Flood forecasting system based on the distributed hydrological model MIKE SHE-MIKE11

Peter Torp Larsen[3], Christian Stocker[1], Ángel Eraso Alberdi1, Torsten Jacobsen[2],
[1]Uraren Euskal Agentzia / Agencia Vasca del Agua (URA), *España*
[2]*DHI Denmark, Denmark*
[3]*DHI España, Spain*

(Presenter: Peter Torp Larsen, ptl@dhigroup.com)

Keywords: real time flood forecast system, Distributed hydrology MIKE SHE-MIKE11.

A pilot flood forecasting and alert system has been implemented for the Urumea catchment. The system consists of an area of 350 km^2, 25 km river (the Urumea and Añarbe rivers), the Añarbe Reservoir with flood lamination capacities.
The real-time operational system is based on MIKE FLOOD WATCH, the hydrological processes are modeled by the distributed model MIKE SHE (2D overland flow, 2D gravity flow in the UZ, and 3D in the SZ), the hydraulic part of the model includes rivers, channels, structures etc and is simulated in MIKE11.
Due to the complicated hydro-metrological and physical conditions in the area, the Flood forecasting system requires both fast and reliable simulations for and therefore a careful balance between accurate representations of the catchment flood processes the flood wave movement and inundation extent and the need for rapid forecasts. The present paper describes the formulation, calibration, validation and real-time implementation of the operational distributed model. The application shows that the MIKE SHE /MIKE11 distributed hydrological model is able to reproduce the rainfall-runoff processes and the propagation of the flood wave through the main river system during six real medium size flood events.
Lumped rainfall-runoff models (e.g. NAM) used with MIKE11 hydrodynamic modeling has been widely used for years. The current approach adopts a physically based, distributed approach partly to simulate runoff considering catchment distributed features and partly to apply distributed rainfall forecasts. The benefits and drawbacks of using lumped rainfall-runoff models, linear reservoir modeling with MIKE SHE or fully distributed models with varying degree of complexity is discussed.

Introduction

This paper describes a pilot study carried out for the Urumea catchment in Basque country. The object was to establish and test a methodology for a global DSS system for the entire Basque country.

The reason for choosing distributed model was based partly on the short comings of lumped models when modeling ungauged watersheds. Calibrated values of lumped models are normally spatial averaged and do not have a direct link to physical processes or parameters, their application are limited to gauged watershed with homogeneous conditions. Thus for certain types of water resources applications, the lumped approach preclude a satisfactory application (REF /1/). As summarized by

Refsgaard in Ref /2/; physically distributed hydrological models use parameters related directly to the physical characteristics of the catchment e.g. soil types, vegetation, and geology) and spatial variability in both physical parameters and metrological conditions.

MIKE SHE is a comprehensive deterministic, distributed, and physically based modeling system capable of simulating all major processes in the land phase of the hydrological cycle, including precipitation interception, infiltration, evapotranspiration, subsurface flow in unsaturated and saturated zones, surface flow, and flow in channel and rivers (REF/2/).

The main part in MIKE SHE is the water movement module, the zero-inertia approximations to the Saint-Venant equations are solved numerically in two dimensions for overland flow and in one dimension for channel flow (MIKE11). The one-dimensional Richards equation (or the simplified gravity equation) is solved numerically for pressure head variation in the unsaturated zone, which in turn is converted to soil moisture content from the soil moisture retention curve. The horizontal movement of water in the unsaturated zone is considered negligible. The model has provisions to allow a percentage of net rainfall to pass through macropores (mainly cracks and root zones). Saturated-zone computations are performed using the three-dimensional Boussinesq equation for ground-water flow.

Due to the location of the study area, on the north coast of the Spanish peninsular, the area is strongly influenced by the weather patterns predominant in the area. This means often short and intense storms, which can cause flash flood type of events (REF /3/). Analyzing historical records of the Ereñozu (REF /4/) gauging station, located at the downstream part of the Urumea river, it can be observed that the river flow can change with a factor 10-30 in 30 min. (e.g. Dec 2002).

The objective set out in this pilot study is therefore, to apply the MIKESHE model to predict discharges and levels in the flash flood prone Urumea River using 10min intervals.

In summery the study included the following components:

- Definition and test of the modeling concept – lumped vs. Distributed.
- Establishment and calibration of a distributed physically based, hydrological model combined with a dynamic hydraulic river model (MIKESHE-MIKE11)
- Incorporate the hydrological/hydraulic model in a simplified operative Decision Support System.
- A simple webpage with publication of flow forecasts in two points.
- Description of a real event that occurred during the project period.

Modeling concept:
With the objective of forecasting peak flows and peak water levels a river hydraulics model and a hydrological model is required. A hydrodynamic model with the ability to include river-flood plain interaction and hydraulic structures is preferred.

In addition the need to use the model in flood forecasting applications makes MIKE11 a suitable choice. The choice of hydrological component is, however, less obvious. Specific requirements are:

1. With the aim of applying radar based gridded rainfall data in forecasting a distributed approach is preferred
2. A physically based approach will allow a consistent parameterization across sub-catchments considering surface and sub-surface physical properties
3. The hydrological model must not require excessive data or time spent on model development and calibration

Traditionally a rainfall-runoff approach, by e.g. NAM, has been chosen in MIKE11 flood modeling projects.

Rainfall data provided by meteorological services for the Urumea project and in general are becoming available as gridded data rather than station based data. These rainfall products are better suited for representing scattered, convective rainfall without assuming homogeneous sub-catchment response.

MIKE11 is dynamically coupled with the distributed hydrological model, MIKE SHE, where appropriate choice of grid resolution will reflect partly the gridded rainfall distribution and the scale of sub-catchment runoff processes.

MIKE SHE is claimed to be a physically based model with a clear physical interpretation of the parameters as opposed to lumped models. It is expected that physically based parameters are better constrained and easier transferred to neighboring sub-catchments (e.g. ungauged) than lumped parameter. The approach also favors the use of spatially distributed GIS data available in the region. The role of groundwater is restricted to alluvial deposits along the valley floors and it does not play a major role on peak river flows but it cannot be ignored in a continuous model with a significant interflow component and both gaining and loosing reaches are found along the rivers.

Whereas MIKE SHE offers advantages in the flood forecasting model with respect to both spatial distribution and physically based parameters it may potentially be less efficient than a rainfall-runoff model due to heavier data requirements and more model parameters leading to more time spent on model setup, calibration and simulation run times without significant improvements with respect to simulated peak flows.

Consequently, it is necessary to consider a mixed approach maintaining the distributed features but potentially lumping model components. The surface components representing overland flow and interflow generation should be distributed in order to properly reflect than rainfall distribution but sub-surface components representing groundwater flow may be lumped.

The groundwater flow is generally of lesser importance and building a full 3-D hydrogeological model is not feasible for a flood project which suggests applying the lumped linear reservoir approach. The linear reservoir module of MIKE SHE is similar (but not identical to) the NAM model and significantly reduce the efforts in model setup and groundwater calibration. A drawback of the linear reservoir method in a mountainous catchment with thin soil layers on the slopes and thicker sediments in the valley is that time constants controlling interflow rates must be distributed by introducing several zones and the method becomes increasingly time consuming with many parameters and poor physical basis.

In addition there is no feedback from groundwater to the surface overland component as the soil becomes saturated during longer term rainfall events since linear reservoir water levels do not represent groundwater tables.

Keeping the full distribution while avoiding detailed groundwater modeling and the availability of soil thickness maps of the area lead to a simplified MIKE SHE approach with one geological layer (2-D) with variable thickness according to the soil maps.

The layer thickness is up to 15 m in the valley and approaching zero when moving up the mountain sides. The drainage component of MIKE SHE is based on a linear reservoir approach and as the thin soil layers in short time gets saturated it produces drainage (or interflow) as a rapid discharge to MIKE11. A better description of sub-surface storage capacity is obtained and the interflow response is distributed as the rainfall input. The key parameters to calibrate are drainage time constants and the hydraulic conductivity of the groundwater aquifer of the valley floor. Since very limited groundwater level data are available peak river discharges are the main focus of calibration.

During the early stages of the Urumea project a distributed surface model in combination with either a lumped linear reservoirs sub-surface model or the 2-D groundwater model approach were tested to determine if they could be calibrated with a minimum of distribution and to see if there were significant differences in run time or model stability. It was found for a catchment similar to Urumea that the 2-D groundwater approach took approximately 50 % longer time to run and it produced equally good results in terms of simulated river peak discharge.
The time spent on model setup was comparable for the two cases and not considered critical in any way in a project context. The time spent on MIKE11 development was significantly higher than the time spent on the hydrological component due to data availability and project focus.

The MIKE11- MIKE SHE approach using a 2-D Boussinesq groundwater flow solver performed well for the Urumea case but it is not without challenges. Geometrical consistency between the DEM used as input for the catchment topography in MIKE SHE and the river cross section data in MIKE11 is a requirement in order to avoid accumulation of overland water and excessive exchange between the aquifer and the river.

Such challenges are common for MIKE11- MIKE SHE users but the combination of relatively steep slopes and locally thin aquifer thicknesses emphasizes the adverse effects of discontinuities in the model simulation. Careful control of levels is necessary and often time consuming.

The MIKE SHE overland component is another challenge as it is the most numerically sensitive component requiring small computational time steps and longer run times.

A modeling concept similar to the one chosen for the Urumea projects is in the authors' views likely to be more widely used in flood modeling due to the increasing availability of distributed rainfall data sets and robust, efficient and distributed hydrological engines are needed. The example given is one possible approach where the pros and cons have been considered and tested. If distributed soil thickness data is not available the approach will likely have to be modified.

Application of the model concept.

Description of the study area; The Urumea Catchment:
The Urumea catchment has an area of 350km2 and is located partly in the Basque country and partly in Navarra in Northern of Spain. The catchment elevation varies from 1100m to 0 m (the sea). The main rivers are the Urumea and Añarbe. The catchment can be divided into 5 sub catchments (fig 1).

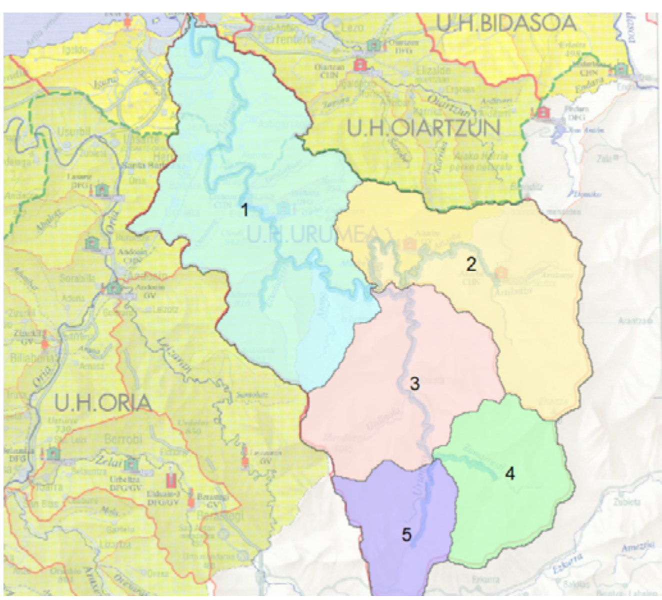

Figure 1: The Urumea catchment and sub-basins

Sub-basin no. 3, 4 and 5 (the upper zone) are all characterized by relative high elevations 100-1000m, steep slopes and unregulated flows. The Añarbe sub-basin (no. 2) has the same characteristics as no. 3, 4 & 5, but includes regulation of the stream flow by the Añarbe reservoir and the Artikutza reservoir.

The Añarbe sub-basin (no. 2) covers approximately 65 km2, and is partly gauged by the Añarbe measuring station, located at the tail of the reservoir. The station covers the 48 km2 of the sub-basin.

The Urumea sub-basin includes the sub-basins no. 1, 3, 4 & 5 and covers approximately 260 km2. The sub-basins are gauged by the Ereñozu measuring station, located 10 km downstream of the confluence.

The lower sub-basins (no. 1), extending from the confluence between Urumea and Añarbe to the mouth of the river, is characterized by lower elevations and lesser topographical slopes. The stream flow in the Urumea is influenced by the operation of the Añarbe dam.

The availability of the two gauging stations makes model calibration against observed discharges possible.

The total Urumea catchment has an extension of around 325 km2.

The annual rainfall varies between 1800 mm/year at sea level, to 2600 mm/year at 350m above sea level (Ref /4/), a quite high variation considering the limited extension. This underlines the relevance's of using distributed rainfall.

The geology is relative homogeneous with impermeable granite and deposits in most of the catchment.

Model setup and parameterization:
In the present application the following model descriptions are applied:

- Overland flow: 2D diffusive wave approximation of the saint venant equations for overland flow
- Saint Venant 1D flow and Muskingum routing for river and channel flow
- 1D gravity equation for vertical flow in the unsaturated zone
- Linear reservoir model for interflow and drains,
- Darcy equation for the river aquifer interaction,
- Kristensen-Jensen model for Evaporation.

Topography
The topographic information (1x1m and 10x10m) was obtained from Dip. Foral de Gipuzkoa and IGME. The topography is used to define de drainage surface of overland flow, and the uppermost surface of the unsaturated and saturated zone. The model was discretised in a 100x100m horizontal grid.

Unsaturated soil properties
The soil depth maps was available for the part of the catchment located in the Basque Country (BC), the part in Navarra was estimated based on the BC data, elevation curves and terrain slope data, see figure 2.

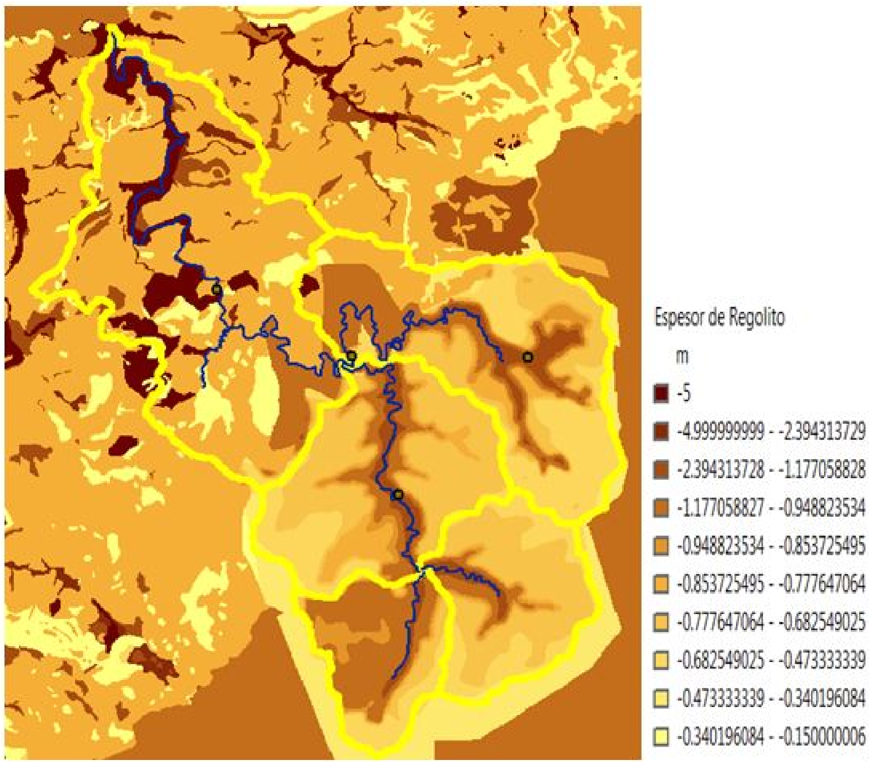

Figure 2: Soil depth given in meters under the surface.

The soil layer varies from 10m in the lower part to 0-15cm in the upper part of the catchment.

Soil types are assigned via a polygon shape file containing 8 predominant soil types (ref /3/). For each of these soils Van Genucthen retention and conductivity curve parameters are specified (ϴ, ϴ, m, n, ɑ, l). MIKE SHE needs these parameters to estimate the water content of unsaturated soil during the simulation. The parameters of these equations are included in the calibration.

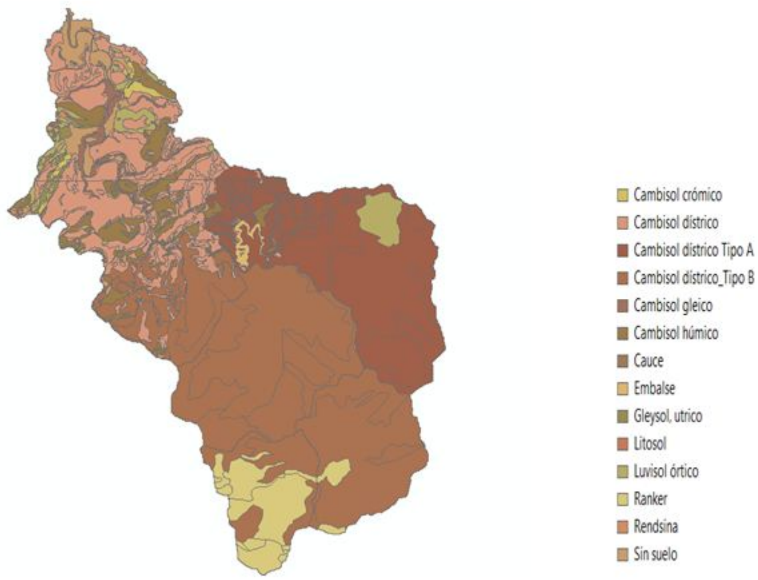

Figure 3: Soil types for the

The land use consist of primarily of agriculture (25%), forest (65%) and urban (10%). Due to the unavailability of measured data for the study site, the leaf area index (LAI) and the root density (RD), values present in the MIKE SHE database where used.

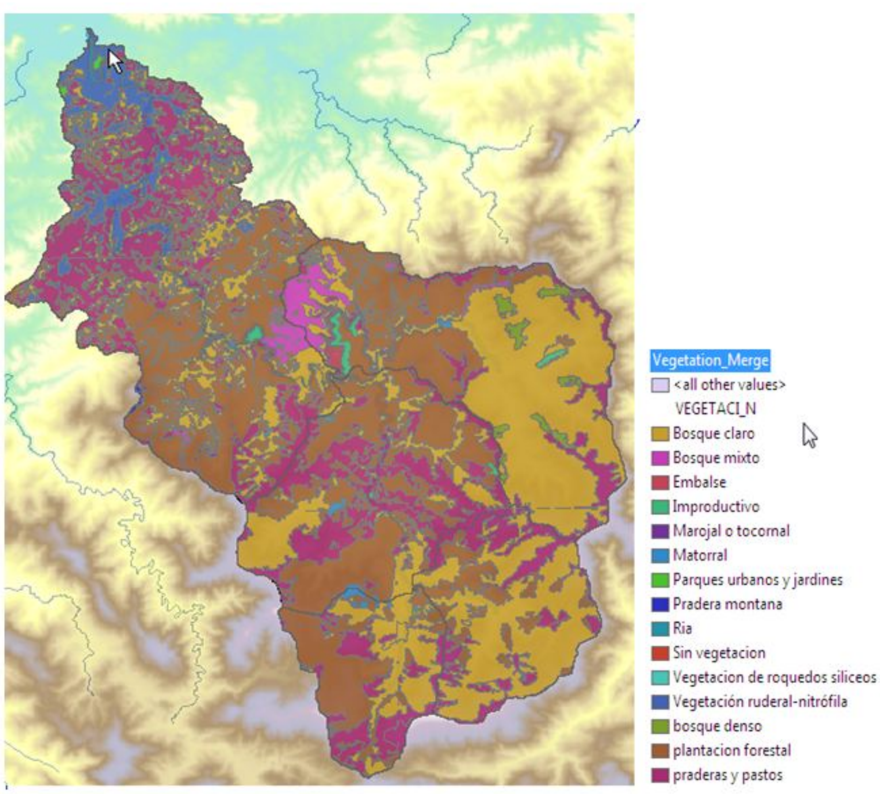

Figure 4: Vegetation coverage.

Drainage depth (DD) and drainage time (DT)
The flow of drainage water is simulated using an empirical formula, which requires a drainage depth and a drainage time constant (i.e., leakage factor) for each cell. The drainage depth and the time constant are used to route the water out of the element. A typical drainage depth is 0.5m - 1 m below the ground surface and a typical feasible value for the time constant is in the range of 10–120 days (DHI, 2003). The effect of the drainage depth depends on the average position of the phreatic surface. Drainage starts when the water table raises above the elevation of the drainage depths and is proportional to the difference in level between the water table and the drainage depths.

The time constant determines the velocity of the drainage and mostly influences the peaks of the hydrograph. The smaller the reciprocal of time, the smaller are the peaks of the hydrograph. The drainage depth can influence the recession of the hydrograph (Ref/6/). A higher value indicates that the flow underestimates the peaks; however, the base flow increases. In the beginning, the drainage depth is set to 0.75 m and the time constant is set to 1e-6 s-1

Saturated zone properties
The fluxes through the soil surface are functions of the vertical hydraulic conductivity of the aquifer. Larger KV values produce higher cumulative infiltration through the soil surface (less runoff or overland flow) with a subsequent increase in ground-water level. Thus, higher KV values produce lower and flatter peaks of stream flow. Lower KV values increase overland flow while reducing the contribution into the aquifer (ref /6/). The vertical hydraulic conductivity is set to 1e-05 m s_1.

The horizontal saturated hydraulic conductivity in the saturated zone influences significantly the base flow as well as the peak flows. Lower values delay the flow reaching the stream. Higher values result in draining the water faster and affect the base flow in the long term if there is no rain for an extended period of time. The horizontal hydraulic conductivity is set to 0.005 m s_1.

Overland flow
The bed resistance is defined by a Manning's number, M (m1/3 s_1). The higher the M value, the faster the water is routed overland toward the nearest river reach; thus peak runoff flows are particularly affected.

As the M values are reduced, the rainwater takes more time to reach the stream, thus more water percolates into the ground. In this case the peak flows are reduced and the base flows are increased. The channel Manning's number is assumed to be constant for all channels and along all river reaches. At the beginning of a simulation, M is set to 15.

River network (MIKE11)
Options for river and stream routing, river hydrodynamics, river-floodplain interaction and structure operation are available in the MIKE11 model. MIKE11 is dynamically coupled to MIKE SHE and runoff computed in the hydrological component is transferred as lateral inflows to the river model in each time step of

the simulation. A river network is digitized branch by branch and connected into a MIKE11 model covering the entire basin. MIKE11 offers a range of solver options.

The optional methods defined for each MIKE11 branch include hydrologic routing by Muskingum, by Muskingum-Cunge or by 'No transformation'-routing. The latter option was used for the upland sub-basins. If on the other hand a hydrodynamic method is preferred, the Saint-Venant equations are solved for kinematic, diffusive or fully dynamic wave approximations. The fully dynamic wave approximation correspond to solving the full 1-D Saint-Venant equation. The MIKE11 network can comprise a combination of different type of solver methods.

The Urumea River, the Añarbe River and 3 of the main tributaries are included in the river model.

The fully hydrodynamic model is applied for the main river branches, Urumea and for the Añarbe Reservoir (Figure 5).

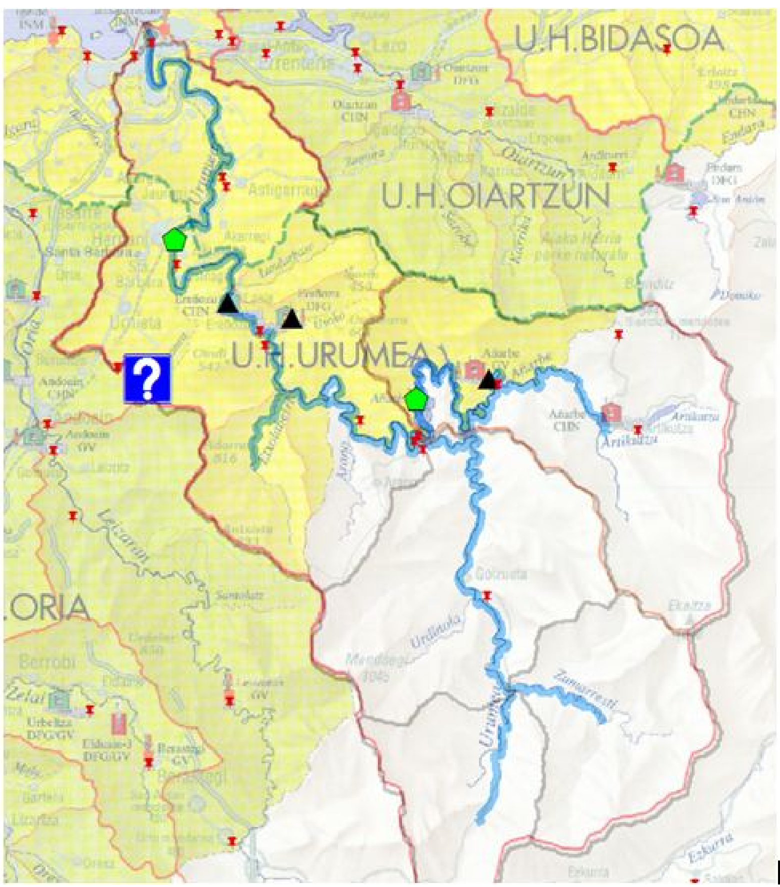

Figure 5: The river system (blue) of the Urumea catchment

The Añarbe reservoir and the downstream branch of the Urumea, are simulated applying a fully dynamic wave approximation.

The Añarbe reservoir was schematized by a single branch combined with cross sections extracted from the bathymetry supplied by Aguas de Añarbe. These cross-sections are expanded into the lakeside applying a 5 meter resolution DEM.

The Añarbe reservoir is connected to the Urumea River via an operational structure simulating the operation of the Añarbe Dam and related releases. The Urumea River downstream of the confluence with the Añarbe Dam is digitized based on available LIDAR data and image files.

The floodplains are schematized in MIKE 11 to allow a quasi 2D simulation of the over-bank spilling and flood-plain flow. The schematization is based on the 1 meter resolution DEM and available images. The schematization must be able to emulate the conveyance dependent flood-routing as well as the storage capacity of the individual flood cells.

The MIKE 11 model is calibrated together with the MIKE SHE hydrological model using available water level and discharge data (Añarbe and Ereñozu).

Structure Operation
The MIKE 11 Structure Operation (SO) module is set up to describe the present operation rules at Añarbe Dam. The SO module should be used whenever the flow through a structure is to be regulated by the operation of a movable gate or if the flow is controlled directly as in the case of a pump.

Connection MIKE SHE – MIKE11
To describe the river-aquifer interaction a thin permeable layer is assumed between the river and the main aquifer. The drainage /interflow level and the time constant of the linear reservoir model are assumed homogeneous in the catchment and are included in the calibration. The empirical parameters in the evaporation model are based on experience values.

Meteorological data and flow measurements
Daily precipitation is available from 5 stations, (Ereñozu, Añarbe, Artikutza, Igueldo, and Goizueta), of which the 4 first ones have 10minutes observations also. Daily potential evaporation is available from 1 station and is used as spatial homogenous input to the model.

Figure 6: The available measuring stations, ref /4/

The available stream flow measurements for calibration consist of 10min data from the 2 automated gauging stations (Ereñozu (268 km2) and Añarbe (46 km2). Data from the period 2000-2002 was used for calibration, and 2002-2004 for validation.

Figure 7 shows and example of the fully distributed rainfall maps generated from the available rain gauges.

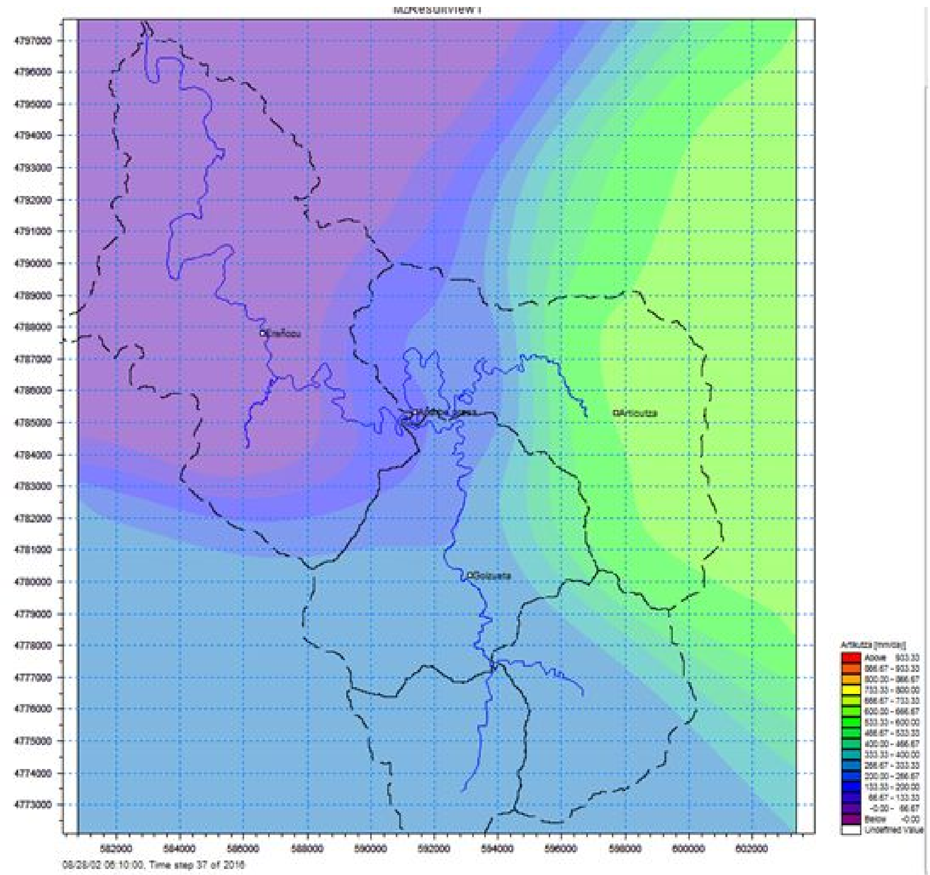

Figure 7: Precipitation map (fully distributed)

Calibration procedure

In a lumped concept, the parameters do not have a physical meaning and the parameterization is an optimization process not restricted to any physical boundaries. On the other hand, by definition, a fully distributed physically based model contains only those parameters that can be accessed from field measurements. This implies that, in principle, calibration is not necessary when sufficient data are available. REF /5/

However, because it is impossible to characterize all the spatial and temporal variability's of the parameters on a watershed scale, the input parameters for the model are spatially averaged values rather than point values obtained from field measurements at selected locations. As a consequence of this discrepancy in scales, lack of data, and measurement errors, distributed models usually have to be calibrated. The goal of the calibration process for physically based models is to find an optimal set of physically realistic parameter values that simulate the behavior of the watershed as accurately as possible (REF /5/ and /9/). The relevance of the output of the hydrological model is highly dependent on the quality and quantity of the input data.

The statistical criteria used to measure the MIKE SHE prediction performance efficiencies are root mean square error (RMSE), correlation coefficient (R), and mean error (ME). The MIKE SHE estimations are optimal if R, ME, and RMSE are close to 1, 0, and 0, respectively.

Sensitivity and calibration analyses

In order to identify the most sensitive parameters a preliminary sensitivity analysis was carried, and based on the results 10 parameters were determined for the calibration (see table 1)

Two objective functions (RMSE) were formulated one for the discharge at Ereñozu and one for the discharge at the Añarbe measuring station.

The results of the Auto calibration (AutoCal, DHI 2005) can be seen in table:

Table 1: Calibrated parameters

Parameter	Symbol	Unit	Value
Soil parameters (UZ)			
Saturated hydraulic cond. of (cambisol Tipo A)	Ks_a	m/s	1e-006
Saturated hydraulic cond. of (cambisol Tipo B)	Ks_b	m/s	1e-006
Van Genuchten n-parámetro suelo Tipo A	n_a	-	1.18
Van Genuchten n-parámetro suelo Tipo B	n_b	-	1.23
Van Genuchten α-parámetro suelo Tipo A	α_a	m^{-1}	0.02
Van Genuchten α-parámetro suelo Tipo B	α_b	m^{-1}	0.0167
Saturated zone (SZ)			
Hydraulic cond. of soil type A (Horz, Vert)	Kh_a	m/s	1e-005
Hydraulic cond. of soil type B (Horz, Vert)	Kh_b	m/s	1e-006
Drainage (Interflow)			
Drainage coefficient	DC	m/s	$1x10^{-6}$

Calibration results

The calibration was carried out in two steps; firstly a long-term (1 year) auto-calibration and validation of the parameters defined in table 1, and subsequently a short-term adjustment by refining and spatial distribution of the drainage coefficient.

The long-term calibration was based on daily precipitation values for 2002 and validated against data from 2003. A station based precipitation distribution was used. Figure 8 shows the long-term calibration results for the period 2002, at the measuring station Ereñozu.

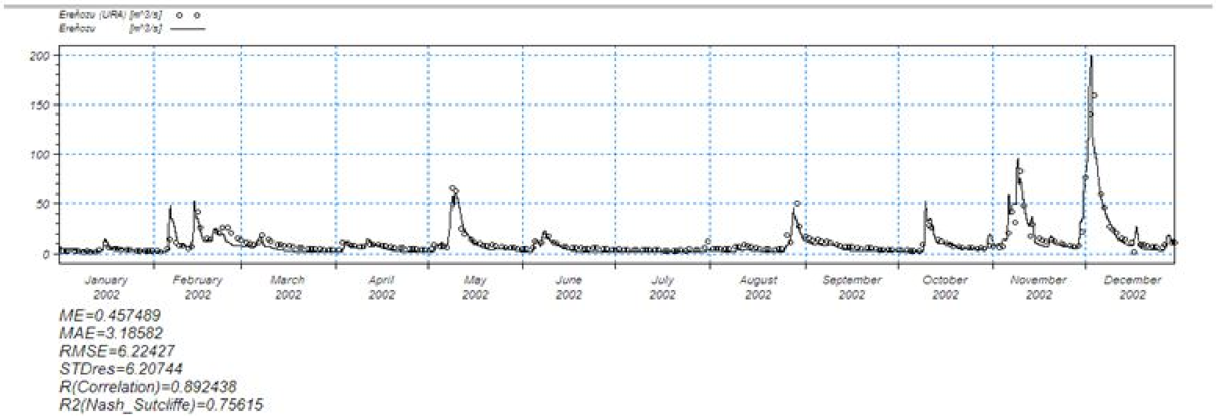

Figure 8: Results of the long term calibration, at Ereñozu.

The short-term adjustment was based on 6 peak flow events, using 10min data. Due to lack of 10min data from the important Goizueta measuring station, the station based approach did not give convincing results, and it was therefore decided to use fully distributed precipitation incorporating 2 stations located outside the area. This improved the results considerably.

Since the objective was to show the applicability of the model for real time forecasting, the short term adjustment was done in a continuo’s manner, as shown in figure 9. Meaning that the adjusted drainage coefficient should be valid (R2>0.7) for all events.

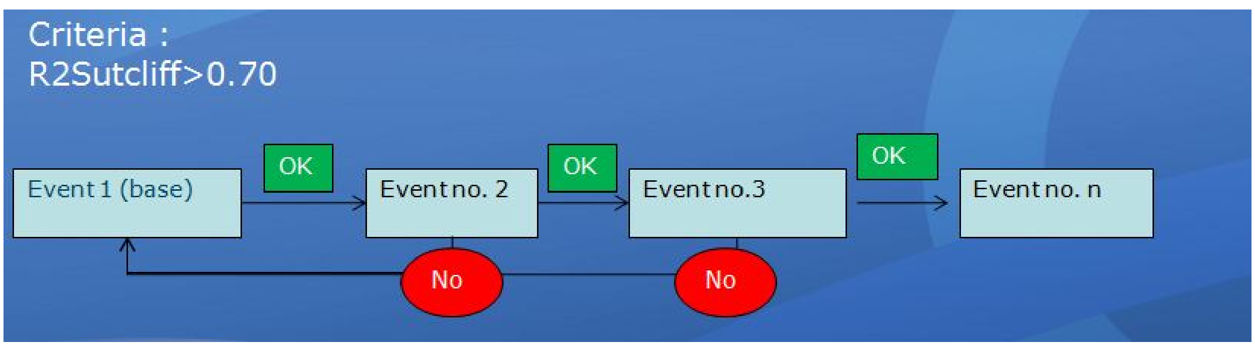

Figure 9: Short term calibration strategy.

This type of calibration, naturally calls for a very critical evaluation of the precipitation data, and flexibility on the calibration criteria, in order not to make it a “never-ending story”.

Figure 10, shows one of the short term adjustment results, in this case October 2000.

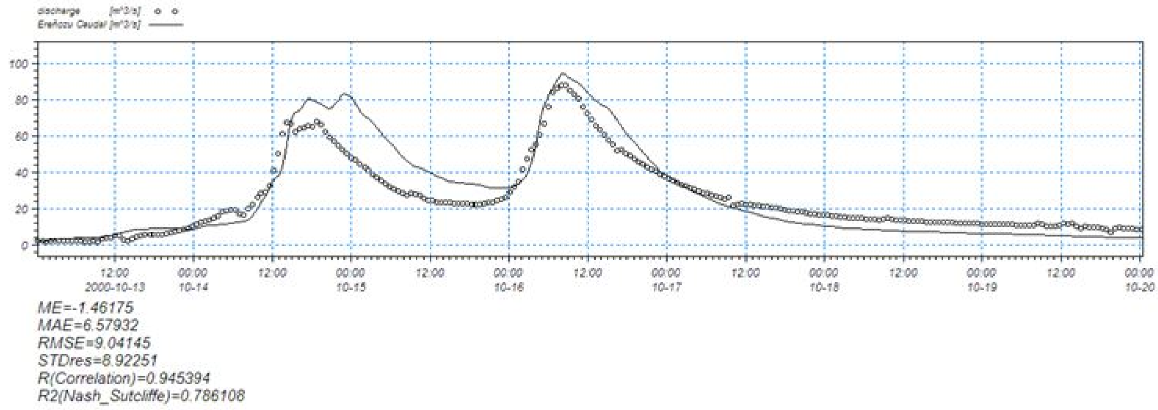

Figure 10: Results of the short term adjustments.

In general the simulations showed a good agreement with both the long-term and the short term model results.

Design and architecture of the DSS system.

One of the main objectives of the present pilot project was to develop, and set up a pilot Decision Support System for the Urumea catchment.

Because of the high stakes involved in water management during a crisis it is essential that a forecast of the emerging situation occurs in a structured and reproducible manner.

The development and implementation of a DSS demands an integration of knowledge management and hydroinformatics. Besides extended knowledge of software development, attention is required for the quality of modeling and the user’s demands concerning presentation and communication of model results.

Experience has shown that if not enough attention is paid to these aspects, there´s a risk of failure and that the system is not used.

The proposed pilot - DSS system consist of 4 component as presented in figure 11

- SAIH-Prediction component: collecting data, checking, saving data and exporting data and information to the other component
- Simulator: simulation and forecasting via Hydrological/hydraulic model (MIKE SHE-MIKE11)
- Database and graphical interface ArcGIS: Flood Watch
- Publication, webpage for online publication of measured data and the model results; river discharge, precipitation.

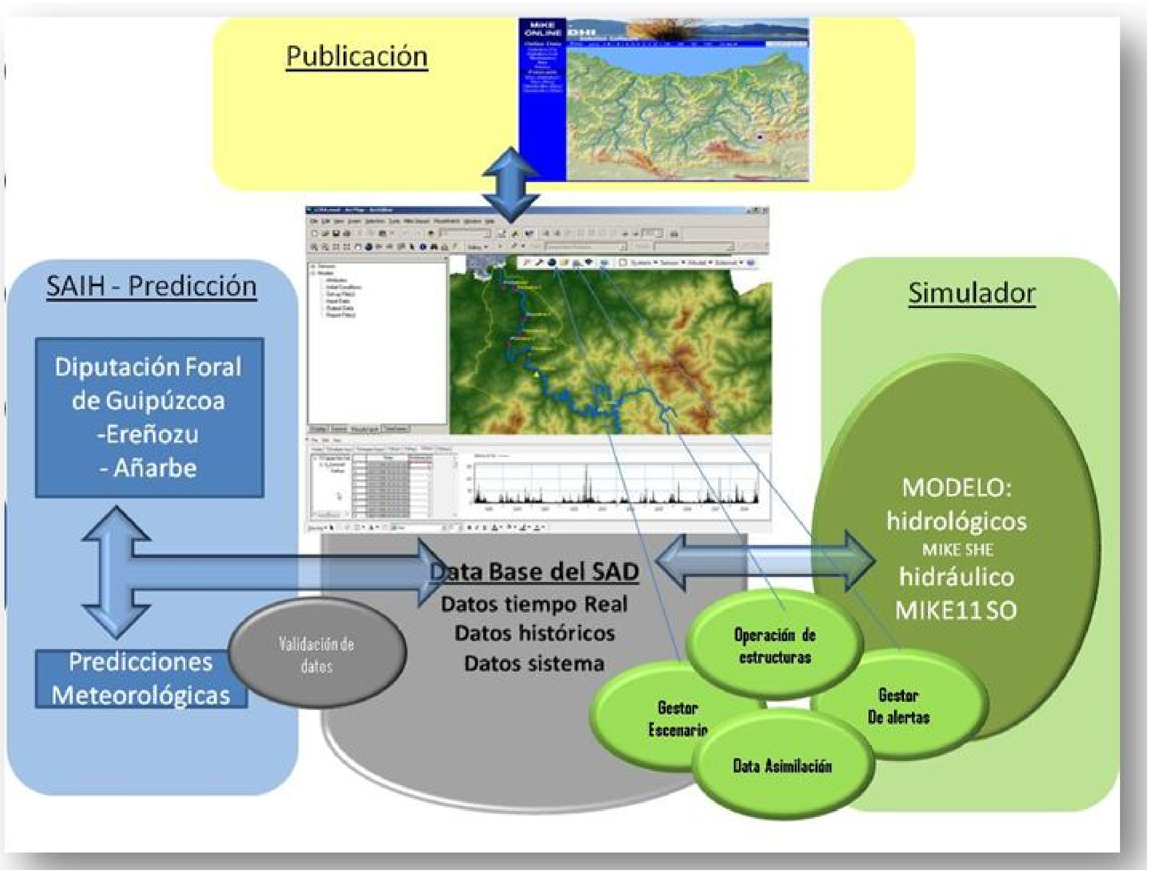

Figure 11: Architecture of the DSS system

The four components functions independently of each other, which makes it possible to add functionality to each component without influencing the other components. Furthermore the components can function on separate computers systems, and therefore management and use can be distributed.

In the Flood Watch component, data from the database are visualized. These data originate from external sources (measurements) and the simulation results.

From the Flood Watch component it is possible to control the simulator, execution of simulation, structure operations and post and pre process data results.

The FLOOD WATCH GIS interface, is a geographically oriented user interface which enables presentation of the different geo referenced elements of a water system, e.g. rivers channels, topographical features, sub catchment etc, using colors and symbols.

In some applications the FLOOD Watch interface is combined with a web interface, in order to facilitate the system to be used by larger groups of users, naturally a web interface will have fewer features and less flexible. In the present Urumea application a web interface was used to present the simulated forecast results. No two ways communication was implemented, only result presentations.

In the simulator the hydrological and hydrodynamic calculations are carried out. Based on measured water levels or discharges in the rivers, and using the measured and forecasted precipitation and evaporation the models calculate the system behavior. Figure 12 shows an example of a graph in which measured and forecasted discharges in Ereñozu are presented.

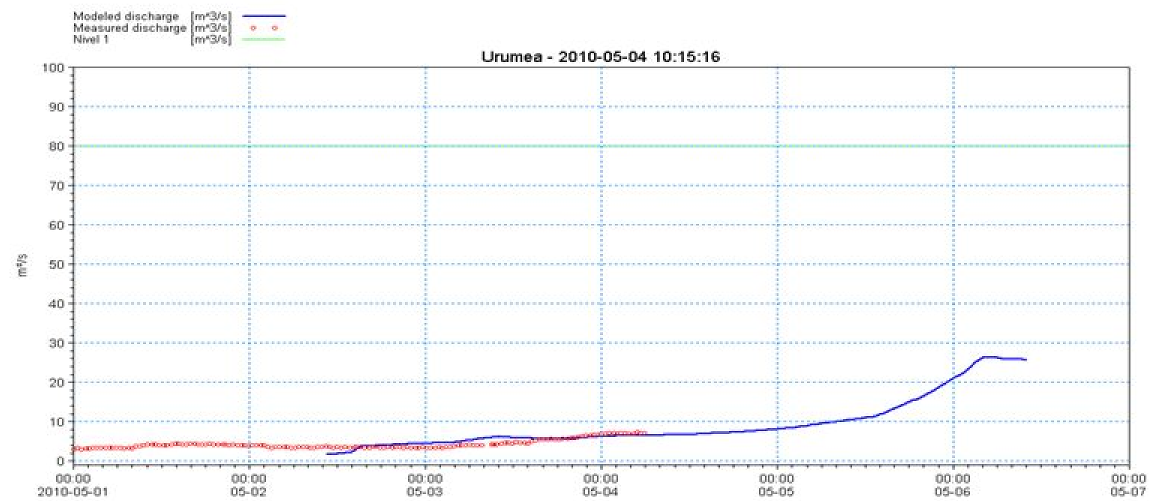

Figure 12: Example of a forecast from the website. (red: observed data and blue: simulated result)

To make and trustworthy forecast of the future situation it is important that the DDS have knowledge of the present hydrological situation of the system, flows levels, soil moisture, groundwater level etc. But since it is not possible to measure all variables at all locations, data assimilation can be applied in order to minimize the initial errors. Also the models will use hot start files from the previous forecast.

After MIKE SHE simulation have finished the results are post processed, some raw data, like water levels and discharges, can directly be put in the FW data base for presentation purposes

Adjustment of the MIKE SHE model to run in real time

In order to run the MIKESHE model in real time some adjustments and assumptions was introduced;

- The precipitation was defined as constant in the entire area with a height adjustment.
- For the hindcast period the observed precipitation at Ereñozu was used.
- For the forecast period precipitation data from a public website was used.
- The flood gates at the Añarbe dam was set as always fully opened
- The bottom culverts at the Añarbe dam always closed.
- Data assimilation was included MIKE 11 river model. The model was updated using the Ereñozu measuring station.

Due to the limitations of the present study, being a pilot project for further studies, a simplification of the task operations was introduced, the different automated task, importation of data, execution of the MIKE SHE model, check of data and publication of data, was programmed directly in a script, which runs directly from flood watch.

The script is automatically executed every 1-2 hours, and follows the scheme described in figure below:

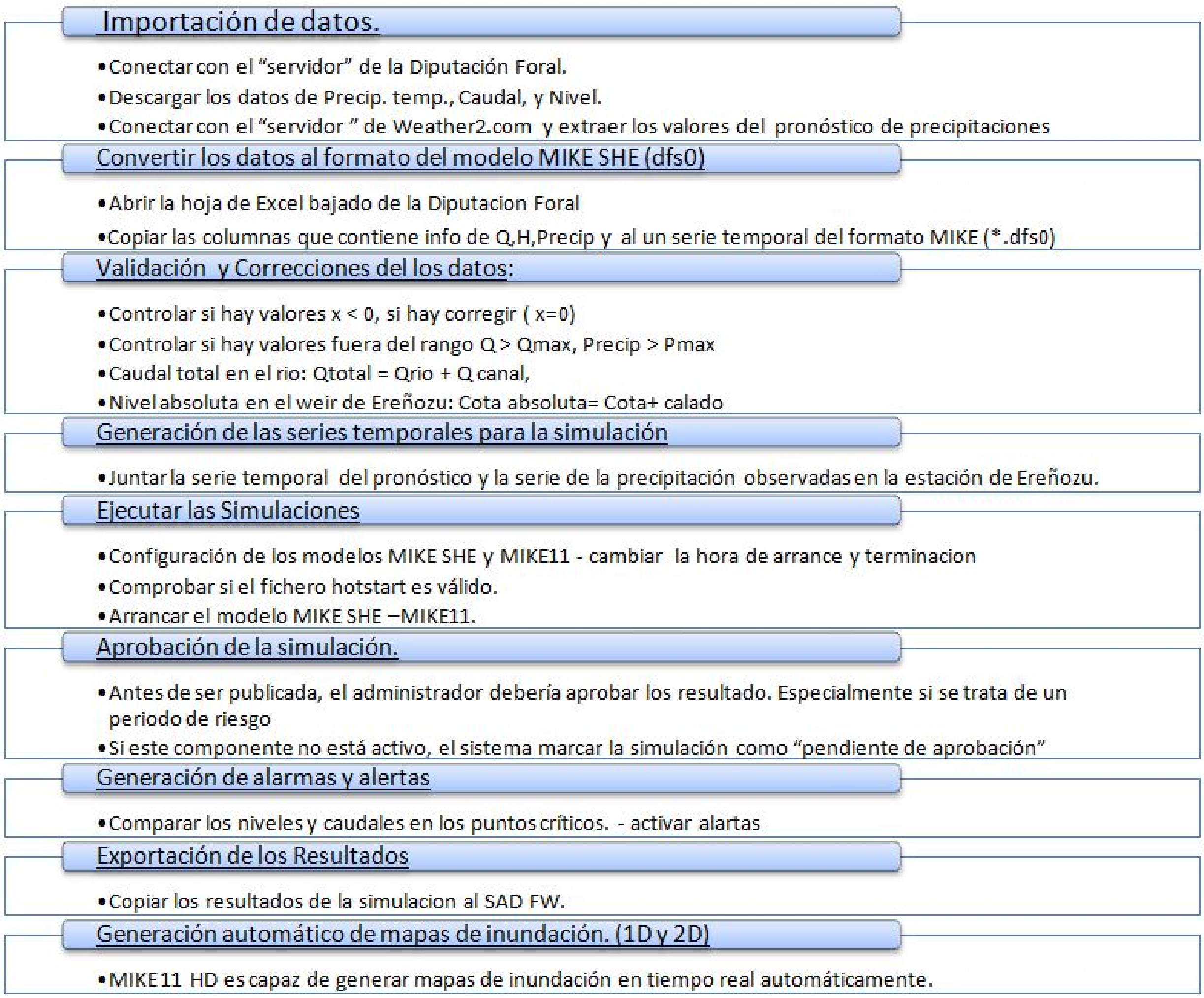

Figure 13: The methodology of the task execution script.

The component MIKE FLOODWATCH was used as a graphical interface where the simulation results and the observations can be analyzed. Figure shows the FW layout (fig 14)

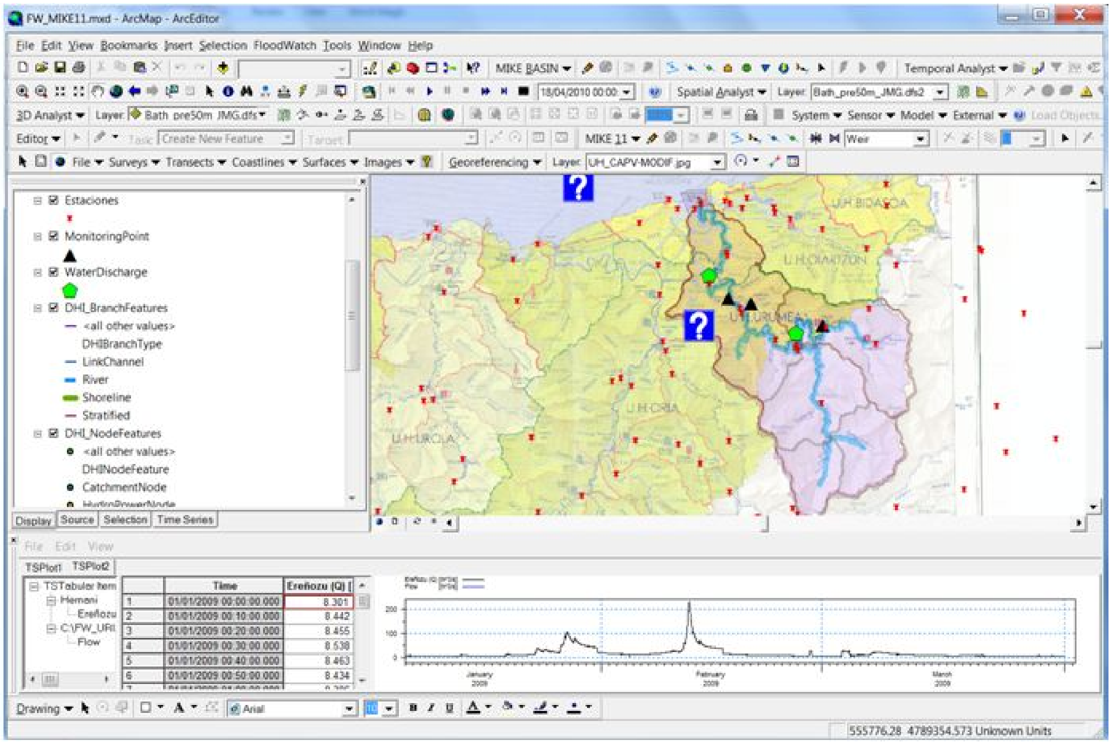

Figure 14: The FW interface for the Urumea river

Publication of results:

The web interface developed offers the possibility to open graphs with model results (discharge at Ereñozu), observed river flow, and precipitation rate at Ereñozu, and the precipitation forecast for the entire catchment. The webpage also contains the calibration results.

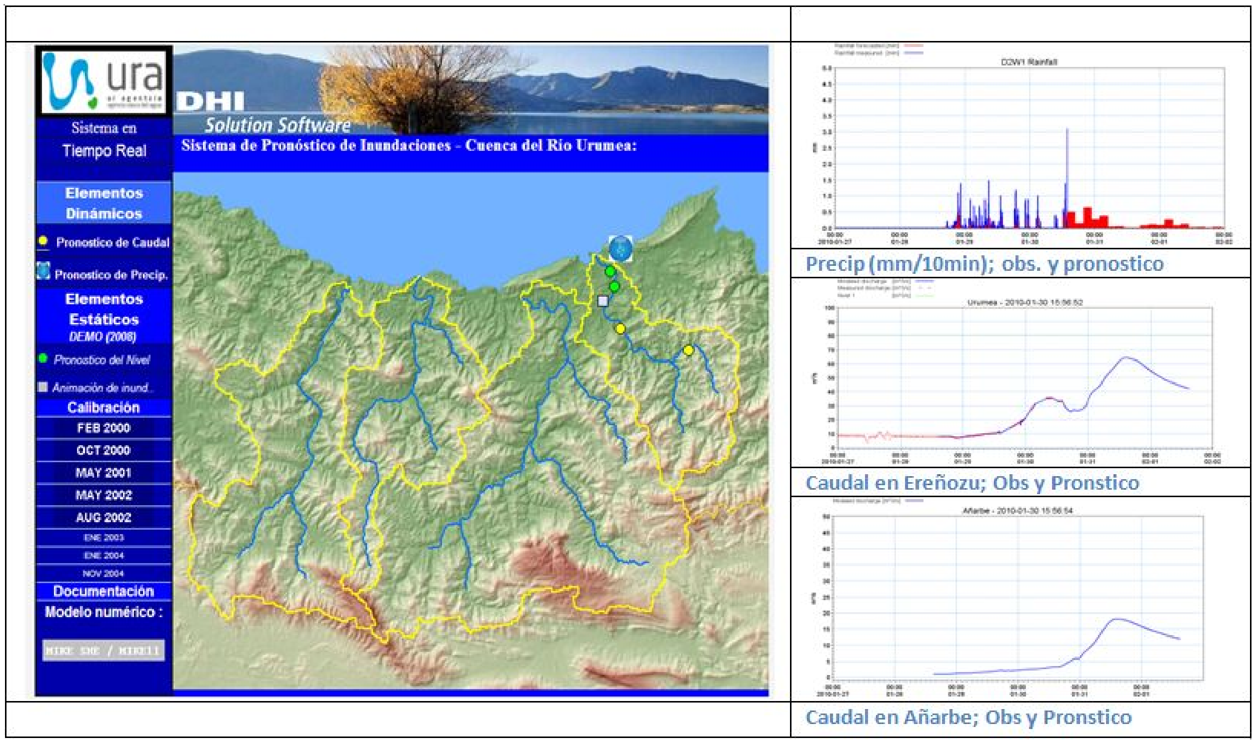

Figure 15: the DSS webpage.

The webpage can be viewed on any PC or mobile phone with an internet connection. The webpage has been secured with a password.

Real event – June 15-17 2010

On the 15- 17 June the weather forecasts for Basque country was indicating a high probability of causing flooding in various zones. This section describes the forecast simulations of the Urumea catchment which was carried out during the event. It was decide to base the simulations only on the forecasts issued by EUSKALMET, which was supplied as 6hours accumulated rainfall, constant for the entire catchment area. For the Urumea catchment the VC-E prognostic was applied.

The forecast was incorporated into the model manually, as the data was received in text format.

The following sections briefly summarize the occurrences from Tuesday the 15 June to Thursday 17. June, the data used and the simulation results, and finally gives a few general comments on the flood forecasting system

Precipitation y caudal

Table 2 shows a summary of the prognostics issued by EuskalMet for the area, and the observed precipitation at the measuring stations controlled by the Diputacion Foral de Gipuzkoa and the Metrological institute de Navarra.

Column 3-6 shows the forecasted precipitation received during the event, meaning that the first forecast was issued and received around 0930 the 15 of June and the last on 16/06-1900.

Table 2: Forecasted and observed data.

		EuskalMet Pronósticos y observaciones				Dip. Foral GIPUZKOA Observaciones			Meteo de Navarra Observaciones		
	Hora	15/06 0930	15/06-1930	16/06-08.30	16/06 - 1900	Añarbe (6h)	Ereñozu (6h)	Ereñozu (24h)	Artikutza	Goizueta	Arrabida
	0-6	10	6			3	2.3				
	6-12	20	12			10	3.3				
	12-18	20	5			22	na				
15-junio	18-24	20	15	34	34	55	4.8	10+	9.6	11	28
	0-6	30	20	7	7	30	4.1				
	6-12	30	30	30	25	14	14.8				
	12-18	25	30	30	25	-	23.4				
16-junio	18-24	20	30	30	30	-	37.6	80	88	77	106
	0-6	15	20	20	20		7				
	6-12	10	20	20	20		2				
	12-18	5	5	15	5		0				
17-junio	18-24	5	10	10	5		0	9	18.5	5	10

The figure 16 y 17 shows the discharges observed in Ereñozu (Urumea) and in Añarbe during the event.

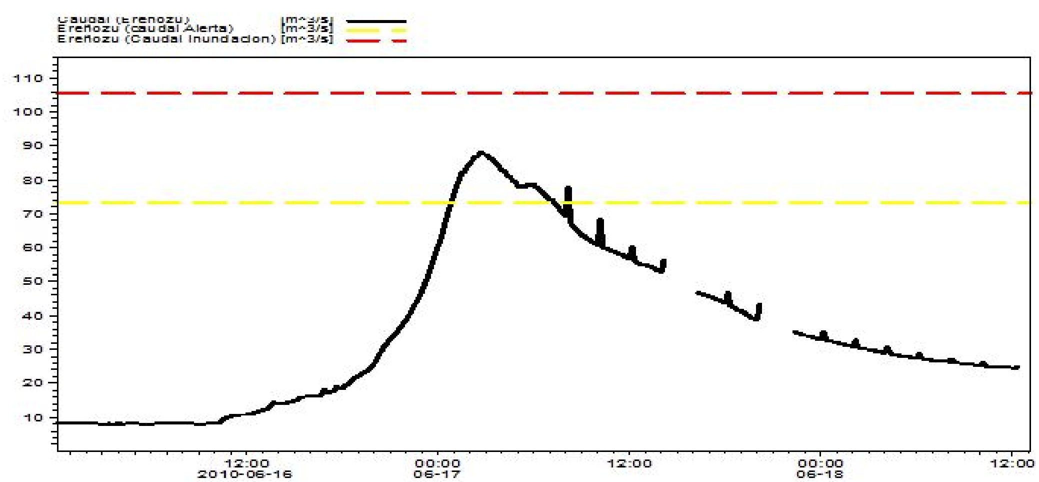

Figure 16: Caudal observado en la estación de Ereñozu

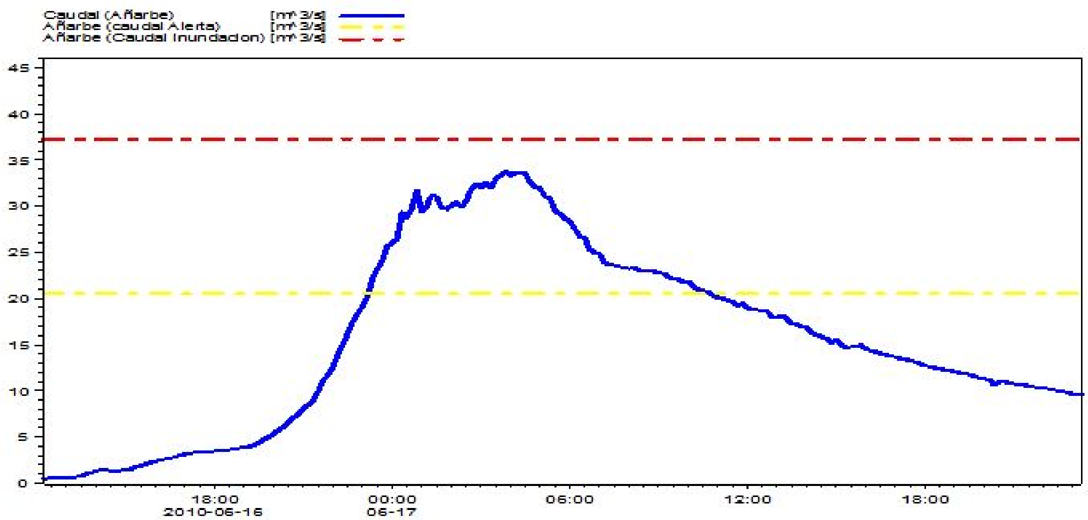

Figure 17: Caudal observed in Añarbe

As it can be seen the peak flow occurred at 5:00 -07:00 on the 16: Both stations reached alert levels but did not exceed the inundation level

Results of the forecast simulations

The following section shows the simulation results in a chronologically order. The applied precipitation corresponds to precipitation values given in table 2: (row 3-6). Two simulations was carried out for each forecast, one applying the full precipitation and one applying 70% of the forecasted precipitation

Figure 18-21 shows the results of the 2 simulations full and 70% (blue lines) versus the observed discharge. Also indicated on the graphs are the alert levels (red and yellow)

As it can be seen the forecasted discharge lies more or less within the uncertainty band defined as 30%, except for the first forecast. In general the timing of the peak flow is well forecasted.

All in all an acceptable match between simulated and forecasted values, taking into consideration that the forecast was made on 6hours time intervals and with no spatial variation.

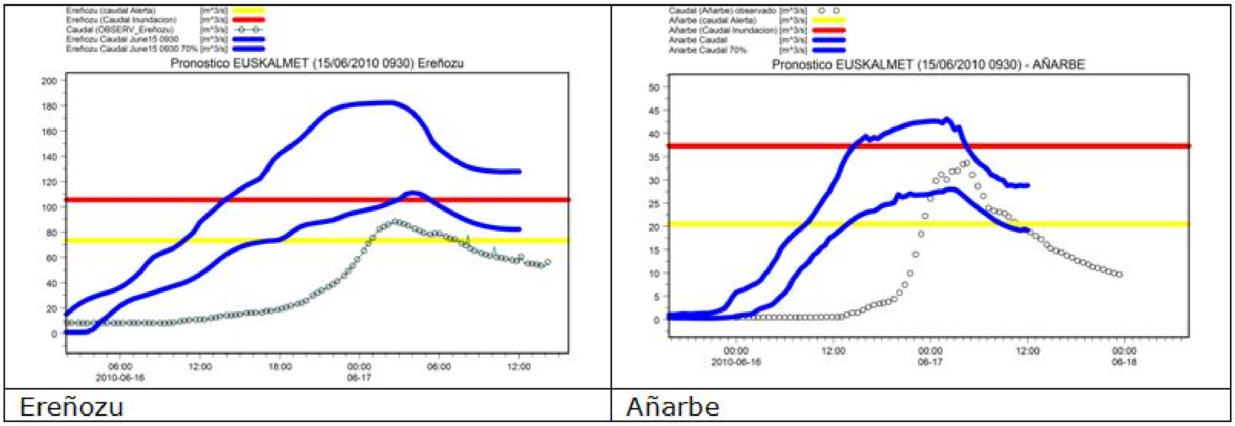

Figure 18: Forecasted and observed discharge and the Ereñozu measuring station

The first simulations shows that the peak discharge will reach a critical level, within 24-36 hours from the forecast time, and could reach levels simular to a 10 year flood event

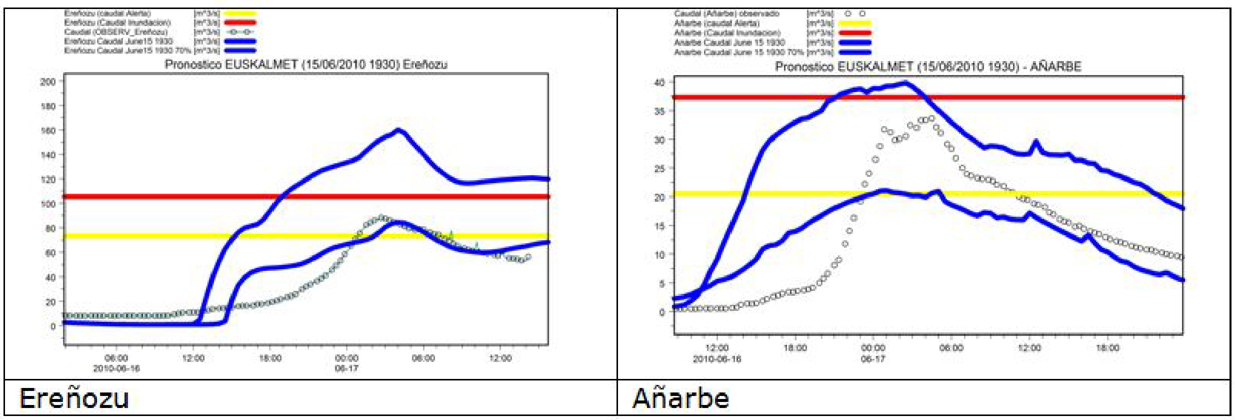

Figure 19: Forecasted and observed discharge and the Ereñozu measuring station

The second simulation, shows a decrease in the peak flow, but still predicts a potential flood event. The peak time is similar to the first simulation

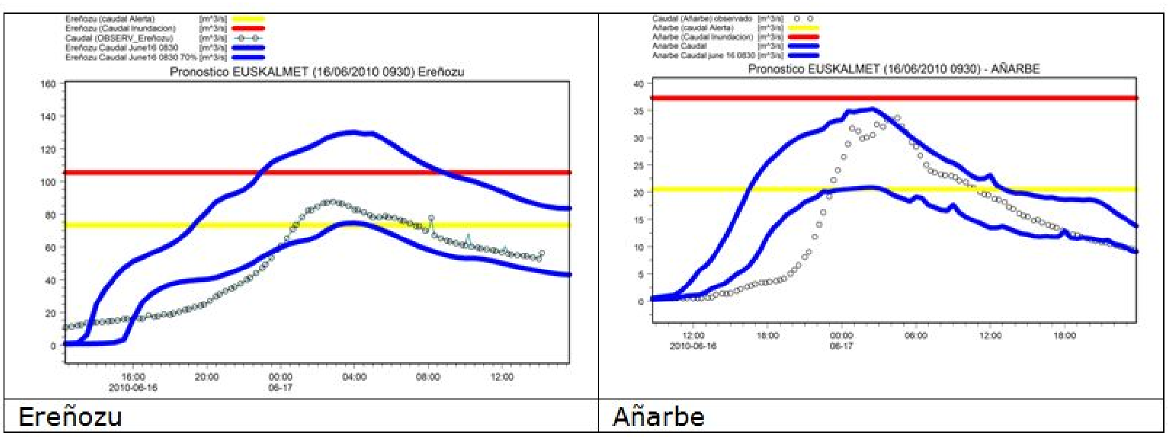

Figure 20 Forecasted and observed discharge and the Añarbe measuring station

In the third simulation, the decreasing trend of the 2 first simulations continues, but the Max flow is still above the defined flood level. The min flow (70%) just reaches the alert level.

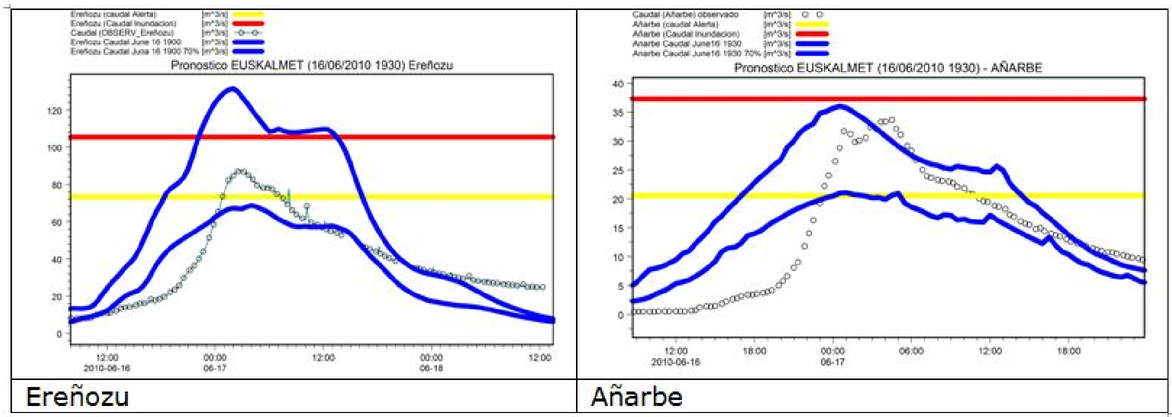

Figure 21: Forecasted and observed discharge and the Ereñozu and Añarbe measuring stations

The last simulation was carried out on the 16/06 at 20.00, 8 hours before the observed peak flow, shows a still decreasing peak flow and a similar peak time. The simulated flows (max, min) correspond well with the observations.

Conclusion

A distributed physically based hydrological model combined with a dynamic hydraulic river model has been established for the Urumea catchment. The model concept applied includes distributed rainfall, infiltration and evapotranspiration in combination with a distributed linear reservoir model representing interflow and a 3D finite difference model representing the groundwater flow.

A sensitivity test was carried out on a selected number of key parameters, using DHI´s AUTOCAL tool. Based the sensitivity test results an automatic optimization/calibration of the most sensitive parameters was done.

The calibration and validation was firstly based on daily precipitation values, and secondly adjusted manually using 10min fully distributed precipitation data.

Due to the fact that no groundwater data was available, the calibration was based only on river flows at the measuring stations of Ereñozu and Añarbe.

The results of the calibration showed a satisfactory correspondence between the observations and the simulated flow and water level. Slightly better results was obtained in Ereñozu than in Añarbe

The integrated model has been incorporated into a DSS system using DHI Flood Watch management tool. The system comprises of automated real-time importation of online river data and metrological forecast data, a data checking tool, a scenario manager

The system has been running online since January 2010, with publication of forecast every 2 hours. Due to the nature of the meteorological forecast data, which is downloaded directly from a free webpage, the forecasts are of a varying quality. The forecast is a 3 hour accumulated value constant for the entire catchment.

The Modeling system was applied during the event June 15-17, using metrological data sent directly from EUSKALMET. Taking into consideration the uncertainties and roughness of the precipitation forecasts, the model displays a very good correspondence with what actually happened, the peak flows was predicted with an uncertainty of 20-30%, with a lead time of 48 and 24 hours.

REFERENCES

/1/ Knudsen, J., Thomsen, A., Refsgaard, J.C., 1986. WATBAL: A semi distributed, physically based hydrological modeling system. Nordic Hydrology 17, 347–362.

/2/ Refsgaard, J.C., 1997. Parameterization, calibration and validation of distributed hydrological models. Jornal of Hydrology 198, 69–97.

/3/. ESTUDIO DE EVALUACIÓN DE LOS RECURSOS HÍDRICOS TOTALES EN EL AMBITO DE LA CAPV, INTECSA – GOBIERNO VASCO, 2003

/4/. Diputación Foral de Guipúzcoa (web site)

/5/. Calibration and validation of a physically distributed hydrological model, MIKE SHE, to predict stream flow at high frequency in a flashy mountainous Hawaii stream.

/6/ Feyen, L., Vázquez, R., Christiansen, K., Sels, O., Feyen, J., 2000. Application of a distributed physically-based hydrological model to a medium size catchment. Hydrology and Earth System Sciences 4 (1),

/8/ AutoCal Manual (DHI-2005)

/9/ Sooroshian, S., Gupta, V.K., 1995. Model calibration. In: Singh, V.P. (Ed.), Computer models of Watershed Hydrology. Water Resources Publications, Colorado, USA, pp. 23–68.