The Datacrossing DSS: a data-GRID web based approach to groundwater modelling

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Abstract— The complexity of groundwater resources management in coastal regions presents an increasing challenge to policy makers. A multidisciplinary approach is needed to collect, use and analyse large amounts of heterogeneous data, apply environmental models and to design management strategies. The purpose of this study is to develop a web-based, distributed, user-friendly Decision Support System, to analyse coastal groundwater systems: Datacrossing DSS is a basin scale groundwater model conceived to support decision making in the field of sustainable water resources management. It is accessible through a Web interface (http://datacrossing.crs4.it) that relies on a distributed experimental Data-GRID framework. An application, based on a groundwater code and pre/post processing tools was developed, to model, analyse and visualize the seawater intrusion dynamics. Such module provides a framework to predict the impact of management and policy options on the dynamic balance between freshwater and saltwater. Digital datasets are stored in geographically distributed resources and made available via a Data-GRID environment. This provides participating institutions with complete control on the selection of data they wish to assess. The code is the CODESA-3D model, a three-dimensional finite element code of coupled density-dependent and variably saturated flow and transport. The DSS has been tested to the multiple layer aquifer of Portoscuso, located on the South-West part of Sardinia, Italy, threatened by sea water intrusion and inorganic residuals from the local industrial activities. A significant deterioration of groundwater quality due to seawater encroachment has been observed in the wells located on the cost line. Moreover field data indicate that contamination is present in both the phreatic and the confined units.**This paper describes the approach and the technologies adopted to design Datacrossing DSS and its application to the study of the Portoscuso case. It also illustrates the original solutions provided by Datacrossing DSS for an advanced collaborative approach based on enabling grid technologies.**

I. Introduction

In recent years the progress in GIS-DataBase technologies, computer simulation, and high performance computing has highly extended the possibilities in environmental sciences, and have changed the way in which land management systems can operate.

Since 2000, users, public and private entities moved to the Internet client-server paradigm, searching ever more for data, models and applications. Nowadays, more then 3 million users can access the net and their services, a number destined to enormously increase in the next future.

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Public and private environmental agencies often interoperate little even when solutions require an integrated interdisciplinary approach. Large-scale networking can contribute to moving from a local to a global scale, so to increase the exchange of ideas and collaborations among scientific communities sharing the same motivations. Recent advances on distributed heterogeneous knowledge networks and the experience made during many European projects let us imagine that water and environmental management, disciplines largely based on GIS applications and hydrological numerical modelling, might draw a huge benefit from the use of web-based technologies and collaborative computing.

This paper describes the approach and the web-based technologies we adopted to design environmental applications, to study a coastal aquifer in Sardinia (Italy).

The site under study is found on the plain of Portoscuso, western coast of south Sardinia. During the last decades, the plain has gone through profound changes. Historically this region was renewed for the mining activities which generated mostly of the local income. Today the area is characterized by a very active industrial settlement for the production of alumina and electric energy mostly (Pazzaglia, 1986). Other economic activities of increasing importance, and one that draws on the traditions and culture of the local population, are fish farming, and agro-zootechnical activities. The current situation, not uncommon in Mediterranean areas, is the product of many years of poor management policies that often neglected the need to protect water and soil resources.

II. Description of the Study Area

The plain of Portoscuso is located in the west-southern part of Sardinia (Fig. 1) and is surrounded by hills (the "Concali de su Carboni" on the north and the "Cuccuru sa Funtana e Figu" on the south-east) and by the sea on the west, with an average height of about 43 m.. The climate is typical Mediterranean, with a rainfall peak in December, a minimum in July, and an average of about 650 mm/year, of which 65-70% is lost to evapotraspiration.

The aquifer system underlying the plain is characterized by the presence of three groundwater formations, a shallower phreatic aquifer, a deeper confined-semiconfined aquifer, located in the Quaternary deposits released by the main rivers, and a third system located in the ignimbrite formation (Barbieri and Ghiglieri, 1994, 1998). The first two units are separated by a variable thickness aquitard that is been commonly considered a continuous formation. The thickness of the first two aquifer units ranges from a minimum of 16 m close to the hills and a maximum of 75.5 m close to the sea.

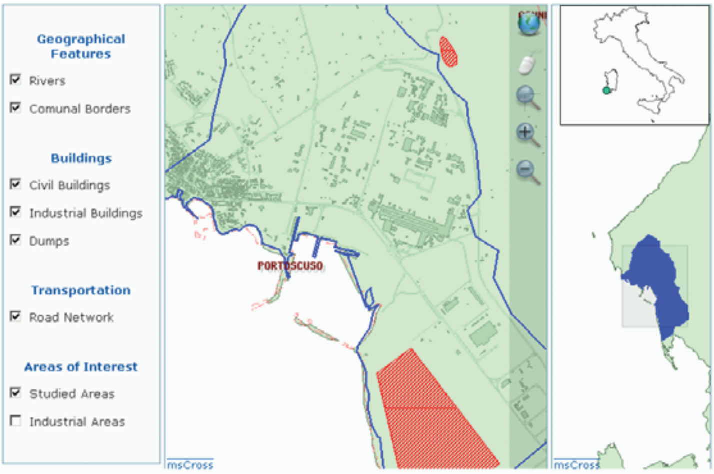

Figure 1. Location of the study site and main geographical features viewed on the web application

Approximately a thousand wells are estimated to be present in the study region, although the number of wells that are actively withdrawing water from the aquifer system for agricultural and industrial uses is not known. About 55 wells of those within the site have been monitored during the last years by the Dipartimento di Ingegneria del Territorio dell'University of Cagliari, Italy. Data have shown increased electrical conductivity values in the wells located closest to the coastline, suggesting possible salt water intrusion. In some control points, data evidenced high contamination levels in both the phreatic and confined aquifers, supporting the idea that the separating layer is not continuously impermeable and suggesting that even wells may constitute a preferential path of communication.

The area is on the list of the sites of national interest to undergo remediation. In 1990, on November 30, the Italian Government declared with a National Directive the area to be under "high environmental risk". On April, 23, 1993, a remediation plan has been enacted and, in 2003, March 12th, the perimeter of the Sulcis-Iglesiente-Guspinese site (where the Portovesme area is located) has finally been delimited by the national authority (Gazzetta ufficiale, May 27th 2003, N. 121).

III. Conceptual and Computational Model

The numerical simulator used in this work is the CODESA-3D (Lecca 2000) which relies on the classical variably saturated-flow and advection-diffusion of a soluble contaminant equations coupled through the density term (Gambolati et al. 1999). The model is a distributed, fully three dimensional finite element code that can account for spatial and temporal variability in parameters and boundary conditions. The model uses a standard Galerkin finite elements with tetrahedral elements and linear basis functions for the spatial discretization, complemented by a weighted finite difference time stepping scheme. Newton and Picard-based linearization schemes handle the coupling and nonlinearities inherit in the seawater intrusion model and the nonlinearities in the unsaturated flow component. This model can be used in coupled flow and transport mode or in flow only mode.

Three major units were used in the schematization: a phreatic aquifer with average thickness of 12 m, a confining layer with an average thickness of 3 m, and a confined aquifer with an average thickness of 32 m..

A three-dimensional grid of the study domain is obtained by first triangulating the land surface of the region into 2753 elements and 1432 nodes. This is then replicated vertically forming 10 layers of variable thickness that discretize the three units following the geological layers. The resulting three-dimensional mesh contains 15752 nodes and 82590 tetrahedral elements (Fig. 2). Zero flux Neumann boundary conditions are imposed on the northern and southern boundaries. Dirichlet boundary conditions with values taken from available data are imposed on the eastern boundary, and on the seaside. The surface nodes are subject to atmospheric forcing, with the net rainfall/evaporation rates considered uniform in space but variable in time with a one-month resolution. The pumping wells have been clustered in three zones of the confined aquifer and production rates have been estimated on the basis of water needs mainly for industrial purposes. The flow model has been calibrated against the data taken in the year 1999 assuming the clayey layer as continuously impermeable (Cau and Gallo, 2002).

IV. The Datacrossing DSS and the Web-Based Technology

Groundwater management and remediation of contaminated media is a worldwide problem of growing concern to water resources managers. The Portoscuso case is just one example where a multidisciplinary approach is needed to collect, use and analyse large amounts of heterogeneous data, run mathematical models, and design management strategies. The web-based applications were developed using free software (www.gnu.org) technologies. Such approach has proved to be an efficient and reliable way to improve software, model application and groundwater management. The Datacrossing Decision Support System is an open web-based environment for groundwater management developed for managers, local municipalities, and end users. The DSS is made of different modules that allow users to: query data collections; visualize maps; simulate the hydrodynamics of the aquifer; identify, given in situ measurements, the location of a point/non-point source of pollution; predict the time of the spill; help hydrologists to design monitoring networks (where and when to measure); plan and control remediation strategies, and alert users of possible contaminations.

Within the experimental grid infrastructure, modules have been developed to run applications based on numerical solvers, run pre- and post-processing codes, query and map results through the web viewer. One of the purposes of this study is to use large datasets that are stored among remote resources within a grid infrastructure and run distributed applications using these data. It also aims at providing participating institutions with complete control on the selection of data they wish to process. The data grid is expected to supply an abstraction layer between the classical archives (end users are usually interested in requiring semantically classified objects for their research), the data dissemination mechanism and the computing tasks performed for the geo-process. The SDSC Storage Resource Broker (SRB - http://www.npaci.edu/dice/srb) technology has been used to design the data-grid infrastructures (Arcot et al, 2003). SRB is client-server middleware that provides a uniform interface for connecting to heterogeneous data resources over a network and accessing replicated data sets. It allows the organization of data from heterogeneous systems into easily accessible logical collections, and, in combination with the Meta data Catalog, it supports location transparency by accessing data objects through queries on their attributes rather than their physical locations.

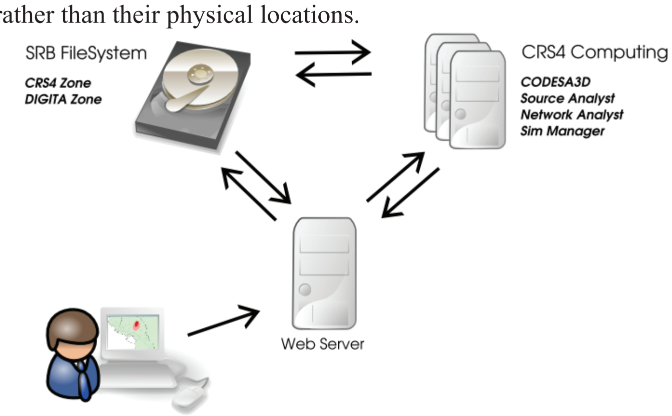

Figure 2. Logical organization of data flows. Users access only the front end, through which computing resources and data are accessed.

Within the web platform, the fallowing modules have been developed:

Simulation manager: users can simulate on the web viewer the source of pollution within the modelling domain (the source of contamination is highlighted on a map). The corresponding simulation is retrieved, and results are displayed on the web GIS. The time evolution of the contamination plume can be dynamically controlled and overlaid with any geographical layers (e.g. pumping wells).

Source analyst: The DSS detects the areas that are the most likely sources of the observed contamination and estimate the time of the leakage event (Cau and Manca, 2005).

Network analyst: the DSS is used to predict and improve the acquisition coverage. Such coverage is time dependent. The aquifer domain is divided into elements tagged by a Boolean value at different times. The true value makes out the elements controlled by the monitoring network at each time step. The controlled area is expected to increase with time until a steady state is reached.

Salt Water contamination tool: described below

V. The Saltwater Contamination Tool

This tool is aimed at designing management scenarios based on the physical characteristics of the aquifer and simulate the effect on the saltwater dynamic balance. The tool work in three steps:

1. Users identify the position of wells, their depth and pumped water directly from the web portal. Through the Mapserver application the position of wells is identified directly on the map and pumped water associated to each well as shown on figure 3.
2. By clicking "*submit*" the job is submitted and the model is run
3. Outputs are processed and visualized on the GIS viewer.

By clicking on the map, the user can identify the position of wells to be activated within the Portoscuso plain. By clicking Calculate the simulation is run in real time, post-processed (this module produce a real time geo-raster by means of the open source GRASS tool -http://grass.itc.it/-) and visualized on the msCross web viewer.

VI. Results and Future Work

Data-GRID and web-based technology involves sharing heterogeneous resources based on different platforms, hardware and software architectures, and computer languages, located in interconnected centers belonging to different public and private domains. The datacrossing DSS has shown that applications, which rely on virtualization technologies, can be efficiently developed, however, with some organizational effort.

The SRB data-GRID framework offers an infrastructure for solving massive data-sharing problems in a distributed and multi-user environment. In general, the web-based paradigm is of paramount importance to control the redundancy of replicated datasets, and it allows the user to retrieve updated certified information, avoiding the latency due to administrative and technological barriers. As a matter of fact, the environmental applications can benefit from real-time data processing, making territorial management and planning more efficient.

A friendly Web interface was designed to hide the users the complexity behind our Datacrossing DSS and no specific expertise is required in data management and security standards. Water managers can run their applications and query the results, benefiting from an enlarged production environment.

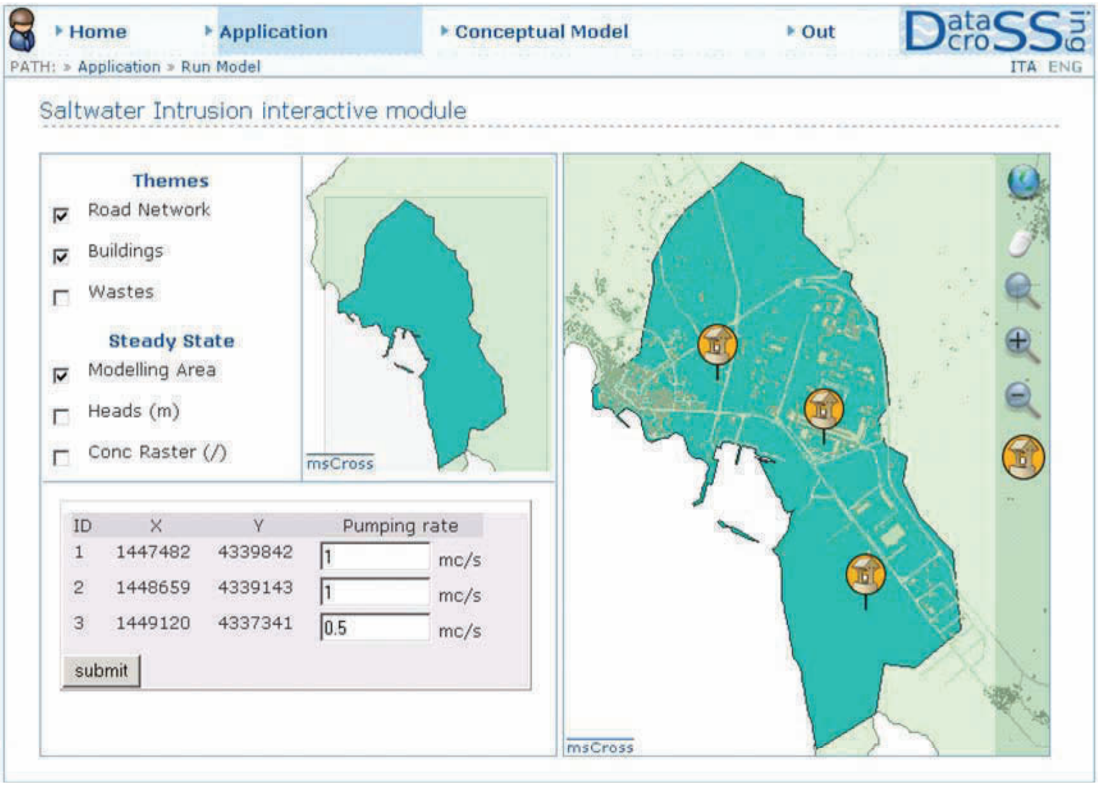

Figura 3. Water managers can easily design exploitation scenarios and evaluate the impacts on the seawater intrusion process

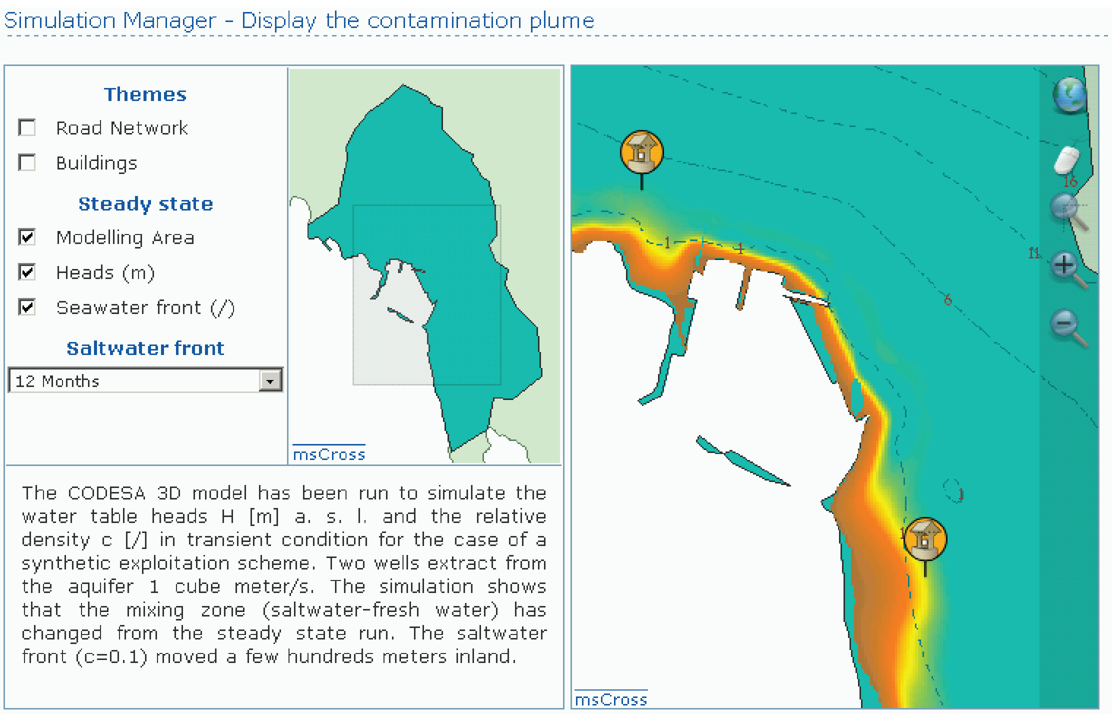

Figure 4. This module produce a real time geo-raster showing the salt water intrusion by means of the open source GRASS module. The effect of pumping is spatially dependent.

The undertaken collaborative initiative gives rise to an ideal ground to develop tools - combining simulation software and geographical information systems - that will help the taking of wise management decisions. Application deployment on a web-based environment might be cumbersome, because of the complexity, that can be harnessed only by multidisciplinary teams, of the involved technologies.

Environmental agencies are moving and consolidating valuable data into relational databases to improve the interoperability, integrating spatial data analysis and map visualization into key business applications to improve decision-making and service delivery. For the future, client/server environmental applications are moving to the Internet cyberspace, using more and more often web services to extract meaningful information from distributed data in the territory. We expect to be able to deeply contribute to national programmes with the development of integrated systems for the processing and the exchange of information relative to environmental applications. This, by no means, exhaustive analysis, nonetheless, illustrates the manner in which a GRID based decision support system can be developed and applied to a regional water management problem.

REFERENCES

[1] P. Cau & S. Manca, *The Data-crossing approach to locate point source pollution*. The Portoscuso case (Sardinia). Published in the journal "L'Acqua N. 2, Apr-May 2005.

[2] Arcot Rajasekar, Michael Wan, Reagan Moore, Wayne Schroeder, George Kremenek, Arun Jagatheesan, Charles Cowart, Bing Zhu, Sheau-Yen Chen, Roman Olschanowsky, "Storage Resource Broker - Managing Distributed Data in a Grid*". Computer Society of India Journal*, Special Issue on SAN, Vol. 33, No. 4, pp. 42-54 Oct 2003.

[3] Cau P. and C. Gallo. *Estimating interconnections between a phreatic and confined aquifer using a data crossing method the Portoscuso plain (Sardinia, Italy) case*. *Conference proceding of the Model Care, Calibration and Reliability in Groundwater Modeling*, Praga Czech, pp 645-648, 2002.

[4] Lecca G.. *Implementation and testing of the CODESA-3D model for density-dependent flow and transport problems in porous media.* Environment Area, CRS4. Pula, Italy. (Internal report), 2000.

[5] Gambolati, G., M. Putti & C. Paniconi. *Three-dimensional model of coupled density-dependent flow and miscible transport in groundwater*. In Bear et al. (eds.) Seawater intrusion in coastal aquifers: Concepts, Methods, and Practices, chapter 10, pp. 315-362, Kluwer Academic, Dordrecht, The Netherlands, 1999.

[6] Barbieri G. & G. Ghiglieri (1998), *Inquinamento degli acquiferi sabbiosi nell'area industriale di Portovesme (Sardegna Sud-Occidentale)*. Associazione Mineraria Sarda, Iglesias, Digita Università di Cagliari. Cagliari 9-10-11 Oct 1998. Atti della Facoltà d'Ingegneria, Vol. 42, n. XXVII, Cagliari, Ottobre 1999, pag. 27-35.

[7] Barbieri G. & G. Ghiglieri, *Artificial recharge tests in a sandy aquifer*. Water Down Under 1194, Adelaide, South Australia, 1994.

[8] Pazzaglia L., *Gli inquinamenti in Sardegna*, Cap XIV, Edizione della Torre, pag 109-114, 1986.