Groundwater Modelling:
Emilia-Romagna Resource Planning and Managing Support Tools

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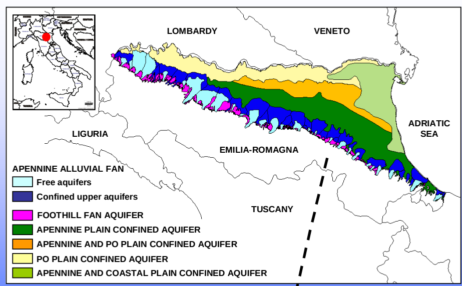
THE EMILIA-ROMAGNA GROUNDWATER FLOW MODEL

The Emilia-Romagna government has supported its water planning tools with the development of mathematical modelling of the whole alluvial groundwater system. The model has been firstly developed in 2003 and then updated in subsequent years.
The model has been used as a basis for several other more detailed analysis some of which are here presented.

MAIN MODEL CHARACTERISTIC

- Modflow 3D groundwater flow model
- Model extension: 12.000 km²
- Spatial discretization: 400.000 cells / 35 layers
- Transient flow simulation (20 seasonal periods)
- Simulation period available: 2002-2006

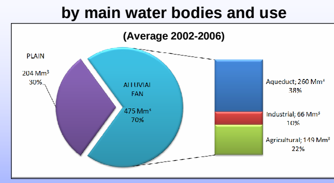
HYDROGEOLOGICAL CONTEST OF EMILIA-ROMAGNA PLAIN



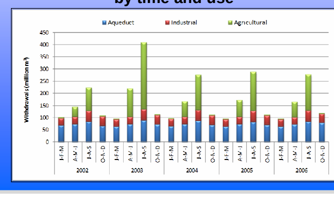
Most of Emilia-Romagna groundwaters belongs to a large (12.000 km²) alluvial plain limited by the northern Apennine margin (S), the Po river (N) and the Adriatic Sea (E).
Apennine alluvial fans are characterized by the presence of both free aquifers, where the main recharge from Apennine rivers and rain occurs, and confined systems, these latter laterally connected to the formers along the SW-NE direction.
Further north, lowland plain mainly consists of confined aquifers, the origin of which is both alpine and apenninic.

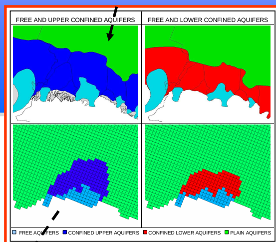
GROUNDWATER WITHDRAWALS

by main water bodies and use



by time and use

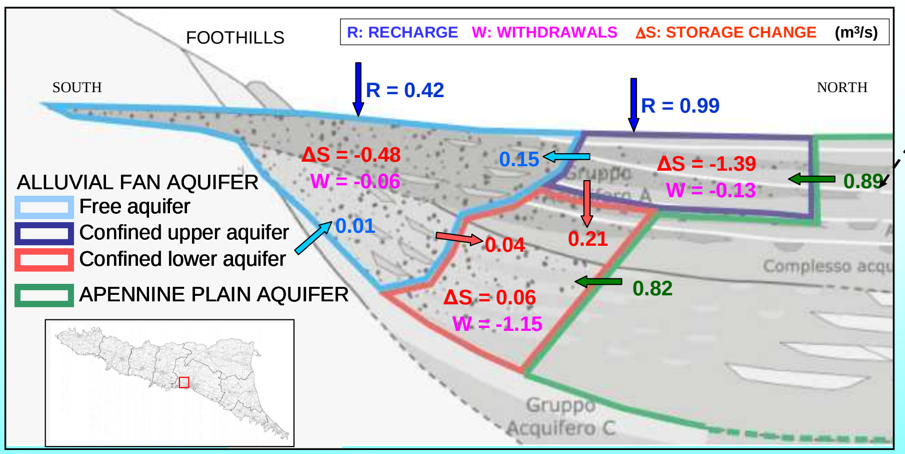




WATER BODIES and NUMERICAL MODEL SUPERPOSITION

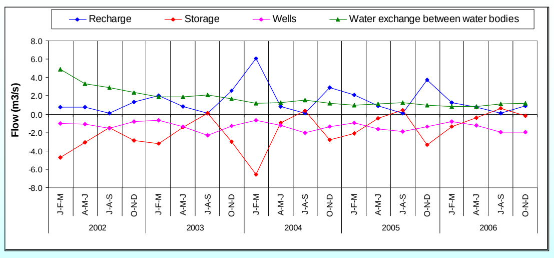
Water bodies, also defined in the third dimension, have been projected on the model allowing its division in terms of reservoir volumes in order to compute the water budget of each of them in space and time.

LOCAL GROUNDWATER BODIES AND FLOW



The modeled water budget has been applied all over the Emilia-Romagna plain in terms of water balance and exchange of fluid between parts of the system. The analysis was realized for some aquifer subsystems (10 alluvial fan groups) which give evidence of planning initiatives, resource management and monitoring organization.
Here the main items of the hydrogeological balance are arranged to give the pattern of groundwater flow. The flow rates (m³/s) are given as average of 5 years of available simulations (2002-2006).

WATER BUDGET TEMPORAL ANALYSIS



The temporal analysis could be done for every groundwater body, related to free or both upper or lower confined aquifer. It let to highlight the main terms of the water hydrogeological balance and the presence of seasonal variations or trends.

COMPARATIVE MODELLING SCENARIOS

WHAT IF SCENARIOS: last year's model input data (R), are replaced by scenario data (A,B):

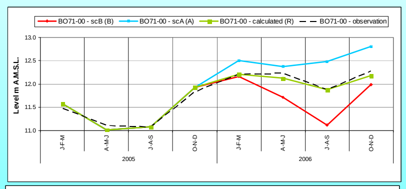
A: HIGH RECHARGE – LOW WITHDRAWALS
B: LOW RECHARGE – HIGH WITHDRAWALS

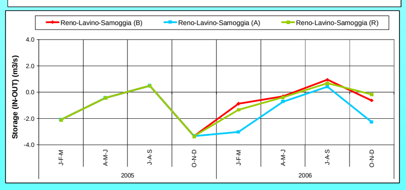
Recharge data: A: 75°Percentile - B: 25°Percentile evaluated from 1971-2000 soil water balance data (CRITERIA)

Withdrawals data: A: year 2002 – B: year 2003 respectively with high and low groundwater withdrawals

Each model run is verified with respect to:

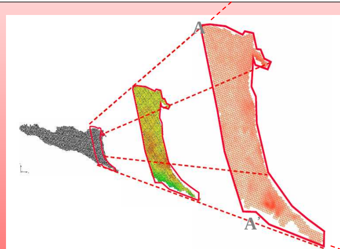
- piezometric levels
- water budget



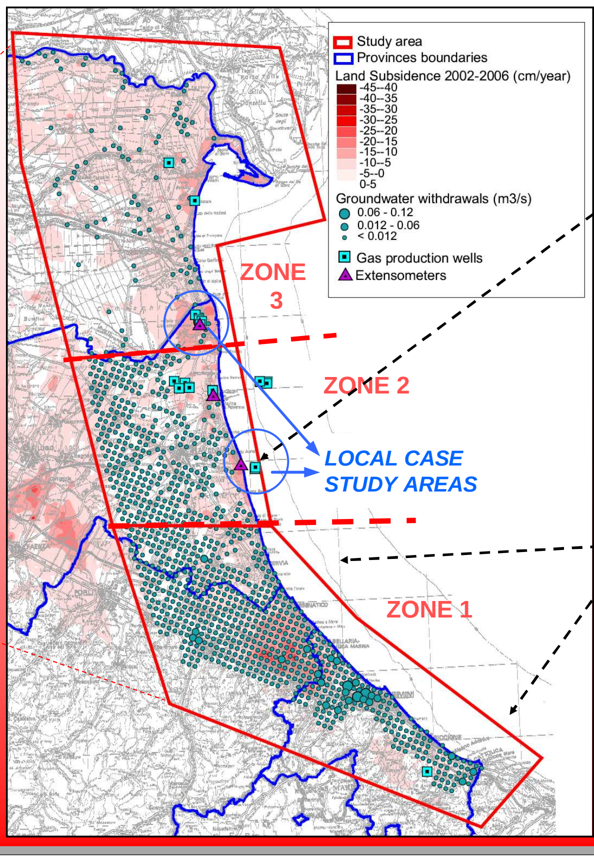


COASTAL AREAS LAND SUBSIDENCE

To improve the understanding of cause-effect relationships between groundwater withdrawals and land subsidence, the flow simulation model was used in conjunction with a vertical soil compaction simulator.
The soil compaction simulator has been applied to a band of about 20 km parallel to the coastline for a surface of approximately 2.400 km² and it has been possible to estimate the land subsidence rate between 2002 and 2006, which is the period of the available measures.



FROM REGIONAL TO COASTAL FLOW MODEL



PROBLEM COMPLEXITY:

The interpretation of the results of model simulations has required the joint assessment of the following aspects that, together or individually, may affect the calculated value of soil compaction: distribution of the compressibility coefficients, natural land subsidence and gas exploitation.

MODEL RESULTS ANALYSIS

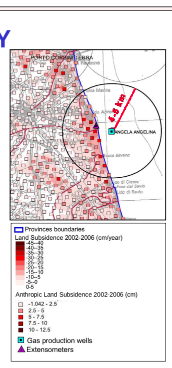
The coastal zone has been divided into three areas considering the following criteria:
ZONE 1: no gas exploitation;
ZONE 2: gas and groundwater exploitation;
ZONE 3: as zone 2, but with a very limited contribution of groundwater withdrawals.
These areas may also be distinguished for a different behaviour of natural subsidence.

ZONE 2 RESULTS: LOCAL CASE STUDY

- Average 2002-2006 gas exploitations (UNMIG): 1 GSm³
- Gas field radius of influence estimation: 4.5 km and land subsidence due to gas extraction estimation (from CENAS, 4)
- Fiumi Uniti extensiometric data

Local land subsidence averages:

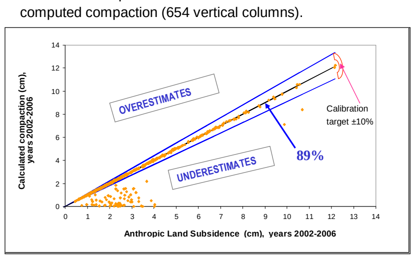
Total (observed, 1)	8.1 mm/y
Natural (estimated, 2)	1.5 mm/y
Due to gas extraction (estimated, 4)	4.0 mm/y
Due to groundwater withdrawals (estimated, extensometric data)	2.7 mm/y
Calculated from model simulations	3.8 mm/y



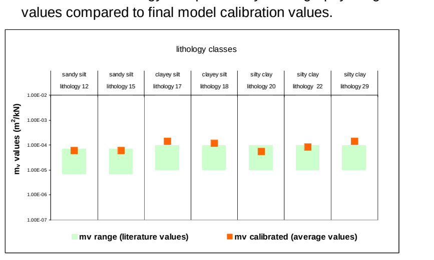
Results show that available compressibility data (from bibliography and observations) can explain the land subsidence due to groundwater withdrawals. The further step of the analysis, in zone 2, has attempted to identify the specific contributions to the land subsidence due to simultaneous presence of multiple causes. It must be reminded that results are strongly dependent by the values assumed for the natural subsidence and by the good calibration of the groundwater flow model.

ZONE 1 RESULTS: ZONE ANALYSIS

ZONE 1: comparison between observed ad model computed compaction (654 vertical columns).



Zone 1: fine lithology compressibility: bibliography range values compared to final model calibration values.



CONCLUSIONS

- The technology here employed is the result of almost 10 years of models development.
- The analysis here reported has allowed to verify the possibility of using the existing regional flow model to evaluate the flow dynamics of hydrogeological subsystems and to obtain quantitative information about the status of water bodies.
- At the same time a regional to local model (coastal) groundwater flow model implementation was experienced.
- Soil compaction modelling was used to improve the understanding of cause-effect relationships between groundwater withdrawals and land subsidence in the coastal zone where multiple cause-effect mechanism are to take into account.
- It is important to update models over time (model management) to achieve and maintain this kind of results.
- These models can now be employed as a systematic service, also in terms of forecasting purposes.
- These tools can be used for different purposes: designing, planning, management and even for water emergencies, and can be adapted to specific situations through the construction of appropriate scenarios and / or predictions.

Acknowledgment:
Servizio Tutela e Risanamento Risorsa Acqua e Servizio Difesa del Suolo, della Costa e Bonifica (Regione Emilia-Romagna).

Thanks to: Daniele Cristofori, Paolo Spezzani, Marco Marcaccio (Arpa Emilia Romagna-Direzione Tecnica), William Pratizzoli (Arpa SIMC), Paolo Severi (Regione Emilia-Romagna Servizio Geologico Sismico e dei Suoli).

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