Session HS8.2.4

GROUNDWATER FLOW UNDERSTANDING IN WATER MANAGEMENT AND ENVIRONMENTAL PROBLEMS

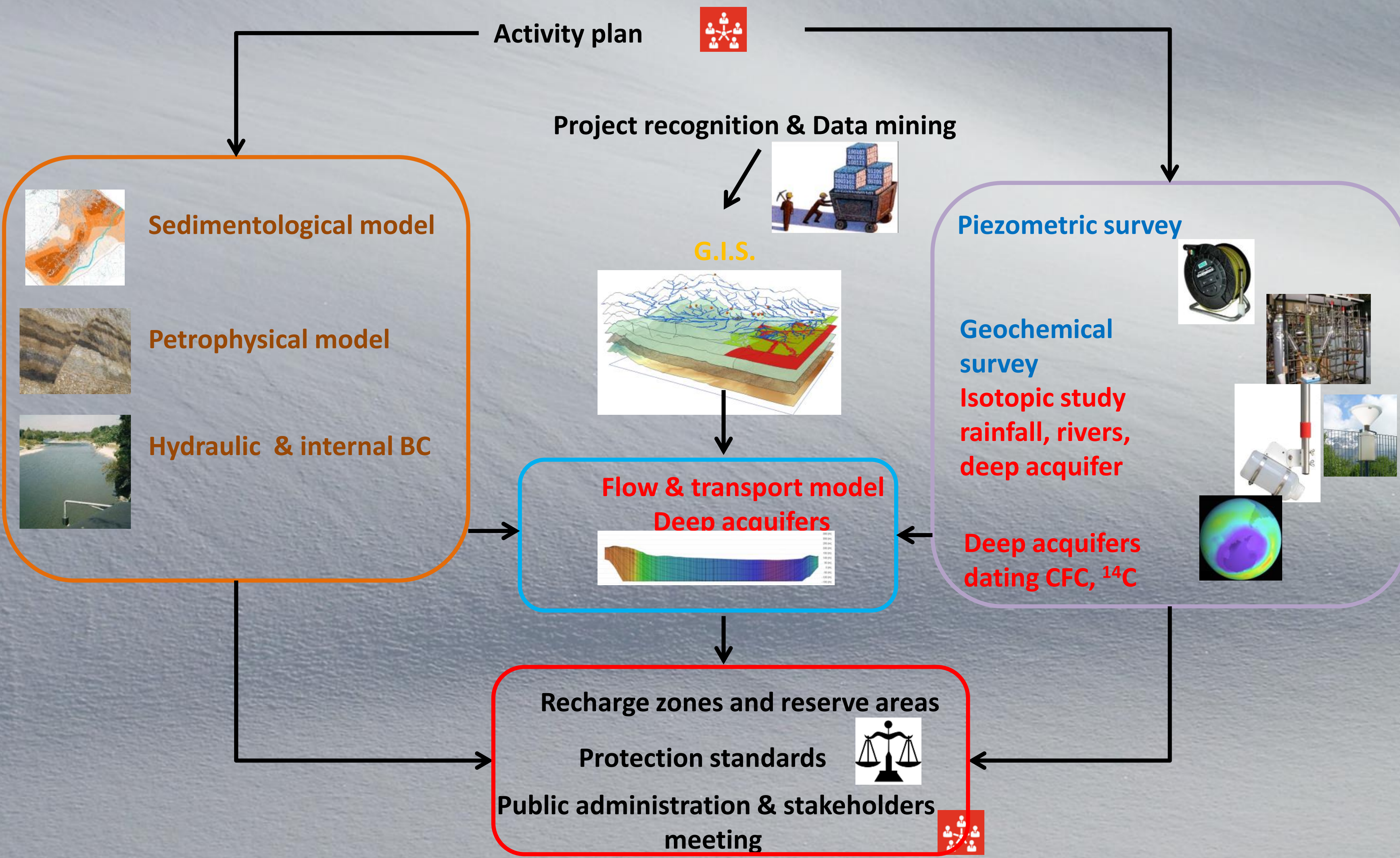
MULTI-TECHNIQUE GROUNDWATER FLOW SYSTEM ANALYSIS AND DATING OF DEEP AQUIFER IN ALESSANDRIA BASIN (PIEDMONT)

Nicola Quaranta[1], Elena Cogo[1], A.Simoni[2], Mariachiara Caschetto[3], Massimo Marchesi[3]

[1] GEOengineering s.r.l., Torino (TO-IT); [2]EGATO6, [3]Isotope Tracer Technologies Europe (IT2E) Milano (MI-IT)

Photography encouraged

Work flow


Activity plan
Project recognition & Data mining
G.I.S.
Sedimentological model
Petrophysical model
Hydraulic & internal BC
Piezometric survey
Geochemical survey
Isotopic study rainfall, rivers, deep acquifer
Deep acquifers dating CFC, ^{14}C
Flow & transport model
Deep acquifers
Recharge zones and reserve areas
Protection standards
Public administration & stakeholders meeting

Context Analysis

- NW Italy, Piedmont, Alessandria district, EGATO6 (Water Authority): Population 0.3 M inhabitants
- Study Area ≈ km^2 1.000
- GWB abstraction rate = 2.1 m^3/s ÷ $65*10^6$ m^3/y (IT Piedmont District Water Protection Plan, 2018).
- Water distributed for human use: $30*10^6$ m^3/y (Water Authority Area Plan, 2007); 40% from wells
- River Tanaro mean flow Q_m = 174.2 m^3/s => 40% River Po – Piedmont outflow (ARPA – IT Piedmont District Environmental Agency)

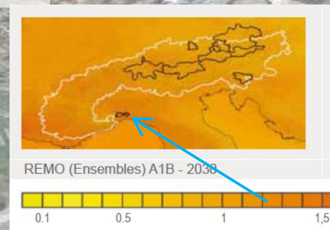
Study target

- General reconstruction of deep aquifers flow system
- Mapping «**recharge areas**» of deep aquifers, preventing diffusive pollution and depletion
- Zoning «**reserve areas**» (portion of «deep» aquifers with good quantitative & chemical state, to protect as a future water supply

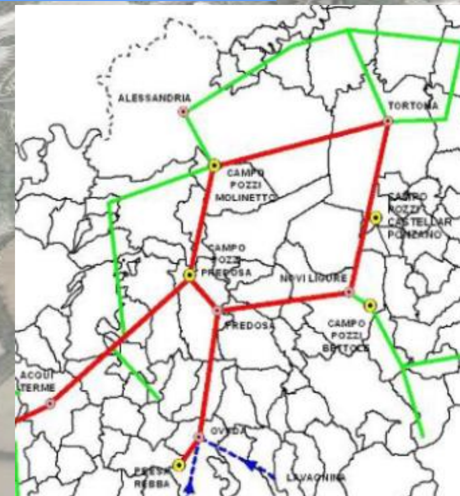
Environmental problems

DRIVERS

- «Climate change» (EU - CLISP project – AL District): +1.3°C at 2030 (av. 1961-1990)



- «Terzo Valico» railway & tunnel (EU TEN-T core network), 6.2G€, start 2022. Logistic platform & hub development

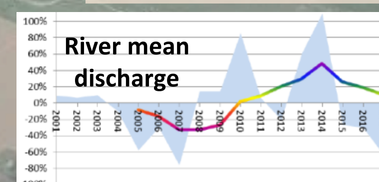


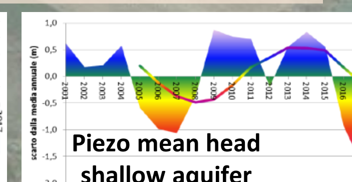
RESPONSES

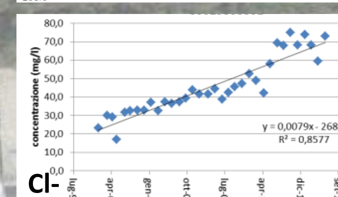
- Water authority upgrade plan (AL)
- Regional Piemonte Water Protection Plan (2018)
- Remediation planes of contaminated sites (IT)
- GWD Groundwater Directive 2006/118/EC
- Nitrate directive 91/676/CE

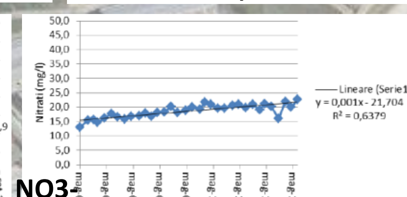
IMPACT

- Streamflow < 20% (scenario 2099 compared to 1981-2000)
- Water scarcity (in shallow aquifer)
- Increasing Cl-, NO_3 pollution







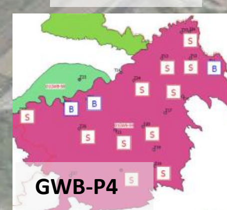


PRESSURES

WISE (Water Information System for Europe) EEA

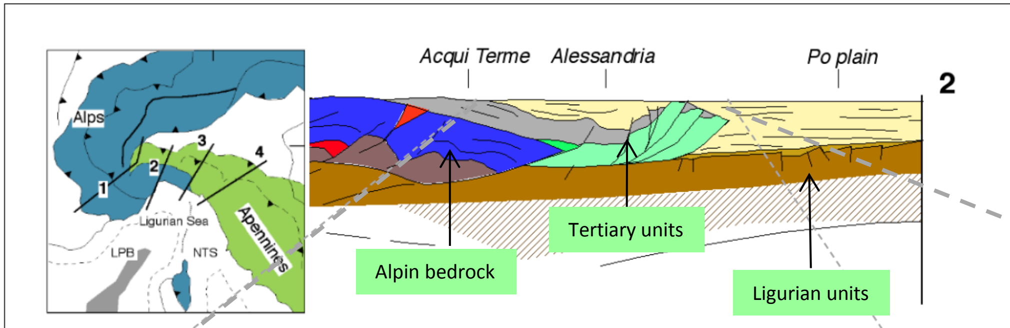
- WISE 1.5 Contaminated sites, Waste disposal, Quarries
- WISE 2.1, 2.3 Urban run-off and leaching
- WISE 2.2 Leaching of agricultural land
- WISE 3.1-> 3.7 Abstraction well (increasing water demand)
- WISE 6.1 Changes in aquifer recharge. Increasing impermeable surface. Urban land consumption :
  > 10% - 20% in 20 years; mean district rate : 1.2%/y

STATE

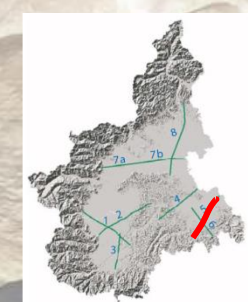


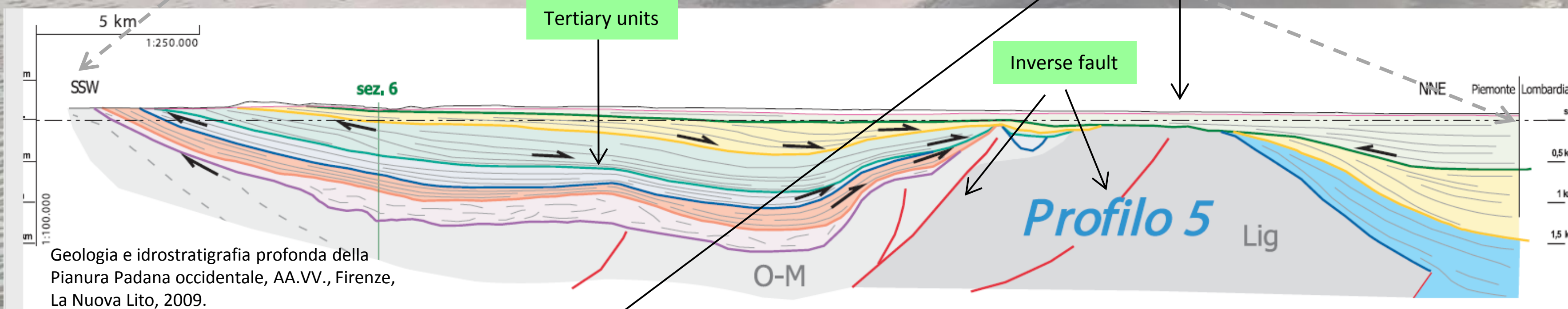
Flow understanding

SEDIMENTOLOGICAL AND HYDROGEOLOGICAL MODEL

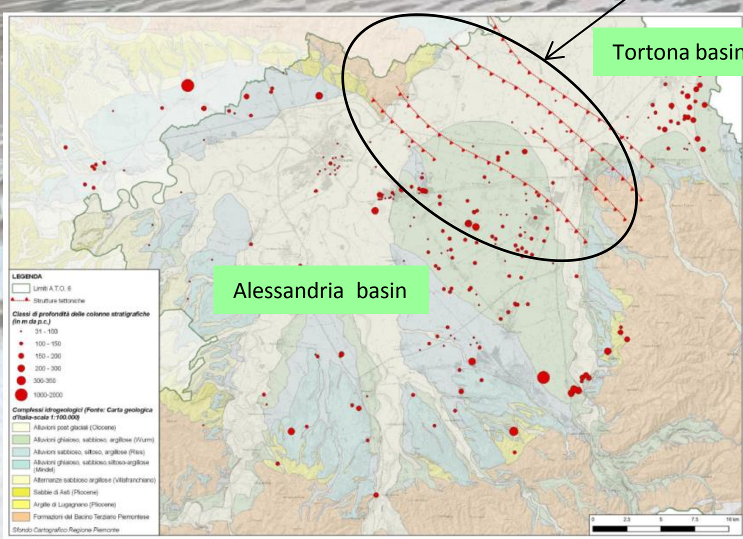


Tortona-Montecastello buried dorsal= closing element of the depositional basin Alessandria with respect to the adjacent Tortona basin





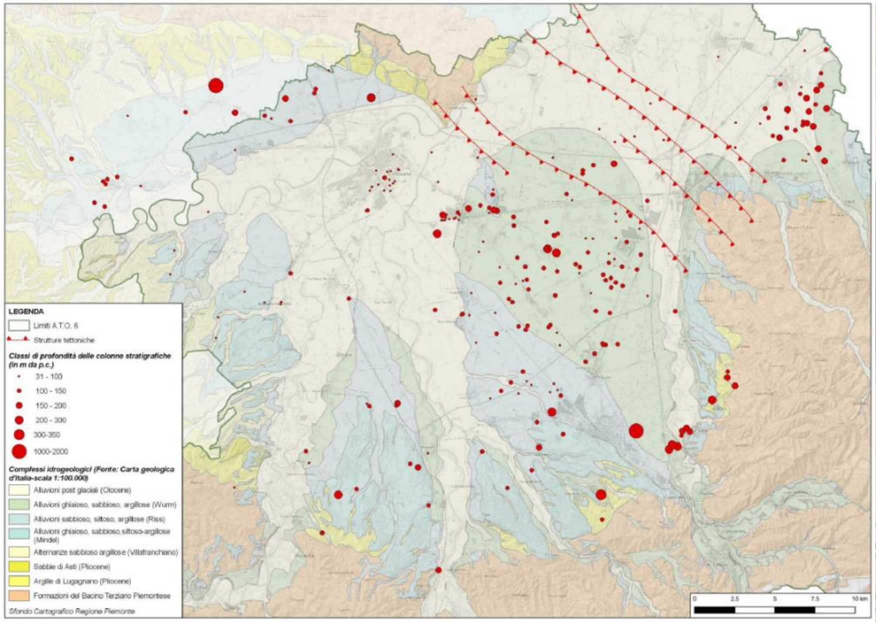
Geologia e idrostratigrafia profonda della Pianura Padana occidentale, AA.VV., Firenze, La Nuova Lito, 2009.



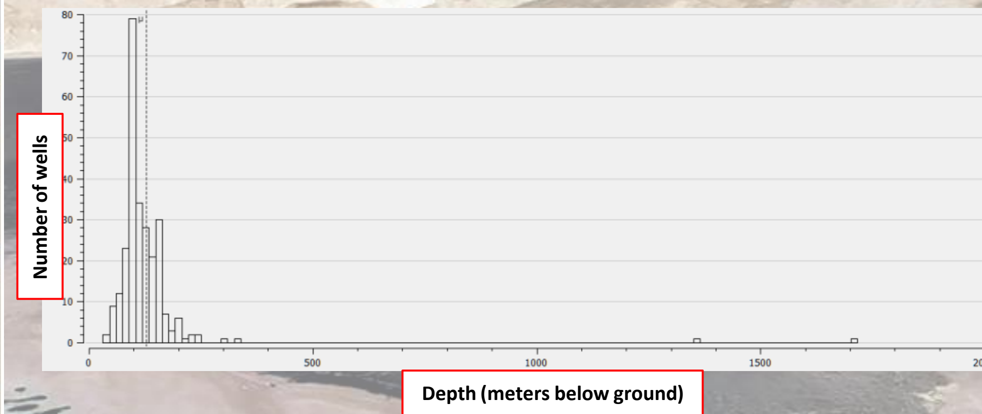
AGE		SEDIMENTOLOGICAL UNITS			HYDROGEOLOGICAL UNITS	
OLOCENE	0.01 Ma	DEPOSITI FLUVIALI E E FLUVIO-GLACIALI		Q2	A	AI AII AIV
PLEISTOCENE	superiore					
	medio					
	inferiore 1.8 Ma	"VILLAFRANCHIANO SUPERIORE"		Q1	B	BI BII BIII
PLIOCENE	superiore 2.6 Ma					
	medio	"VILLAFRANCHIANO INFERIORE" ASTIANO		P3	C	CI CII CIII
	3.6 Ma					
	inferiore	"VILLAFR." "ASTIANO" "PIAC."		P2	D	DI DII DIII DIV
	5.3 Ma	"PIACENZIANO"	M/P	P1	E	EI EII EIII EIV
MIOCENE	Messiniano superiore	"MESSINIANO" "CASSANO-SPINOLA"		M2	F	FII FIII
MIOCENE		"MESSINIANO" "F. GESSOSO-SOLF."		M1	G	GIV

Flow understanding

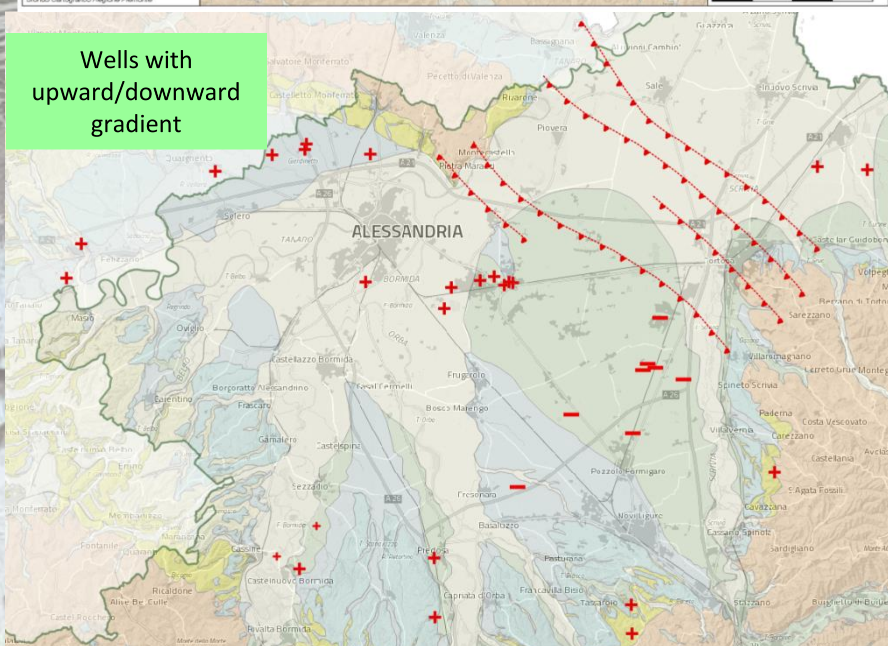
SEDIMENTOLOGICAL AND HYDROGEOLOGICAL MODEL

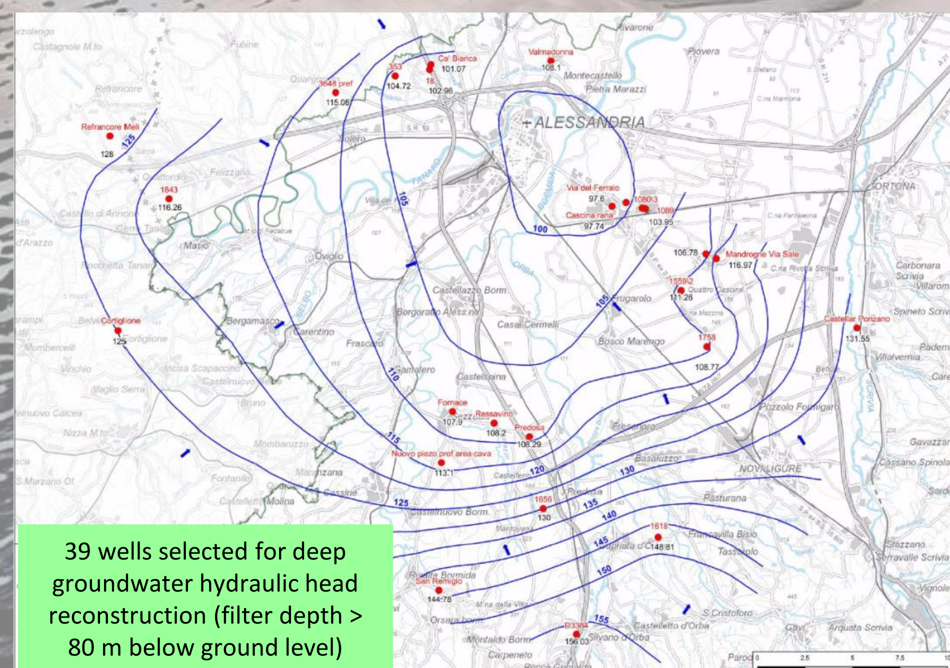


N° Wells with stratigraphy=263
Depth = from 31 to 1716 m below ground



Wells with upward/downward gradient

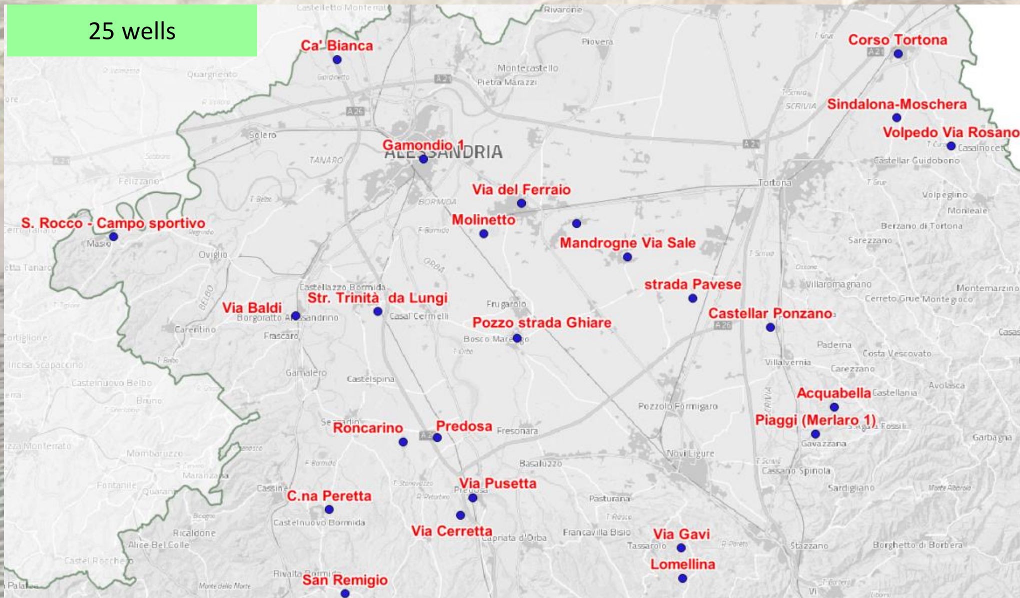


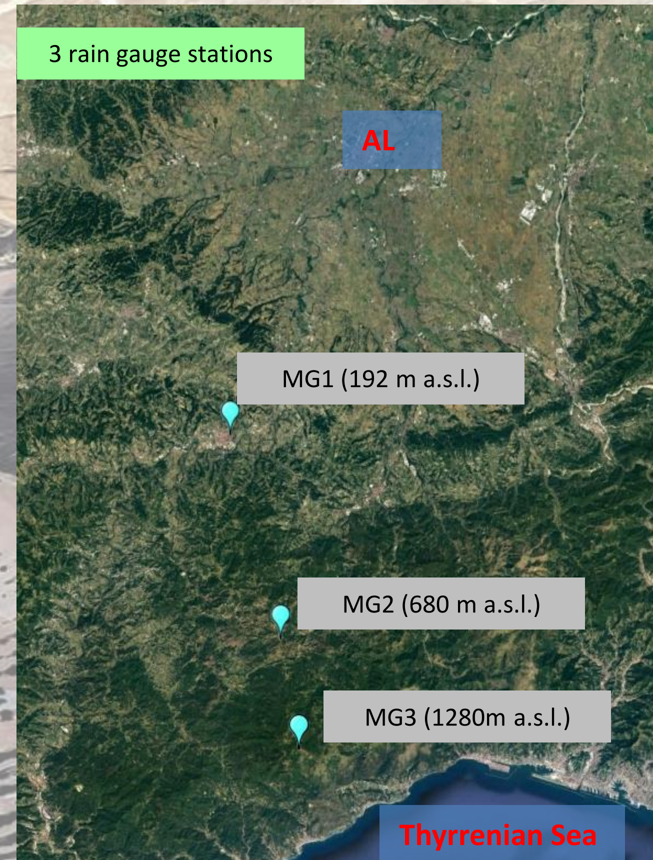


39 wells selected for deep groundwater hydraulic head reconstruction (filter depth > 80 m below ground level)

Flow understanding

MONITORING NETWORK SELECTION

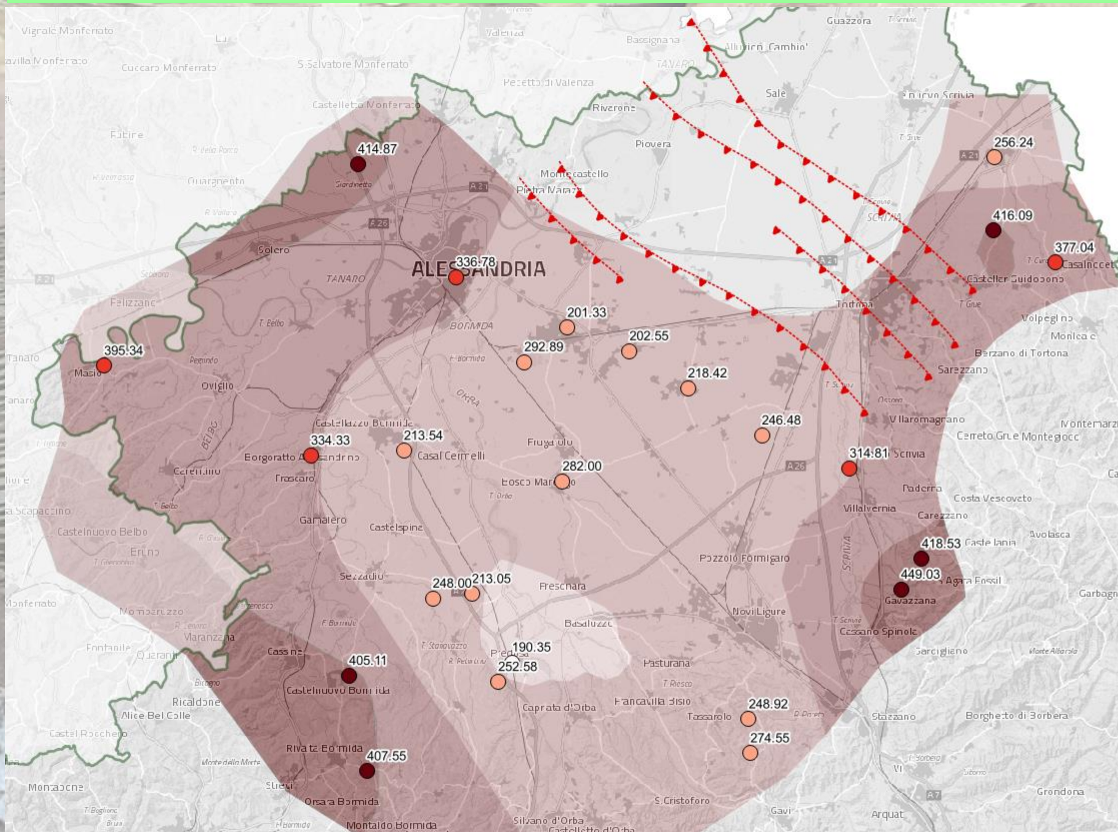




Flow understanding

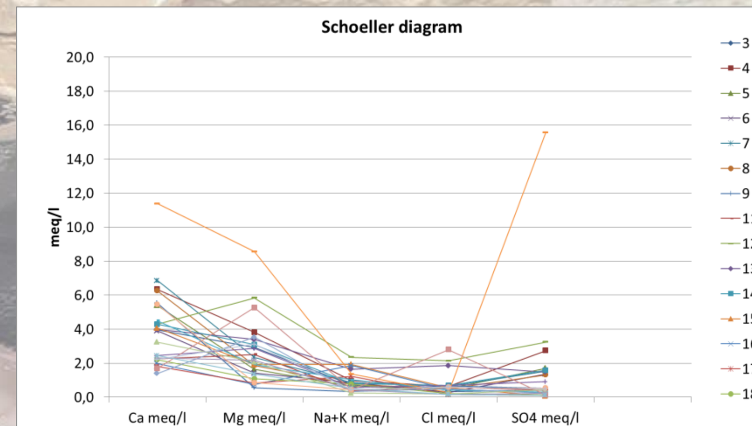
HYDROGEOCHEMICAL GROUNDWATER MONITORING

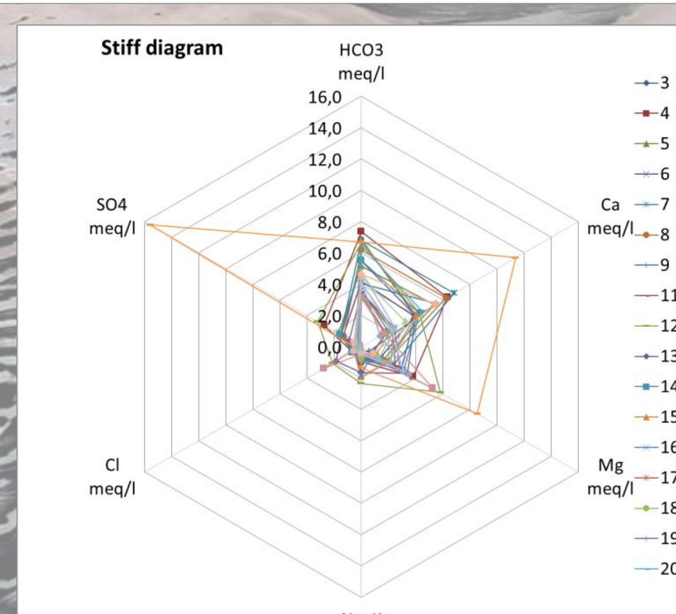
Analysis of ionic relationships
Discrete evolution from basinal margins to the center



Maximum mineralization on borders due to Tertiary units outcrops
Minimum mineralization on alluvial basin depocentre,
due to shallow water mixing

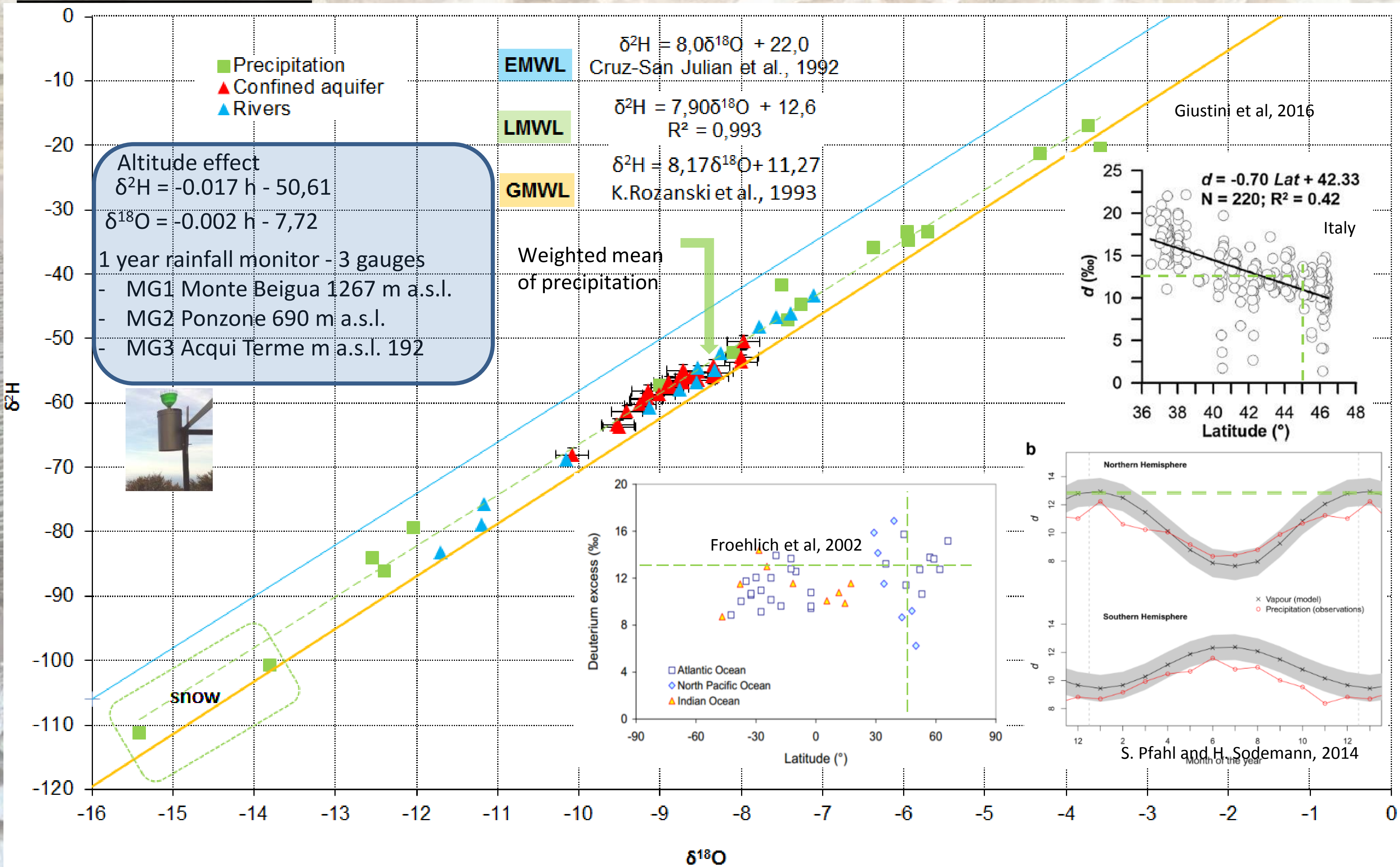
Dominant bicarbonate-calcium-magnesia facies





Flow understanding

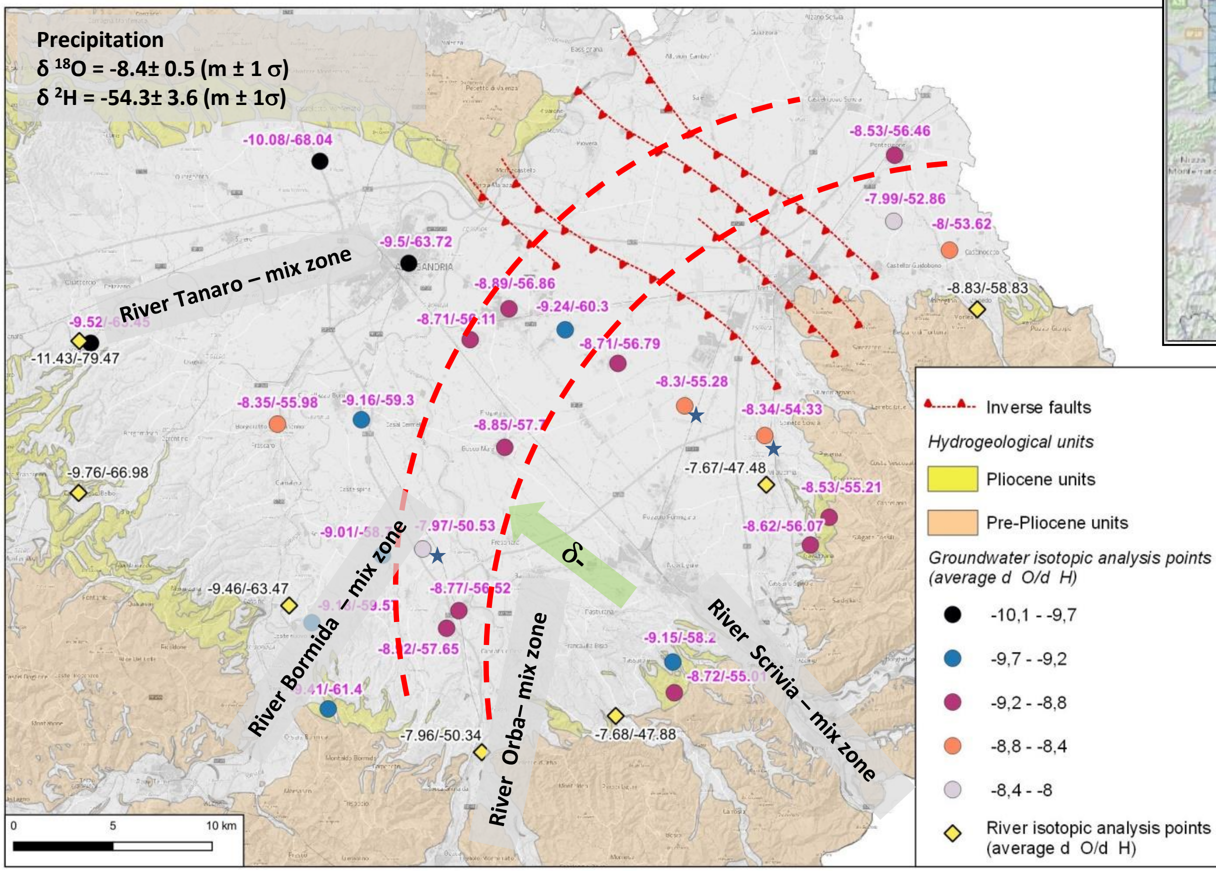
ISOTOPIC ANALYSIS

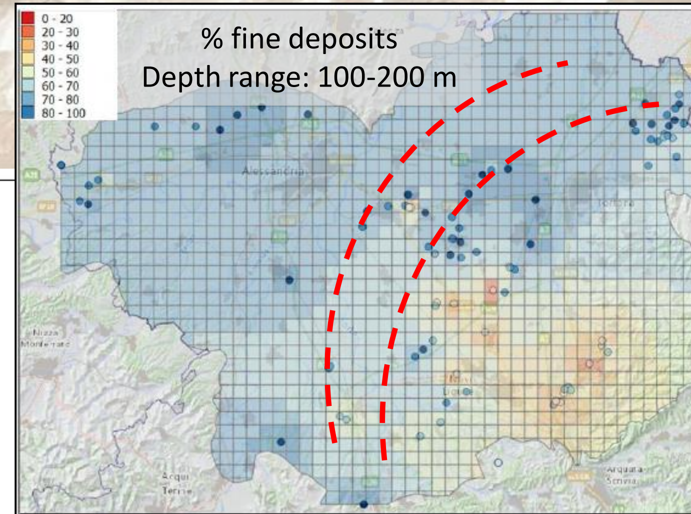


ISO4 – Laboratory of Turin University, TO (IT)
Measurement uncertainity ±0,2 δ^2O, ±1,0 δ^{18}H

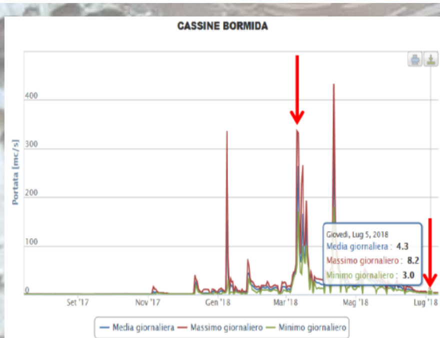
Flow understanding

ISOTOPIC ANALYSIS

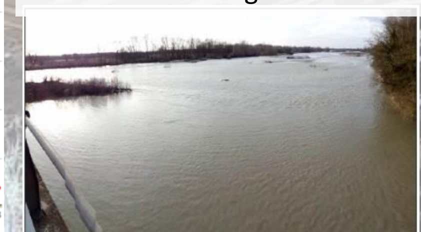




- 2 sampling rounds in winter, summer 2018 (wet & dry conditions)
- 90% of wells: $\Delta\delta^{18}O$ < 5% (stable isotopic composition = medium/high degree of confinement, low vulnerability)
- ★ 10% of wells: $\Delta\delta^{18}O$ > 5% to 10% (significant fluctuation of isotopic composition = semi-confined conditions with flow through aquitard layer; medium –low vulnerability)
- River fluctuation of isotopic composition from winter to summer: +12% $\delta\,^{18}O$ and +15% $\delta\,^{2}H$
- Mean recharge elevation of the aquifer based on isotopes depletion: 210-270 a.s.l.



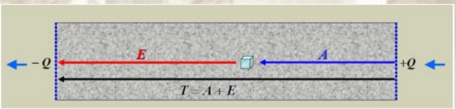
March 2018 – aquifer recharge «full bank discharge»



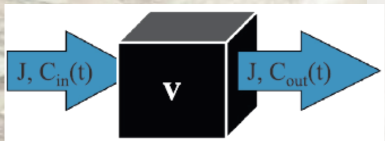
July 2018 – aquifer drainage low-flow channels

Flow understanding

DISTRIBUTION OF «APPARENT TRACER AGE»

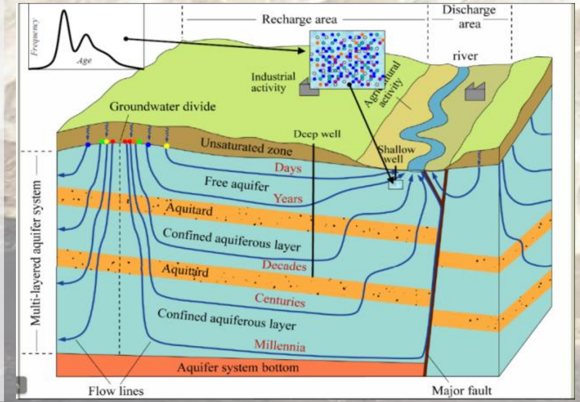


Cornaton (2016)



Mean ResidenceTime average travel time between the point of recharge and the point of discharge

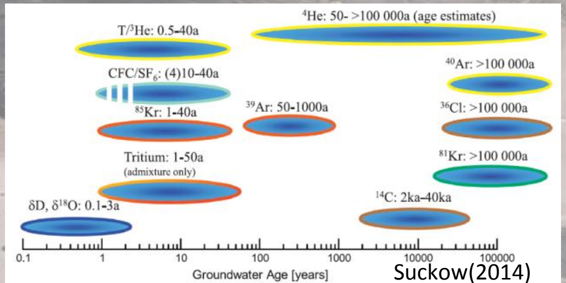
- ✓ In the real world groundwater samples are taken from wells with multiple screens and represent a mixture of "idealized" ages
- ✓ From "idealized" age of a single water particel (parallelism of single age in a population) to "age distribution" (distribution function of ages in a mixture/population)
- ✓ Combined investigation approach: multiple tracer measurements
  - a. anthropogenic tracers => upper regional aquifer system ("young groundwater" - short residence time)
  - b. conventional radiocarbon age => deep regional aquifer system ("old groundwater" long residence time)



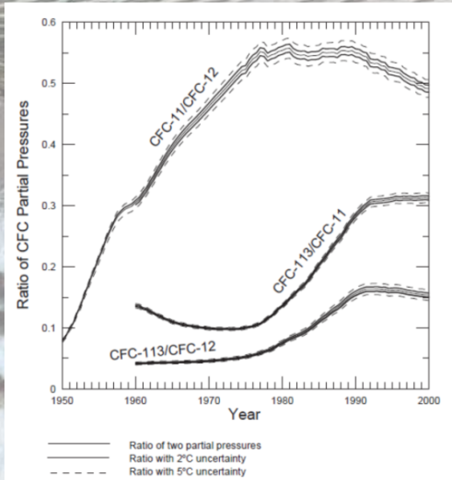
LUMPED parameters models

a. anthropogenic tracers

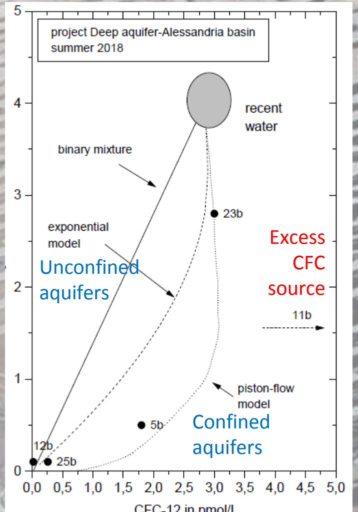
Tracer output concentrations are computed using
- the input concentration
- the "transit time distribution function" (age-dependent weight function)



Suckow(2014)



CFC IAEA Guidebook (2006)



Exponential model $g(\tau) = \frac{1}{T}\exp\left(-\frac{\tau}{T}\right)$

Piston-flow model $g(\tau) = \delta(\tau - T)$

H.Oster (2018)

sampling site	used tracers	model ages in years	1σ standard–deviation (years)
5B	CFC–12 CFC–113 SF_6	36	±3
11B	CFC–113 SF_6	26	±5
12B	CFC–12 CFC–11 (CFC–113) (SF_6)	67	±1
23B	CFC–11 CFC–113 SF_6	27	±3
25B	CFC–12 CFC–11 (CFC–113) (SF_6)	54	±1

vulnerability	high	medium	low
Calendar year of recharge	1970–present	1950 – 1970	< 1950
Groundwater age (yr)	0 – 35	35 – 55	> 55
^{3}H (12.32)[1]	5 – 25	< ~1 or > 25	< 0.5
^{39}Ar (269)[2]	> 90	70–90	< 70
^{14}C (5730)[2]	> 50	40–60	< 50

Hinsby K. (2001)

DISTRIBUTION OF «APPARENT TRACER AGE» - PRELIMINARY RESULTS

b. conventional radiocarbon age

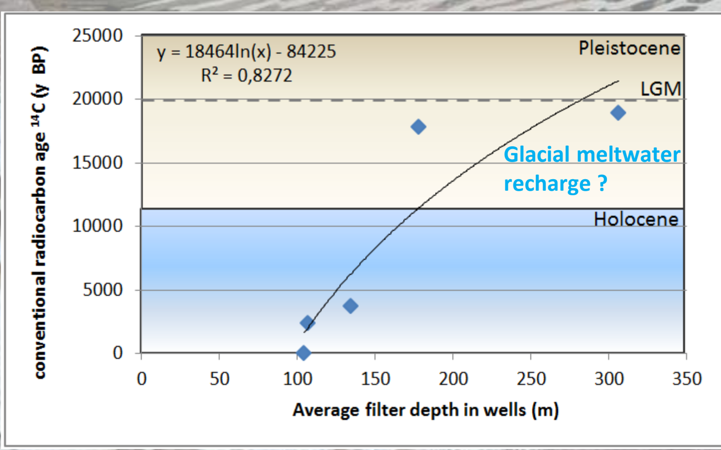
$$t = \tau \ln\left(\frac{N(^{14}C,0)}{N(^{14}C,t)}\right)$$

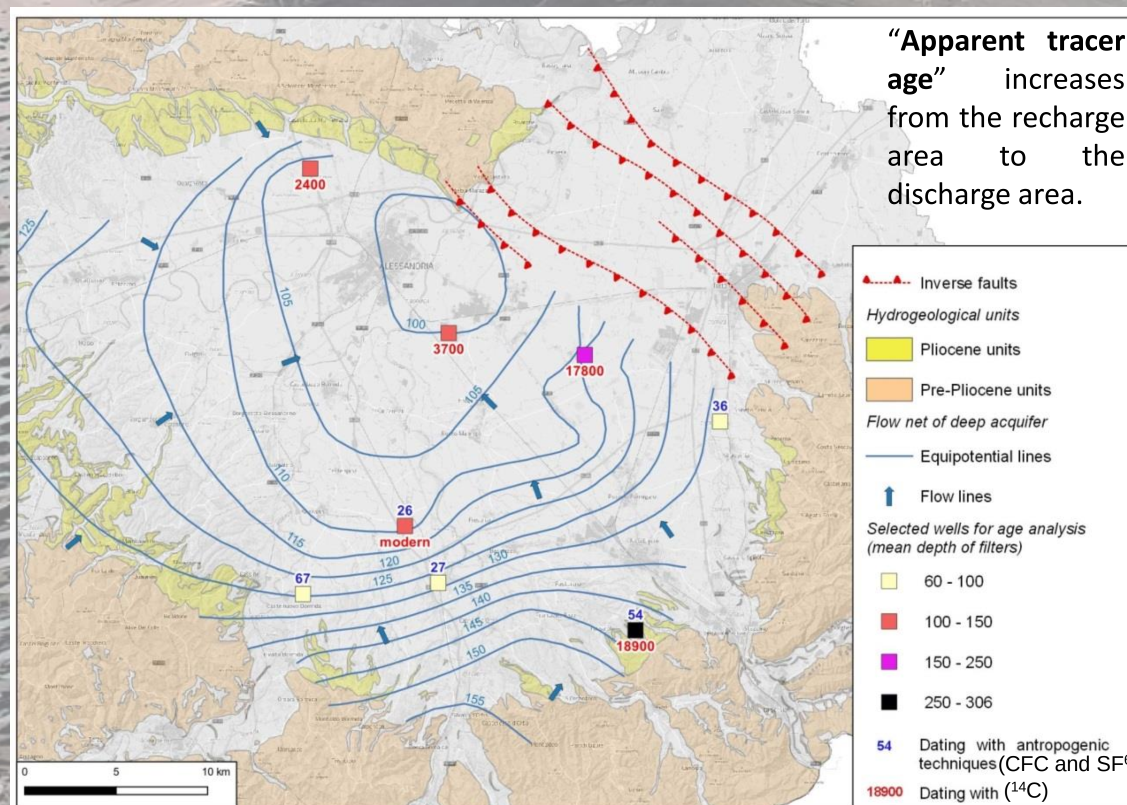
Standard corrections

Experimental value

Half-life ^{14}C = 5.73 ky

Sample ID	$\delta^{13}C$ (VPDB)		^{14}C				
	result	±	^{14}C yr BP	±	$F^{14}C$	±	^{14}C yr corrected
15B	-13,75	0,4	6253	32	0,4591	0,0018	2400
25B	-8,8	0,2	25736	225	0,0406	0,0011	18900
11B	-14,2	0,2	805	28	0,9046	0,0031	modern
16B	-8,6	0,1	24806	243	0,0456	0,0014	17800
26B	-10,2	0,2	9814	48	0,2947	0,0018	3700



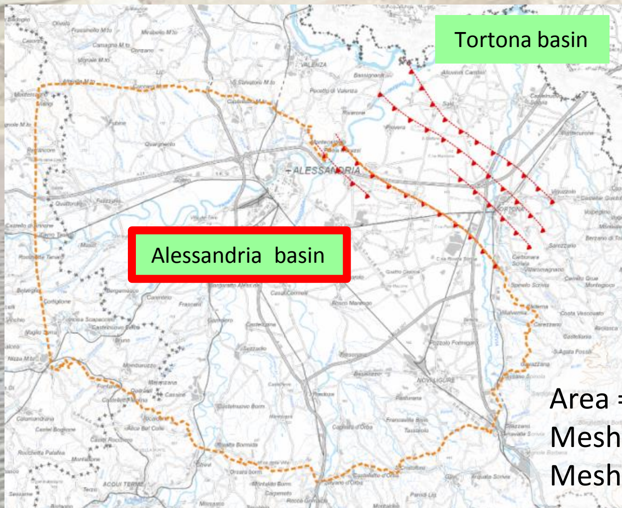


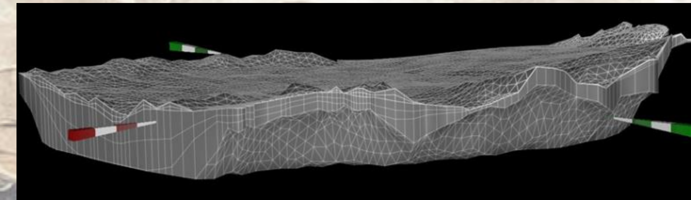
"**Apparent tracer age**" increases from the recharge area to the discharge area.

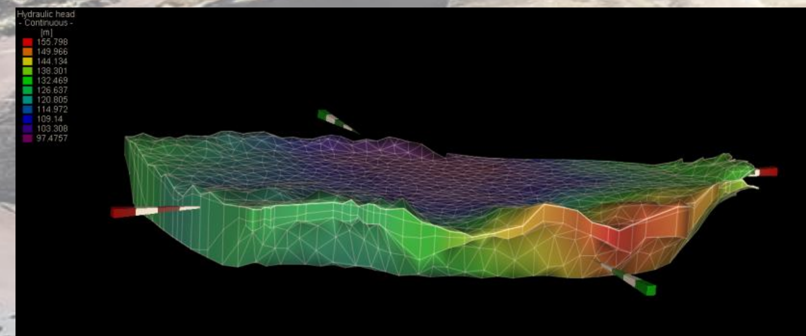
Flow understanding

3D NUMERICAL MODEL IMPLEMENTATION (FEflow – steady state)

Horizontal and vertical spatialization



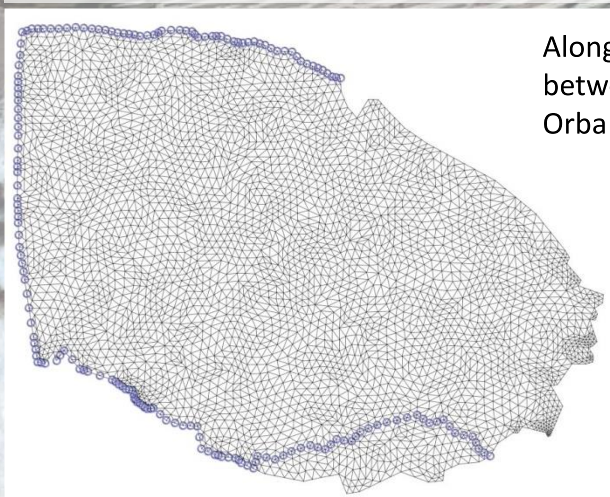




Area = 1000 Km^2
Mesh elements= 1.674.477
Mesh nodes = 931.810

Boundary conditions

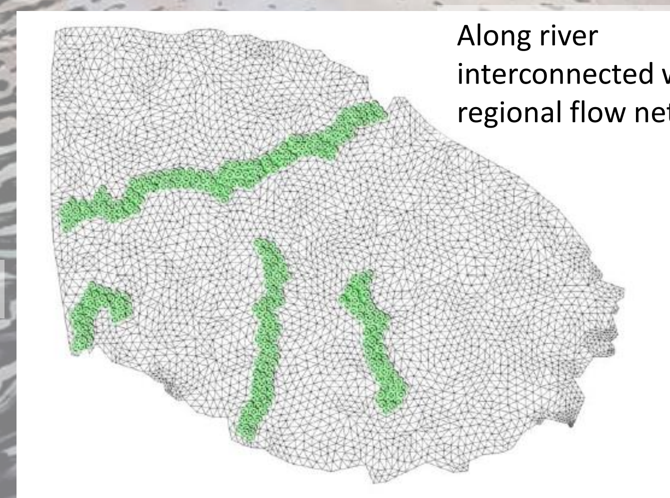
Dirichlet "Hydraulic Head BC" – 1st kind condition (fixed piezometric head, well-known at boundary)



Along terraced reliefs between Bormida and Orba valley

Mesh refinement

Cauchy "Fluid Transfer BC" – 3rd kind condition (Fluid Transfer)

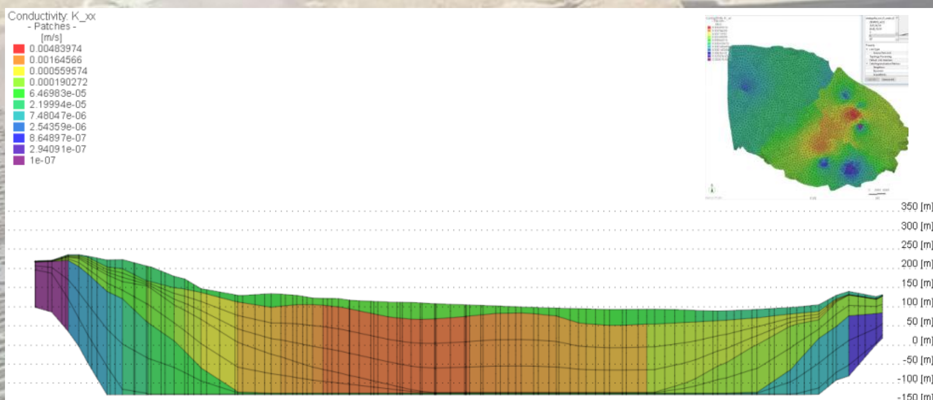


Along river interconnected with regional flow net

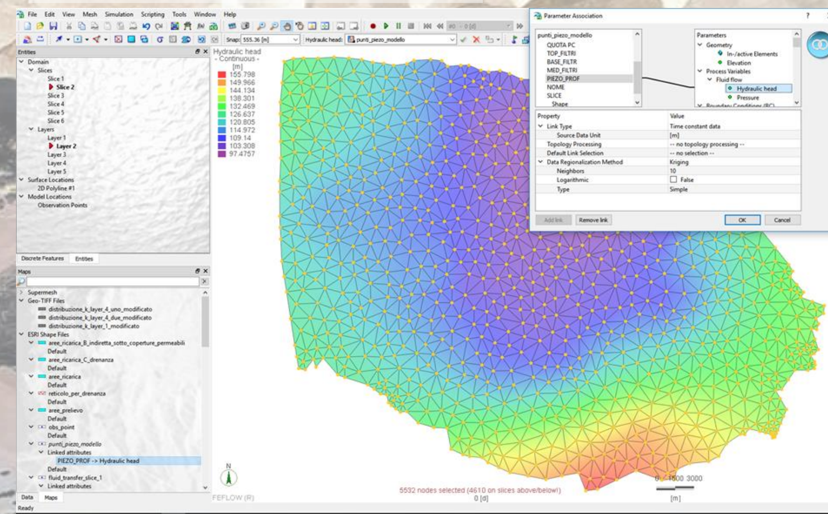
Flow understanding

3D NUMERICAL MODEL IMPLEMENTATION (FEflow-steady state)

K_h distribution

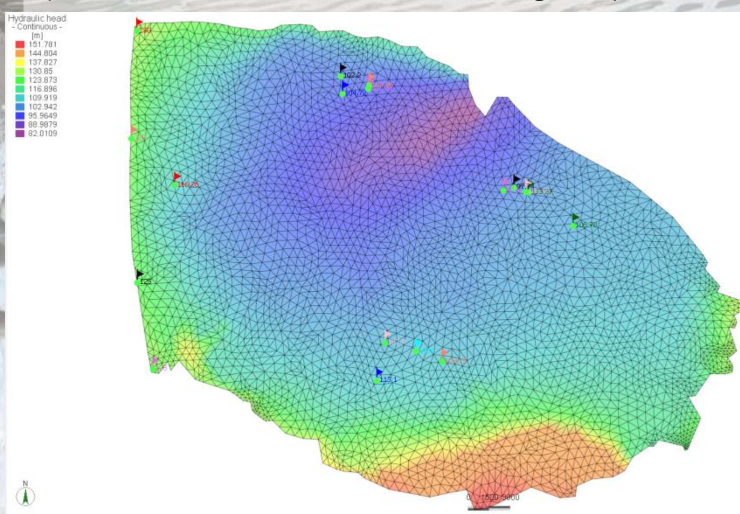


Initial head data

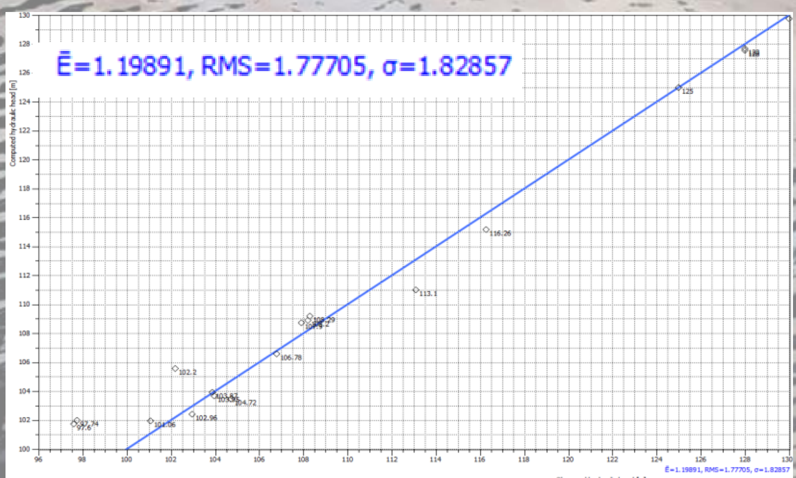


Target of calibration

(available and reliable well monitoring data)

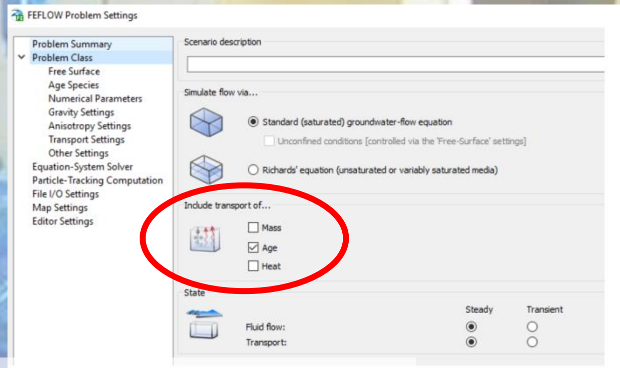


Calibration



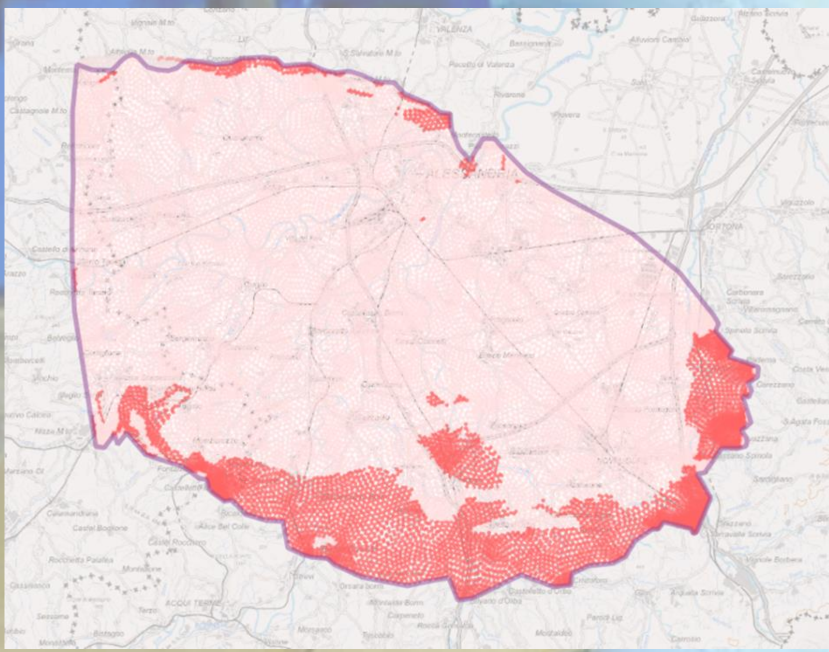
Water management

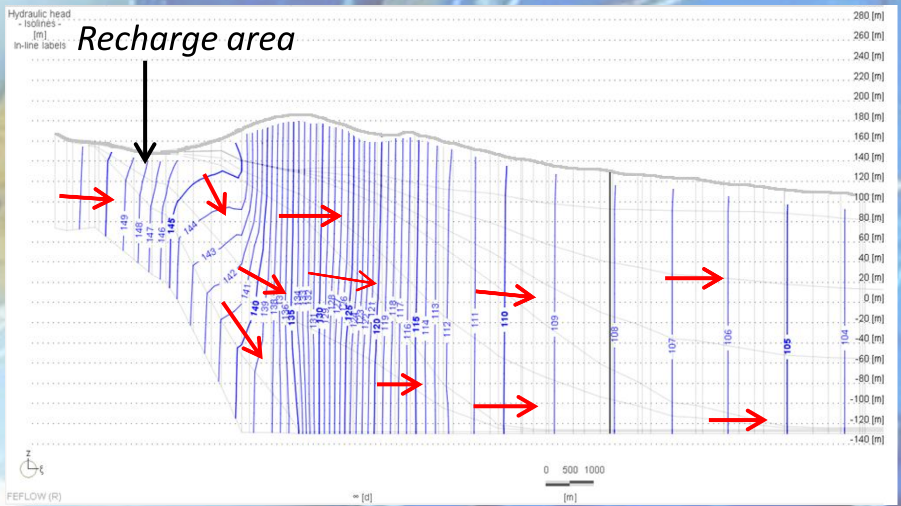
USE OF NUMERICAL MODEL AS A SUPPORT TOOL ON:



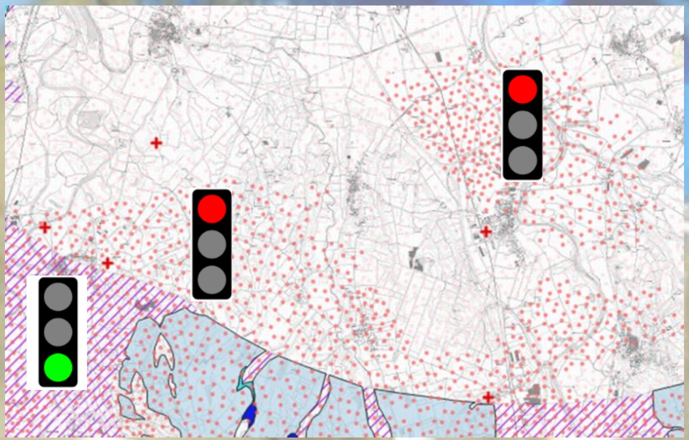
1. Mapping the **«recharge areas»,** starting from the analysis of flow distribution

A. Extrapolation of model cells with highest fluid velocity = «draft» recharge area





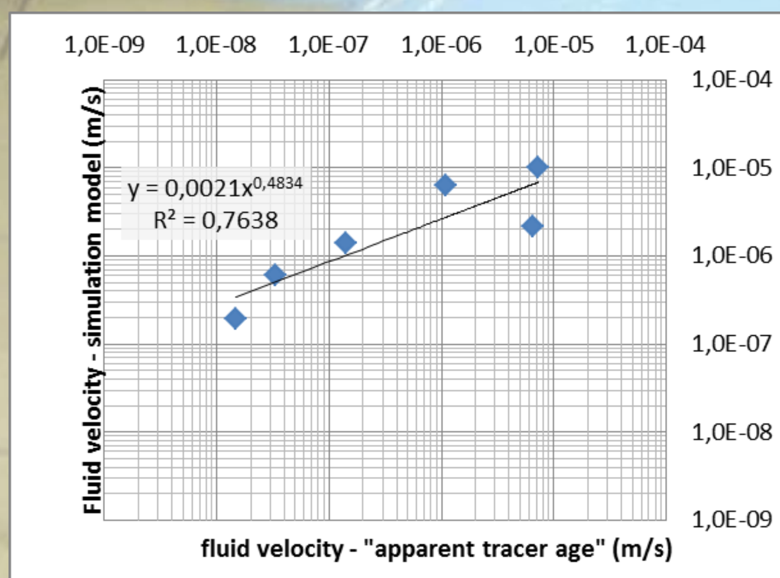
B. Correction with vertical hydraulic gradient data (cutting zones with upward gradient from «draft» recharge areas)



USE OF NUMERICAL MODEL AS A SUPPORT TOOL ON:

Cross-validation of fluid-velocity distribution

		Fluid velocity - "apparent tracer age"						Fluid velocity-computed	
Obs. Well name	Well-ID	tracer	year	km	km/y	m/g	m/s	m/s	comp. lay
Predosa	11B	CFC	26	6	2,3E-01	6,3E-01	7,3E-06	1,0E-05	layer 3
Pusetta	23B	CFC	27	5,5	2,0E-01	5,6E-01	6,5E-06	2,1E-06	layer 3
Peretta	12B	CFC	67	2,3	3,4E-02	9,4E-02	1,1E-06	6,4E-06	layer 3
Molinetto	26B	^{14}C	3700	16,5	4,5E-03	1,2E-02	1,4E-07	1,4E-06	layer 6
Mandrogne Via Sale	16B	^{14}C	17800	8,3	4,7E-04	1,3E-03	1,5E-08	1,9E-07	layer 6
Ca Bianca	15B	^{14}C	2400	2,5	1,0E-03	2,9E-03	3,3E-08	6,0E-07	layer 6



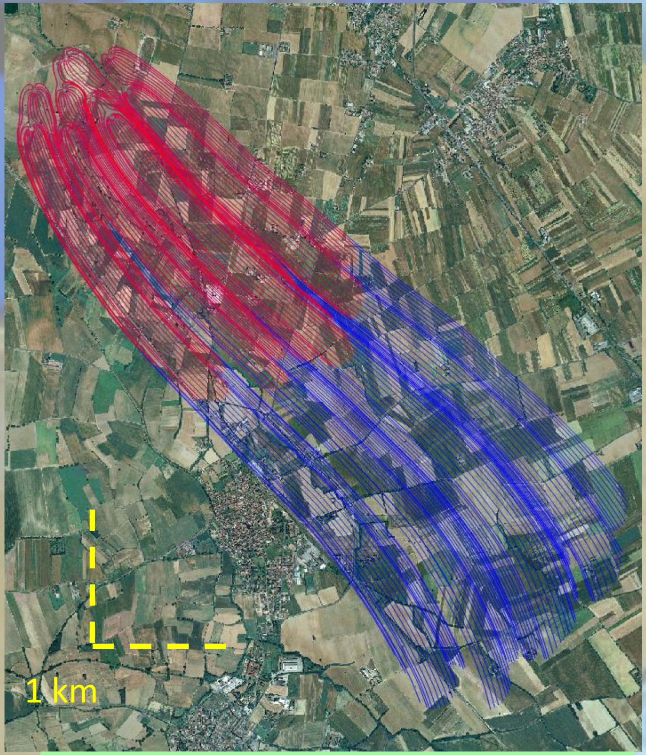
Water management

USE OF NUMERICAL MODEL AS A SUPPORT TOOL ON

2. Zoning of «**reserve areas**» =

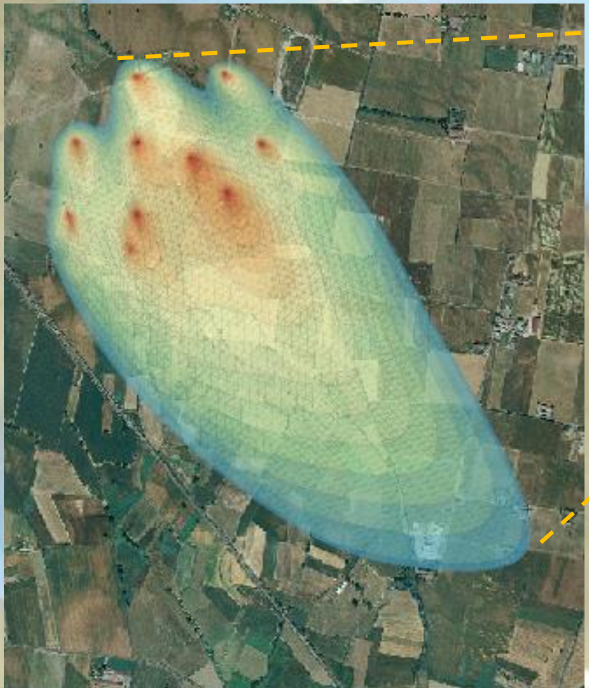
- legal instrument for District Water Authority to prevent groundwater depletion
- allow future development of well fields for human supply, with assigned sustainable abstraction rate

A. Purely advective flow & transport conditions (particle tracking technique)



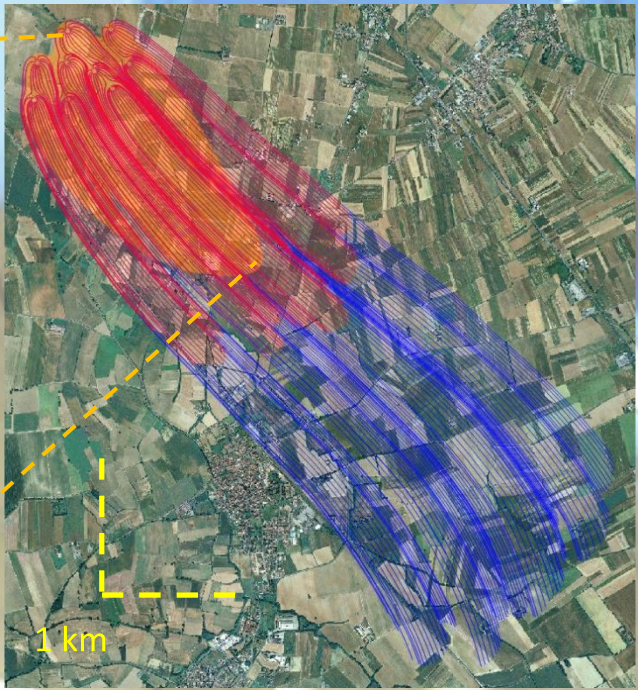
Time interval = 25 years (according with Local Water Authority Area Planning)

B. Advective and dispersive flow & transport (more realistic !!)
Life Time Expectancy – LTE reservoir distribution. Goode, D. J., 1996
αL = 50 m
αT = 5 m
LTE = 0 (Well BC-age)
Hypothetic abstraction = 0.4 m^3/s



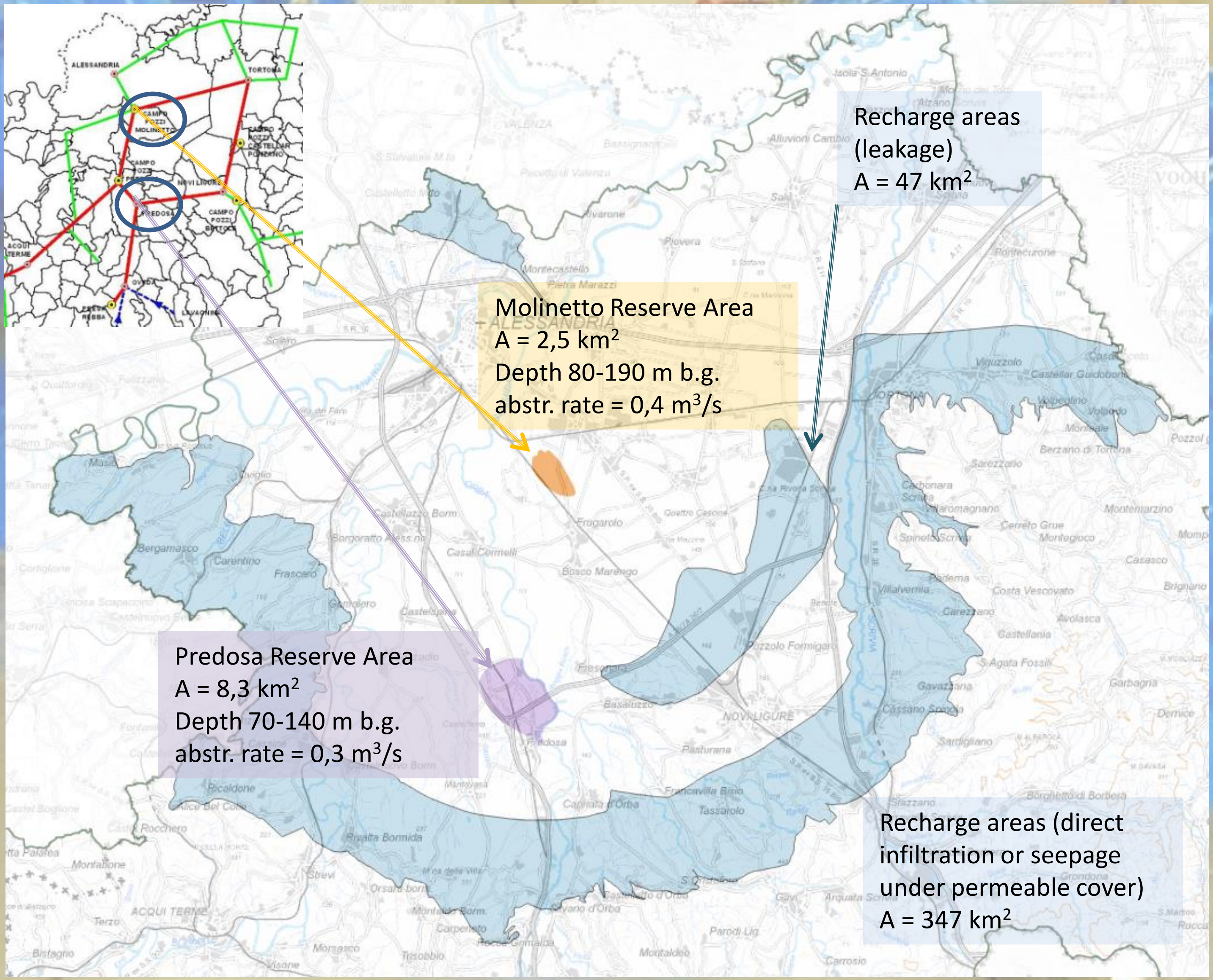
Influence of dispersivity on filtration time: differences of reserve areas with “purely advective flow” and “LTE advective & dispersive flow&transport”

IMPACT ON THE LAND-USE AND APPLICABILITY OF STANDARDS



Water management

1. RECHARGE and RESERVE AREAS



CONCLUSIONS

Target	Techniques	Next steps
Flow understanding in «Deep Aquifer System»	Stratigraphy Piezometric levels Hydraulic parameters Numerical model Geochemical surveys	Increase number of monitoring points Increase monitoring frequency From steady-state to transient numerical model
Recharge areas	Isotopic surveys Use of «age tracer» Numerical model	Use of multiple «age tracer», covering a wider chrono-range
Reserve areas	Numerical models (adv-disp.flow) LTE zoning	Increase pumping test on existing well (better evaluation of heterogeneities in hydrodinamic parameters)

Danke für Ihre Aufmerksamkeit…

… Wir sehen uns in Acqui Terme !