SID&GRID towards FREEWAT: GIS-integrated modeling tools for water resources management

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MAR Commission

Outlook

- Introduction on GIS-integrated hydrological modeling
- SID&GRID modeling platform: key features and capabilities
- A new version of SID&GRID: FREEWAT
  - Software concept
  - How it works: a test example

Integration of GIS and hydrological modeling
WHY?

- As for any other environmental sector, in geosciences basic information for a modeling study is inherently geo-referenced
- Similarly, in a model study, any final User requires that output data are geo-referenced, to exploit as much as possible the model results (visualization, integration with other pieces of information, etc.)

➢ Using GIS for pre- and post-processing is a MUST!

Integration of GIS and hydrological modeling
PROBLEMS

- Codes for solving mathematical problems are based on a discretization of model domain [*grid* or *mesh*]
  - The majority of input data should be assigned to each of the model domain element [*node, cell, finite element, etc.*]
- (In general) input data for numerical codes are in text format (or other proprietary format – not in GIS format)

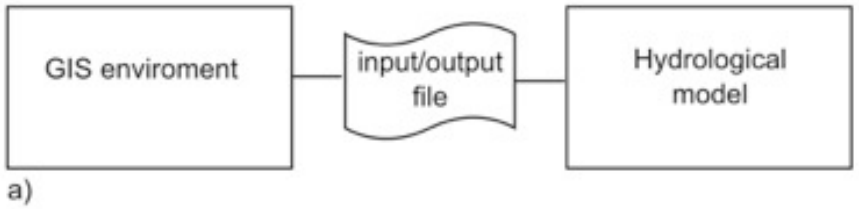
➢ Need of converting geographical coordinates in "grid" coordinates

➢ Need of translating base data in format compliant with the model standard

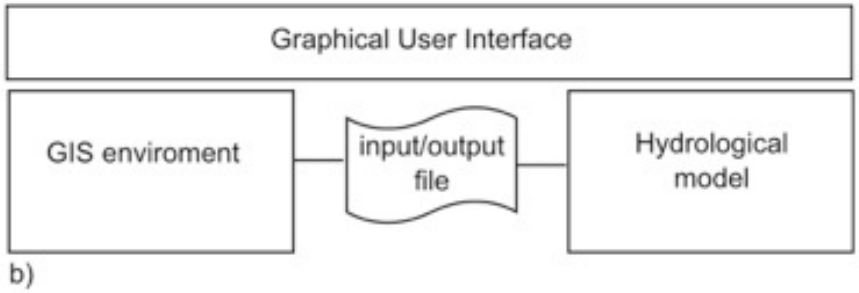
Integration of GIS and hydrological modeling *SOLUTIONS*

Three different coupling strategies: [Watkins et al. (1996) and Carrera-Hernandez et al. (2005)]

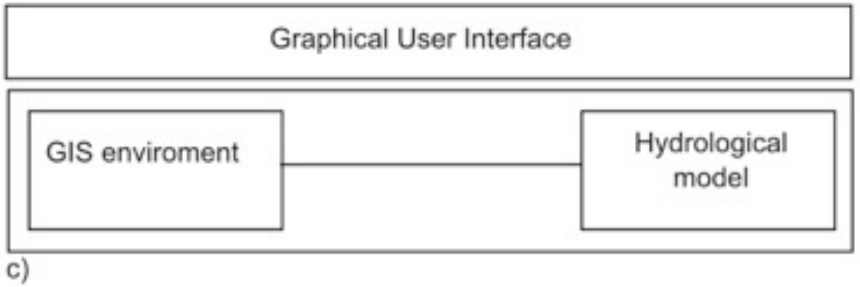
Loose coupling



Tight coupling



Embedded environment



Integration of GIS and hydrological modeling
EXAMPLES

Research efforts on this topic started by the late ‘80s

Since 2000 several developers have designed tools to manage spatial and temporal data for hydrological modeling within a GIS environment:

- Many of them adopt loose coupling strategy
- Few examples of tight coupling approach, and often performed via proprietary software
- Some interesting example of coupling free and open source modeling codes with open source GIS (e.g. PIHMgis, based on Qgis) [tight coupling]

➢ This background motivates the interest on developing freely available software, to diffuse modeling within public bodies (local governments, river authorities, water utilities, …) and to enhance their water management capabilities by a technical point of view.

SID&GRID Project:

Simulazione e sistemi IDroinformatici per la Gestione delle Risorse Idriche

Funded under POR FSE 2007-2013 by Regione Toscana

Started in April 2010 and concluded in March 2013

Scientific partnership:

Dept. of Mathematics, University of Firenze

Land Lab, Scuola Superiore S.Anna, Pisa

CNR--ISTI, Pisa

End-users partnership:

Ingegnerie Toscane S.r.l., Pisa

Autorità di Bacino Pilota del Fiume Serchio, Lucca

H2O Ingegneria S.r.l., Pisa

SID&GRID Project:

Simulazione e sistemi IDroinformatici per la Gestione delle Risorse Idriche

Final goal of the project

To develop a 3D physically based distributed hydrological model (surface/subsurface water) to be used as helpful tool by public bodies and/or private companies in order to simulate the whole hydrological cycle and perform spatial-temporal analysis for water management and planning

All the project was developed using **open source and free codes**.

SID&GRID architecture is based on:

1. integration of a DBMS (Data Base Management System);
2. development of tools/toolbar into a GIS framework;
3. integration and development of groundwater (saturated and unsaturated zone) and surface water hydrological modeling codes in the GIS platform.

SID&GRID Project:

Simulazione e sistemi IDroinformatici per la Gestione delle Risorse Idriche

Technical/scientific staff

Core group (developers):

Iacopo Borsi (formerly Univ. of Firenze) [numerical code modifications & integration]

Rudy Rossetto (Scuola Superiore S. Anna) [hydrological supervision and testing]

Claudio Schifani (formerly CNR – ISTI) [GIS interface and DB]

Scientific supervisors:

M. Primicerio (Università degli Studi di Firenze)

E. Bonari (Scuola S. Anna)

P. Mogorovic (CNR - ISTI)

SID&GRID: software capabilities

A GIS platform as pre- and post-processor to simulate the hydrological cycle

(in addition to standard GIS functionalities)

Model output can be analyzed and integrated with any other GIS-based data (e.g. for urban planning, new infrastructure design, environmental assessment, etc.)

Input and output data may be published on the web via WMS

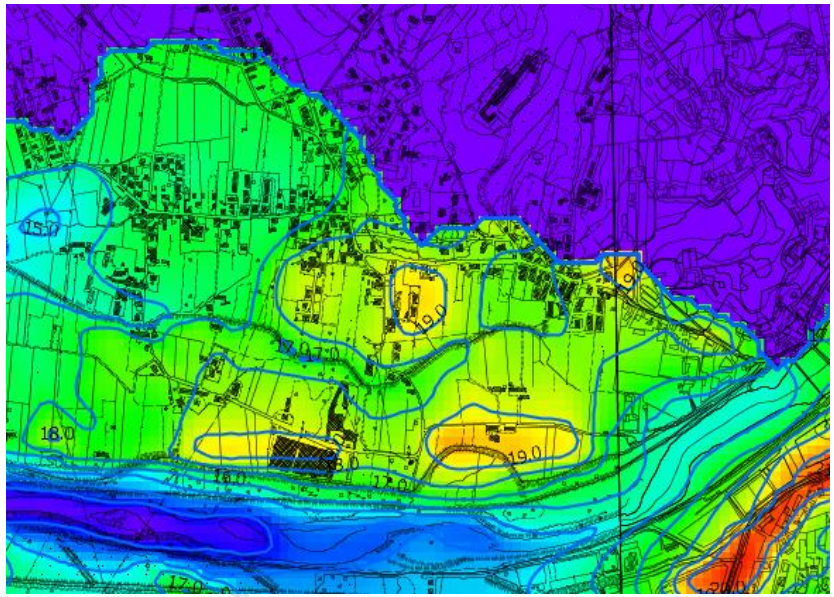
SID&GRID: software capabilities (ctd.)

SID&GRID allows to know the distribution of the water resource in space and time

For each simulation a water budget and a contour map of total head in the aquifer are produced

Data on discharge and head at selected locations of a surface water body may be produced

All the data produced may be used for critical decisions in water resource management and planning

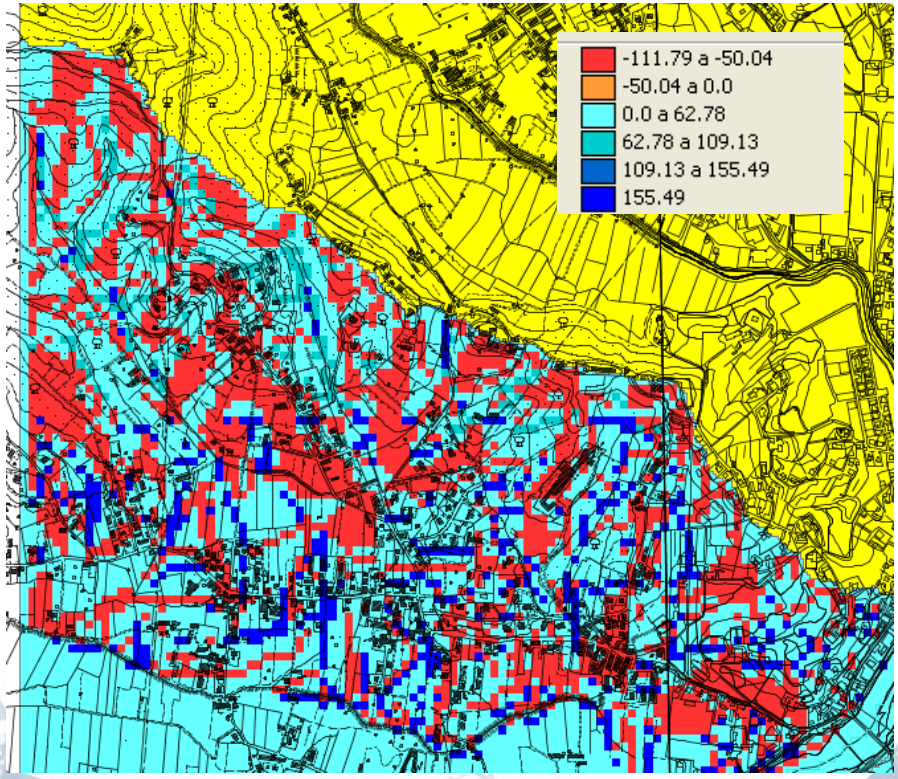


SID&GRID: software capabilities (ctd.)

Assessment of impacts on the hydrological cycle caused by climate change and or urban sprawling

Simulations of recharge variations to aquifers in areas run by fire.

How urban sprawling impact on groundwater recharge?

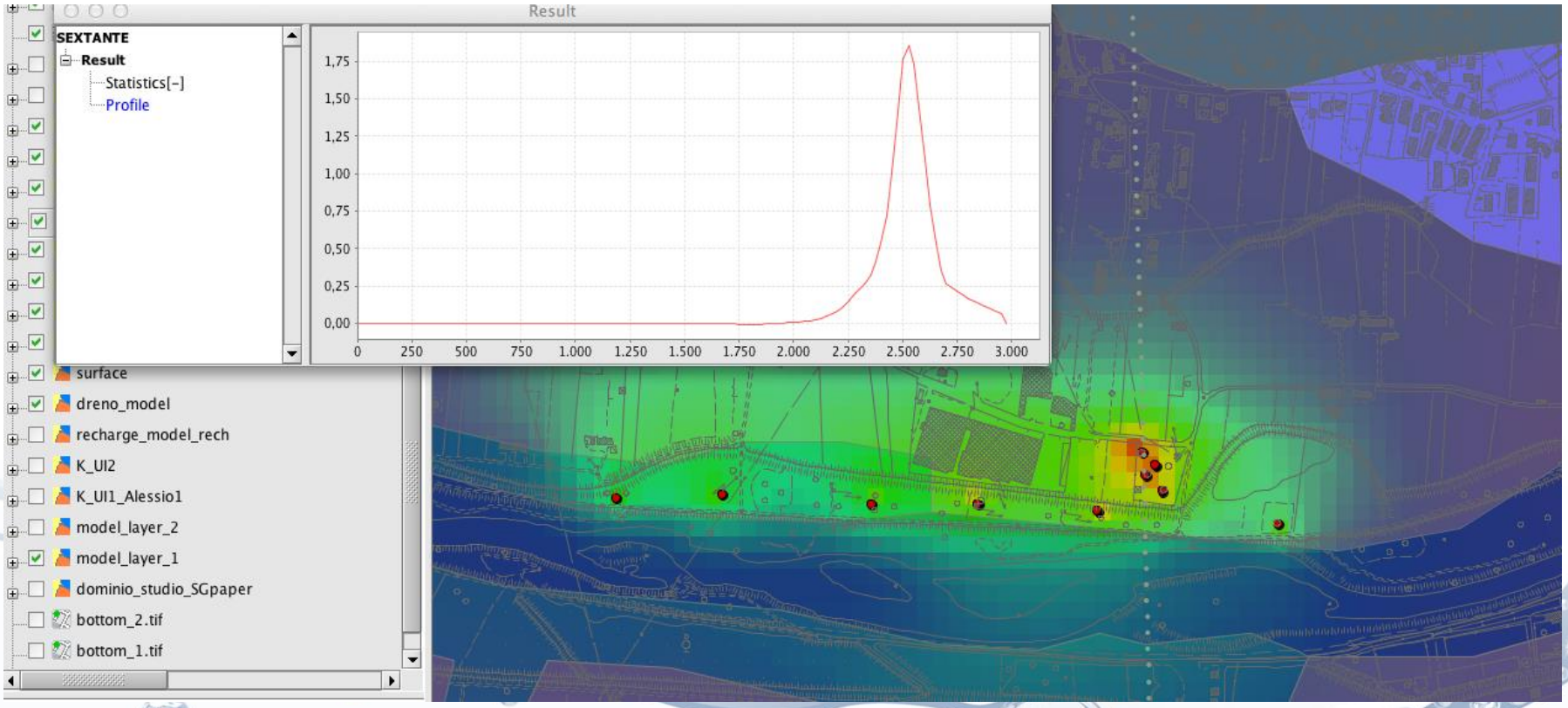


Example: run off generation on a slope

SID&GRID: software capabilities (ctd.)

Assessment pumping wells impact in sensitive areas

Example: Simulation of the expected drawdown at the end of a dry season or the groundwater head increase at the end of the recharge period



SID&GRID: hydrological model

SID&GRID numerical core is composed by a set of numerical packages, derived by the well-known MODFLOW "family" (U.S. Geological Survey): the user can simulate the whole hydrological cycle or just parts of it.
In red: tools specifically developed or adapted in SID&GRID).

1. Groundwater flow, activating one or more "stresses":
    - Effect of Well(s)
    - Interaction with River/Streams or Drains
    - Direct aquifer recharge
    - Other boundary conditions (e.g. constant head, general head bnd., etc.)
2. Water flow in the unsaturated zone with two options:
    - 1D infiltration model (with evapotranspiration)
    - Full 3D solution (+ evaporation, transpiration, pond, seepage flow)

SID&GRID: hydrological model (ctd.)

3. Water flow in stream/river (1D Saint-Venant eq. (kinematic—wave approximation) and interaction of surface/subsurface flows.

4. Possibility to activate Local Grid Refinement(s) in selected areas of interest, and there solve the full 3D unstaurated zone (LGR VSF).

5. Overland flow (a new MODFLOW package to be connected with UZF or VSF)

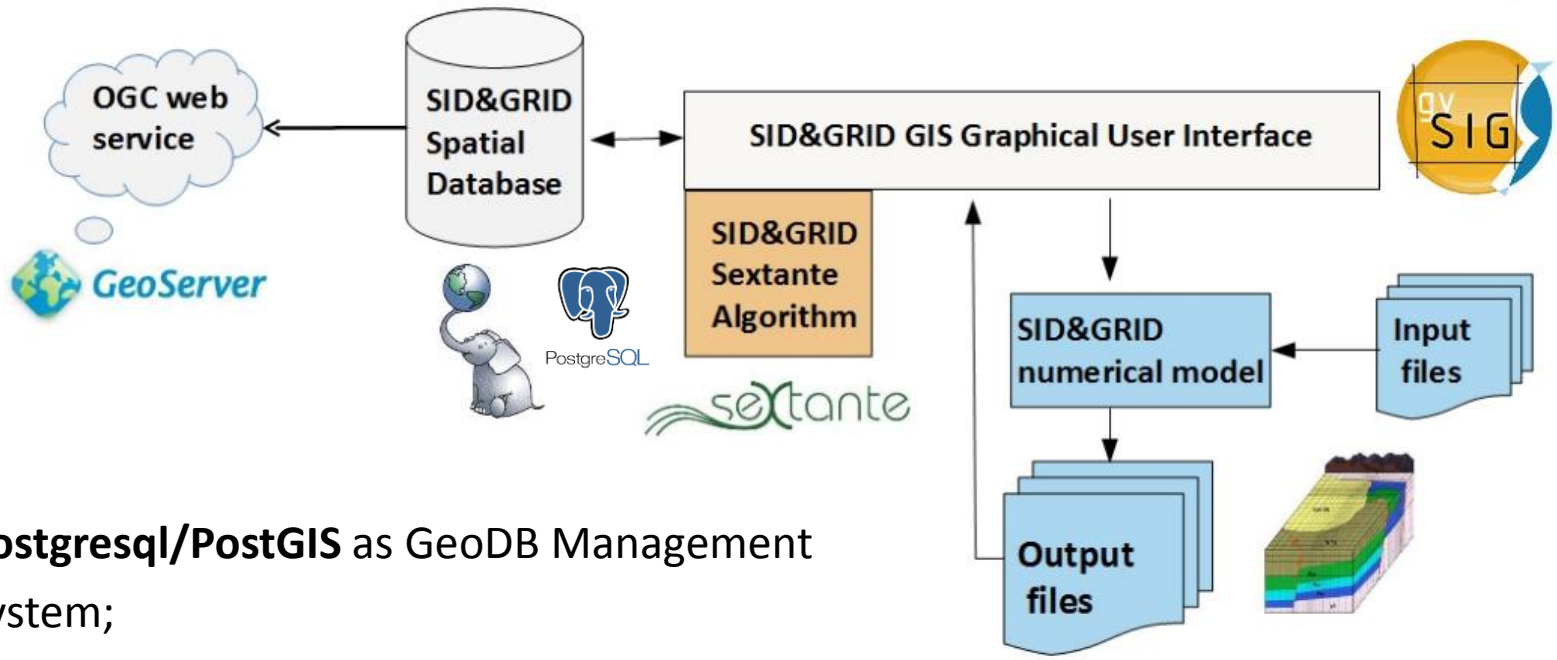
6. New Jython algorithms (directly embedded in gvSIG -) to compute:

   the PET (Potential Evapotranspiration) term;

   Canopy interception: the net rainfall rate reaching the soil surface.

SID&GRID: DB and GIS interface

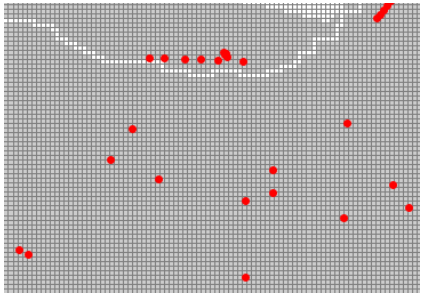
Tight coupling approach



- **Postgresql/PostGIS** as GeoDB Management System;
- **gvSIG** with **Sextante** geo-algorithm library capabilities and **Grass** tools as desktop GIS
- **Geoserver** to share and discover spatial data on the web

SID&GRID: data flow

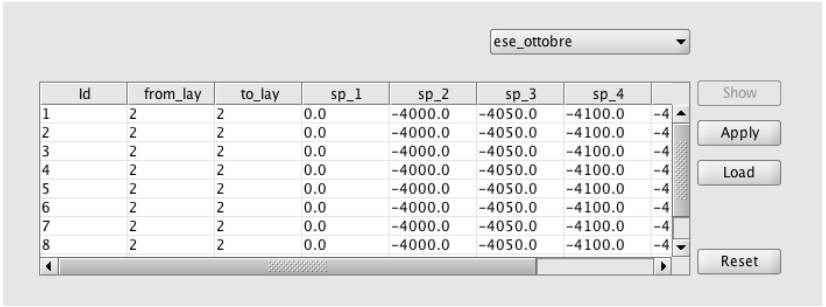
Geographical data

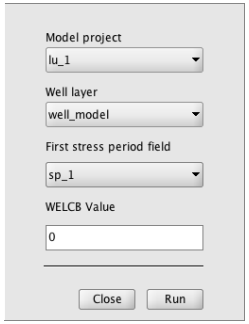


UI for
MDOs creation

Model Data Object (MDO):

"Grid coordinates" and Temporal discretisation





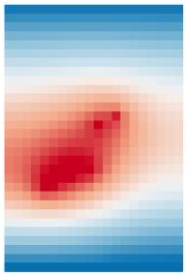
Wrapper for
input data
generation

Native input files
(text files)

**.exe* file

Native output files
(text or binary files)

UI to
Load & view
Model output



Geo-referenced output
(raster)

SID&GRID: training & dissemination

About **50** technicians were trained to the use of SID&GRID (Regione Toscana, Province, ARPAT, Basin Authorities, water utilities) in **6 training periods**

Dissemination

Web site: **http://sidgrid.isti.cnr.it**

LinkedIn (Italian Group) – SID&GRID Gruppo utenti (117 members)

Presented at (more than) 25 **National and International Congresses**

SGI 2010, Geoitalia 2011, GFOSS 2011, SIMAI 2012, FlowPath 2012, AIGA 2012-2013, ASITA 2010-2012, EGU 2011 e 2012 (Austria), WRH 2012 (Germany), Hydropredict 2012 (Austria), gvSIG (Spain), AGU 2012 (USA), IAH 2012 (Canada)

From SID&GRID to FREEWAT

The successful development of SID&GRID suggested to boost its usage and to improve its capabilities.

Road map:

- Including capability to simulate heat and solute transport in aquifer(s), for instance to model to model contamination plumes, well field protection areas, sewater intrusion, geothermal plants (very low/low enthalpy), managed aquifer recharge plant
  - In FP7 MARSOL Project
- Extending its usage and related community: larger community of users and developers, a more rich set of GIS plug-in to be used in synergy with models
  - Regione Toscana co-financed the porting of the system to Qgis
- Including many other capabilities, especially linked with water management issues
  - H2020 FREEWAT Project

From SID&GRID to FREEWAT

In particular, in few months FREEWAT will be available as modeling platform, to perform hydrological data analysis and simulations, including:

- Capabilities already included in SID&GRID
- Heat and solute transport in the saturated zone
- Solute transport in the unsaturated zone
- Specific modules for sensitivity analysis and calibration
- Pre-processing tools for hydrogeological data analysis and interpretation tools
- A water management module
- Modules for Irrigation management and crop growth modelling

FREEWAT: key components

- Qgis as GIS desktop interface

- SpatiaLite (spatial extension of SQLite) as GeoDB Management System

- FloPy as reference Python library to connect Qgis with hydrological codes

A simple model to show FREEWAT software concept

- A three-layer model; limited domain (1 Km x 1.5 Km)
- Constant Head and No Flow as boundary conditions
- Objectives: estimating the potential effect of 6 pump-and-treat wells on the groundwater flow [qualitative analysis]
- Steady state simulation

… see the movie …