Using cave data for improving the reliability of karst groundwater flow models

Mario Parise and Isabella Serena Liso
University Aldo Moro, Department of Earth and Environmental Sciences, Bari, Italy

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mario.parise@uniba.it
**EVOLUTION OF KARST SYSTEM**

1. Initial discontinuities in limestone: bedding, joints, faults

Karst processes:
- Water flow enlarges the initial discontinuities
- Fluctuation of karst base level

2. Complex network of channels, conduits and fractures, variable in space and time
**KARST GROUNDWATER FLOW MODEL**

The conceptual model is usually physical, an interconnected sequence of recharge areas, permeability distributions, and geologic substrates that collectively provide a visualization of the way in which water is added to the system, stored in the system, transmitted through the system, and discharged from the system (White, 2003).

**CLASSICAL GEOLOGICAL FIELD WORK**
*(AT THE SURFACE)*

+ **DIRECT OBSERVATIONS AND MEASUREMENTS IN CAVES** *(UNDERGROUND)*

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Hartmann et al., 2014
Table 11.1. Summary of methods available for hydrogeological investigations in karst areas.

<table>
<thead>
<tr>
<th>Method or group of methods</th>
<th>Data obtained/advantages</th>
<th>Disadvantages/limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geological methods</td>
<td>Aquifer framework and geometry information</td>
<td>Data not necessarily directly related to groundwater</td>
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<tr>
<td></td>
<td>Karstifiability of the rock</td>
<td>Often not a predictable and unambiguous relation between lithology and hydrogeology</td>
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<td></td>
<td>Orientation, location, type and frequency of potential flow paths</td>
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<tr>
<td></td>
<td>Theoretical hydraulic conductivity and porosity</td>
<td></td>
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<tr>
<td>Geomorphological methods</td>
<td>Degree of karstification</td>
<td>Data mainly from the surface (indirect)</td>
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<tr>
<td></td>
<td>Types of recharge</td>
<td>Sartor framework rather than hydrodynamics</td>
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<td></td>
<td>Historical hydrogeomorphology</td>
<td></td>
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<tr>
<td>Speleological methods</td>
<td>Locating and mapping conduits in 3D</td>
<td>Limited data from covered karst</td>
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<td>Monitoring water quality and quantity within the aquifer</td>
<td></td>
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<td>Determining the temporal evolution of conduit systems</td>
<td>Access to cave systems may be limited or non-existent</td>
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<tr>
<td>Hydrological methods</td>
<td>Water budget compilation</td>
<td>Specialist speleological skills required</td>
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<tr>
<td></td>
<td>Characterisation of flow systems by spring hydrograph analysis</td>
<td>Only a small and perhaps unrepresentative part of the aquifer is likely to be accessible</td>
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<tr>
<td>Hydraulic methods</td>
<td>Determination of transmission and storage characteristics</td>
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<td>Determination of piezometric level</td>
<td></td>
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<td></td>
<td>Determination of groundwater velocity and flow direction</td>
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<tr>
<td>Hydrochemical methods</td>
<td>Hydrochemical characterisation of groundwater bodies</td>
<td>Water budget often incomplete, as catchment boundaries are not always clear, and not all inputs and outputs can be monitored</td>
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<td></td>
<td>Information on water quality and contamination problems</td>
<td>Hydrograph alone gives limited information of the origin of the water (needs to be combined with chemograph)</td>
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<td>May be used as natural tracers for the origin and movement of the water</td>
<td>Many methods not wholly appropriate under non-Darcian conditions</td>
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<td>Estimates of flow directions and magnitudes may not be accurate</td>
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<td>Pumping tests may not give representative results</td>
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<td>Difficulties in developing an adequate sampling strategy</td>
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<td></td>
<td></td>
<td>(high temporal variability)</td>
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<td></td>
<td></td>
<td>In karst aquifers, microbial contamination is often of greater importance than chemical</td>
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<tr>
<td>Isotopic methods</td>
<td>May be used as natural tracers for the origin and movement of the water; this includes:</td>
<td>Input function not known precisely</td>
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<td></td>
<td>Identifying sources of karst waters and mixing processes</td>
<td>Ambiguities possible in interpreting data</td>
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<td>Determining residence time of karst waters</td>
<td></td>
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<tr>
<td>Tracer methods</td>
<td>Determination of flow routes and velocities</td>
<td>Difficulty in recognising &quot;negative&quot; tracings</td>
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<td>Determining contributing areas for springs</td>
<td>Usually only gives information for selected points and the hydrological conditions during the tracer test</td>
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<td>Information on contaminant transport</td>
<td>Limited applicability for very deep and large systems with very long transit times</td>
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<tr>
<td></td>
<td>Usually very reliable, precise and unambiguous information</td>
<td>Visible colouring and toxicity concerns for some tracers</td>
</tr>
<tr>
<td>Geophysical methods</td>
<td>Determining geological structures and overburden thickness</td>
<td>Results may be difficult to interpret without ambiguity (non-uniqueness)</td>
</tr>
<tr>
<td></td>
<td>Locating conduits, fractures and other preferential flow paths</td>
<td>Resolution vs. depth of investigation (i.e. the greater the depth, the lower the resolution)</td>
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<td></td>
<td>Data can be obtained over wide areas</td>
<td>Some techniques require very precise location control (gravimetry), others have noise problems or require heavy or expensive equipment</td>
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<td>Information on the structure and properties of the underground without drilling, i.e. at relatively low cost</td>
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</table>

Goldsheider & Drew, 2007
FIRST ATTEMPT TO APPLY GROUNDWATER FLOW MODEL TO APULIAN KARST

Apulian caves
More than 2,000 caves registered in the regional inventory
STUDY AREAS

Inghiottitoio di Masseria Rotolo and Vora Bosco

• Apulian caves that reach groundwater far from the shoreline.
• Direct groundwater monitoring.
• Perfect natural, hydrogeological labs.
FIELD ACTIVITIES
LIMESTONE OUTCROPS

BEDDING, STRUCTURAL AND KARST DISCONTINUITIES
GEO-STRUCTURAL SURVEY

ROCK MASS DISCONTINUITIES CHARACTERIZATION
DISCONTINUITIES: IMAGE PROCESS SOFTWARE

STATISTICAL ANALYSES:
- orientation
- size
- frequency
- pervasiveness
SINKHOLES
ENDORHEIC BASINS

MORPHOMETRIC PARAMETER:
Orientation of main axis

MORPHOMETRIC PARAMETER:
Shape

LEGEND

Rotolo Cave

EGU

ENDORHEIC BASINS
WEATHER DATA COLLECTION
Rock sampling

STRATIGRAPHY

A) Mudstone  B) Limestone
C) Wackestone/packstone  D) Packstone
E) Floatstone  F) Mudstone
The ROSE DIAGRAM shows the preferential CONDUITS development direction of the Rotolo Cave, that is in E-W direction.
Canale di Pirro polje

Polje orientation: W-E

Regional tectonic trend (Anti-Apenninic trend): SW-NE
EXPLORATION OF FLOODED CHANNELS

ROTOLO CAVE

Max depth: 
-60 m below water table
MULTIPARAMETER PROBE IN CAVE

Multi-parameters probe (water) OTT
T, level, EC
Orpheus mini (Vora Bosco)
EcoLog800 (Grotta Rotolo)
DATA COLLECTION

Cave climate (air)
T, RH
HOBO Pro v2 - onset

Comune di Monopoli - Località Cavalluccia
Coordinate ingresso: 40°49'52.8" N - 17°17'16" E
Quota ingresso: 300m s.l.m.
Dislivello negativo: 324m
Sviluppo planimetrico: 1.270m
Sviluppo totale: 1648m

Rilevato: Angela Petti, Marco Saveri, Luca Castellotta, Massimo Zuccaro, Nico Lippolis, Fabio Gala, Maria Schiavo, Nina Masselli, Vito Barone, Luca Potrigli.
Karst aquifer characterization for modeling

**NEEDED INFORMATIONS**

Area of the groundwater catchment;
Inflow:
- ALLOGENIC
- INTERNAL RUNOFF
- DIFFUSE INFILTRATION
- FROM PERCHED CATCHMENTS

Conduits geometry
Matrix hydraulic conductivity
Fracture system hydraulic behaviour
Conduit-system response time
Conduit-fracture coupling effect

**GEOLOGIC BOUNDARY CONDITIONS**

Karst aquifer architecture
Surface catchment architecture
Catchment relief
Lithologic factors
Stratigraphic factors
Structural influence and fluxes control

[Diagram showing connections between hydraulic, hydrogeology, geomorphology, geology, and karst processes and aquifer flow models.]
Ongoing activity

- Hobo sensors data collection
temperature and humidity of cave air

- Statistical study of system delay
  Rain VS water level

- Groundwater samplings
  chemical and microbiological analysis

- Biospeleological samplings
  Checking for environmental markers