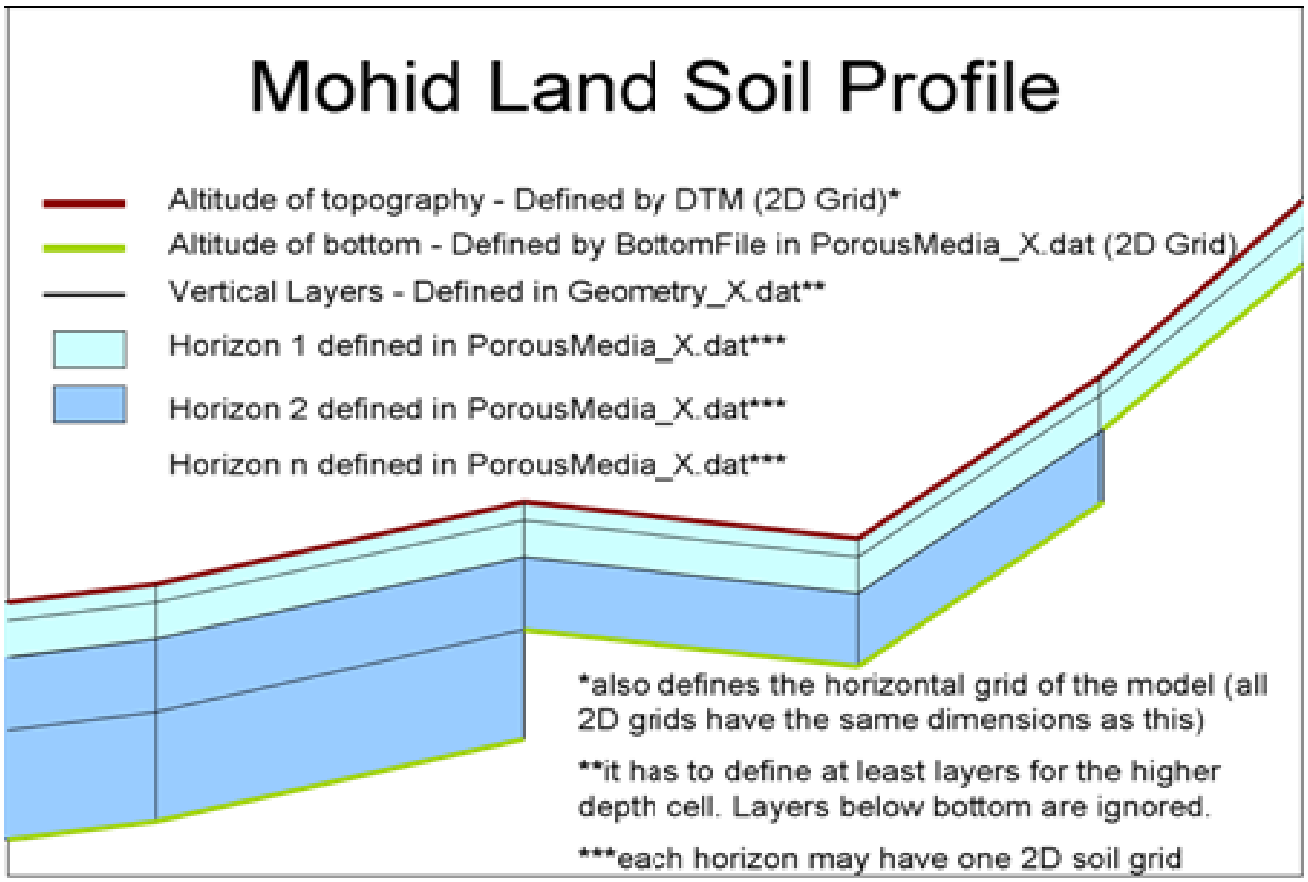


Figure 3.6: Mohid Land soil profile

Water Flow

Soil contains a large distribution of pore sizes and channels through which water may flow. In general the water flow determination is based on the mass conservation and momentum equation Equations. In the case of soil it is assumed that acceleration is close to zero since velocities are very low; therefore the balance is reduced to the forces of pressure, gravity and viscous. The equation that describes the flow through soil is the Buckingham Darcy equation (Jury et al, 1991).

$$v = -K(\theta)\left(\frac{\partial H}{\partial x_i}\right) \quad (1.1)$$

where:

v is the water velocity at the cell interface (m/s)
H is the hydraulic head (m)
θ is the water content (m^3/m^3)
K is the hydraulic conductivity (m/s)
x_i is direction i

The hydraulic head is given by the formula:

$$H = h + p + z \quad (1.2)$$

where:

h is the hydraulic head (m)
p is hydrostatic pressure (m)
z is the topography (m)

When in saturated conditions, hydraulic head is zero and hydrostatic pressure may occur (if water is at rest or decelerating). In unsaturated conditions hydrostatic pressure is zero and hydraulic head exists.

The soil is a very complex system, made up of a heterogeneous mixture of solid, liquid, and gaseous material. The liquid phase consists of soil water, which fills part or all of the open spaces between the soil particles. Therefore it is possible to divide the soil in two parts:

- Saturated soil ⟹ The soil pores are filled by water
- Unsaturated one ⟹ The soil pores are filled by water and air

Water content

Water content is the quantity of water contained in the soil (called **soil moisture**). It is given as a volumetric basis and it is defined mathematically as:

$$\theta = \frac{V_w}{V_T} \quad (1.3)$$

$$V_T = V_s + V_v = V_s + V_w + V_a \quad (1.4)$$

where:

θ is water content (m^3/m^3)
V_w is the volume of water ($m\ s^3$)

V_T is the total volume (m ^{3})
V_s is the soil volume (m ^{3})
V_a is the air space (m ^{3})

Module Basin

Module Basin works as an interface among the different modules of Mohid-Land. Indeed it manages fluxes between modules as precipitation, evapotranspiration, infiltration etc. and updates water column and concentration after each module call. This module is able to compute a water and mass balance for each property transported in all mediums.

Main Processes

The processes made in the Module Basin can be summarized as following:

- Reading entering data and grid construction
- Atmospheric processes (precipitation, leaf interception, leaf drainage, evaporation) in order to obtain the potential water column
- Call of Module PorousMedia giving potential water column and obtain the infiltration rate
- Update of the water column and send it to ModuleRunoff (the holder of water column)
- Call of Module PorousMediaProperties and update of water column concentrations send it to the ModuleRunoffProperties
- Call of Module Runoff giving the remaining water columns to be transported
- Call of Module RunoffProperties

(When Module Runoff and RunoffProperties run as they are the holders of water column and water column concentration, no update is needed).

- Call of Module DrainageNetwork to route the water in the river and the new transfered from groundwater and from runoff.
- Output of the different components of the water and property flux

Evapotranspiration

Some water may be extracted from the soil because of the evaporation and transpiration processes, which become a sink in soil water profile. These two processes are currently named Evapotranspiration and Potential Evapotranspiration may be modeled using the Penmann Monteith equation:

Energy flux rate Volume flux rate

$$\lambda_v E = \frac{\Delta R_n + \rho_a c_p \;\; \delta q \;\; g_a}{\Delta + \gamma(1 + g_a / g_s)} \Leftrightarrow ET_0 = \frac{\Delta R_n + \rho_a c_p (\delta q) g_a}{\Delta + \gamma \;\; 1 + g_a / g_s \;\;\; \lambda_v}$$

λ_v = Latent heat of vaporization. Energy required per unit mass of water vaporized. (J/g)
L_v = Volumetric latent heat of vaporization. Energy required per water volume vaporized. (L_v = 2453 MJ m^{-3})
E = Mass water evapotranspiration rate (g s^{-1} m^{-2})
ET_o = Water volume evapotranspired (m^3 s^{-1} m^{-2})
Δ = Rate of change of saturation specific humidity with air temperature. (Pa K^{-1})
R_n = Net irradiance (W m^{-2}), the external source of energy flux
c_p = Specific heat capacity of air (J kg^{-1} K^{-1})
ρ_a = dry air density (kg m^{-3})
δe = vapor pressure deficit, or specific humidity (Pa)
g_a = Hydraulic conductivity of air, atmospheric conductance (m s^{-1})
g_s = Conductivity of stoma, surface conductance (m s^{-1})
γ = Psychrometric constant ($\gamma \approx 66$ Pa K^{-1})

Mohid Land has a sub-daily time step. According with FAO-56 Hourly Time Step ET is calculated with the equation below. This is the equation used in Mohid-Land.

$$ET_0 = \frac{408\Delta(R_n - G) + \gamma \frac{37}{T_h + 273} u_2 (e^0 \cdot T_h - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

ETo = reference evapotranspiration [mm hour-1]
Rn = net radiation at the grass surface [MJ m-2 hour-1]
G = soil heat flux density [MJ m-2 hour-1]
T_h = mean hourly air temperature at 2m hight [°C]
Δ = saturation slope vapour pressure curve at Th [kPa °C-1]
γ = psychrometric constant [kPa °C-1]
e°(Th) = saturation vapour pressure at air temperature Th [kPa]
e_a = average hourly actual vapour pressure [kPa]
u_2 = average hourly wind speed at 2m hight [m s-1].

Calculate Psychrometric constant:

$$\gamma = \frac{c_{p\ air} \cdot P}{\lambda_p \cdot MW_{ratio}}$$

$\gamma =$ psychrometric constant [kPa $°C^{-1}$],
P = atmospheric pressure [kPa],
λ_v = latent heat of water vaporization, 2.45 [MJ kg^{-1}],
c_p = specific heat of air at constant pressure, 1.013 10-3 [MJ kg^{-1} $°C^{-1}$],
MW_{ratio} = ratio molecular weight of water vapor/dry air = 0.622.

Equation of γ becomes:

$$\gamma = 0.665 \cdot 10^{-3} \cdot P$$

Calculation of the atmospheric pressure based on the heigth simplification of the ideal gas law

$$P = 101.3\left(\frac{293. - 0.0065 \cdot Elevation}{293.}\right)^{5.26}$$

G beneath a dense cover of grass does not correlate well with air temperature. Hourly G can be approximated during daylight periods as: G=0.1Rn and during nighttime periods as: G=0.5Rn

The net radiation (Rn) is the difference between the incoming net shortwave radiation (Rns) and the outgoing net long wave radiation (Rnl):

$$Rn = Rns - Rnl = \left[\ 1 - 0.23\ \ \cdot SolarRadiation\right] - \left[5.669e - 0.8 \cdot\ T_h + 273.15\ \ \cdot 4 \cdot LwradCorrection\right]$$

$$LwradCorrection = \ 0.34 - 0.14 * VP ** \ 0.5\ \ \ * \ 1.35 * ATMTransmitivity - 0.35$$

The Penman Montheith Potential Evapotranspiration computation will be active if in basin file

```
EVAPOTRANSPIRATION: 1
```

and the property evapotranspiration is not read from file.

If the user is running with vegetation than Crop Evapotranspiration is obtained from Potential Evapotranspiration using crop coefficient from Module Vegetation (dependent on crop).

$$CropEvapoTransp = PotentialEvapoTransp * CropCoefficient$$

Also if the user is running with vegetation a differentiation in Crop Evapotranspiration between Potential Transpiration and Potential Evaporation may be done using LAI:

```
EVAPOTRANSPIRATION_METHOD: 2
```

$$PotentialTrans = CropEvapoTransp * (1 - e^{-0.463 * LAI})$$
$$PotentialEvap = CropEvapoTransp - PotentialTrans$$

3.2 Description of study area

Portugal, is a country located in Southwestern Europe, on the Iberian Peninsula. It is the westernmost country of mainland Europe, and is bordered by the Atlantic Ocean to the west and south and by Spain to the north and east. Apart from continental Portugal, the Portuguese Republic holds sovereignty over the Atlantic archipelagos of Azores and Madeira, which are autonomous regions of Portugal. The country is named after its second largest city, Porto, whose Latin name was *Portus Cale*.

3.2.1 Enxoé catchment description:

General characteristics

The Enxoé river basin forms part of the basin of the Guadiana River and is located in Serpa Municipality, in Beja District. The study area, corresponding to the Enxoé catchment area of the reservoir, is 6080 ha and has an average altitude of about 200 m. The main river is Ribeira do Enxoé that has a length of around 10 km from headwaters up to the reservoir. The Enxoé reservoir has a total volume of 10.4 hm^3 a surface area around 2 km^2 and an average depth of 5 m.

Hydro-climatic conditions

The hydrological regime of the catchment is pluvial and is characterized by strong inter-annual and intra-annual variations in discharge. The Enxoé basin has dry Mediterranean characteristics, with hot summers, high insolation and high evapotranspiration. The annual average precipitation in the basin is about 500 mm, but the inter-annual distribution of precipitation is extremely irregular, with more than 80% of the annual total concentrated between October and April (usually occurring intense and concentrated precipitation events that create flood rise and fall in couple of hours). During summer, the Enxoé river frequently runs dry (flow is really low or absent). The annual average temperature is about 16°C and annual reference evapotranspiration varies between 1200 mm and 1300 mm.

Soil characteristics

In the Enxoé catchment, the dominant soils are Luvisols (FAO, WRB 2006) covering 45% of the area (13% Calcic Luvisols), Cambisols covering about 30% and Calcisols about 15%.

Land use

The dominant land uses in the Enxoé basin are olive groves (2740 ha), and agro-forestry of holm-oak (2005 ha). Winter crops, maize and pastures (1050 ha), water (205 ha) and urban area (80 ha) are also important land uses to consider.

Picture 3.1: A common landscape of the Enxoé study site.

Picture 3.2: The Enxoé River after a flood event

The main component of floods and specifically of fast floods (or flush floods) in arid or semi-arid region (without macropore or karstic flow) is runoff water or subsurface water that arrives faster to the river than groundwater flow. In Enxoé watershed flood peaks occur within 1 to 5 hours after flood start and as a direct response of rain events.

The process of runoff generation in flush floods may have origin in water that is unable to infiltrate (because of soil impermeabilization or storm water drainage in urban areas) or if infiltration in soil occurs, the predominance of infiltration excess, subsurface stormflow or saturation excess will depend on rain intensity, soil properties (e.g. conductivity, water content etc) and slope.

One aspect that may influence flood formation is soil sealing as reduces infiltration and promotes runoff formation. Soil surface sealing may result from:

- Compaction (e.g. livestock, urban impermeabilization);
- Fire
- Biological activity
- Rain

Rain may also have a compact effect, destroy soil aggregates and the released material may fill soil pores – locally generated or transported by runoff. In Enxoé, silty soils occur and approximately 60% of the total area (occupied by olive trees and annual crops) has tillage and/or wheeling and in montado area (30% of the total area) extensive cattle production exists. The observation in Enxoé of river flood events even after dry season as a direct response to first rain events, suggest that soil sealing and/or compaction/impermeabilization may be an important process on first flood formation.

Monitoring data is usually scarce, especially in cases where floods rise within minutes to hours and collection frequency need to be high (need for automatic schemes that are costly). As so, in order to fill data gaps and to be able to predict their occurrence, models have been developed especially suited for floods.

The first feature needed to simulate a flood is that the model has to have a time step that can represent the flood rise and fall; in flush floods that may represent hourly or sub-hourly time steps (Boughton and Droop, 2003). The second feature, since in flush floods most of the water in the river arrives from surface water or storm drainage systems (in urban areas) than the model should be able to simulate impermeabilization, runoff generation and routing and storm drainage systems (Hsu et al. 2000).

Enxoé was an ungauged watershed in the river, thus, to define the state of the river and validate the model, data collection was performed during 2010-2011 in the two main tributaries to the Enxoé reservoir (Enxoé river and the river that passes through the only village, entering Enxoé before the beginning of the reservoir). Flood data was obtained with an automatic sampler and a coupled multiparametric YSI 6000 probe (measuring level, turbidity, temperature, conductivity and oxygen). Automatic sampling was performed when measured level raised or lowered more than 10 cm. the river manual data in low water conditions was collected in a weekly basis during winter and spring and when available water existed during summer (temporary river). In terms of flow validation, monthly data from Enxoé reservoir discharges and consumption, precipitation and evaporation were used to estimate reservoir inflow (2006-2009). Level measures obtained during floods by probe in 2010-2011 were also used to validate MOHID Land ability to describe the processes.

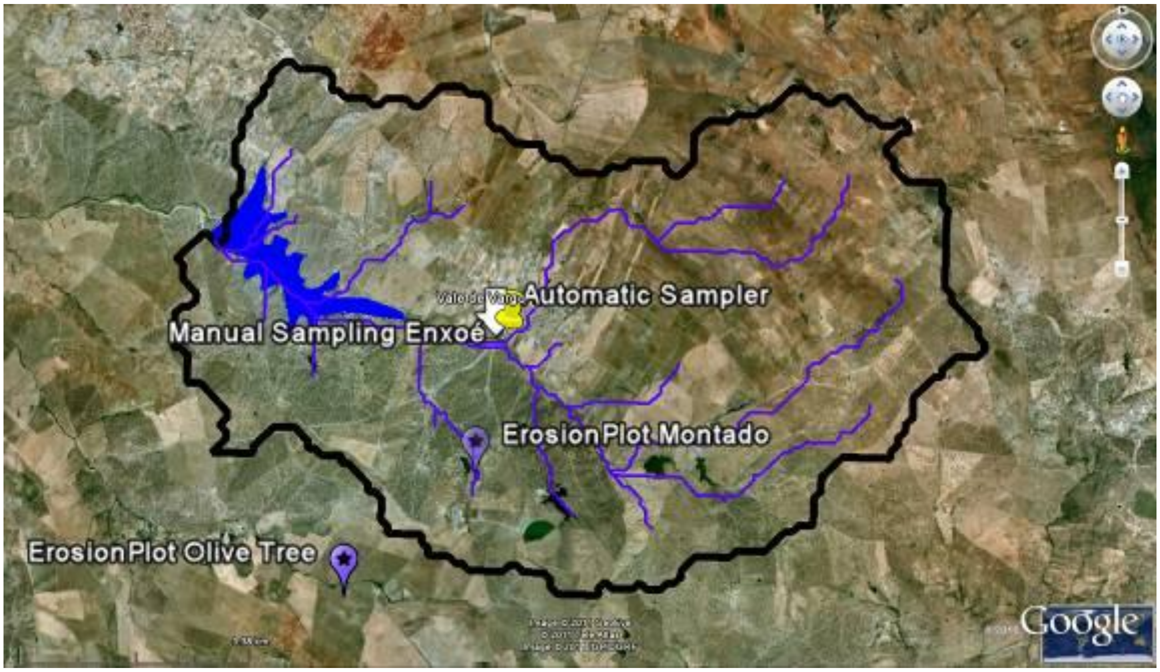


Fig. 3.7 Enxoé watershed

3.3. MOHID Land implementation

For MOHID Land implementation, the data was introduced in model interface MOHID Studio that integrates preprocessing tools, project management, model simulations and result visualization. MOHID Land uses ASCII file format for input data as configuration files (with processes connected/disconnected) and time series or grid data and HDF format for time and space variant data/results.

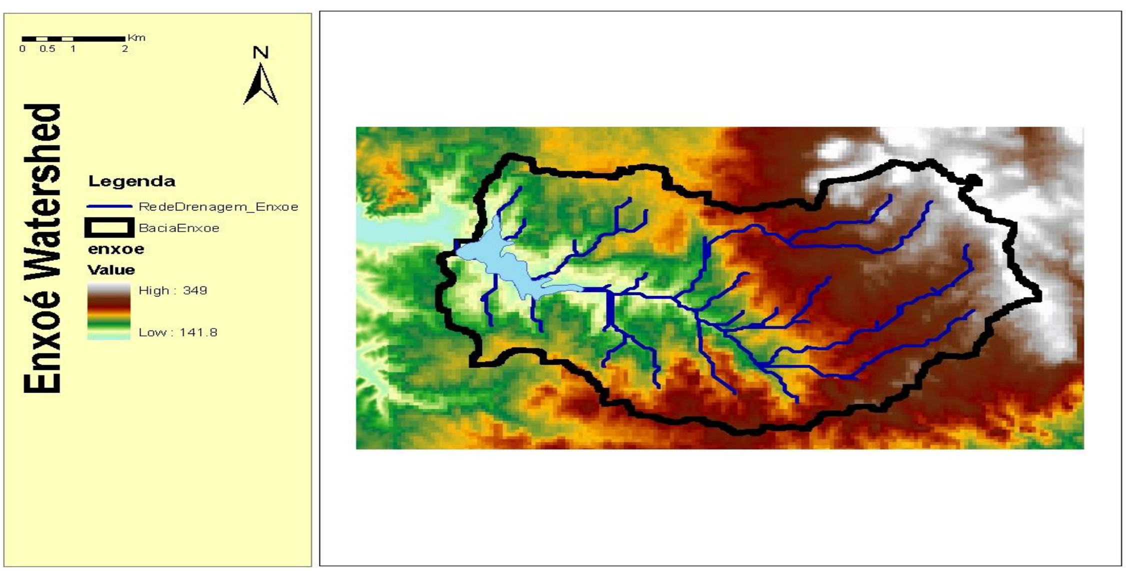


Fig. 3.8 DTM. Source: NASA

The main land uses in Enxoé it is presented in fig. 3.11 and consist in olive trees, oak-pasture mixed system and annual crops (each with around 30% of total area) and only 1% is urban.

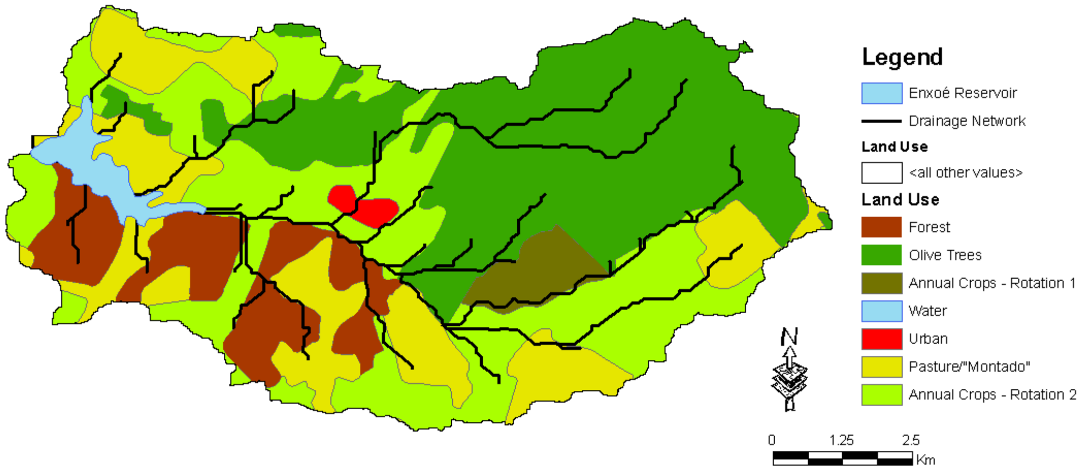


Fig.3.9 Land use in Enxoé. Source: Corine 2000

The river sections were spatially interpolated with an automatic tool and verified against field observations. Since water level was one of the results to compare to data, the section geometry definition was of great importance. The water level sampling location is in a permanent pool (so that probe sensors were always inside water) and at the station topography has a depression that is not shown by Digital Terrain Model resolution (100m) – Figure 3.10.

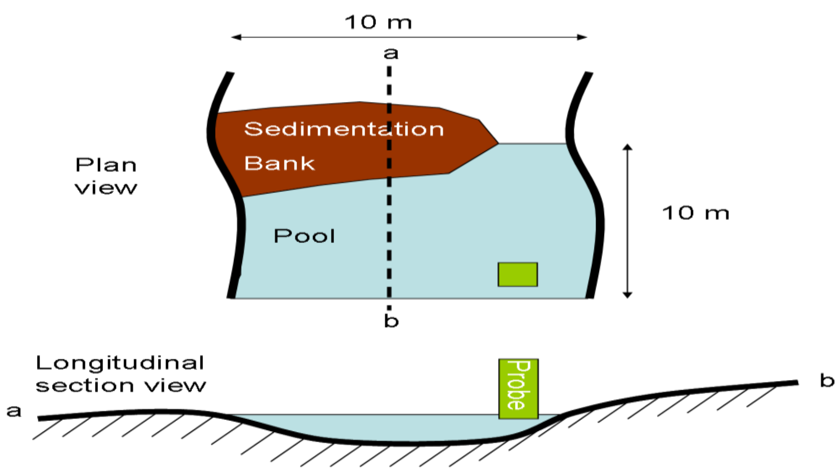


Figure 3.10: Level sampling river section

Calibrating parameters for floods

Model calibration is an essential process needed to assure that the simulation outputs are close to real observations.

From the recorded floods with automatic sampler in Enxoé (four floods, two in October 2010, one in February 2011 and one in March 2011), in general, the first peak rises observed in level field data seemed to be missing in first MOHID simulations because the precipitation water was infiltrating and was not getting to the river.

For model validation monthly data from Enxoé reservoir discharges and consumption, precipitation and evaporation were used.

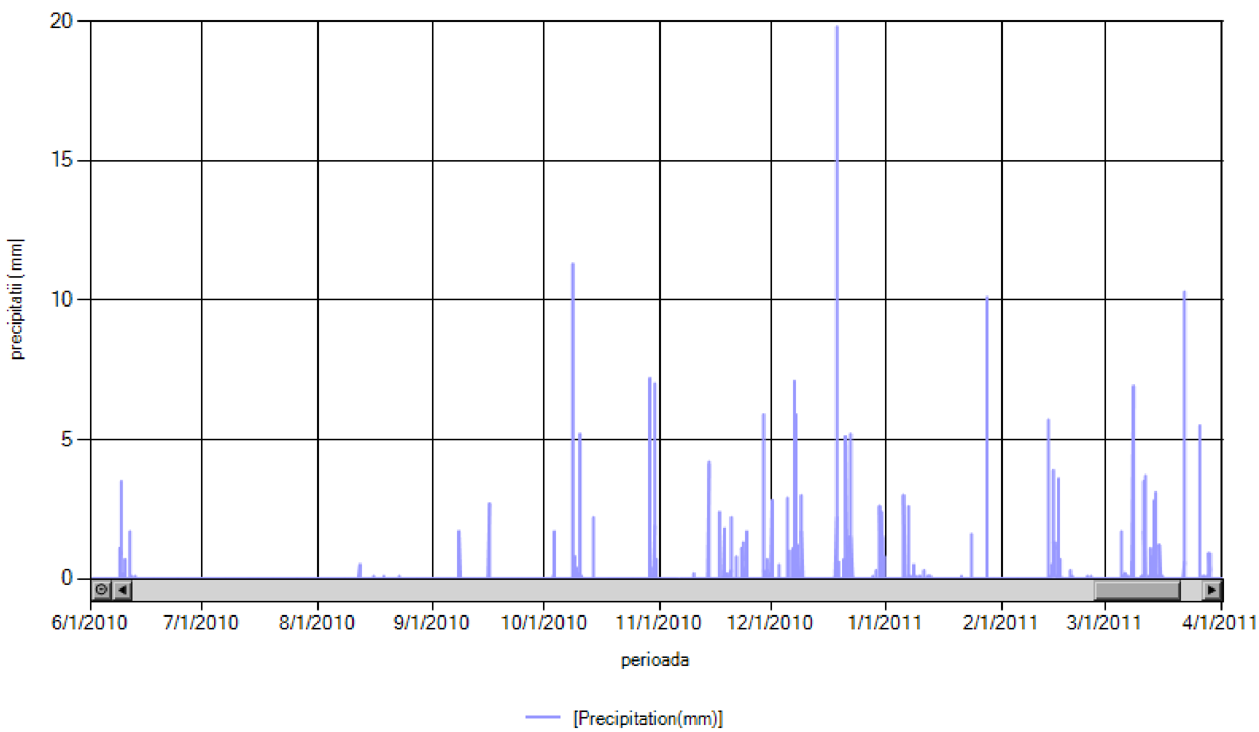


Fig. 3.13 Monthly precipitation. Source: SNIRH, National Water Institute

Regarding the simulations performed with the model MOHID Land, my work for this paper was carried out in several stages.

The first step was to understand how the program works, making some tests with different modules inactive.

The second step was to start running simulations similar to those in the project Eutrophos. The simulation period was 1.06.2010 - 31.03.2011 and the cell size was 200m.

In the last stage, to play a finer resolution of the flooded area, I realized with MOHID Land Studio a flood modeling from 28 to 31 December 2009. In this simulation the cell size is 40 m, the Porous Media module it is inactive and the step time is half an hour.

4th Chapter. Results and Conclusions

4.1 Simulation of the period 1.06.2010 – 31.03.2011

After running the program MOHID Land with initial data inputted it has resulted the following graph of the simulated water level in the river Enxoé. As it can be seen, at the top of the chart was represented precipitation in mm for the period fixed for the simulation (1.06.2010-31.03.2011). At the bottom of the graph the program simulated water levels in the river Enxoé, over which I overlapped four peaks of flood levels measured in the field.

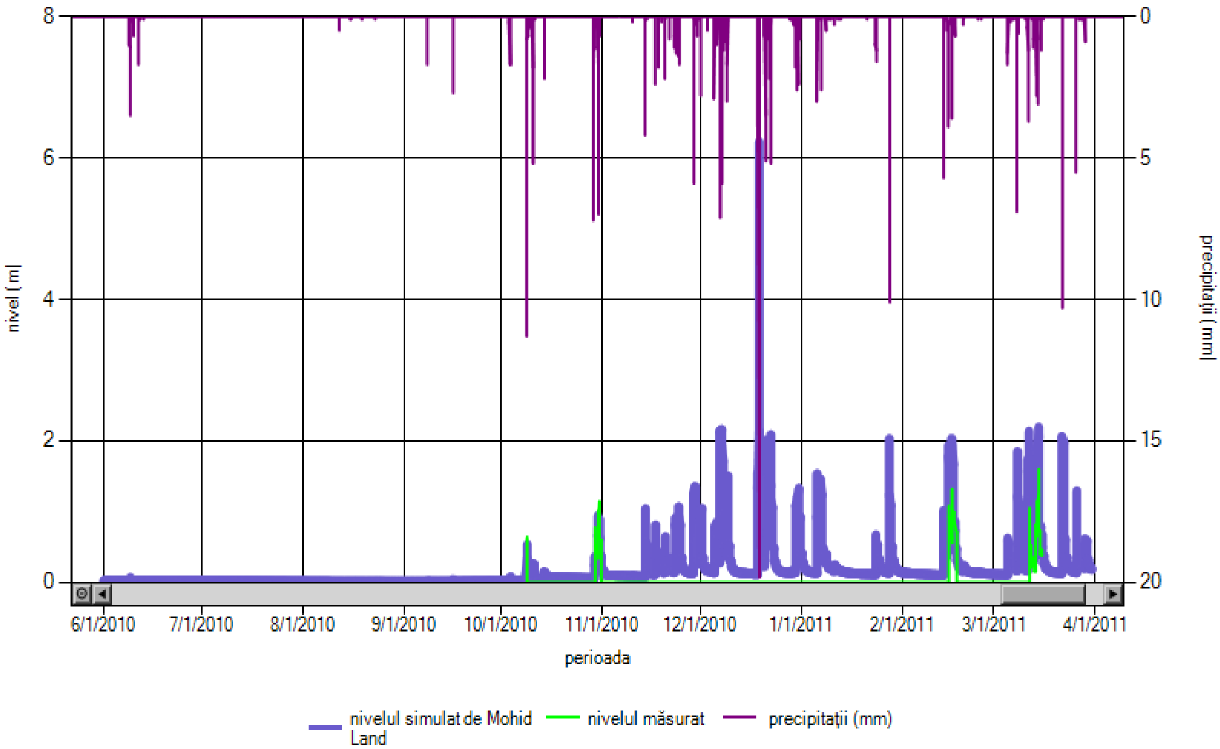


Fig. 4.1 Graph of the simulated levels by MOHID Land

The program also simulates the water content in the soil.

Since 08.10.2010, when the first peak of the flood occurs it can be seen the increasing water content in the soil (Fig. 4.2.). The next day the soil is already saturated (Figure 4.3.).

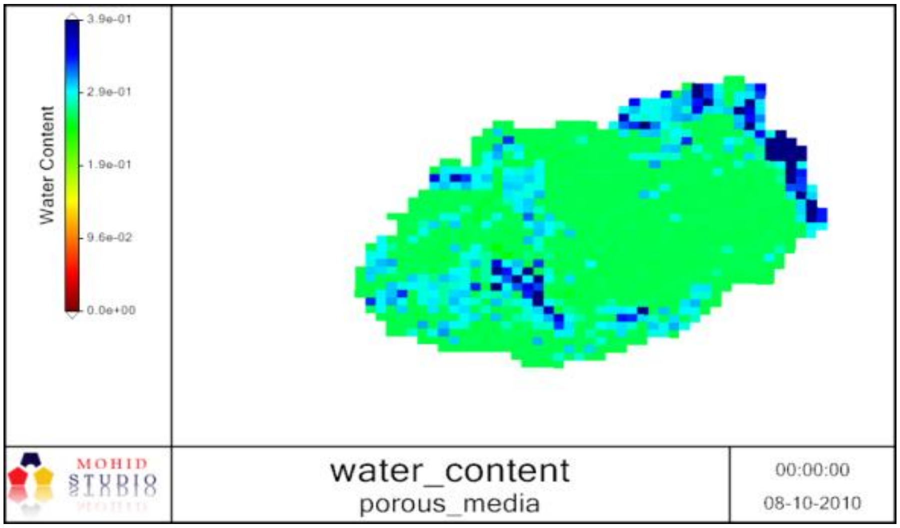


Figure 4.2 Water content in soil - 8.10.2010

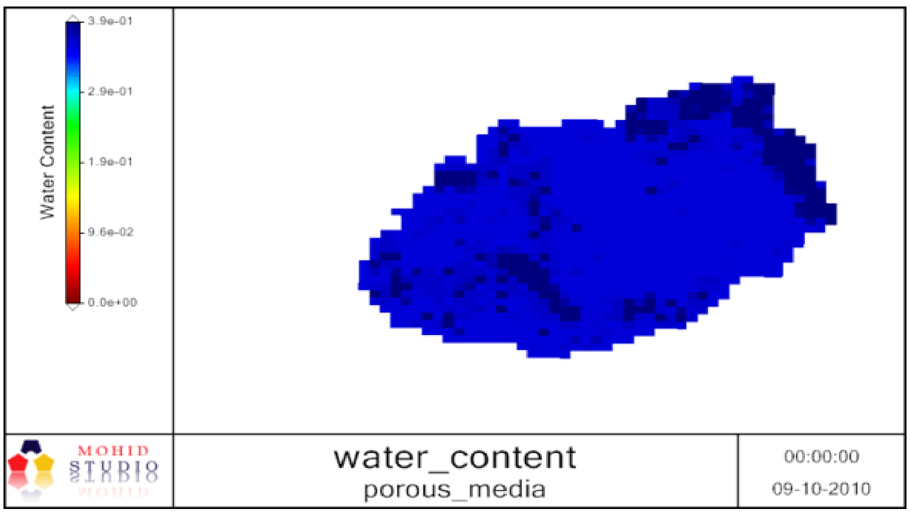


Figure 4.3 Water content in soil - 9.10.2010

In order to make a comparison of simulated and measured levels, hereinafter is presented a detail of the simulation graph in the four peaks of the measured level in field.

- Detail of the first peak 8.10 – 9.10.2010

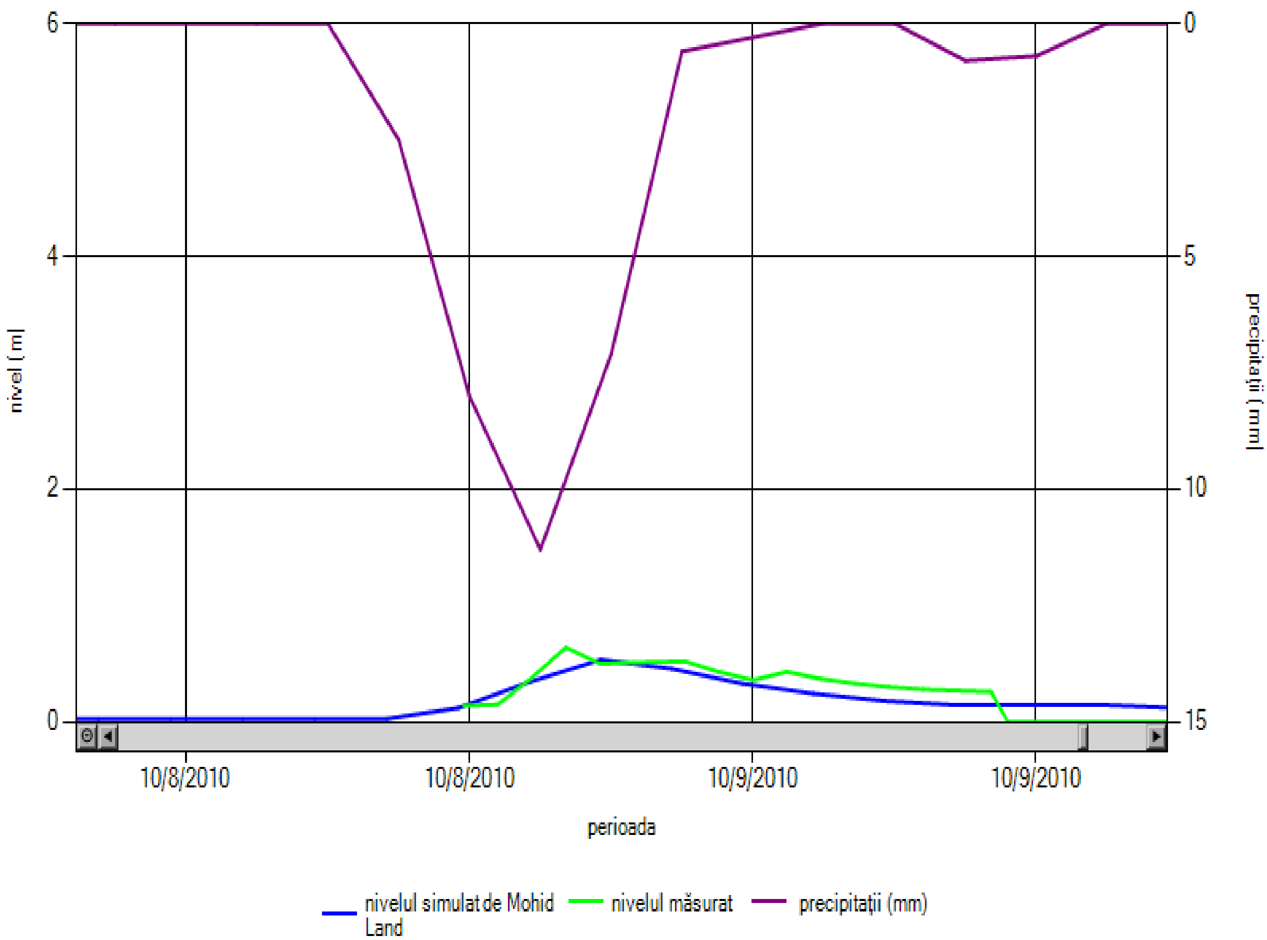


Fig. 4.4 detail of the first peak observed

From this graph it can be seen that the allure of the level simulated by MOHID Land it overlaps over the measured levels in field.

- Detail of the second peak

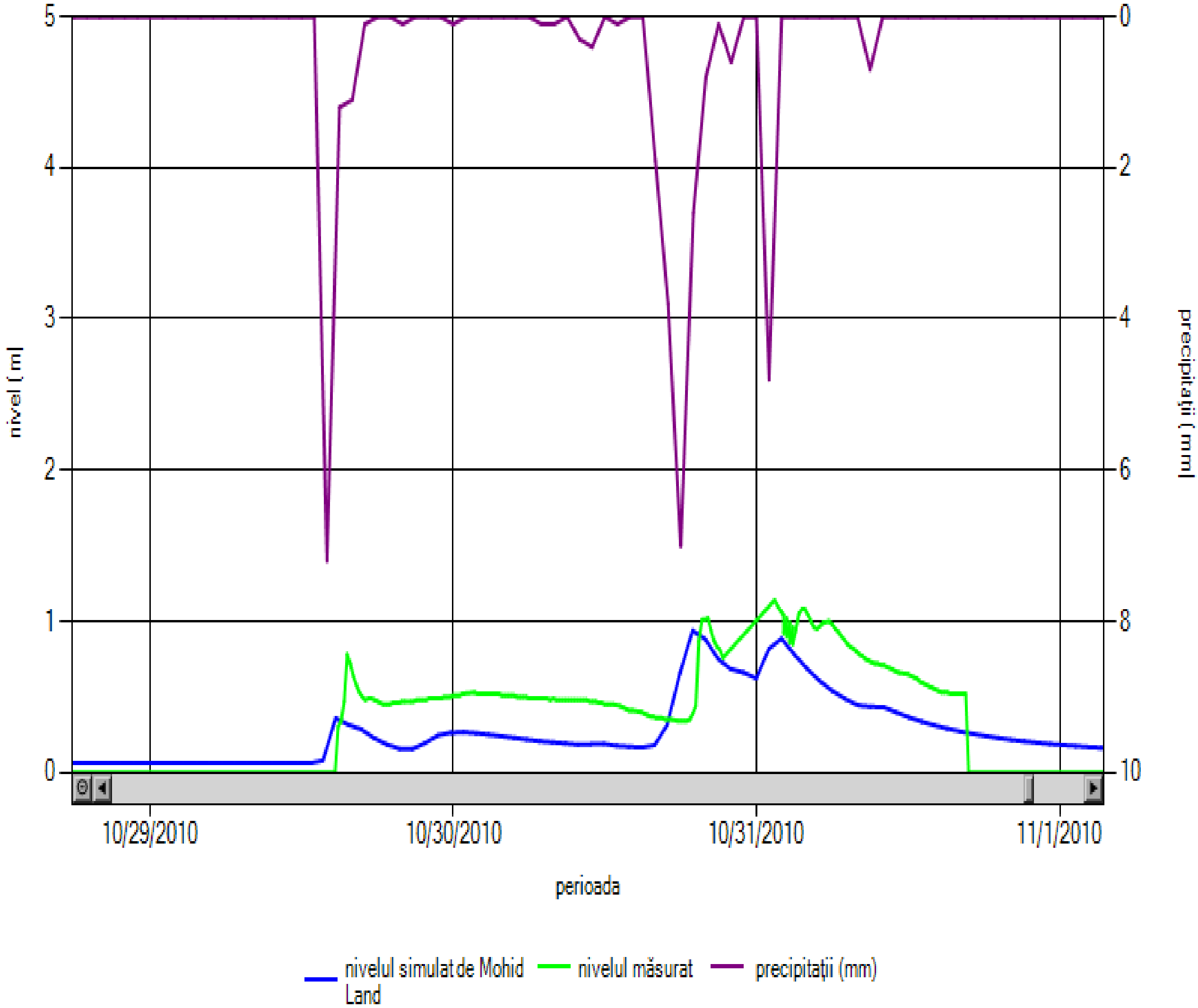


Fig. 4.5 detail of the second peak

From Figure 4.5 it can be seen that the allure of the simulated level in MOHID Land is similar to the allure of the measured level. The same thing can be seen in Figures 4.6 and 4.7.

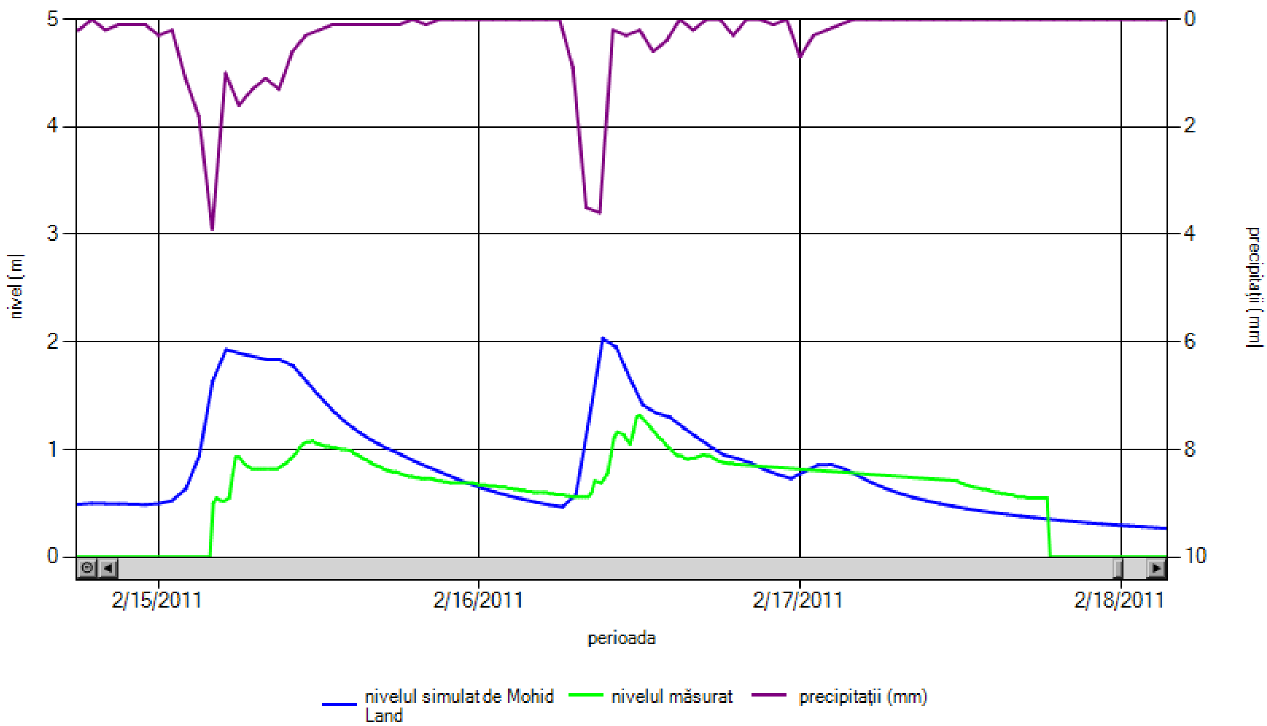


Fig. 4.6 detail of the third peak

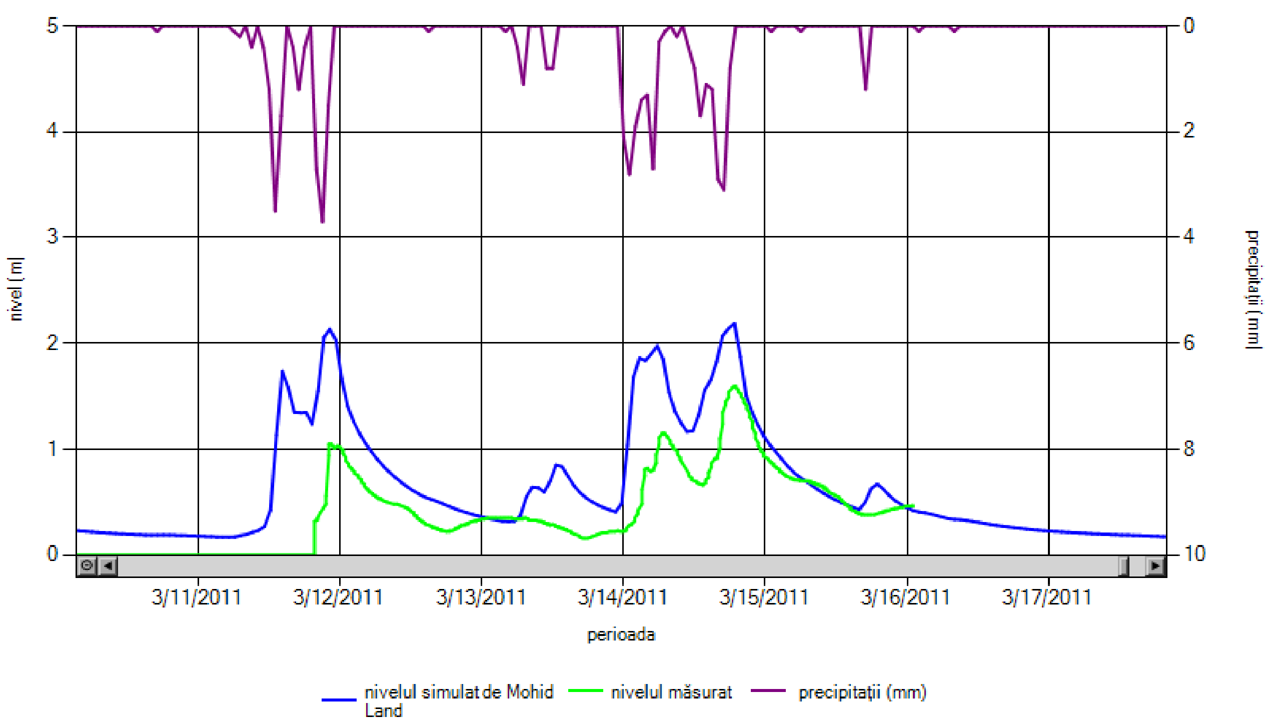


Fig. 4.7 detail of the fourth peak

As the results provided by MOHID Land are close to the measurements, further we made a simulation of the flood from December 2009. For this flood there were no data measured in field.

4.2. Flood from 28 – 31 December 2009 (cell grid dimension: 40m)

To study the dynamics of floods in turbulent regimes, such as the one in Enxoé watershed, where flood can grow in an hour, it is needed a model with time steps of seconds, minutes in order to accurately predict processes and loads.

The flood in December 2009 had a return time of the order of decades or even a century. In the beginning of December there was reduced flow and in the end the month it flooded the plains and the small town Vale de Vargo.

Below is presented the graph of the simulated flood of 28 to 31 December 2009 for a cell with size of 40 m.

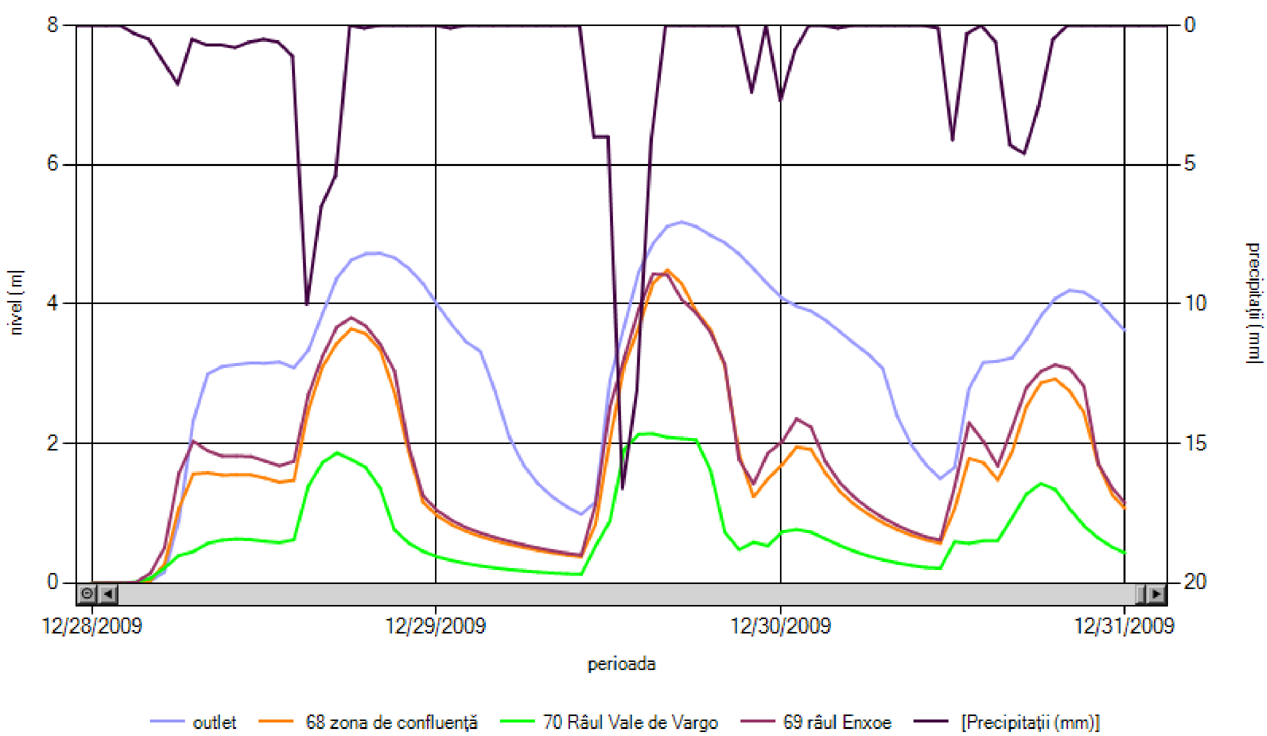


Fig. 4.8 Simulated levels

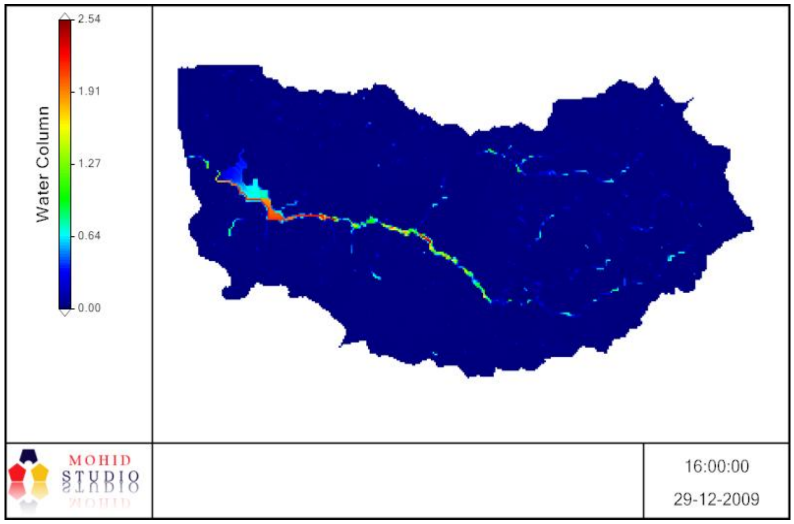


Fig. 4.9 Water column

As it can be seen, at the top of the chart was represented precipitation in mm during the flood (28.12.2009-31.12.2009). At the bottom of the graph the program has simulated the water level by four lines representing: the water level in tributary river, Vale de Vargo, at the confluence of the tributary river with Enxoé, in Enxoé river and at the outlet.

In fig 4.9 it is presented the water column in Enxoé watershed of the same period.

4.3 Conclusions

Simulation of water dynamics with MOHID Land showed that the program can reproduce the movement of water in soil in a 1D acceptable simulation but it is necessary that the input data such as precipitation, temperature and soil characteristics (hydraulic parameters) to be representative for the study area. This is a necessity for the implementation of each hydrological model.

Following the results obtained from the simulations it can be concluded that MOHID Land is a program suitable for short description (floods) and long term (monthly and annual) of water dynamics.

The model can serve as a base for building a flood forecast model and for a pre-warning system for floods.

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