Deliverable D1.2.1 Application description, including use cases for Task 1.2

WP1 , Task 1.2, CrossGrid Application Development

Document Filename:	**CG-1.2-D1.2.1-003-SRS**
Work package:	**WP1 CrossGrid Application Development**
Partner(s):	**II SAS, SHMI**
Lead Partner:	**II SAS**
Config ID:	**CG-1.2-D1.2.1-003-SRS-2.1**
Document classification:	**PUBLIC**

Abstract: This document provides a description of the initial specification and the requirements for Grid tools needed in task 1.2 of the WP1 **"Flooding crisis team support"**

Delivery Slip

	Name	Partner	Date	Signature
From				
Verified by				
Approved by				

Document Log

Version	Date	Summary of changes	Author
1-0-DRAFT-A	03/26/02	Draft version	L. Hluchý, J. Astaloš, M. Dobrucký, O. Habala, B. Šimo
2-0-DRAFT-A	05/14/02	Revised draft version	L. Hluchý, J. Astaloš, M. Dobrucký, O. Habala, B. Šimo
2-1	05/31/02	Corrected version after IRB review	L. Hluchý, J. Astaloš, M. Dobrucký, O. Habala, B. Šimo, K. Martinka, K. Hajtášová, D. Kotláriková, I. Machara, J. Mašek, I. Ondruš, I. Strmiska, O. Španiel

CONTENTS

II SAS *1*

1. INTRODUCTION **4**

1.1. PURPOSE 4
1.2. SCOPE 4
1.3. DEFINITIONS, ACRONYMS, AND ABBREVIATIONS 5
1.4. REFERENCES 6
1.5. OVERVIEW 7

2. OVERALL DESCRIPTION **8**

2.1. PRODUCT PERSPECTIVE 11
2.1.1. System interfaces *11*
2.1.2. User interfaces *11*
2.1.3. Hardware requirements *11*
2.1.4. Software interfaces *12*
2.1.5. Communication interfaces *12*
2.1.6. Memory constraints *13*
2.1.7. Operations *13*
2.1.8. Site adaptation requirements *13*
2.2. PRODUCT FUNCTIONS 13
2.2.1. Possible usage scenarios *13*
2.2.2. Use cases *14*
2.3. USER CHARACTERISTICS 17
2.4. CONSTRAINTS 17
2.5. ASSUMPTIONS AND DEPENDENCIES 17
2.6. APPORTIONING OF REQUIREMENTS 18

3. SPECIFIC REQUIREMENTS **18**

4. APPENDICES **19**

4.1. ALADIN METEOROLOGICAL MODEL 19
4.2. HYDROLOGICAL SIMULATION (RAINFALL-RUNOFF MODELING) 28
4.3. HYDRAULIC SIMULATION 30
4.4. DATA ACQUISITION FOR PILOT SITE 38
4.5. MILESTONES OF TASK 1.2 47

5. INDEX **48**

1. INTRODUCTION

1.1. PURPOSE

The purpose of this document is to define the functionality of the system to be developed in the scope of the task 1.2 "Flooding crisis team support" of the WP1 "CrossGrid Application Development" and the requirements for Grid tools that will be used in the process of design and implementation. The intended audience is both the task itself and all the dependent tasks in the CrossGrid project.

One of the important outcomes of this description will be the requirements related to:

- Internal interfaces
- Other CrossGrid workpackages
- External resources, such as Globus, Cactus, Nimrod/G, MPICH-G2.

1.2. SCOPE

In this task we propose to develop a support system for establishment and operation of Virtual Organization for Flood Forecasting (**Figure 1**) associating a set of individuals and institutions (different boxes in data sources represent different data providers) involved in flood prevention and protection. The system will employ a Grid technology to seamlessly connect together the experts, data and computing resources needed for quick and correct flood management decisions. The main component of the system will be a highly automated early warning system based on hydro-meteorological (snowmelt) rainfall-runoff simulations. Moreover, the system will integrate the advanced communication techniques allowing the crisis management teams to consult the decisions with various experts. The experts will be able to run the simulations with changed parameters and analyze the impact (what-if analysis). The use of Grid resources is vital especially in the case of flood crisis when the simulations have to be performed as fast as possible.

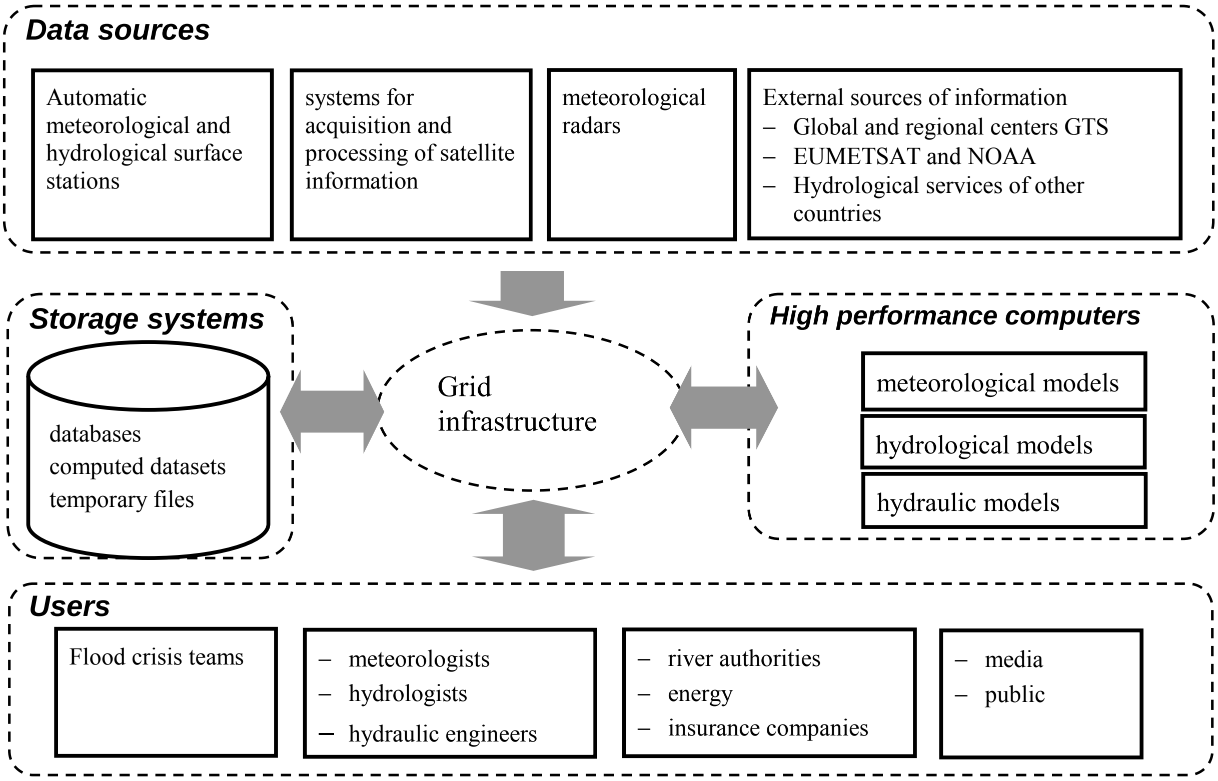

Figure 1 Virtual Organization for Flood Forecasting

1.3. DEFINITIONS, ACRONYMS, AND ABBREVIATIONS

ALADIN	Meteo France mesoscale model nested within ARPEGE http://www.cnrm.meteo.fr/aladin/
ALADIN / LACE	Limited Area Central Europe, http://www.chmi.cz/meteo/ov/lace/
ALADIN / Slovakia	ALADIN for Slovak Republic, http://www.shmu.sk/aladin/predpoved/index.html
ANFAS	Data Fusion for Flood Analysis and Decision Support (IST-5FP project) http://www.ercim.org/anfas/
EO GRID	DataGrid: Earth Observation Science Applications, http://styx.esrin.esa.it/grid/wp9_intro.html
Globus	http://www.globus.org/
GrADS	Grid Analysis and Display System, http://grads.iges.org/grads
GVK	Grid Visualization Kernel – CrossGrid Task 1.1.3, Univ. Linz http://www.gup.uni-linz.ac.at/gvk
HBV	http://www.indic-airviro.smhi.se/HBV/intro.htm http://www.smhi.se/sgn0106/if/hydrologi/main.htm
HEC-1	http://www.hydromodels.com/ifwmsmd.htm
HSPF	http://water.usgs.gov/software/hspf.html
Meteo GRID	EuroGRID: WP2 Meteo GRID, http://www.eurogrid.org/wp2.html
Nimrod/G	http://www.csse.monash.edu.au/~davida/nimrod.html
NLC	lumped rainfall-runoff model
SMS	Surface-Water Modeling System, http://www.ems-i.com/sms.htm
TBD	To Be Defined
VO	Virtual Organization
VOFF	Virtual Organization for Flood Forecasting
WMS	Watershed Modeling System, http://www.ems-i.com/wms.htm

1.4. REFERENCES

1. Gallopoulos, S., Houstis, E., Rice, J.: Computer as Thinker/Doer: Problem-Solving Environments for Computational Science. IEEE Computational Science and Engineering Magazine, 1994, Vol. 2, pp. 11-23.
2. Fine, S. S., Ambrosiano, J.: The Environmental Decision Support System: Overview and air quality application. American Meteorological Society: Symposium on Environmental Applications, pp. 152-157. 1996, Atlanta, USA.
3. SMS: 2D surface water modeling package: http://www.bossintl.com/html/sms_overview.html
4. WMS: Watershed Modeling System: http://www.bossintl.com/html/wms_overview.html
5. I.S. Duff, H.A. van der Vorst: Developments and Trends in the Parallel Solution of Linear Systems, Parallel Computing, Vol 25 (13-14), pp.1931-1970, 1999.
6. Y. Saad, M. H. Schultz: GMRES: A generalized minimal residual algorithm for solving nonsymmetric linear systems. SIAM J. Scientific and Statistical Computing, Vol. 7, pp. 856-869, 1986.
7. R.S. Dembo, S.C. Eisenstat, T. Steihaug: Inexact Newton methods. SIAM J. Numerical Analysis, Vol. 19, pp. 400-408, 1982.
8. W.D. Gropp, D.E. Keyes, L.C. McInnes, M.D. Tidriri: Globalized Newton-Krylov-Schwarz Algorithms and Software for Parallel Implicit CFD. Int. J. High Performance Computing Applications, Vol. 14, pp. 102-136, 2000.
9. MPICH - A Portable Implementation of MPI http://www-unix.mcs.anl.gov/mpi/mpich/
10. PETSc The Portable, Extensible Toolkit for Scientific Computation. http://www-fp.mcs.anl.gov/petsc/
11. H. Vorst: Bi-CGSTAB: A fast and smoothly converging variant of Bi-CG for the solution of nonsymmetric linear systems. SIAM J. Scientific and Statistical Computing, Vol. 13, pp. 631-644, 1992.
12. P. Sonneveld: CGS, a fast Lanczos-type solver for nonsymmetric linear systems. SIAM J. Scientific and Statistical Computing, No. 10, pp. 36-52, 1989.
13. FESWMS - Finite Element Surface Water Modeling. http://www.bossintl.com/html/feswms.html
14. Ziébelin, D., Parmentier, T.: Distributed Problem Solving Environment Dedicated to DNA Sequence Annotation. Knowledge Acquisition, Modelling and Management, pp. 243-258, 1999.
15. X.C. Cai, M. Sarkis: A restricted additive Schwarz preconditioner for general sparse linear systems. SIAM J. Scientific Computing Vol. 21, pp. 792-797, 1999.
16. D. Froehlich: Finite element surface-water modeling system: Two-dimensional flow in a horizontal plane. User manual.
17. Y. Saad, H. Vorst: Iterative Solution of Linear Systems in the 20-th Century. J. Comp. Appl. Math, Vol. 123, pp. 1-33, 2000.
18. K. Ajmani, W.F. Ng, M.S. Liou: Preconditioned conjugate gradient methods for the Navier-Stokes equations. J. Computational Physics, Vol. 110, pp. 68-81, 1994.
19. Fox, G., Furmanski, W.: Problem Solving Environments from Simulation, Medicine and Defense using the Web. CRPS Annual Meeting, May 1996. http://www.npac.sur.edu/users/gcf/crpcsemay96/fullhtml.html

20. L.Hluchy, V.D. Tran, J. Astalos, M. Dobrucky, G.T. Nguyen and D. Froehlich: Parallel Flood Modelling Systems. In: Proc. of the 2002 International Conference on Computational Science, Amsterdam, The Netherlands, April 21-24, LNCS 2329, Springer-Verlag, 2002, pp. 543-551, ISSN 0302-9743, ISBN 3-540-43591-3.
21. Hluchý L., Nguyen G.T., Halada L., Tran V.D.: Cluster Computation for Flood Simulations. High-Performance Computing and Networking HPCN'2001, Amsterdam, The Netherlands, LNCS 2110, Springer-Verlag, 2001, pp. 425-434. ISSN 0302-9743, ISBN 3-540-42293-5.
22. L. Hluchy, J. Astalos, O. Habala, V. D. Tran and D. Froehlich: Problem Solving Environment for Flood Forecasting. To appear in EuroPVM/MPI 2002 Conference, Linz, Austria.
23. Hluchy L., Tran V.D., Astalos J., Dobrucky M., Nguyen G.T., Froehlich D.: Flood Modeling System and its Parallelization. In: International Conference on Parallel Computing in Electrical Engineering - PARELEC, 2002. IEEE Computer Society Press, September 2002, Warsaw, Poland, to appear.
24. Hluchý L., Nguyen G.T., Halada L., Tran V.D.: Parallel Flood Modelling. In: Parallel Computing - Fundamentals & Applications. Proceedings of the International Conference ParCo 2001. E.H.D'Hollander et al. (Eds.), Imperial College Press, 2001, to appear.
25. L. Hluchý, D. Froehlich, V.D. Tran, J. Astaloš, M. Dobrucký and G.T. Nguyen: Parallel Numerical Solution for Flood Modelling Systems. In: Proc. of 4-th Intl. Conf. on Parallel Processing and Applied Mathematics PPAM'2001, R.Wyrzykowski et.al. (Eds.), Naleczow, Poland, September 9-12, 2001, LNCS Springer-Verlag, to appear.

1.5. OVERVIEW

The rest of this document is organized as follows:

Section 2 provides the overall description.

Section 3 provides the requirements and relations with other WPs.

2. OVERALL DESCRIPTION

Flood forecasting requires quantitative precipitation forecasts based on the meteorological simulations of different resolution from mesoscale to storm-scale. Especially for flash floods, high-resolution (1 km) regional atmospheric models have to be used along with remote sensing data (satellite, radar). From the quantitative precipitation forecast, hydrological models are used to determine the discharge from the affected area. Based on this information hydraulic models simulate flow through various river structures to predict the impact of the flood (**Figure 2**). The results of simulations can be interactively reviewed, some of them accepted and forwarded to the next step, some rejected or re-run with modified inputs (**Figure 3**).

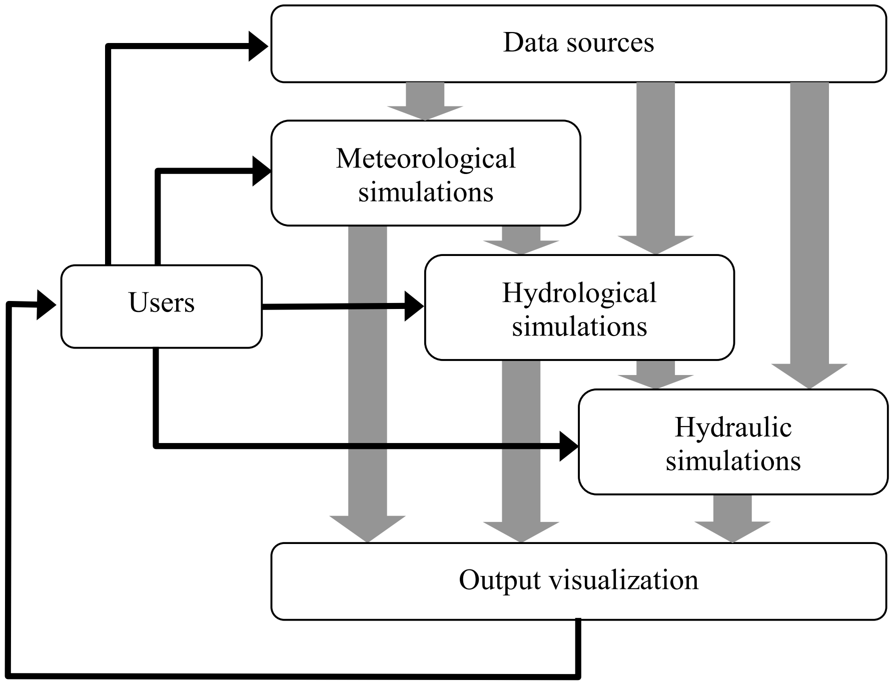

Figure 2 Cascade of flood simulations

The VOFF support system will consist of these Grid-aware components (not all of these are to be developed within CrossGrid):

- data sources (radar and satellite images, topographical data,…)
- permanent and temporary storage management (operational database , archive database)
- portal
- meteorological simulation models
- hydrological simulation models
- hydraulic simulation models
- authentication & authorization infrastructure
- visualization tools (2D and also 3D).

(The system should be able to include new modules if reqiured, so this list will evolve with the changing needs of the VO participants.)

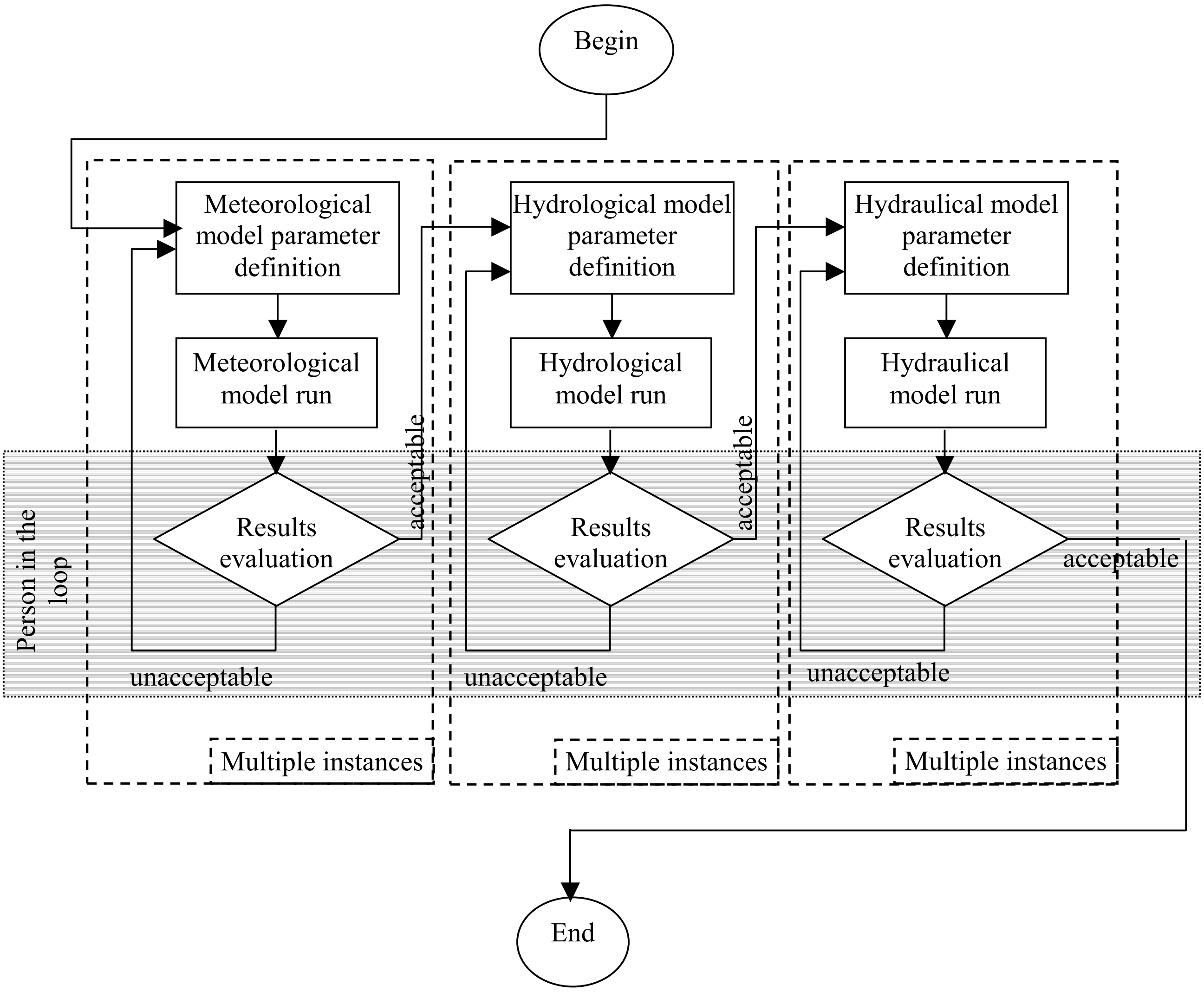

Figure 3 Interactive evaluation of flood forecasting

The final product will be a Problem Solving Environment, consisting of:

- a sophisticated user interface (portal), implemented by a set of HTML pages, dynamically generated HTML, PHP technology etc., and accessible through a web server and a common client
- a set of simulation models, as described above
- a set of visualization tools.

Portal (subtask 1.2.3): The portal will act for users as an interface to VO. It will provide means for the exchange of information between different experts as well as for the dissemination of information to various users. Flood crisis teams will be able to access the historical data and consult the decisions with the experts. Through the portal, experts will be able to run their simulations on Grid resources. In cooperation with our partners from task 3.1, we will also add support for mobile users and roaming access.

Meteorological models (subtask 1.2.2): The meteorological models are generally computationally intensive and they are usually running on the supercomputer class systems. Our simulation will use output from such a supercomputer (as the border conditions). We will port the parallel version of the

ALADIN/Slovakia (Appendix 4.1.) simulation model to a PC-Linux cluster, connected to the Grid. The output of limited area models is used by meteorologists as boundary conditions for regional models. This nesting requires efficient management and transfers of large (tens to hundreds of megabytes) datasets. The prediction of flash floods will require employment of high-resolution storm-scale models.

Hydrological models (subtask 1.2.2, Appendix 4.2.) are used to simulate precipitation-runoff process in each of the sub-basins (portions of the river basin). Representation of component requires a set of parameters, which specify the particular characteristic of the component and mathematical relations, which describe the physical process. The result of the modeling process is the computation of stream-flow hydrographs at desired locations in the river basin. As the next step in cascade simulation is hydraulic simulation, in which more tributaries are taken into account, more independent hydrological simulations are performed, i.e. high throughput computing is applicable here. Hydrological models like HEC-1, NLC, HBV and HSPF will be used. They will be prepared for Grid operation by adding the necessary communication interface and enabling their usage in an HTC environment.

The input data for hydrological models include topographical data, precipitation hyetograph (sub-basin average rainfall or snowfall over a computational interval), data from historical storms (total amount of precipitation for the storm and a temporal pattern for distributing the total precipitation or weighted precipitation gages) or data for synthetic storms, snowfall and snowmelt data (temperature data, air temperature lapse rate, snowpack), interception/infiltration data (precipitation losses), unit hydrograph (different for each sub-basin). Input data can be divided into two groups: time-dependent and user-specified. User specified input data will be managed through portal and with help of WMS user interface. Time-dependent input data are coming from previous step in cascade simulation - from meteorological simulation.

Hydraulic models (subtask 1.2.2, Appendix 4.3.) are used to assess flood impact. They simulate the propagation of flood wave through various river structures and can be 1-D or 2-D. 2-D models are generally more accurate than 1-D models, however they are computation intensive. The input data of hydraulic models are: topographical data (cross-sections, control structures, terrain map), boundary conditions (hydrograph), initial conditions, roughness. The output data of hydraulic models are water levels and velocities. The sizes of input/output data of 2-D models depend on density of meshes, number of time steps and can be up to hundreds of megabytes. The sizes of input/output data of 1-D models are much smaller, about several to hundred kilobytes. The FESWMS model we will use is currently enabled for parallel operation and we will add the apropriate Grid communication functions. The same solution will be usable with other finite element models, using the same solution scheme (RMA2).

Authentication & authorization (subtask 1.2.3): every action taken either by user, through the portal, or by any software component of the VOFF has to be secure - its initiator has to be clearly identified, and its authorization for the action has to be verifiable. Therefore, we will use Grid-aware security system (Globus GSS) to accept users entering the portal, and whenever a connection between two components will be established.

Data storage (subtask 1.2.1): some of the models used in flood forecasting require a huge amount of temporary storage, or produce massive output sets. We will handle their needs by means of Grid-aware storage management, using distributed storage systems available in the testbed. There is also possible need for storing of several (possibly hundreds of) pre-simulated situations, in order to reduce the response time in critical situations. All of this data will be well-described by elaborate meta-data structure. Of course, all measured data will be archived. The technology needed to solve these problems will be partly covered by the task 3.4.

Visualization (subtask 1.2.2): outputs from a meteorological or hydraulic model are quite useless, unless well visualized by an elaborated tool. The users of the VOFF will have access to such tools (through the portal). It will be possible to display meteorological forecasts, predicted hydrological status of a target area, and estimated water flow and endangered areas. These tools will also be able to produce some quantitative assumptions on possible damage caused in flooded areas, and by means of expert system pick out critical installations, populated areas etc. We plan to use mainly existing visualization tools and the Grid Visualization Kernel developed by our CrossGrid partners (WP1.1) for hydraulic simulation.

2.1. PRODUCT PERSPECTIVE

The final product will be a decision support system [2] for flood forecasting and prevention – it will be a computer program application that analyzes computed and measured data and presents it so that users can make decisions more easily. It will operate according to the needs of its end users - meteorological and hydrological experts, public authorities and common people, who need weather prediction information.

The system will operate in a Grid-aware environment, and therefore its performance will depend upon this environment's stability. The system will be highly fault-tolerant and will try to process requests in an intelligent way, selecting used resources, hardware and networks according to the Grid paradigm.

2.1.1. System interfaces

- data sources (radar, synoptic stations…) – fundamental inputs of data used in simulations (see Appendix 4.4.)
- permanent and temporary storage management (operational database, archive database, WP3.4)
- portal (WP3.1)
- meteorological simulation models (see Appendix 4.1.)
- hydrological simulation models (see Appendix 4.2.)
- hydraulic simulation models (see Appendix 4.3.)
- authentication & authorization infrastructure
- visualization tools (2D and 3D).

2.1.2. User interfaces

Interactions with users will be performed via **portal** that will allow users to manipulate with input data, to perform simulations, to visualize results and to cooperate with other users in VO.

2.1.3. Hardware requirements

No special hardware will be needed. We will use mainly common workstation clusters and supercomputers, if available. The amount of nodes needed will vary according to the number of running simulations. For testing purposes, we will need a minimum of three geographically distributed clusters, of 16 nodes each. A cluster node should have at least 256 MB of RAM.

QoS management in networking should be able to guarantee a stable interconnection of PSE components. In crisis operation mode its stability and speed has to be guaranteed.

The system will archive an excessive amount of pre-calculated simulations, measured and computed historical data and therefore will be quite demanding in the terms of storage capacity of the testbed. The initial estimation is approximately 100 GB for the whole testbed.

The required testbed answer time is 10 minutes to get simulation results, including resources allocation time.

2.1.4. Software interfaces

The system will use complex Grid services, which include Grid Scheduling (possibly Scheduling Agents provided by WP 3.2) and also Grid monitoring (WP 3.3).

- Data sources
  - Grid-FTP
- Permanent and temporary storage management
  - WP3.4 (Data Replica, Data Access)
  - SQL compliant relational database on selected sites, first instance at the II SAS
- Portal
  - HTTP server
  - PHP3
  - CGI
  - JAVA
  - Roaming access
- Meteorological simulation models
  - ALADIN
  - MPICH-G2
  - MPI
  - Globus, Resource management, MPI debugging, Interactive and semiautomatic performance evaluation tools
- Hydrological simulation models
  - HEC-1, HSPF, NLC
  - Globus, Condor, Nimrod-G, MPICH-G2
- Hydraulic simulation models
  - FESWMS, RMA-2
  - Globus
  - MPI, MPI debugging, Interactive and semiautomatic performance evaluation tools
- Authentication & authorization infrastructure
  - Globus GSI
  - OpenSSL CA Management
- Visualization tools (2D and also 3D)
  - Vis5D, GrADS

2.1.5. Communication interfaces

- **Data sources**

  Basic technology used in accessing data sources will be the Grid-FTP protocol and associated tools, developed by the Globus project. The data will be provided by the users of the system, mainly by the SHMI. According to an agreement between the II SAS and the SHMI, the data will be provided on a Grid-FTP accessible server inside the SHMI, from where it will be periodically downloaded and incorporated into databases and datasets at the II SAS testbed site.

- **Permanent and temporary storage management**
  This will be done using the tools provided by task 3.4 and the Grid-FTP protocol. Some of the data used in our application will be stored in files on the testbed servers, some will be in databases (Grid-FTP, task 3.4 software, ODBC, SQL.
- **Portal**
  The portal will be based on a web server and accessible through the standard HTTP and/or HTTPS protocol. The main requirement is compatibility with all common web browsers and other devices (PDA).
- **Simulation models**
  MPI, MPICH-G2 will be used in communication between parts of a parallel simulation.
- **Authentication and authorization infrastructure**
  Globus GSI will be used to perform all authentication inside our application.

2.1.6. Memory constraints

Our requirements for primary and secondary memory are described in section 2.1.3. .

2.1.7. Operations

Normal operation mode

Weather forecasting

Hydrological forecasts

Flood prediction

Crisis operation mode

Flood evaluation

Damage assessment

Flood prevention simulation

2.1.8. Site adaptation requirements

TBD

2.2. PRODUCT FUNCTIONS

The system will perform tasks as mentioned in sections 2 and 2.1 above, and its basic functions include:

- weather forecasting and modeling
- hydrological status forecasting
- flash flood prediction
- hydraulic simulation in case of possible emergency
- data archiving
- status reports to designated authorities
- on-demand simulations of custom scenarios.

2.2.1. Possible usage scenarios

<u>Normal operation mode</u>

In the normal operational mode, the system will be used for common meteorological and/or hydrological forecasting. Meteorological forecasts will be computed (according to common habits of SHMI) twice a day, with the possibility to issue more simulation runs based on more accurate and topical data, when needed. Based on the results of the meteorological simulation, hydrological models may be (and will be) started, to predict river status. Currently, the main user (SHMI) doesn't use this cycle for hydrological simulation, at least not on a regular basis. Therefore it is not clear, whether hydrological simulations will be issued twice a day, once a day or with other period – this is to be specified by the SHMI experts. The last step of the cascaded forecasting – hydraulic simulation – will be probably used only in the case of a substantial increase in water level of the target flow, when there is higher possibility of a flood.

The data gained by running common meteorological model, i.e. the ALADIN model, will be evaluated in order to assess possible local flash flood danger. When there is such a danger, another more accurate and detailed (and also more demanding) model will be used on the locality threatened by the flash flood.

Pre-calculated scenarios

While in normal operational mode, the system will not utilize all of the resources available, therefore it is possible to run some simulations based on *possible* weather scenarios, and to store the results for future use, when the output will be needed in a time shorter than the simulation is able to achieve. This is useful especially for the flash flood prediction and for other critical situations.

Pre-calculated scenarios will be retrieved either manually by the user based on a description of the scenario, or automatically based on matching situation and condition.

Crisis operation mode

When an exceptional event, such as flood or flash flood is about to occur, the system will concentrate its resources on the solution thereof, suppressing all common activities, described in the previous paragraph. The users-experts will need to run simulations for a set of possible weather evolutions, and also the pre-calculated scenarios will be used.

The word *mode* does not refer to a real mode of operation, which is to be set explicitly by the user. There will be an optional priority of a running simulation.

2.2.2. Use cases

The use cases of our application are defined in **Figure 4** and **Figure 5**. There are 5 basic types of users, each of them authorized to perform only certain tasks.

Administrator

This user can manage the whole portal, its users and security settings. He can also manage computational resources in the Grid.

Developer

This user is responsible for model development. He can therefore create, modify and debug models in our application; he can also analyze their performance (WP3.3 will produce this) and store them into repository. Furthermore, he is also responsible for the development of portal interface.

Expert

This user is a meteorological expert. He manages the model repository and prepares input data for simulations. He is also responsible for model validation and calibration, definition of simulation parameters and settings and consumer support. In crisis operational mode, this user performs what-if analysis (this can be done also in normal operational mode, as a preparation for a possible crisis scenario).

Operator

This user is responsible for the common tasks, performed within our application. He runs simulations, creates tasks consisting of one or more linked simulations, selects data for these simulations and distributes products of these simulations to their consumers.

Consumer

This is a common information consumer – it may be just an ordinary civilian, a TV or radio employee responsible for weather forecasts, an insurance analyst, or anyone else interested in the products of our application. S/he can retrieve information (some of them maybe only according to a paid subscription), visualize and analyze them; s/he can also consult experts, when needed.

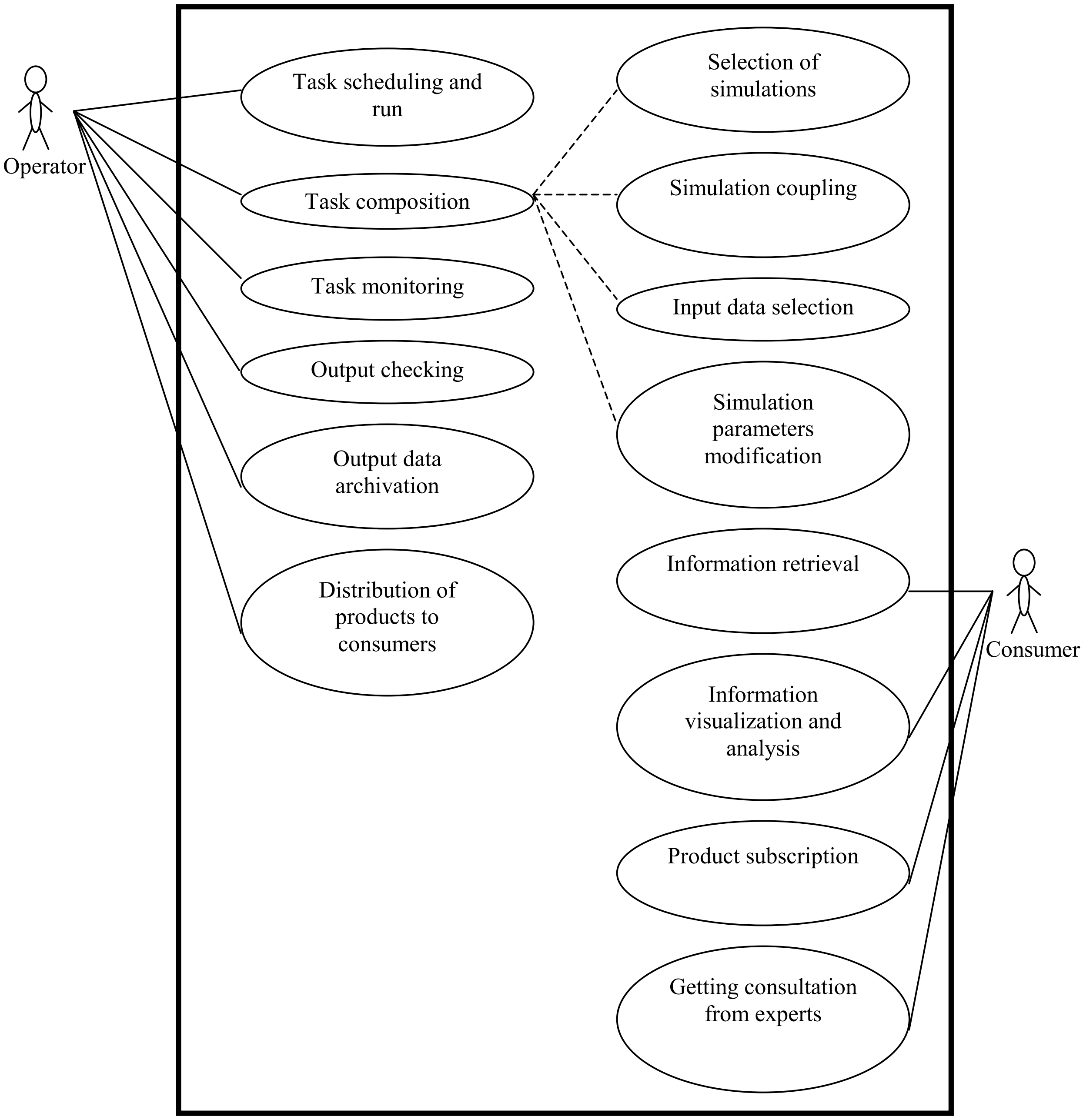

Figure 4 Use cases diagram – part 1

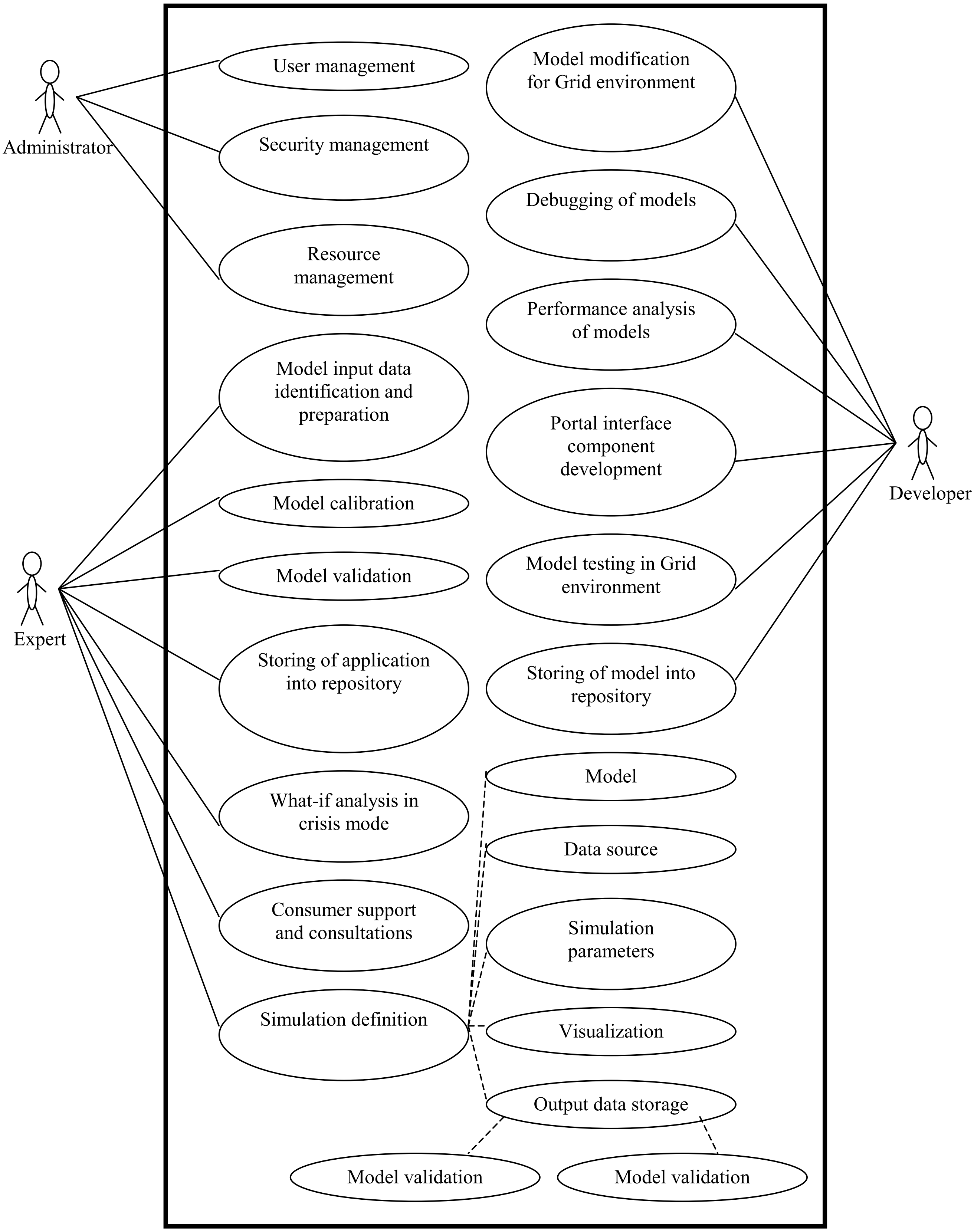

Figure 5 Use cases diagram – part 2

2.3. USER CHARACTERISTICS

The participants in VO can be divided by their role in VO into four basic categories (**Figure 6**):

- Data providers – the owners of the data needed for flood simulations
- Cycle providers – the providers of computational resources
- Storage providers – the providers of temporary and permanent storage space
- Users – will perform flood simulations and disseminate the results to the other users in VO.

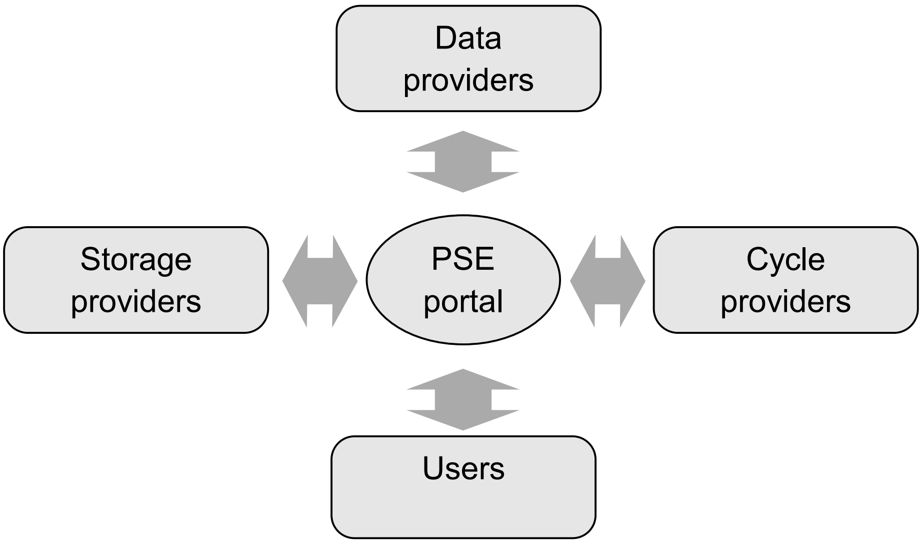

Figure 6 Roles of users in VO

The system will have a dynamic user structure, and each human entity in the system can act and interact with the system in several ways. Basic user groups will be:

- Crisis management team – will use the system in decision process. They will be able to access historical data, pre-defined flood scenarios defined by experts in advance and to consult the decisions with them.
- Various experts - will use the system for simulation and prediction purposes. They will use it to create weather forecasts, hydrological reports, etc.
- Authorities - will receive common and emergency reports about hydrological situation, possible threats, and will be responsible for taking appropriate steps in accordance with their authorization in public life (e.g. river authorities).
- Public – the information from simulations (weather forecasts, flood warnings…) will be disseminated through the portal to various users.
- System administrators – will be responsible for stability and availability of the system.

2.4. CONSTRAINTS

TBD

2.5. ASSUMPTIONS AND DEPENDENCIES

The system is designed for use in a distributed network environment. It will be deployed on several computers running the Linux OS. Some topological data for hydraulic and hydrological simulations are currently prepared in a Windows™ application, but this step will not be performed in the Grid environment. The final user of the designed system may also change her/his requirements.

Requirements to other workpackages:

WP	Requirement	Intended use	Dependancy
1.1.3	Grid Visualization Kernel	Effective visualization of remote simulation results	Low
2.2	MPI code verification and debugging	Support for porting simulation models to grid environment	Medium
2.4	Performance evaluation tools	Needed during integration phase	Medium
3.1	Portals and roaming access	Building unified and consistent user interface	High
3.2	Grid resource management	Efficient running of simulations in the grid	High
3.3	Grid Monitoring	Providing information about grid to the user	High
3.4	Optimisation of data access	Optimal data access	Medium

2.6. APPORTIONING OF REQUIREMENTS

To this date no requirements are known, which could be delayed. Our application will be one final product developed accordingly to the requirements stated in this document.

3. SPECIFIC REQUIREMENTS

The specific requirements of the system will depend on specific needs of participants in the VO. Therefore they cannot be expressed in early stages of the design process. As the system will be evolved and first prototypes of components will be available, the specific requirements will be added. For milestones see Appendix 4.5.

In the first year, we will concentrate on adaptation of meteorological, hydrological and hydraulic models to Grid environment (as they are essential for operation of the system). Models appointed by experts will be ported by developers to the Intel Linux architecture and prepared for running in the CrossGrid testbed. The prototypes will be analyzed and their requirements for performance, storage, and interfaces will be specified. Then we will start to build VO portal and the prototypes of the models will be made available to the experts. The development of the portal will start from basic functions needed for authentication of users, for job submission and monitoring. The requirements of the users will be gathered and functionality of the portal will be enhanced according to their needs.

4. APPENDICES

4.1. ALADIN METEOROLOGICAL MODEL

The meteorological simulation model proposed for our application is the ALADIN model, currently in use at the SHMI. We plan to run its parallel version, suitable for workstation clusters in the CrossGrid testbed on our local PC cluster. The simulation model is computation-intensive, requiring currently about 90 minutes on a single workstation. Its input and output data sets are relatively large, ranging from 50 to 150 MB per simulation run. Because of the fundamental role of weather forecasts in our application, this part of the cascaded simulation requires high availability of resources (24/365).

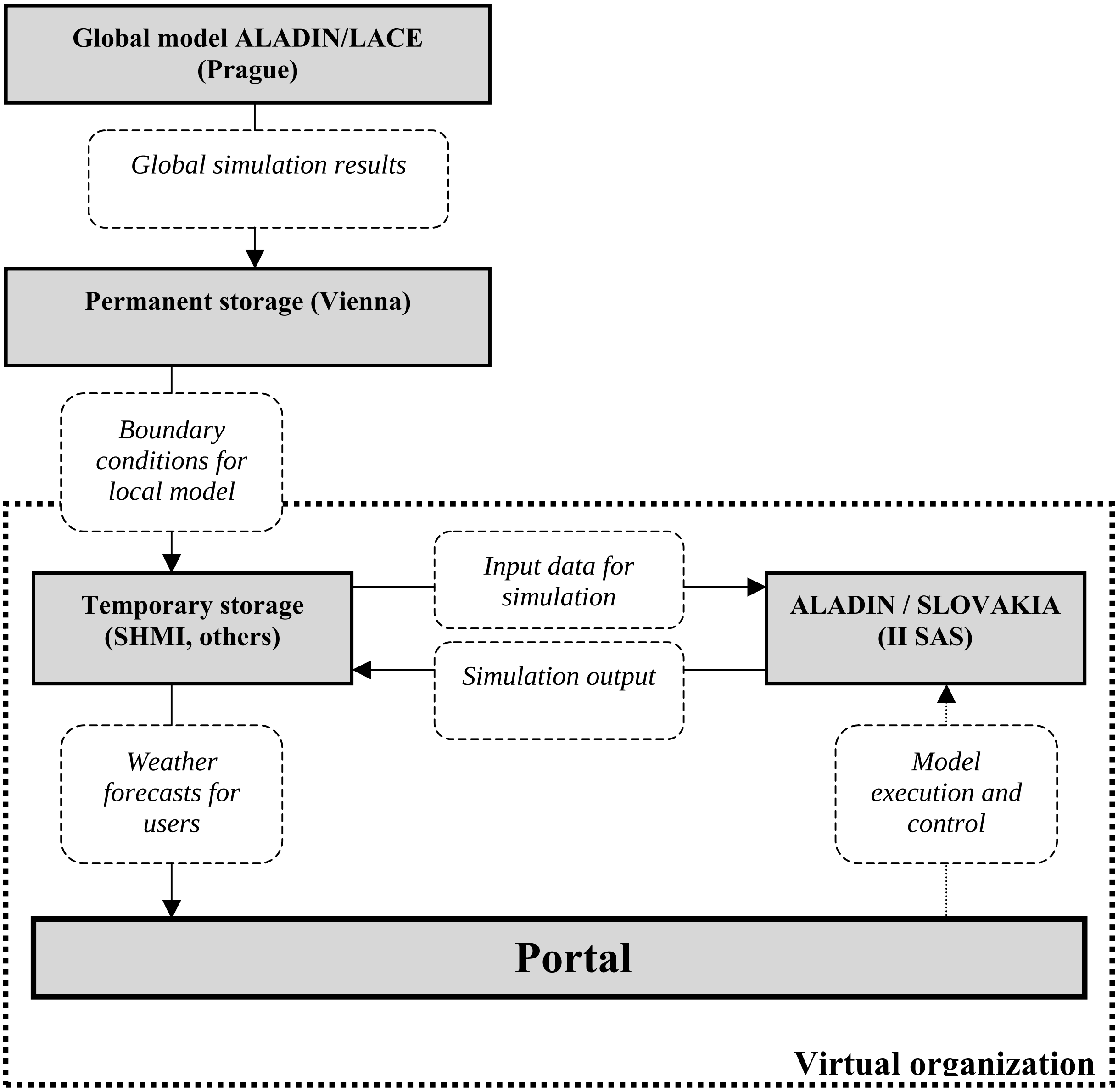

Figure 7 Meteorological simulation scheme

The input data is taken from ALADIN/LACE global model, computed in Prague. This data is stored in Vienna, and from there it is transferred via FTP connection to SHMI. Here it comes into our VO. It is stored in a temporary storage area, and when needed, used to simulate local weather development via the ALADIN/SLOVAKIA simulation model. The results of this model are transferred to the storage space of our application (**Figure 7**). They can be used for visualization, analysis and – of course – for the hydrological simulation.

The ARPEGE -> ALADIN/LACE -> ALADIN/SLOVAKIA model chain

ARPEGE is a global NWP (Numerical Weather Prediction) model operated in Météo France. It is part of the ARPEGE/IFS system developed in cooperation between Météo France and ECMWF (European Centre for Medium range Weather Forecast).

ALADIN is a LAM (Limited Area Model) developed jointly by Météo France and cooperating countries. It can be viewed as an extension to ARPEGE. The main purpose is to provide more detailed short range forecasts inside a limited domain of interest. At present, the ALADIN model is operated in 13 Euro-Mediterranean countries. `

Borders of ALADIN integration domain act as open boundary. LBC (Lateral Boundary Conditons) must be specified on such boundary. They are provided by driving model – global model or LAM integrated on larger domain (there can be multiply nested models). Interaction between driving model and nested model is called coupling. In ALADIN one way coupling is used. It means that driving model is not affected by nested model.

Integration of each NWP model starts from initial state, so called analysis. In case of global model, analysis is a combination of observations and first guess – model forecast from previous integration valid at analysis time. This combination is done in optimal way, so that it minimizes analysis error. Including of observations into initial state is called data assimilation.

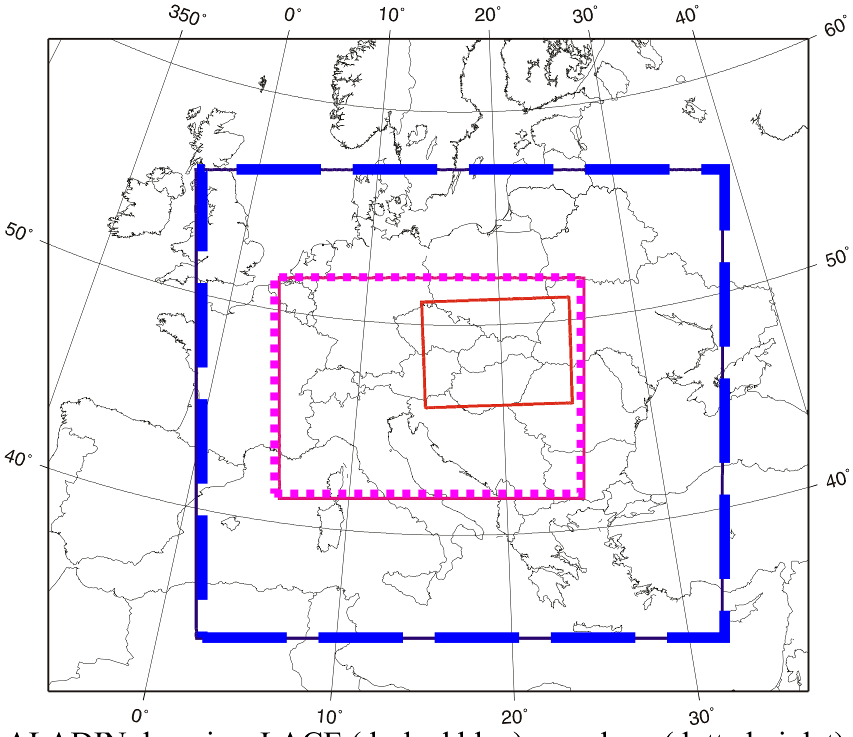

Figure 8 ALADIN domains: LACE (dashed blue), envelope (dotted violet), SLOK (red)

In case of LAM, there are two main possibilities. The initial state can be taken directly from driving model without including new observations. Analysis is just interpolated into finer mesh of nested model. Such approach is called dynamical adaptation, since nested model only adapts forecast of driving model to better resolved orography and climate data.

The second possibility is to use analysis of driving model in combination with observations. Assimilated observations bring new information on scales which are resolved in nested model, but are missing in driving model. Influence of assimilated observations to LAM forecast disappears after first few hours of integration, because evolution is dominated by LBC. LAM data assimilation is therefore important mainly for nowcasting.

Somewhere between is the method called blending. LAM analysis is prepared using large scales from driving model analysis and small scales from LAM first guess. Blending is not true data assimilation, since no observations are used on LAM level.

Six Central-European countries (Austria, Croatia, Czech Republic, Hungary, Slovakia and Slovenia) are associated in the LACE (Limited Area for Central Europe) community. Common application is operated in Prague – ALADIN/LACE. It is coupled to ARPEGE. LACE domain covers the central part of Europe (dashed blue line in **Figure 8**).

Most of LACE countries have their national applications coupled to ALADIN/LACE. In order to reduce the volume of transmitted data, only coupling data from envelope domain are distributed (dotted violet line in **Figure 8**). The domain was chosen to covers all national subdomains.

Since the orography of Slovakia is complicated, SHMI (Slovak HydroMeteorological Institute) operates its own application – ALADIN/SLOVAKIA. It is coupled to ALADIN/LACE. SLOK domain covers mostly the territory of Slovakia (red line in **Figure 8**).

Model description

The ARPEGE and ALADIN models are unified to the maximum degree possible. There are the following common features:

- Dynamical part: hydrostatic primitive equations (Euler equations modified by hydrostatic assumption)
- Basic prognostic variables: wind components *u*,*v*, temperature *T*, specific humidity *q* and surface pressure p_S
- Spectral transform method (part of computations is performed in spectral space)
- Time integration scheme: 2-time level with semi-implicit correction
- Advection treatment: semi-Lagrangian
- Vertical coordinate: hybrid η (coordinate surfaces follow terrain close to the ground and approach pressure levels aloft)
- Parametrization of subgrid scale processes: gravity wave drag, turbulent diffusion, convection, precipitation, radiation, soil processes
- Horizontal diffusion (simulates energy cascade towards unresolved scales)
- Initialization: Dolph-Chebishev filter (suppresses unrealistic gravity wave activity in early stages of integration).

The ARPEGE, ALADIN/LACE and ALADIN/SLOVAKIA models are compared in **Table 1**. The main differences between ARPEGE and ALADIN models arise from geometry.

ARPEGE as global model uses spherical domain which does not have lateral boundary. It uses stretched grid with variable resolution. The highest resolution is around pole of contraction, which is placed in central France. The lowest resolution is at the opposite side of the globe. Spherical geometry implies the usage of spherical harmonical functions as a basis for spectral decompositions. Expanded fields have to be truncated at certain wavenumber. Triangular truncation is used, since it respects isotropy.

ALADIN is LAM. Integration domain is bounded, therefore LBC are required. One of the following conformal projections is used: Mercator (equatorial regions), Lambert (middle latitudes) or polar stereographic (polar regions). The integration domain is rectangular in chosen map coordinates. Sines and cosines are used for spectral decompositions. This requires biperiodic fields. Biperiodicity is achieved by adding artificial extension zone, so that domain becomes topologically equivalent with torus. Elliptical truncation is used to preserve isotropy.

Table 1: Comparison of ARPEGE, ALADIN/LACE, ALADIN/SLOVAKIA models

	ARPEGE	ALADIN/LACE	ALADIN/SLOVAKIA
Projection	stretched spherical geometry (*c*=3.5)	Lambert conformal	Lambert conformal
Grid size (points)	600×300	229×205	109×79
Truncation	T199	E79×71	E36×26
Horizontal resolution	19 – 235 km	12.2 km	7.2 km
Number of vertical Levels	41	37	31
Timestep	900 s	514.3 s	337.5 s
Forecast length	96 h	48 h	48 h
Daily integrations	00,06,12,18 UTC	00,12 UTC	00,12 UTC
Driving model	–	ARPEGE	ALADIN/LACE
Coupling frequency	–	3 h	6 h
Data assimilation	4D var	blending	none
Computer platform	Fujitsu VPP5000 (31 processors)	NEC SX4/3A (3 processors)	DEC Alpha XP1000 (1 processor)

Observations

In the ARPEGE → ALADIN/LACE → ALADIN/SLOVAKIA model chain only ARPEGE has its own assimilation cycle. It uses the following types of observations:

- Surface measurements: synoptical stations, ships, buoys
- Upper air measurements: radio probes, profilers, aircrafts
- Distant measurements: satellites.

Some slowly varying parameters are kept constant during integration. They can be initialized either by analyzed values or by monthly climatological means. Typical examples are sea surface temperature or vegetation index.

Products and users

NWP models work with most complete 3D reperesentation of atmospheric state. They can predict not only prognostic fields, but in principle every parameter which can be diagnosed from prognostic variables.

In case of ALADIN/SLOVAKIA, surface fields are of greatest interest. Upper air fields are not so interesting, since SLOK domain is too small from synoptical point of view. Most frequently used parameters are temperature, wind, cloudiness and precipitation (**Figure 9–Figure 12**). Vertical profiles and cross sections are important mostly for meteorology and aviation (**Figure 13–Figure 16**).

Outputs from ALADIN/SLOVAKIA model can be used by a wide range of users. Most important of them are:

- General public
- Specialists in meteorology, hydrology and air quality
- Dispersion models
- Hydrological models
- Civil Defence Agency
- Nuclear Safety Agency
- Transportation
- Agriculture.

There are two main limitations of forecast usability; namely range and precision. ALADIN/SLOVAKIA is integrated for 48 hours, so it provides forecasts valid for today and tomorrow only. Longer integration would be desirable for some applications. However, increasing the forecast range would lead to unreliable results, since error of the driving model becomes dominant for longer forecast times.

The second constraint is forecast precision. Imprecise forecast is of low value. Some weather phenomena, such as storms or fogs, are strongly sensitive to local conditions. It is impossible to predict particular storm six hours in advance; however, the model can usually at least indicate that there will be conditions suitable for storm activity.

In NWP models there are three sources of errors; none of them can be suppressed completely. They are:

- approximations used in model formulation (physical approximations, discretization, finite precision of computer arithmetic)
- uncertainty in initial conditions (finite density of observations, instrumental errors)
- uncertainty in external forcing (a priori specification of conditions at opened boundary).

Outputs for hydrological models

At present ALADIN/SLOVAKIA does not provide data for any hydrological model. In general, hydrological models require information about water exchange between atmosphere and land surface (precipitation, evapotranspiration), as well as about processes which can influence runoff (snow accumulation/melting). All these parameters are represented explicitly in ALADIN, but not all of them can be input to hydrological models directly.

Evapotranspiration is very sensitive to vegetation and soil type. Resolution of ALADIN/SLOVAKIA model becomes insufficient if this parameter should be supplied into hydrological model with much denser grid. Another problem is that in ALADIN soil processes are treated separately for each gridbox. If the soil water content in a gridbox is reduced due to "runoff", neighbouring gridboxes are not affected by this change.

Situation is even worse concerning snow cover, since there is no assimilation of snow in ARPEGE. Snow is initialized by its monthly climatological value, which can be very different from the current state. Snow cover from ALADIN is therefore unusable for runoff models.

One possible solution is to provide precipitation and surface temperature as inputs to hydrological model. In such case this model must contain proper scheme for diagnosing evapotranspiration and snow melting.

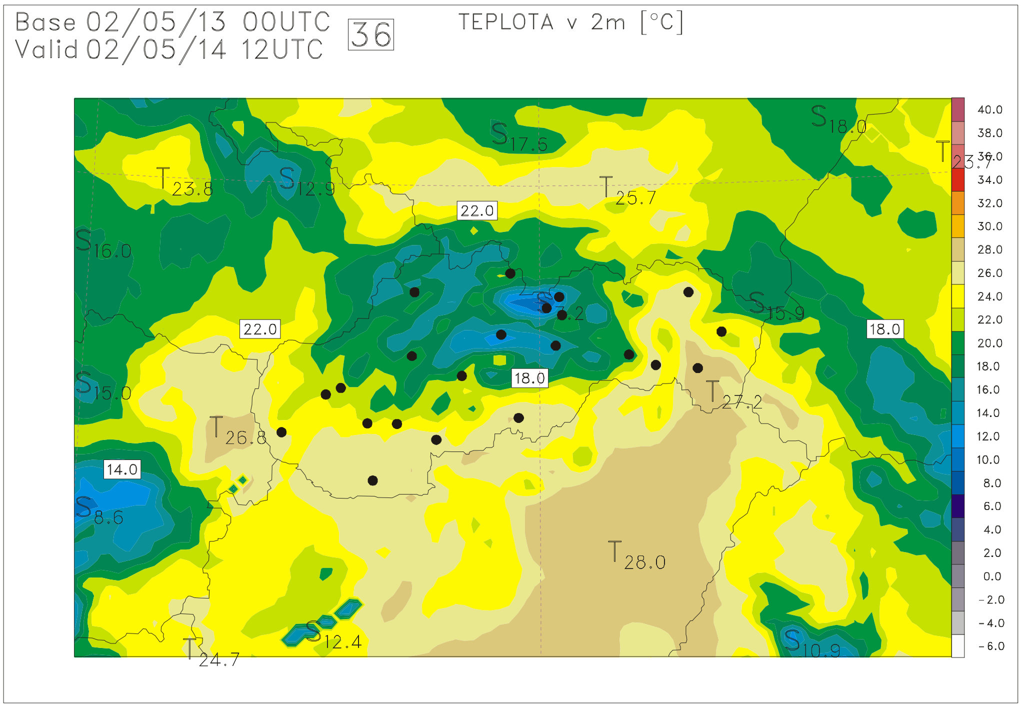

Figure 9 Forecast of 2m temperature

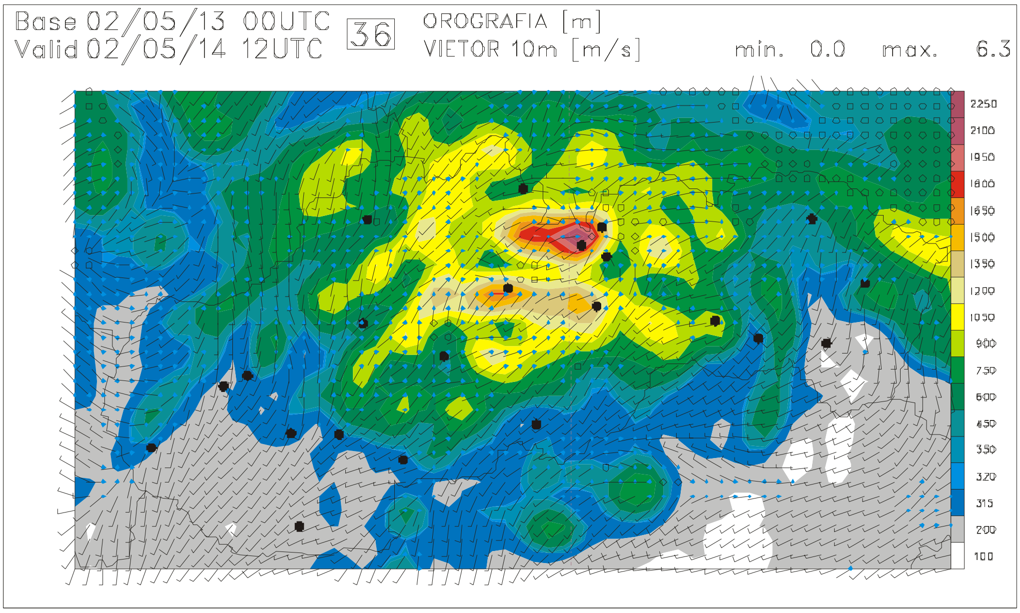

Figure 10 Forecast of 10m wind

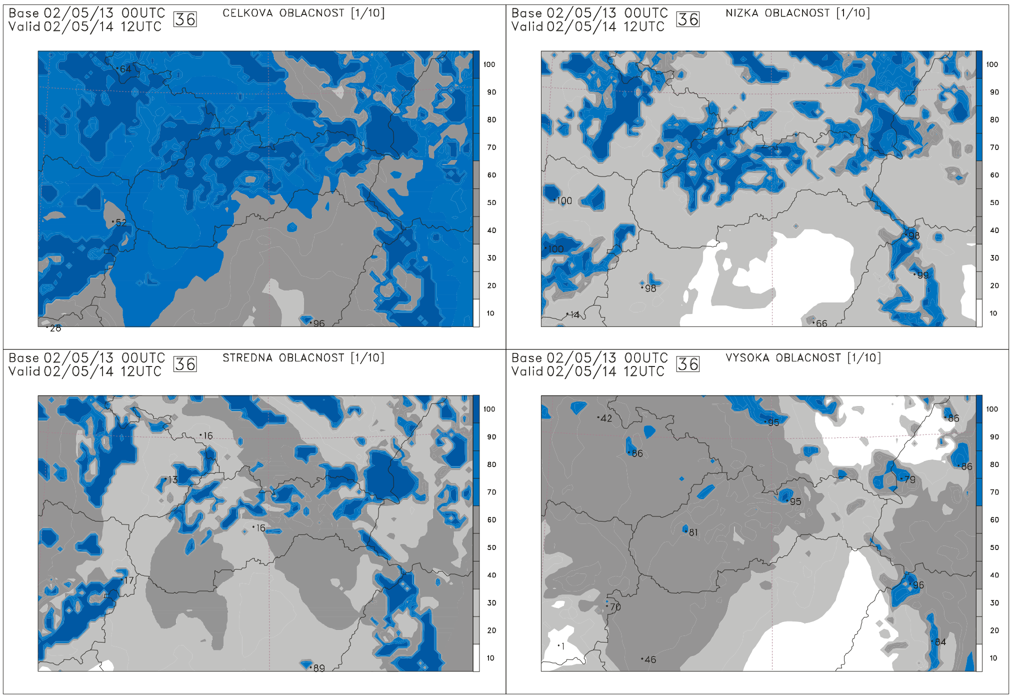

Figure 11 Forecast of cloudiness (total, low, medium, high)

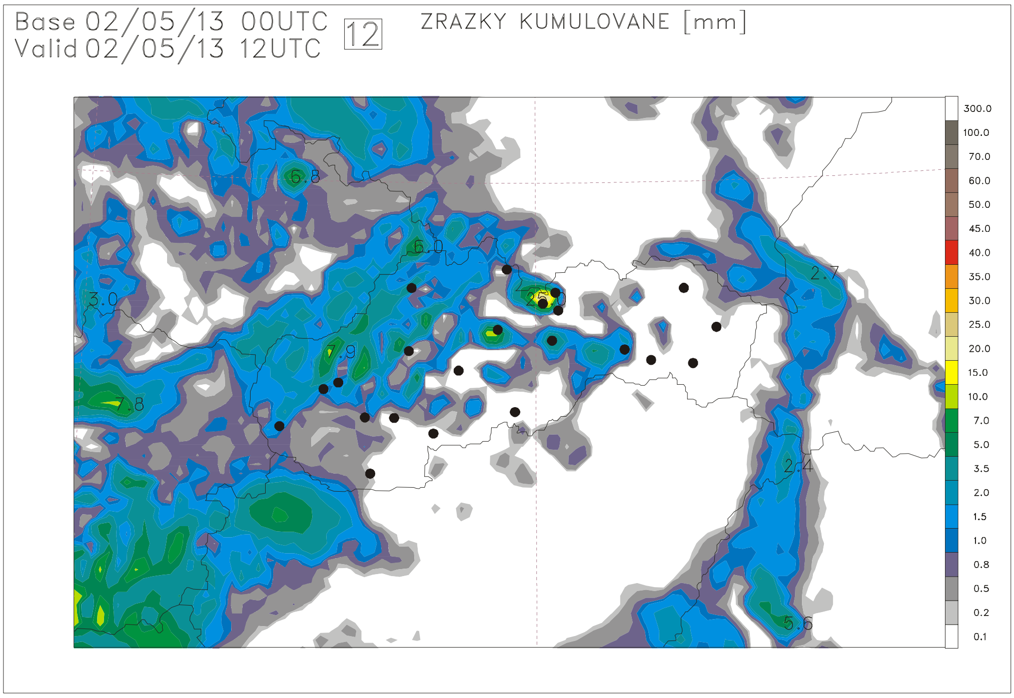

Figure 12 Forecast of cumulated precipitation

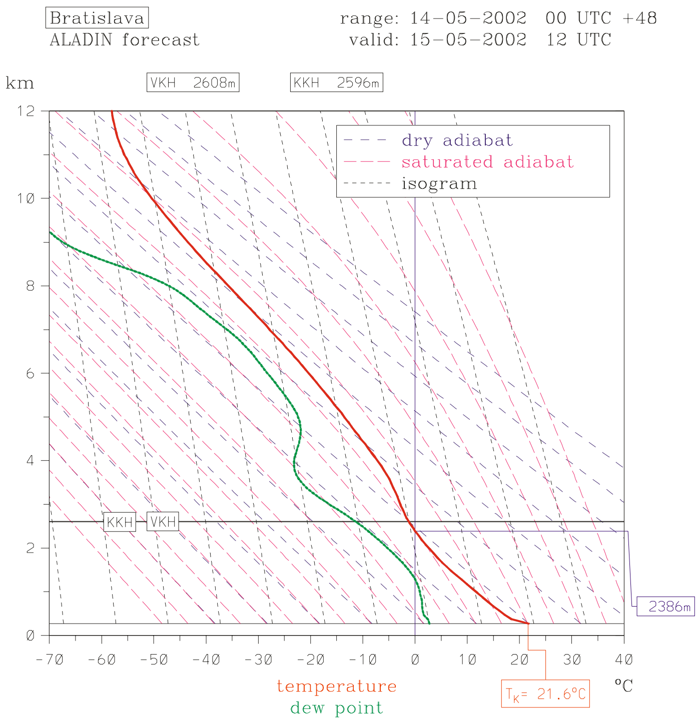

Figure 13 Vertical profile of temperature and dew point

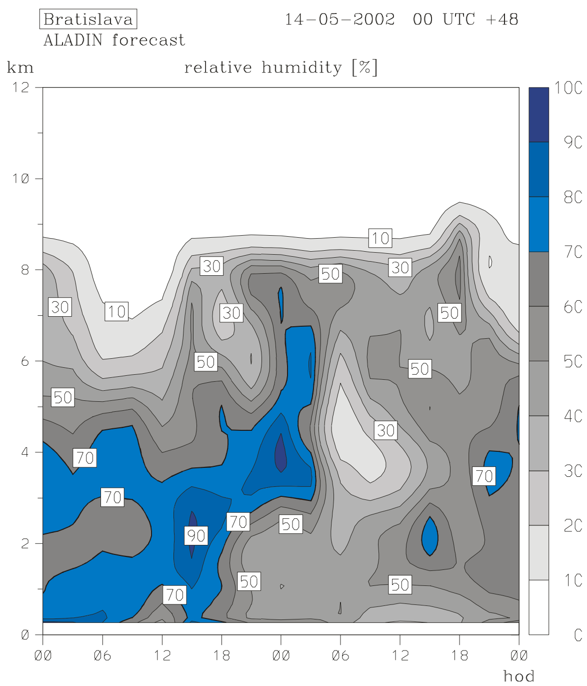

Figure 14 Time cross-section of relative humidity

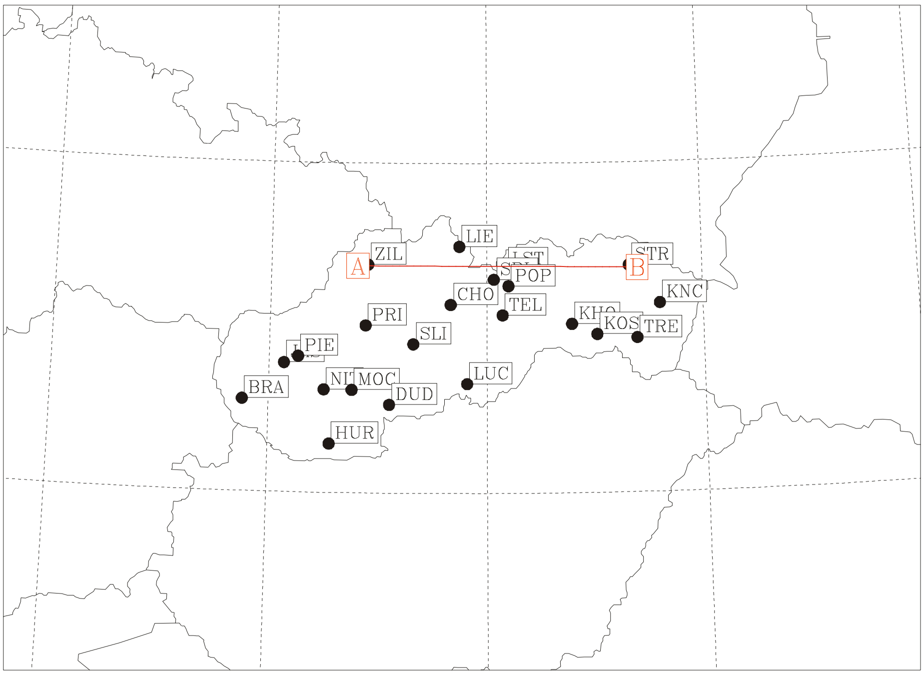

Figure 15 Geographical position of space cross-section

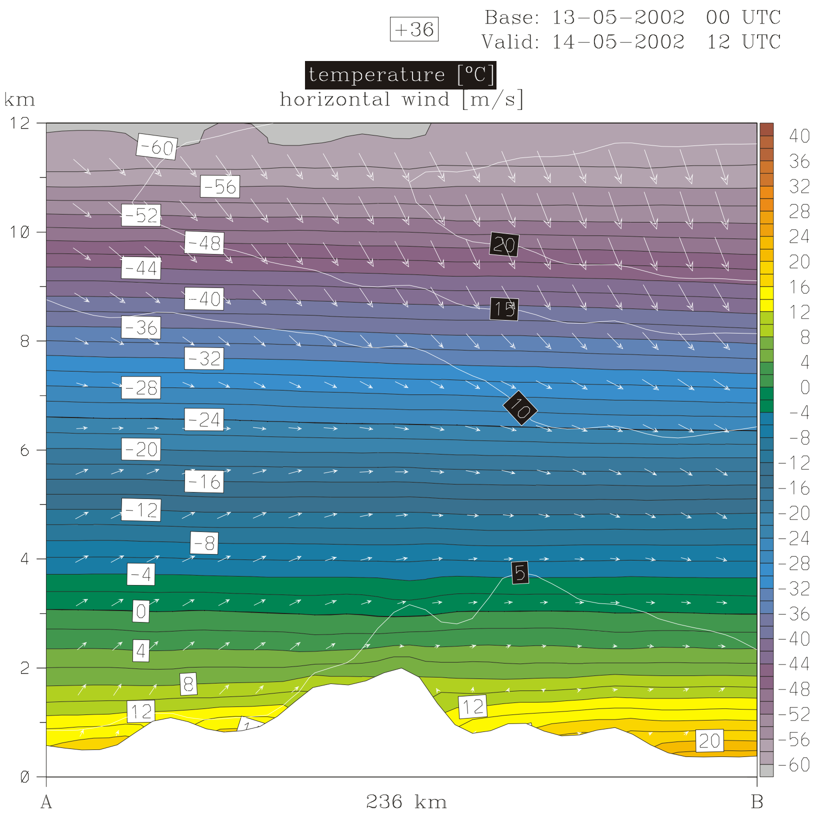

Figure 16 Space cross-section of temperature and wind

4.2. HYDROLOGICAL SIMULATION (RAINFALL-RUNOFF MODELING)

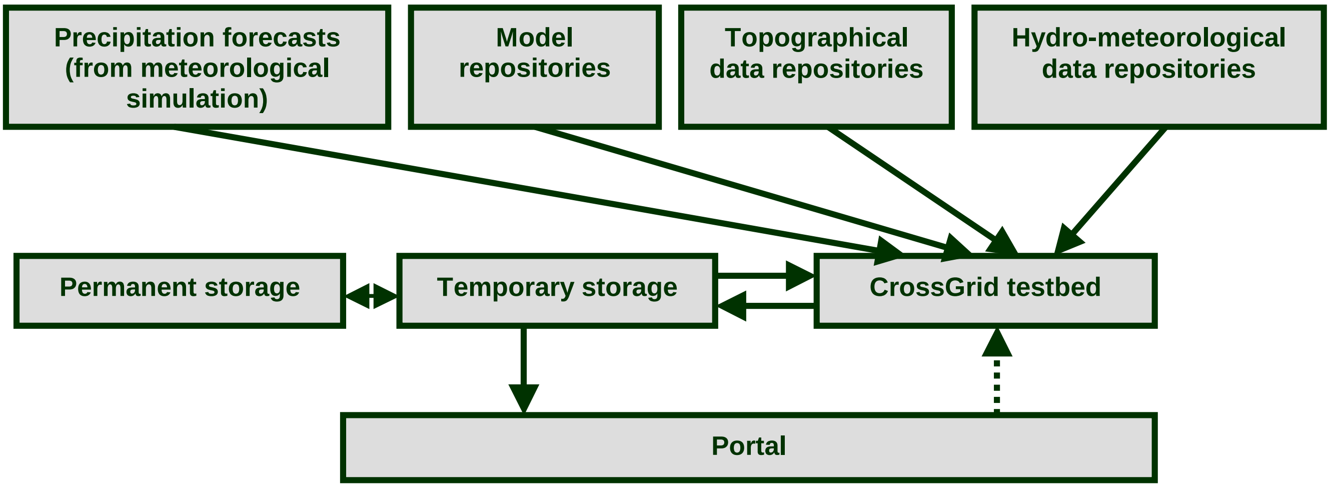

Figure 17 Hydrological simulation in CrossGrid

We will use several hydrological simulation models:

- **NCL** (Non-linear cascade model) available in the form of source program in FORTAN under OS DOS. (For river modeling non-linear cascade model (NLN) in the form of source program in FORTRAN under OS DOS and in Visual Basic under WINDOWS is available).
- The **TR-20** computer program assists the engineer in hydrologic evaluation of flood events to be used in analysis of water resource projects. The program is a physically based event model which computes direct runoff resulting from any synthetic or natural rainstorm. There is no provision for recovery of initial abstraction or infiltration during periods of no rainfall within an event.
- Technical Release 55 (**TR-55**) presents simplified procedures to calculate storm runoff volume, peak rate of discharge, hydrographs, and storage volumes required for floodwater reservoirs. These procedures are applicable in small watersheds, especially urbanizing watersheds, in the United States.
- The **HEC-1** model is designed to simulate the surface runoff response of a river basin to precipitation by representing the basin as an interconnected system of hydrologic and hydraulic components. Each component models an aspect of the precipitation-runoff process within a portion of the basin, commonly referred to as a subbasin. A component may represent a surface runoff entity, a stream channel, or a reservoir. Representation of a component requires a set of parameters which specify the particular characteristics of the component and mathematical relations which describe the physical processes. The result of the modeling process is the computation of streamflow hydrographs at desired locations in the river basin.
- **HSPF** Program for simulation of watershed hydrology and water quality for both conventional and toxic organic pollutants. The HSPF model uses information such as the time history of rainfall, temperature and solar radiation; land surface characteristics such as land use patterns; and land management practices to simulate the processes that occur in a watershed. The result of this simulation is a time history of the quantity and quality of runoff from an urban or agricultural watershed.
- **NLC** Lumped rainfall-runoff model consisting of two principal components: non-linear reservoirs cascade (see NLN) for simulation of the direct runoff, and a single linear reservoir for simulation of the groundwater flow. Input: rainfall, temperature (catchment average), output: discharge at the catchment outlet point.

- **HBV** Semi-distributed rainfall-runoff model based upon the water balance of all model components. Water balance elements: rainfall, evapotranspiration, groundwater runoff, direct runoff. Model components: subcatchments, elevation zones. Inputs: rainfall, temperature, potential evapotranspiration (area averages over all components). Output: flow at outlet points of all components.
- **NLN (River model - hydraulic model)** Lumped river system model based on the non-linear cascade concept. Each river section is simulated by equal fictional reservoirs in series. Model accounts for a tree–shaped river system with topography defined by several parameters. Inputs: flows at the upstream - most points of all tributaries. Output: flows at the downstream - ends of each of the river sections.
- **ERM (Empirical - Regressive Model)** The conception of developing ERM is based on principle of autoregressive model created by Box and Jenkins. These models are used for hydrological forecasting. The simplest regressive model is relational with the following discharge $Q_{(N)}$ being function of previous discharge $Q_{(N-1)}$ and previous rainfalls $Z_{(N-1)}$:

  $\mathbf{Q_{(N)} = K * Q_{(N-1)} + P * Z_{(N-1)}}$, where K, P - parameters of regressive model.

  These parameters are determined by regressive analysis of time series of discharges and rainfalls in selected time interval.

  APPLICATION RANGE:

  Basins with area 100-5000 km^2, elevation up to 2000 m a.s.l.

  One day - daily step

  Shortened step – during flood situations, every 3 hours

  FORECAST PURPOSES: water management – reservoir operation

  OPERATIONAL DATA NEEDS: daily precipitation, average daily temperature and discharge data

  OUTPUT DATA: numerical tables and graphs of discharge

  FORECASTING TIMELEAD AND UPDATING CAPABILITY: the model is predestined for forecasting with the use of measured previous discharge for updating. Much less precision is obtained by simulation without updating. All model parameters are externally derived.

  APPLICATIONS: the first application for runoff forecasting in the Bodrog River system - Eastern Slovakia, later for Orava and Liptovska Mara reservoirs.

Processing input data

Input data are processed in WMS (Watersched Modeling System) graphical environment [4], similar environment is used also for hydraulic 2D simulation (see Appendix 4.3.). Example of one of the hydrological models is given below.

4.3. HYDRAULIC SIMULATION

Hydraulic simulation is the last step in cascade simulation. It takes output from hydrological simulation (discharges) as input and computes the state of flood (flooded areas, water levels, depths and velocities).

The main inputs of hydraulic simulation as follows:

- Topographical data: according to used models and available data, topographical data may be cross-sections, LIDAR data.
- Hydrological data: discharges, hydrographs. These data may be obtained from hydrological simulations or historical data.
- Roughness: tables of roughness values of main land categories (forest, high grass,…). Orthophotomap can be used for determining land covers of simulated areas.

There are also several other secondary inputs, which are often not significant: wind, rainfall, evaporation in the simulated areas.

The main outputs of hydraulic simulation are water level and velocities of every mesh-point in the simulated areas. These outputs may be visualized for better perception.

Topographical data

There are several sets of cross-sections at Váh River pilot site. One of them is shown in following figure:

Figure 18 Example of cross-sections in pilot site (light green line segments)

Example of a cross-section looks as follows:

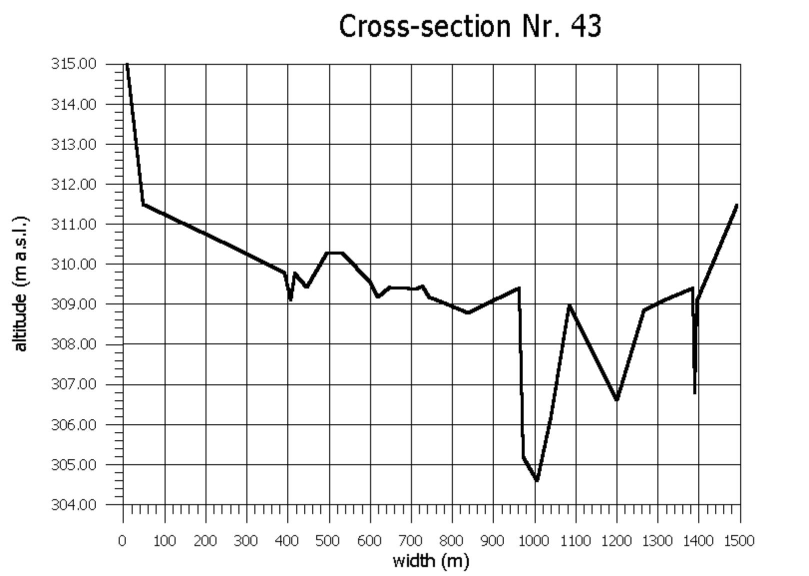

Figure 19 Example of a cross-section

LIDAR (Light Detection and Ranging) data have been obtained for Váh River pilot site. LIDAR data are the best (and the most expensive) topographical data for 2D hydraulic simulation (grid 1x1m, horizontal precision 0.5 m vertical precision 0.15 m). Part of the LIDAR data is visualized as follows:

Figure 20 LIDAR data example – part of pilot site

LIDAR data are large (several hundreds megabytes), they could and are converted into TIN (Triangulated Irregular Network) format in order to reduce its size. In TIN format, nodes inside a plane are eliminated because they can be calculated from the nodes at the corners.

Hydrological data

Hydrological data can be obtained from hydrological simulation or recorded by gauge stations at the simulated areas. They can be also obtained from historical data of previous floods. The discharge of a flood in July 2001 is shown as follows:

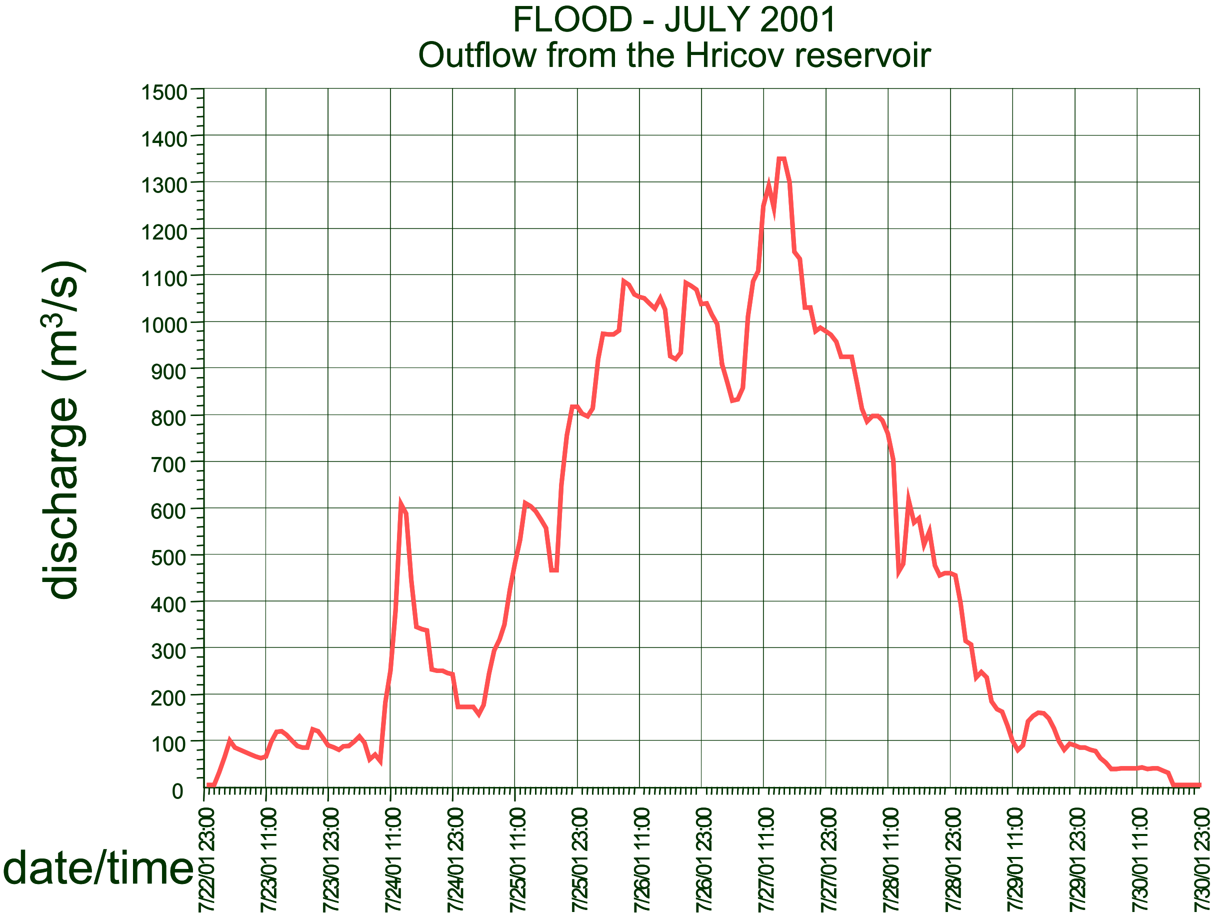

Figure 21 Example of discharge hydrograph

Roughness

Roughness can be determined according to type of land covers. Some values are shown as follows:

Table 2: Estimated values for roughness

TYPE AND DESCRIPTION OF CHANNEL	MANNING´s n	
	Min	**Max**
NATURAL CHANNELS OF A LARGE RIVER		
Regular cross-section without boulders or bush	0,025	0,060
Irregular, rough cross-section	0,035	0,100
FLOODPLAINS		
1. PASTURES WITHOUT BUSH		
Low grass	0,025	0,035
Higher grass	0,030	0,050
2. AGRICULTURAL FIELDS		
Without corn	0,020	0,040
Standing corn	0,035	0,045
Laid corn	0,030	0,050
3. BUSH		
Scattered bush with dense weed	0,035	0,070
Thin weed	0,035	0,080
Dense weed	0,045	0,160
4. TREES		
Dense willows	0,110	0,200
Area of cut trees, with trunks left	0,030	0,050
Forest with bush	0,080	0,160

The types of land covers of the simulated areas can be determined by help of orthophotomap.

Processing input data

Data are processed in SMS (Surface-water Modeling System) graphical environment. The SMS (Surface-water Modeling System) package [3] is one of the most advanced, powerful, and comprehensive two-dimensional surface-water modeling packages available. The software models the water surface elevation, flow velocity, contaminant transport and dispersion, and sediment transport and deposition for complex two-dimensional horizontal flow problems.

SMS has graphical pre- and post-processor for a host of 1D and 2D hydrodynamic modeling of complex river systems, lakes, estuaries and coastal systems (**Figure 22**) including the finite-element analysis packages RMA2, RMA4, HIVEL2D, SED2D-WES, and FESWMS, and the one-dimensional step backwater profile program WSPRO [3]. Feature objects patterned after the ARC/INFO GIS data model are used to construct conceptual models that define the mesh domain and material zones. Boundary conditions and other parameters are assigned to the feature objects. Meshes can be generated automatically from the conceptual model using sophisticated tools available in SMS. Materials and boundary conditions are assigned automatically to the appropriate mesh nodes or elements. SMS is available for Windows and most UNIX graphic workstations. SMS can import data from many different formats. Here are LIDAR data visualized in SMS:

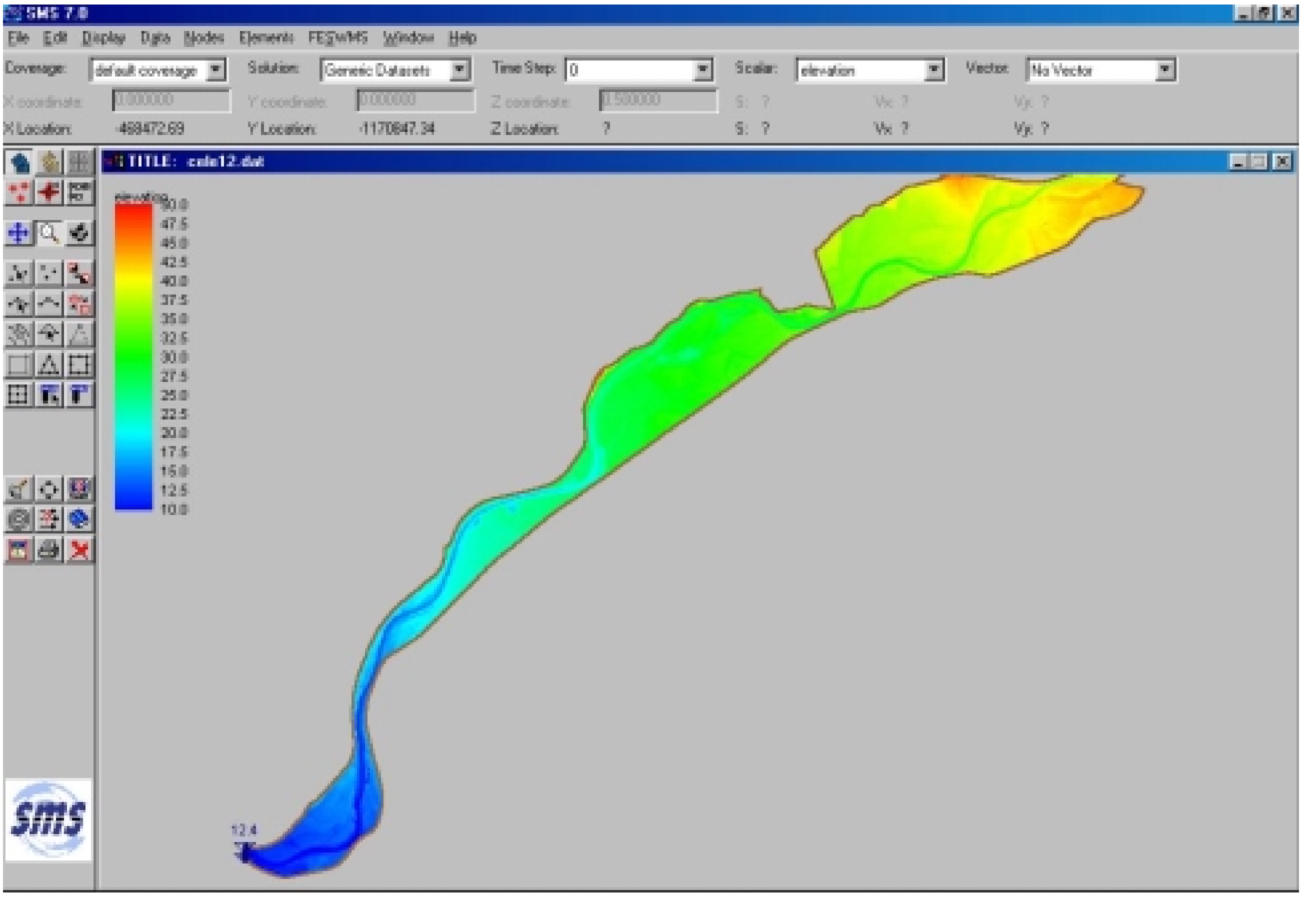

Figure 22 LIDAR data visualized in SMS

A mesh will be generated by SMS for FESWMS (Finite-Element Surface-Water Modeling System) model. Users can select the simulated areas; choose densities in mesh and types of elements.

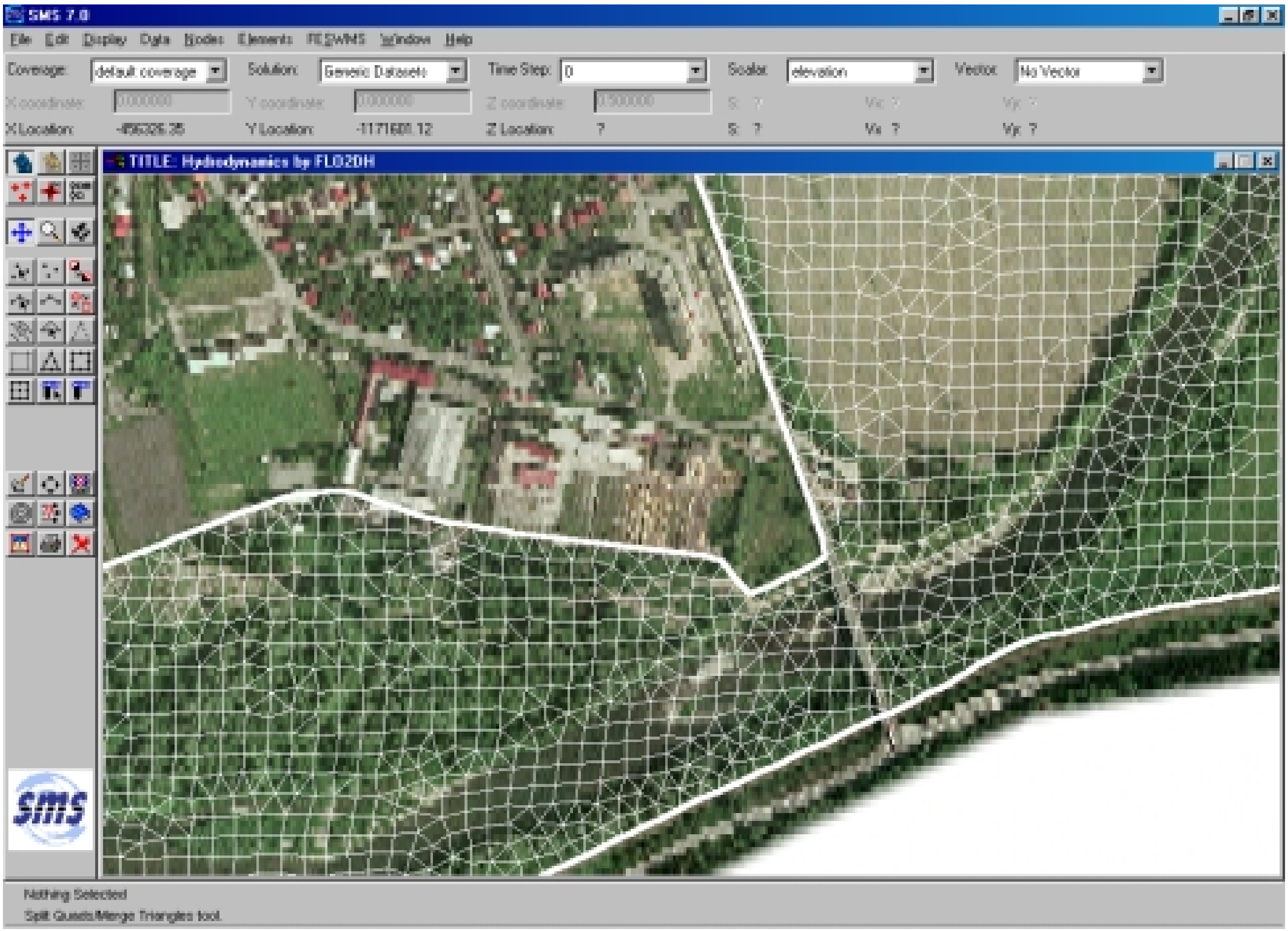

Figure 23 Example of mesh in SMS

Running simulation

FESWMS is computational and memory intensive. For a large area, it may take a long time and need a large amount of memory to run. Therefore, FESWMS has been parallelized by II-SAS. The parallel version has been tested on clusters of workstations as well as SGI Origin 2000.

The execution time of an experiment is shown as follows:

Table 3: Speed-up results

Number of nodes	Time
1,2	Not enough memory
3	20:12
4	15:56
5	13:03
6	11:11
7	10:27
8	10:10

The size of input data of the experiment is about 15MB and the output data is 9MB.

As FESWMS will run on high-performance platforms while SMS graphical environment runs on client PC, a script for remote processing has been written by II SAS. The input/output files are compressed before transferring in order to reduce network load.

Visualization

The results from FESWMS are water levels and velocities. These values need to be visualized for better perception. SMS graphical environment or some GIS (Geographic Information System) software can be used for visualization. Examples of visualized simulation results in SMS are as follows:

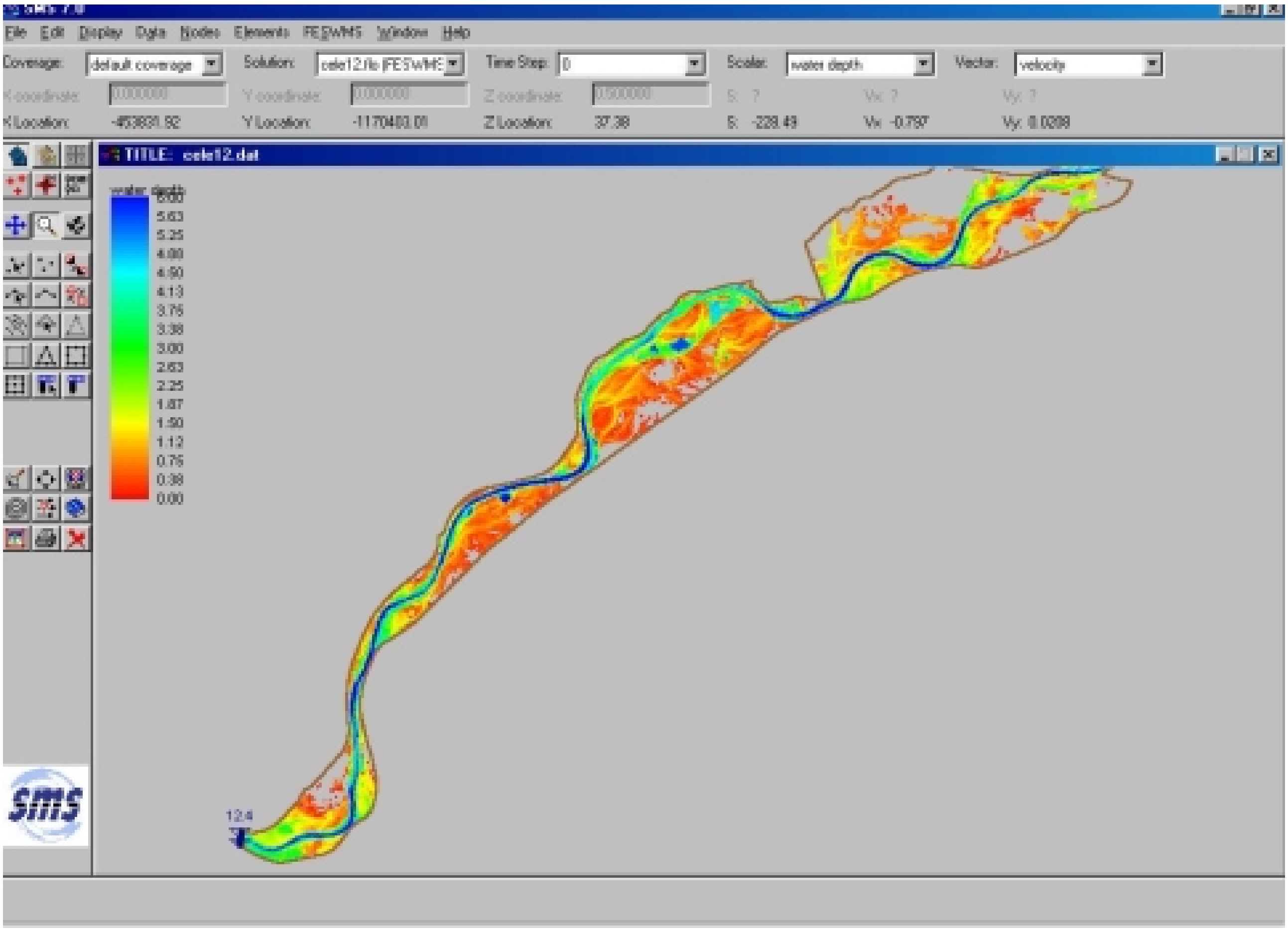

Figure 24 Visualization of water depth at Váh River pilot site

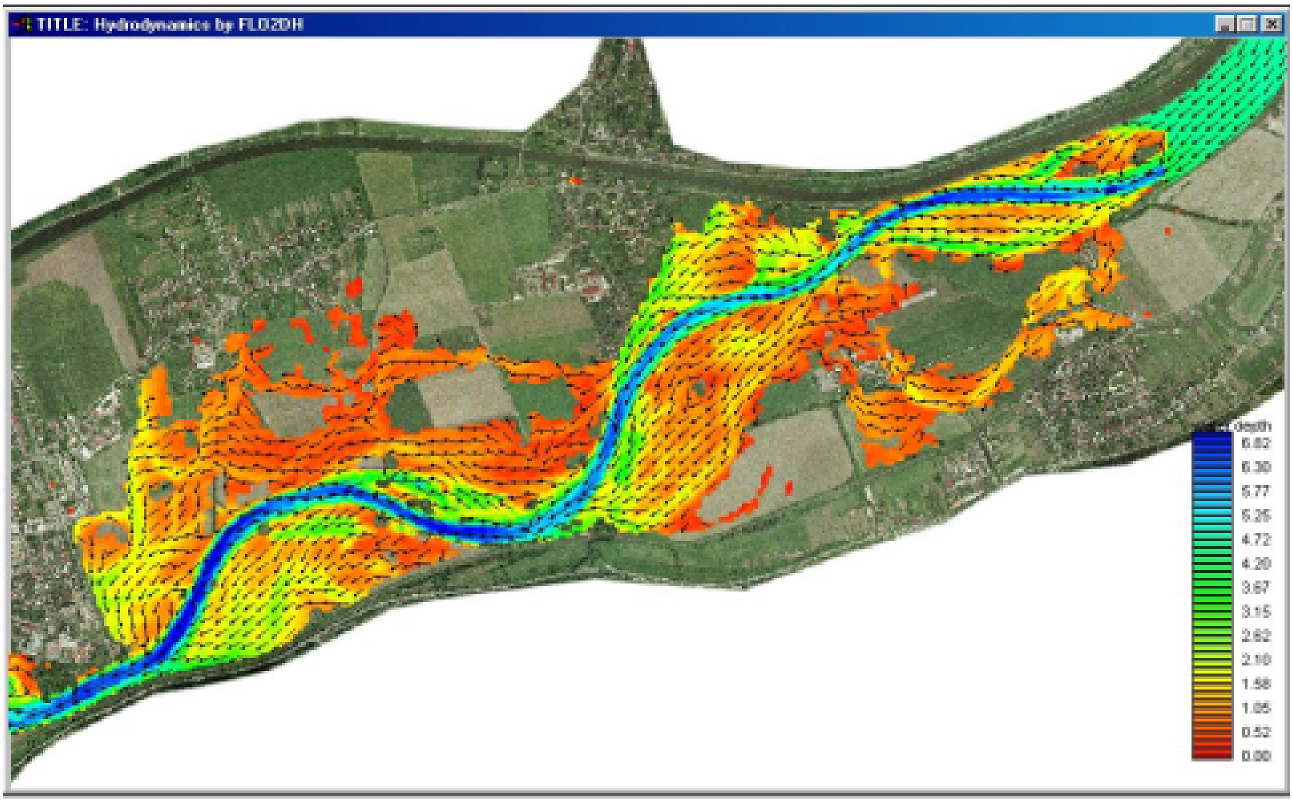

Figure 25 Visualization of water depth + velocity + orthophotomap

Remote processing

The fact is that SMS graphical environment runs on PC client while FESWMS runs on high-performance servers. Therefore, II SAS has written scripts that can execute FESWMS on servers from SMS client via CORBA or SSH. The input/output files are compressed before transferring in order to reduce the load of network.

In the ANFAS project, the connection from ANFAS core server (hosted by EDAS-MS&I) to i-cluster (IMAG-INRIA) is done in two steps in order to get around firewall: the first step via CORBA and the second step via SSH as in the following picture:

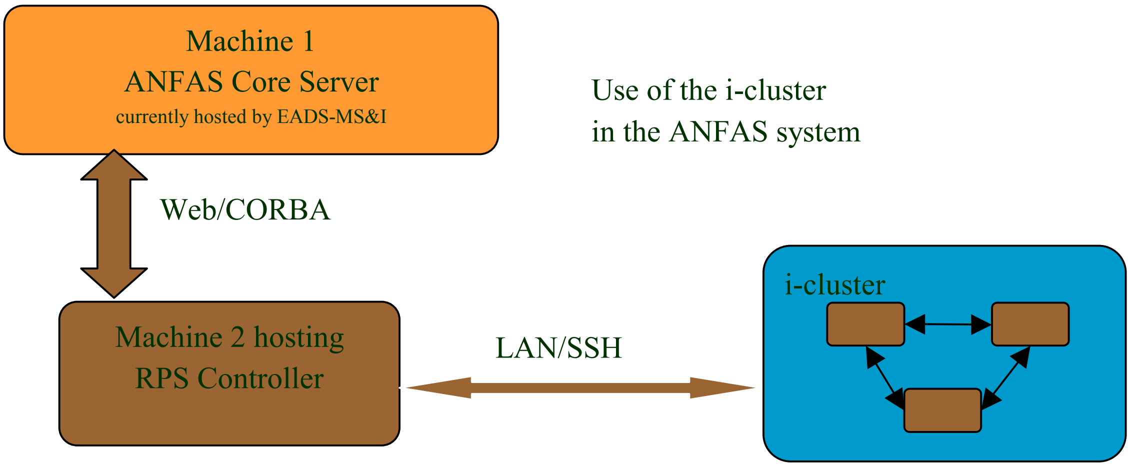

Figure 26 Remote processing

Running hydraulic simulation in CrossGrid

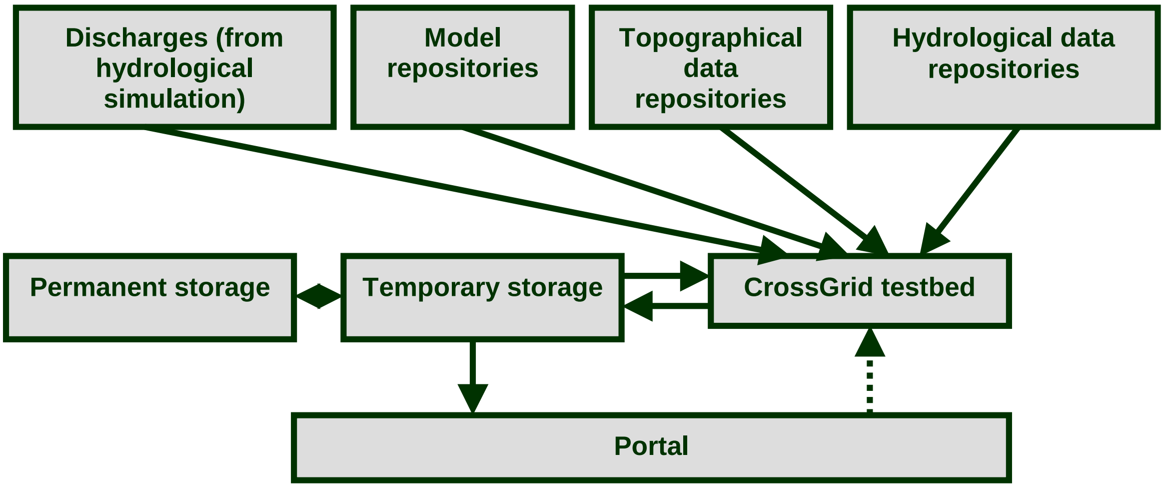

Figure 27 Hydraulic simulation in CrossGrid

Topographical data, codes of models, and some hydrological data do not change frequently so they are stored in the corresponding repositories. Temporary storage can be used to exchange data between models in cascade simulation (e.g. discharge for hydrological simulation). Some results from previous hydraulic simulation (stored in permanent storage) can be used as initial condition. Portal may have metadata of all these data, so users can choose which data will be used in hydraulic simulation. In order to simplify the data flow in CrossGrid testbed, all input data (including topographical data) may be moved to temporary storage first, then they are sent to servers as a single package, so high-performance servers in CrossGrid testbed have to communicate only with portal and with temporary storage. Similarly, output data from simulation are transferred to temporary storage first, before sending to portal for users or storing in permanent storage.

Existing CORBA/SSH scripts work well for remote processing in current ANFAS project; however, the use of advanced Grid technologies is expected for CrossGrid for data transfer (e.g. GridFTP) and remote processing (authentication, reservation, scheduling).

4.4. DATA ACQUISITION FOR PILOT SITE

For application the Váh River reach between Strečno and Nosice has been chosen and the Pilot area is depicted in **Figure 28** and **Figure 31**.

Data for hydrological models´ calibration

- Daily hydro-meteorological data from ground hydrological and meteorological stations (mean discharge, mean water stage, precipitation total, air temperature, height of snow cover, water content in snow-pack) – from hydrological and climatological databases of the Institute
- Potential evapotranspiration – in SYNOP stations will be evaluated in cooperation with Comenius University
- Hourly data:
    - Precipitation from radar measurement – will be evaluated from Czech radar measurement by experts from SHMI
    - 1-hour discharges and water stages – partially (since 1990) in hydrological database

- o 1-hour precipitation coordinates – have to be manually evaluated (by SHMI staff) from recording device (chart of paper) in rain-gage stations which are equipped by recording gage
- Other data – geographical coordinates, altitudes, catchment area, water-gage zero point, chainage, etc. referring to the monitoring networks of SHMI are available.

Data for system operation (one hour time step)

- Quantitative precipitation forecasts (from ALADIN)
- Estimation of the precipitation totals from radar measurements (nowcasting)
- Precipitation totals from ground rain-gage stations
- Water stages and discharges in hydrological stations within the area of interest
- Forecast of reservoirs´operation

Time Series Database

- Historical database:
  - o Data used for models´ calibration (as above)
  - o Historical floods in the region (possibly)
  - o Design of catastrophic flood hydrographs (possibly)
- Operational database
  - o As above - Data for systems´ operation - for the latest year plus all issued hydrological forecasts and warnings and further hydro-meteorological information – API, snow cover, water content in snow, water volume in reservoirs, etc.

Flood Forecasting and Control

- Setting up the Flood Forecasting System
  - o data acquisition, transmission, assimilation and processing
  - o management of the various types of hydrological and meteorological models (meteorological model → rainfall-runoff model → routing in channel and reservoirs model)
- Cooperation with Flood Control Organizations

Early Warning System

- Setting up the threshold values for all types of warnings into the Flood Forecasting System
- Cooperation with Flood Control Organizations

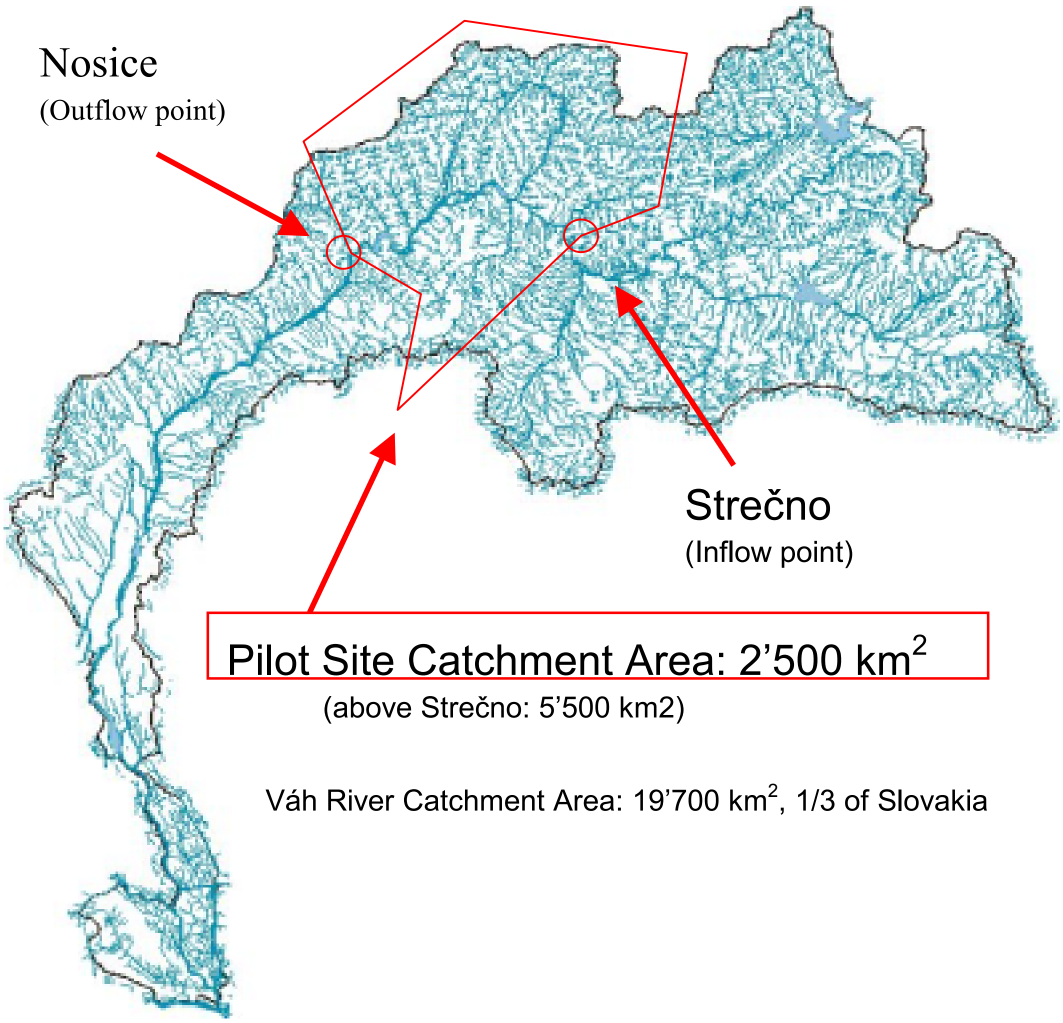

Figure 28 Pilot site area - map

Hydrological elements in the pilot site area:

- River reach: Strečno – reservoir Žilina
- Varínka River subcatchment
- Reservoir Žilina
- Kysuca River subcatchment
- Rajčianka River subcatchment
- River reach: reservoir Žilina – reservoir Hričov
- Reservoir Hričov
- Right-side tributaries between Hričov and Nosice reservoirs
- Left-side tributaries between Hričov and Nosice reservoirs
- River reach: reservoir Hričov – reservoir Nosice

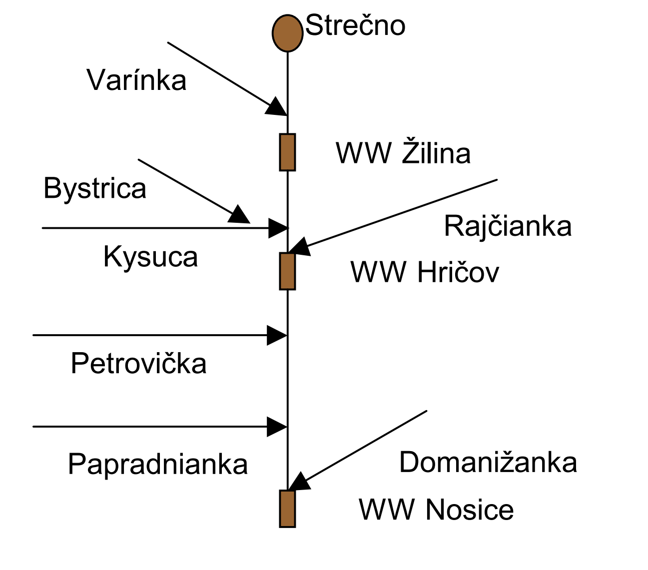

Figure 29 Pilot site area - scheme

Table 4: Pilot site: list of rain - gauge stations

No.	Station	Altitude (m a.s.l.)	No.	Station	Altitude (m a.s.l.)
1	Nezbudská Lúčka	355	19	Kunerád	550
2	Vrátna	620	20	Rajecké Teplice	418
3	Belá	440	21	Turie	460
4	Žilina – Celulozka	338	22	Svedernik - Keblov	342
5	Žilina	365	23	Dolný Hričov	309
6	Makov	574	24	Veľké Rovné	500
7	Korňa	570	25	Bytča	304
8	Turzovka	465	26	Súľov	390
9	Čadca	423	27	Brvnište	372
10	Skalité	540	28	Považská Bystrica MS	302
11	Oščadnica	490	29	Považská Bystrica	314
12	Stará Bystrica	476	30	Domaniža	367
13	Krásno nad Kysucou	389	31	Prečín	359
14	Horný Vadičov	456	32	Horná Maríková - Modlatín	433
15	Kysucké Nové Mesto	360	33	Púchov	267
16	Nesluša	423	34	Lazy pod Makytou	392
17	Rajecká Lesná	492	35	Vydrná	380
18	Rajec	462	36	Zubák	508

Table 5: Pilot site: list of river gauge stations

No	River site	Flow	Q_{mean} (m^3s^{-1})	Q_{max} (m^3s^{-1})	River km	Watershed area (km^2)
1	Strečno	Váh	93,900	***	266,40	5453,25
2	Stráža	Varínka	2,755	226,000	5,10	139,70
3	Čadca	Kysuca	5,436	454,200	29,20	492,54
4	Zborov nad Bystricou	Bystrica	4,730	400,000	6,60	218,07
5	Kysucké Nové Mesto	Kysuca	16,550	850,000	8,00	955,09
6	Závodie	Rajčianka	5,200	163,300	1,55	355,20
7	Bytča	Petrovička	0,690	37,600	2,70	65,10
8	Jasenica	Papradnianka	1,120	50,700	2,40	76,75
9	Prečín	Domanižanka	1,140	16,100	6,10	74,05

***The biggest known flood on the Váh River had occurred in 1813: the peak discharge at Žilina had been estimated to 3 300 m^3s^{-1}

Other big floods: Peak discharge

June 1894	2010 m^3s^{-1}
July 1903	1885 m^3s^{-1}
August 1925	1780 m^3s^{-1}
June 1958	2300 m^3s^{-1}
July 1960	2500 m^3s^{-1}

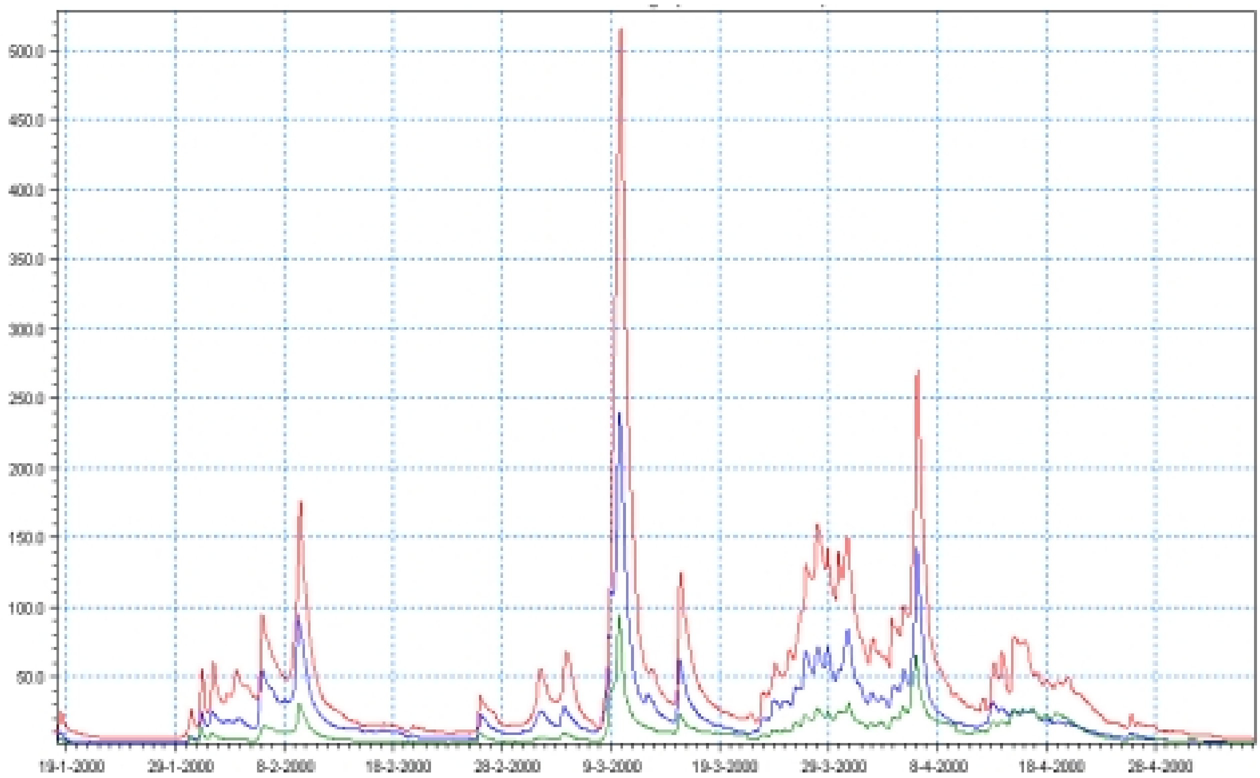

Figure 30 Discharges of Kysuca tributary, March 2000

– **Čadca – Zborov n.B. – Kys. Nové Mesto**

–

Table 6: Pilot site: Subcatchments for rainfall-runoff models calibration

Forecast-ing Site	Catch-ment area (km^2)	Reference Site	Flow	Catch-ment area (km^2)	Rain-gage stations		
					Telemetric	Recording	Others
Varínka-mouth	167,48	Stráža	Varínka	139,7	Žilina	Žilina	Nezbudská Lúčka, Vrátna, Belá
Kysuca - mouth	1037,67	Kysucké Nové Mesto	Kysuca	955,09	Žilina	Žilina, Čadca, Stará Bystrica, Kysucké Nové Mesto	Korňa, Turzovka, Makov,Skalité, Oščadnica, Krásno nad Kysucou, Nesluša, Horný Vadičov
Rajčianka - mouth	359,06	Závodie	Rajčianka	355,2	Žilina	Žilina, Kunerád, Dolný Hričov	Rajecká Lesná, Rajec, Rajecké Teplice, Turie
Right-side tributaries between Hričov and Nosice	743,45	Bytča Jasenica	Petrovička Papradnianka	65,10 76,75	Žilina	Žilina, Veľké Rovné	Svederník, Bytča, Brvnište,Horná Maríková, Lazy pod Makytou, Vydrná,Púchov
Left-side tributaries between Hričov and Nosice		Prečín	Domanižanka	74,05	Žilina	Žilina, Dolný Hričov, Považská Bystrica	Bytča, Súľov, Domaniža, Prečín

telemetric station - automatic station with real-time data transmission

recording station - data are recorded on paper chart

others - station is operated by voluntary observer, 24-hours precipitation totals are measured

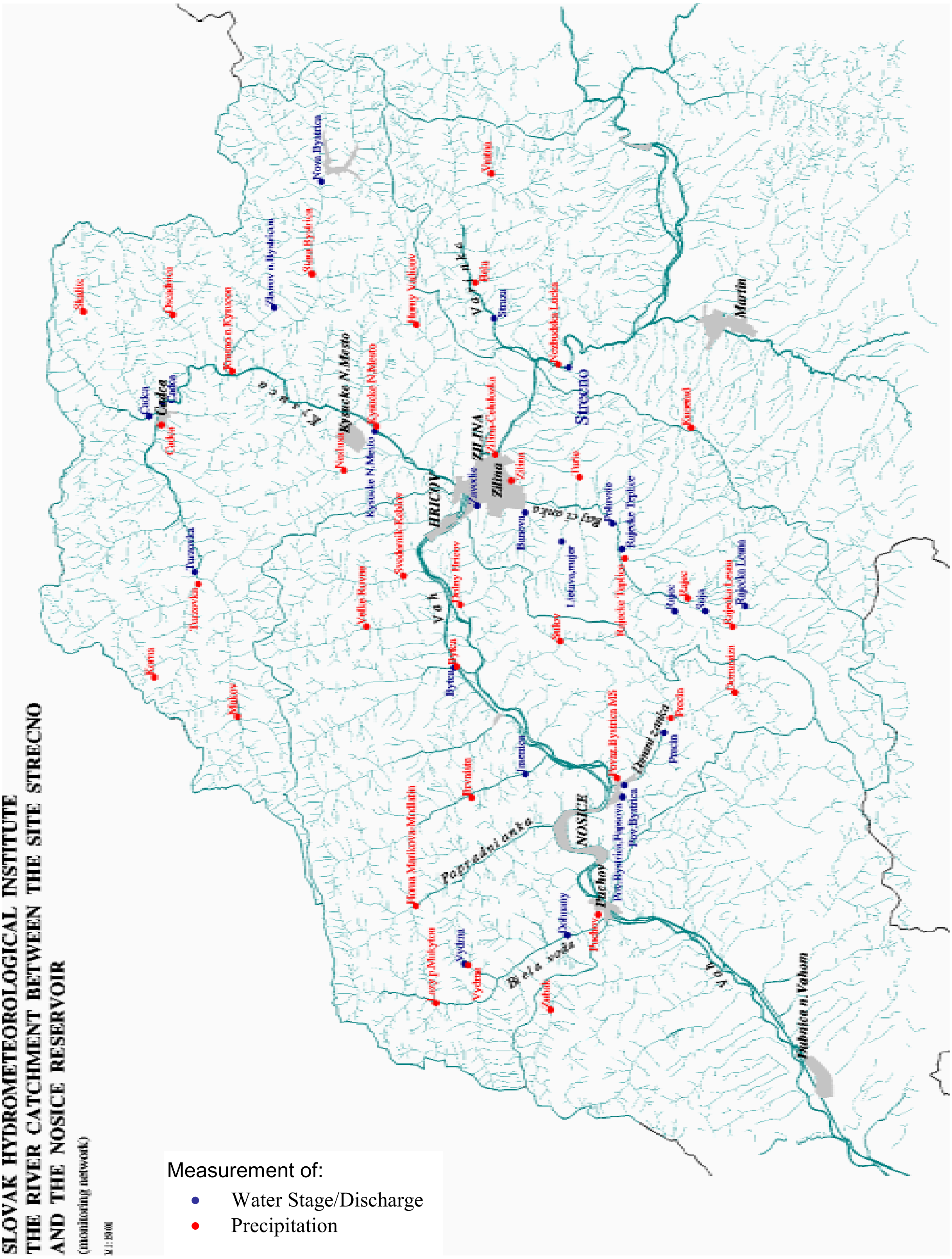

Figure 31 Pilot site area with monitoring network

Weather radars

Weather radars use the capability of water and ice particles to reflect microwave radiation. The modern radars can detect and process very small amounts of microwave energy returned from long distances and therefore they are suitable for remote estimation of precipitation intensities in large areas (approx. 100 000 km^2) surrounding the radar. From the primary intensity data the accumulated rainfall estimates for the specified time period can be calculated. Accumulated rainfalls can be evaluated for different areas, e.g. for specific river basins or critical regions of different size (from tens of km^2).

A further processing of primary radar data allows for example tracking and forecasting of severe storms for several tens of minutes in advance. Weather radars can measure the spatial structure and cloud top height and their development in time and space.

Using modern Doppler radars, it is possible to measure also the radial velocity component of water particles and to estimate wind field in different heights and distances from the radar. Processing of the Doppler data allows to detect other dangerous weather phenomena such as microbursts, gust fronts and tornadoes. Polarimetric weather radars can even distinguish among different types of hydrometeors (droplets, graupels, hail, snow...) and therefore, further enhance the precision of the precipitation estimations.

The effective range of the radar is 80-120 km for quantitative precipitation and wind measurement, and up to 200-250 km for the nowcasting and storm tracking. With the grouping of several weather radars a network of weather radars can be established and composite information from larger areas can be provided.

Weather radar data are utilised in operational meteorology and hydrology, and can also be used as inputs for meteorological and hydrological numerical models.

SHMI weather radar network currently consists of 2 radars – Malý Javorník near Bratislava and Kojšovská hoľa near Košice city.

For the area of interest of this project, data from 2 radars can be used, namely Malý Javorník radar EEC DWSR-92C and the Moravian radar Skalky (Gematronik Meteor AC360). Both radars have similar technical parameters and their distances from the area of interest are also very similar (120-150 km). These radars are Doppler weather radars working in the frequency band C (around 5500 MHz), with the pencil radar beam with the diameter of 1 degree. The output data approximate resolution is 1x1 or 2x2 km.

For the project purposes the precipitation intensities and rainfall total estimates would be used. These estimates could be calculated for the whole area of interest, as well as for the particular subcatchments. The radar rainfall estimates would be efficiently combined and processed with the measurements from the meteorological and hydrological stations.

The amounts of the data from the area of the interest would be several kilobytes per hour.

Figure 32 shows the 24-hour rainfall estimates from Malý Javorník radar. For good coverage of the whole catchment, composite data from both Malý Javorník and Skalky radars would be advantageous and more precise.

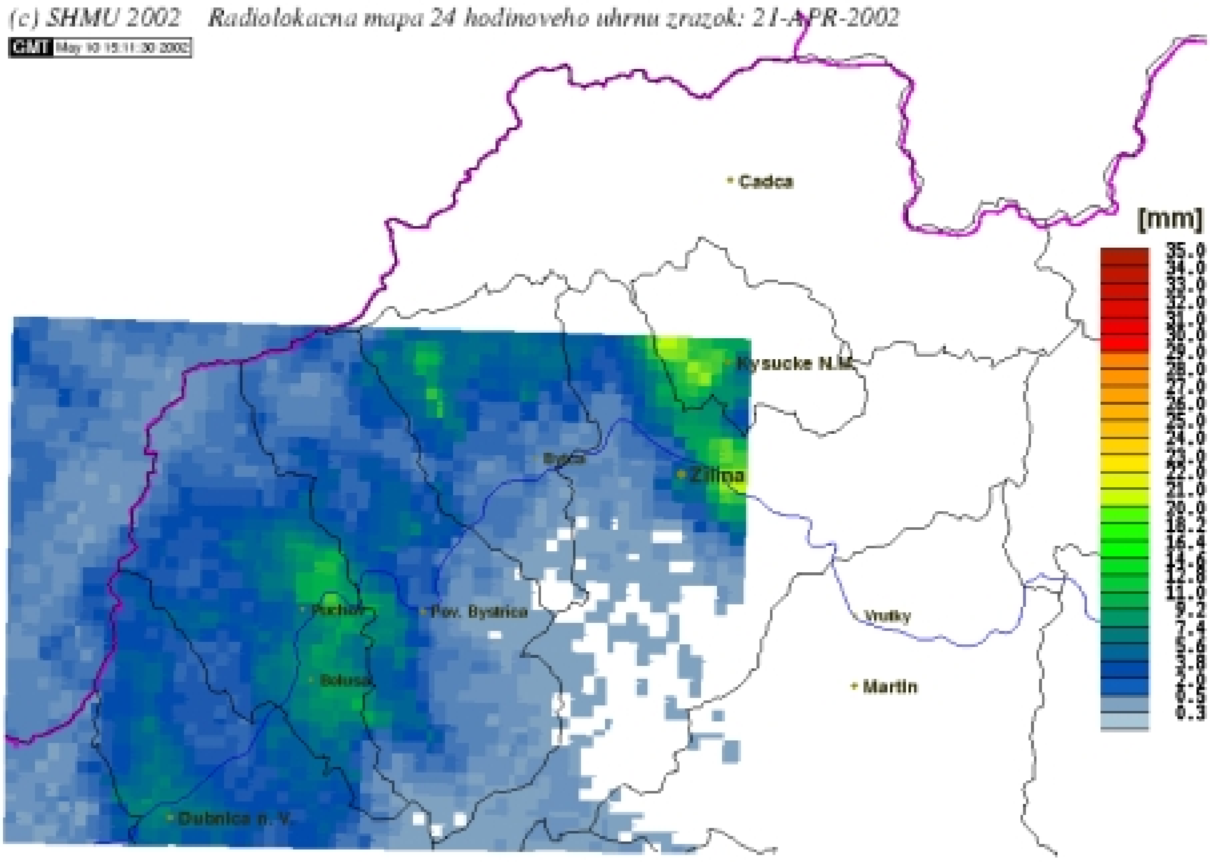

Figure 32 Example of the 24-hour rainfall in part of pilot site

4.5. MILESTONES OF TASK 1.2

The basic milestones are defined in CrossGrid project Annex 1 “Description of work”. We refined them to the following time schedule for developing and adopting our application to Grid environment:

Milestones and expected results		
Milestone	Month	Results
M1 – 1	3	Application descriptions and use cases for all applications Requirements to other workpackages Identification of principal common tasks
	6	Hydraulic part of cascade simulation (Grid version)
	10	Meteorological part of cascade simulation (ALADIN/Slovakia)
	11	Hydrological part of cascade simulation (high throughput computing)
M1 – 2	12	First software releases
	16	Interactive control of hydraulic simulation (through portal)
	17	Interactive control of hydrologic simulation (through portal)
M1 – 3	18	First prototypes up and running on local testbed
	20	Input/output on-line data (available through portal)
	22	Storage management (scenarios, pre-simulated cases, ...)
M1 - 4	24	Second software releases
	27	Roaming access
M1 – 5	30	Second prototypes up and running on global testbed
M1 - 6	33	Final prototypes ready for testing on distributed testbeds

5. INDEX

authentication & authorization, 8, 11, 12
cluster, 11, 19, 35, 37
decision support system, 11
early warning system, 4, 39
fault-tolerant, 11
flash flood, 8, 13, 14
hydraulic
  model, 8
  simulation, 8, 14
hydrograph, 30, 39
hydrological
  forecast, 13
  model, 8, 14
  simulation, 8
  situation, 17
mesoscale model, 5
meteorological
  forecast, 13
  model, 8, 14
  simulation, 4, 8, 14
operational mode
  crisis, 14
  normal, 13, 14
portal, 8, 9, 14, 17
PSE, Problem Solving Environment, 9, 11
remote
  processing, 36, 37, 38
  sensing, 8, 45
storage management, 8
validation and calibration, 14
virtual organization, 4, 5
visualization tools, 8, 9
what-if analysis, 4, 14