DENSITY-DEPENDENT GROUNDWATER FLOW MODELLING STRATEGIES IN COASTAL AREAS: A BRIEF REVIEW OF SIMPLICITY AGAINST COMPLEXITY IN MODELLING EFFECTIVENESS

E. Cascelli, E. Crestaz and F. Tatangelo

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Scope

Current paper briefly discussed on the specific issues relevant to density-dependent groundwater modelling in coastal areas, extremely important to hydrogeological community:
- water supply purposes face to increasing fresh water demand;
- containment policies assessment at contaminated industrial sites.

Approach at different level of refinement and complexity (Anderson & Woessner, 1992; Rushton, 2005):
- problem scope and scale;
- data and financial constraints;
- available resources and time schedule.

Approach should be optimized, highlighting the benefits of simplicity against complexity in modelling effectiveness and confidence building.
Groundwater modelling strategies and guidelines

Different approaches and procedures generally result in order of complexity differences in schematization, time and cost of modelling analysis and communication:

- development times;
- complexity in 2D vs. 3D implementation;
- steady-state vs. transient condition;
- advective vs. reactive transport processes;
- modelling task in “isolation” vs. environmental management system framework development (i.e. SDSS).

Scientific literature provides relevant discussion on applied groundwater modelling guidelines (Refsgaard & Henriksen, 2004; Hill at al., 2004; Hill & Tiedeman, 2007) and models assessment (Bredehoeft, 2003; Hassan, 2004a; Hassan, 2004b). Further research also focuses on key issue of simplicity vs. complexity as Hill (2006) and Manduca & Mogk (2006).
Confidence building in modelling process

“All models are wrong, but some are useful”

Box (1994)

It is impossible that models could accurately represent the actual processes occurring in real systems

Oreskes et al. (1994)

History matching rather than verification and validation

Konikow & Bredehoef (1992)

Scientific and philosophical tradition

Popper’s (1959)

The principle of parsimony should govern decisions in designing and implementing effective models (Hill & Tiedeman, 2007).
Salt water intrusion fundamentals

Density-dependent groundwater flow is conceptually well known, resulting in thinning of fresh water flow section and increasing gradients and velocities close to sea boundary. Immediately below, an intermediate convective and variable density flow zone marks the transition to deeper salt water, phenomena being governed by density contrasts and groundwater flow velocities.

Bear & Verruijt (1987)
Detail of transient density-dependent groundwater flow along a 2D vertical section in a over-exploitation regime
Density-dependet groundwater modelling pros and cons

Groundwater density-dependent flow modelling plays a key role as both an interpretative and predictive tool:
- consistent interpretation of available data;
- revealing unpredicted and/or underestimated patterns;
- supporting long term system dynamics analysis and policies assessment/optimization.

Process dynamics can be easily underestimated, potentially leading to relevant environmental impacts.

Unfortunately, density-dependent simulations are computationally demanding, due to problem non linearity, and often unstable even for relatively simple hydrogeological settings (Simmons, 2005).
Conceptual 2D numerical section

$K_x = 1 \times 10^{-4} \text{ m/s}$
3D finite element mesh to conceptually investigate salt water intrusion

Steady-state configuration in absence of exploitation
3D finite element mesh to conceptually investigate salt water intrusion

Aquifer salinization due to pumping 120% of uphill inflow
Single well vs. multiple wells barrier after 30 years
3D density-dependent flow modelling

3D density-dependent flow modelling is often not an option in real case studies and relate complexity comes at:

- high cost, often requiring that a full-featured GIS is implemented to support modelling process;
- imposing a complete 3D system conceptualization;
- higher difficulties in model building;
- expanded computation times.

Our experience suggests that such a complexity results at least in a order of magnitude increase in overall development times.
Vomano valley: topography and basement
High pumping rates regime

2 years

4 years

8 years
Detail of 3D transient density-dependent groundwater flow in a over-exploitation regime revealing complex 3D salinization patterns

$t = 10950$ giorni

Esagerazione verticale: 2:1

C(mg/l): 0 5000 10000 15000 20000 25000 30000 35000
Simulation scenario

t = 10950 giorni

www.GIScience.it
Advanced visualization

Simulated salinization and groundwater flow pathlines after 30 years of exploitation
Benefits of simpler 2D vs. full 3D modelling

- shorter implementation and updating times
- shorter and/or realistic computing times
- fewer defined parameters, types and number, and supporting; observations
- limited pre- and post-processing requirements and over-realistic 3D conceptualization
- imposing less advanced skills in geospatial applications design/analysis and scientific visualization (ESDA, Exploratory Spatial Data Analysis; 3D and time-dependent visualization)
- integrating and testing knowledge framework, before moving to more complex approach
- easier to build professional and effective presentations to non-technical audience
- definitely, supporting a more dynamic and effective approach to modelling tasks
Conclusions

Conceptual and 2D modelling should be preferred, at least at early analysis stages, as density-dependent modelling is computational extremely challenge.

Simpler approach enables properly focusing on sensitivity analysis and calibration scopes, rather than being captured by excessive details.

As a rule of thumb, simulation run times longer than 30’ would be critical for effective modelling, generally leading to diverge from calibration and sensitivity analysis scopes; Hill (2006) also came to the same conclusion.

However full 3D modelling is often not an option in complex hydrogeological and human settlings relating to impact of coastal geometry and leakage from human-made infrastructures on 3D salt water intrusion.