Direzione Pianificazione
delle Risorse Idriche

ASSESSMENT OF GROUNDWATER RESOURCES USING LARGE-SCALE INTEGRATED SIMULATION MODELS

(REGIONE PIEMONTE, NORTHERN ITALY)

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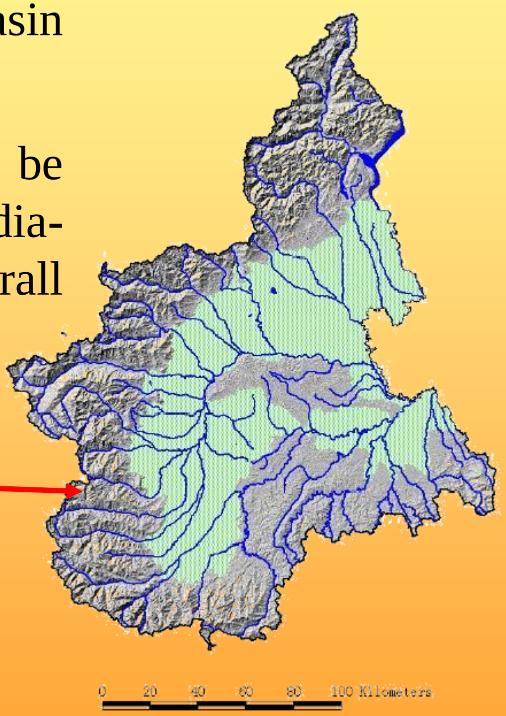
INTRODUCTION

Groundwater system of Regione Piemonte (RP)

- ✓the upper portion of the largest Quaternary basin in Italy: River Po floodplain
- ✓first regional evaluation in Piedmont, could be integrated with similar studies in Lombardia-Emilia Romagna, to complete the overall groundwater balance of River Po floodplain



the most important resource of freshwater for drinking/industrial/irrigation purpose in RP (8% Italian PIL)

GROUNDWATER SYSTEM OF REGIONE PIEMONTE

Quaternary and late Pliocene deposits ≈ 9200 km^2 (36% of RP extension)

<u>Shallow (1st) regional aquifer</u>:

✓recharged by rain+irrigation

✓high exchange rate with rivers

✓groundwater depth depending by topographic surface (old quaternary terraces, morain anphiteatre outside alpine valley)

✓well-known bottom surface (depth <100 m)

✓drainage from springs lines, artificially connected to irrigation channels

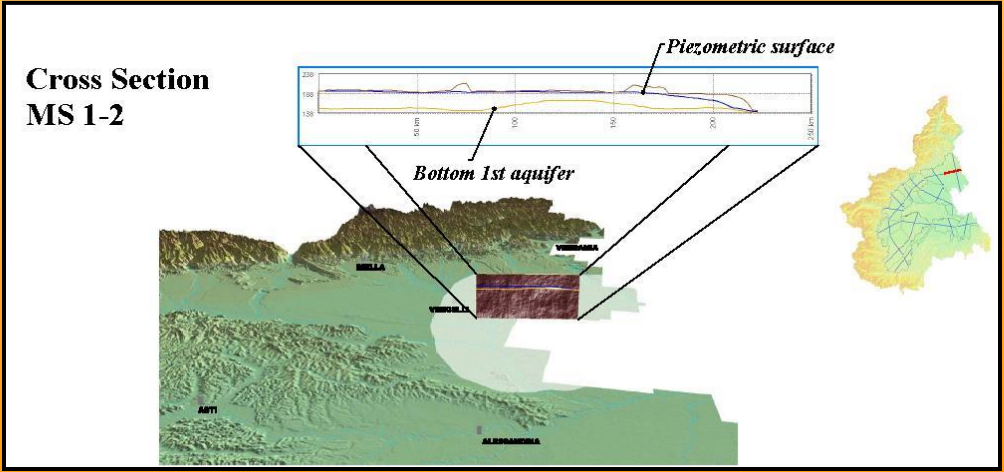
<u>Confined/leaky multi-layer aquifer complex</u>:

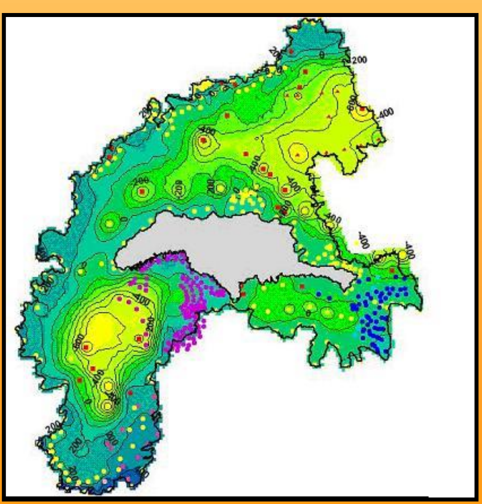
✓extension controlled by major tectonic structures (sedimentary basins/buried anticline)

✓most important groundwater storage (explored thickness ≈ 200 m)

✓bottom surface known by hydrocarbons research (drilling, seismic profiles) and water wells

✓artesian flow (Pliocene sandy deposits)





HYDROGEOLOGICAL SCHEME

Ref.Code	Hydrogeological unit	Simulation model
DF	fluvial deposits (Quat.)	1^{st} computational layer (unconfined conditions)
DG	glacial deposits (Quat.)	lense 1
DVA	fine deposits - “Villafranchiano” (Pleistocene)	lense 2
DVF	coarse/fine interbedded deposits - “Villafranchiano” (Pleistocene - Pliocene)	2^{nd} computational layer (confined conditions)
DM	Pliocenic deposits – “Asti sands”	
DM	Pliocenic deposits – “Lugagnano clays”	regional impermeable layer
DP	Pre-Pliocenic deposits	
DM	Igneous, metamorphic rocks	
DC	Carbonatic rocks (Mesozoic)	lateral recharge to 1^{st}-2^{nd} computational layer

STRUCTURE OF THE SIMULATION MODEL

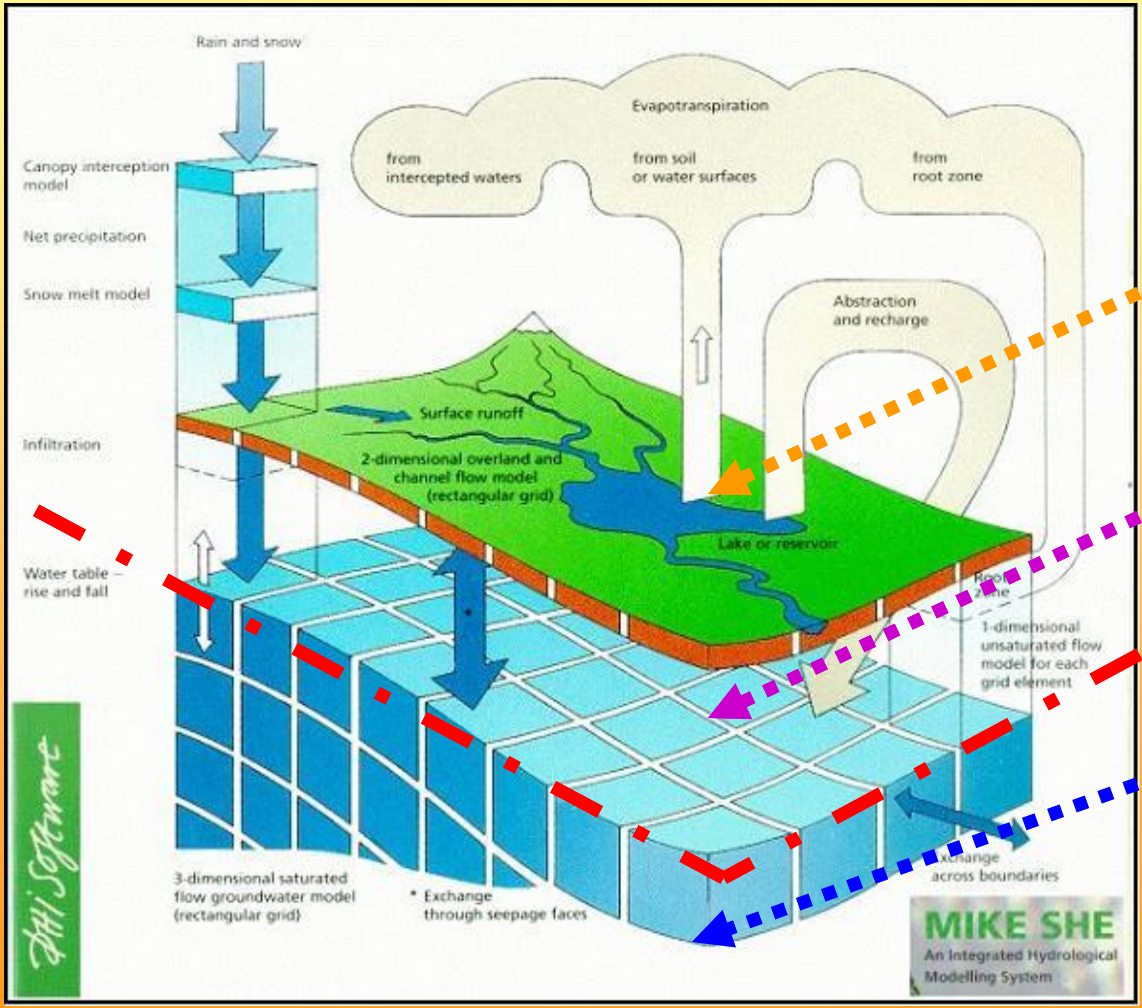
Integrated simulation models for different components of water flow

Flow components	***Model specifications***	***Topics***	***Coupling conditions***
Unsaturated zone	✓DHI DaisyGIS (*) ✓DHI Mike SHE WM – UZ (*)	✓1D distributed percolation model ✓1D distributed percolation model in rice areas (flooding irrigation)	✓off-line (upper boundary conditions for Groundwater model) ✓off-line (id.)
River network	DHI Mike11 HD (*)	1D Hydrodinamic, physically based on river network cross sections and hydro-engineering structures	dynamic coupling with groundwater flow model and with Flood Forecasting System of Regione Piemonte (RR Rainfall-Runoff)
Groundwater	DHI Mike She WM – SZ (*)	3D flow in heterogeneous aquifers, finite difference method	dynamic coupling with channel flow model

(*) DHI Water & Environment - DK

STRUCTURE OF THE SIMULATION MODEL

General features



River network flow model (coupled with Rainfall-Runoff model)

Unsaturated zone flow models

Saturated zone flow model

STRUCTURE OF THE SIMULATION MODEL:

i. Unsaturated zone *(a)*

✓ 1D deterministic, physically based, simulation of water and nutrients flows in unsaturated zone using Richard's equations; extended to non-point application with DaisyGIS

Input data:

A. Soil hydraulic properties (from textures to retention curve and unsaturated hydraulic conductivity using Van Genuchten and Cambell/Burdine pedotransfer functions): 15 groups of soils

B. Land use and agricultural management data (irrigation, fertilization, crop cicle and rotations): 11 groups of geo-referenced land use classes - (Corine Land Cover), with crop distribution inside each one of them assigned from 5° AGRISTAT, referred at municipal scale (8 groups of crops in 560 municipalities)

C. Climate data (temperature, radiation, rainfall – daily frequency): 75 sub-catchments

D. Lower boundary conditions (GW depth): 4 classes + 1 ("free drainage")

E. Paved urban areas (generate runoff to river network nodes according to DTM): identified from Corine Land Cover

Intersection of input data A,B,C,D in DaisyGIS

Computation processes:

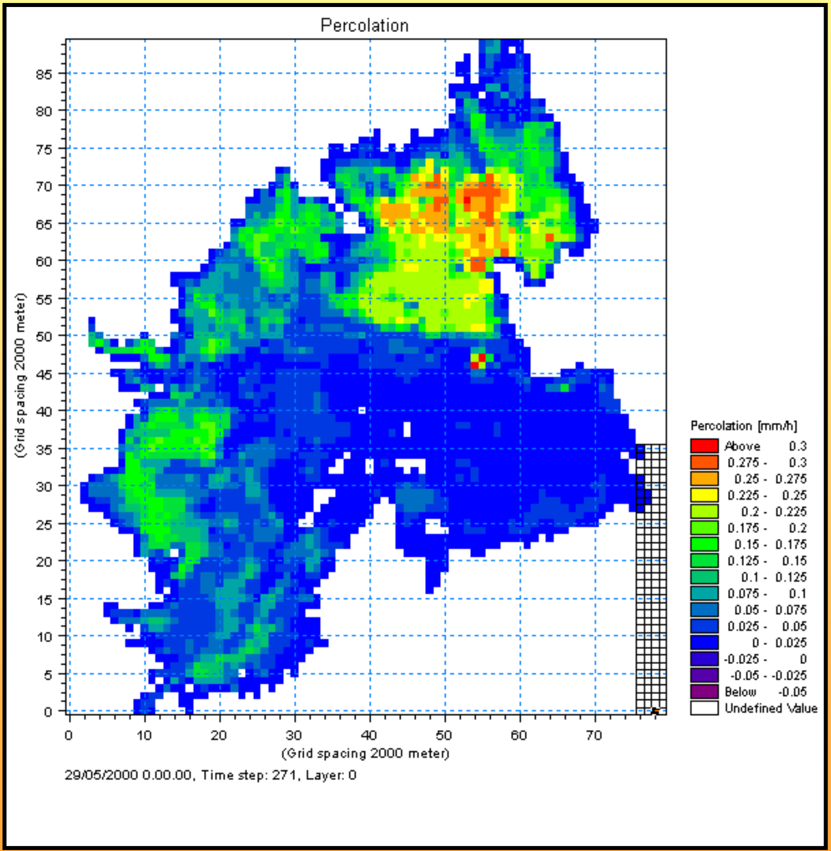
✓ 7100 computation units with homogeneous input data

✓ simulation period: sept.1999-aug.2002

✓ computation time-step: 3h

STRUCTURE OF THE SIMULATION MODEL:

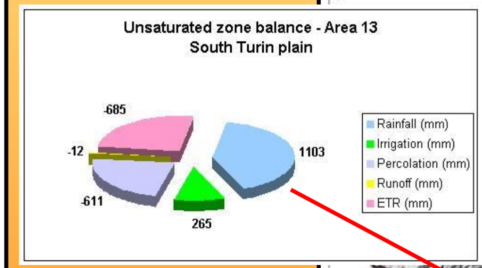
i. Unsaturated zone *(b)*

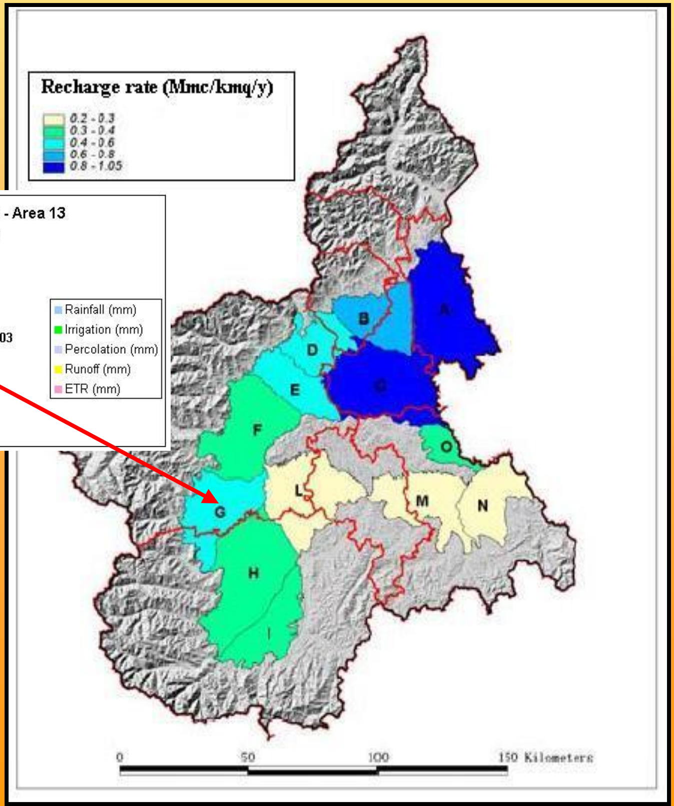


<u>Output data</u>:

✓Time series of percolation rate for each computation column

✓Interpolation of results on a 2*2 km grid, daily frequency = vertical recharge for Groundwater model





<u>Output data</u>:

✓ Dynamic water balance of unsaturated zone for macro-areas

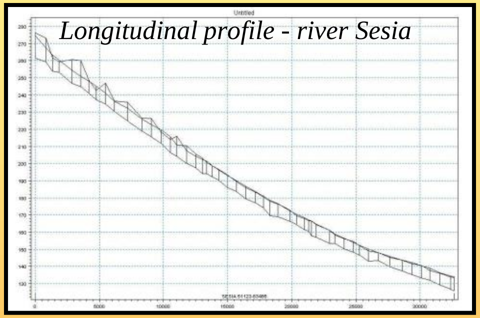
STRUCTURE OF THE SIMULATION MODEL:

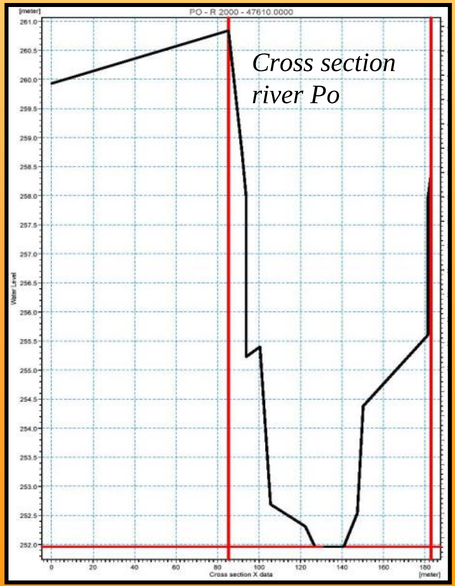
ii. Interaction with river network *(a)*

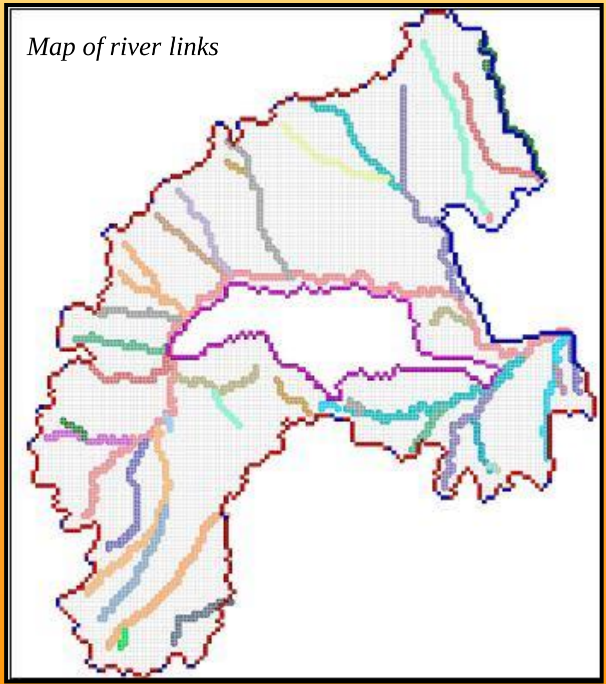
- ✓ **River cross-sections** inserted from topographic surveys; semi-automatic control between DTM and river cross-sections elevation

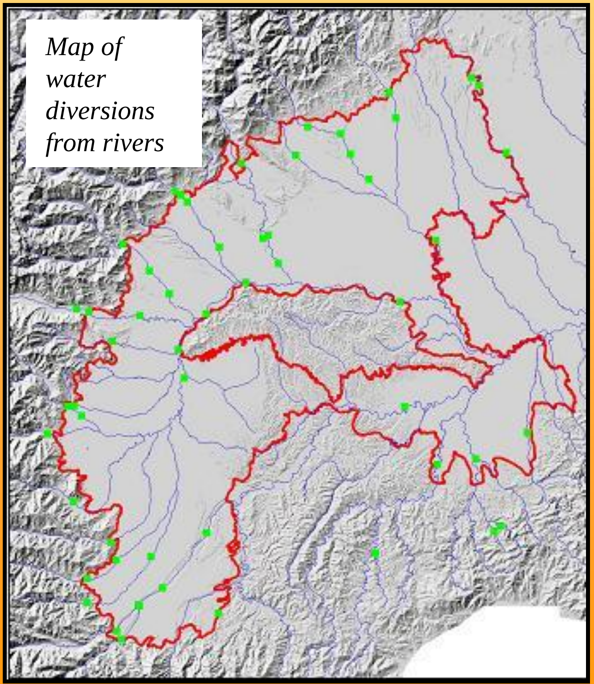
- ✓ **Upper boundary condition**: time-series of discharge generated from RR (rainfall-runoff) model in mountain/hill catchments (or measured in hydrometric station) ⇔ coupling with RP Flood Forecasting System

- ✓ **Internal boundary condition**: time series of water diversion from rivers (for irrigation/hydropower): simulation of “real” discharges available after use









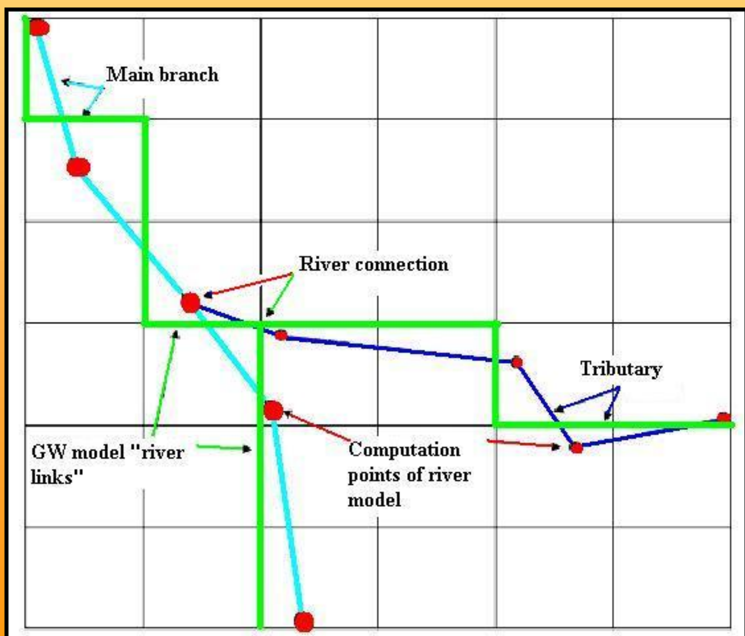
STRUCTURE OF THE SIMULATION MODEL:

ii. Interaction with river network *(b)*

✓ 1D deterministic, physically based, hydrodinamic simulation of river flows and water levels using the fully dynamic Saint Venant equations (MIKE11)

✓ **river-aquifer exchange** = the river is considered a line source/sink located on the "river links" (edge between two adjacent model grid cells)

✓ $Q_{riv\_exchange} = \Delta h_{(riv.-aq.)} * C$



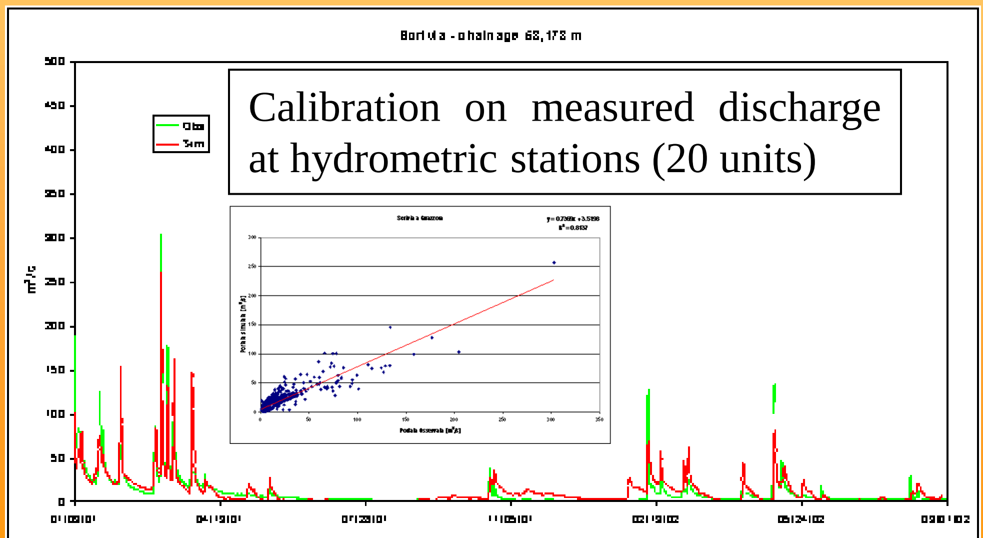
✓ Computation time-step: 10'

✓ Calibration of "river leakage coefficient"- C

$C_1 = f(K_{aquifer})$ – full conctact river/aquifer

$C_2 = f(K_{aquifer}, K_{river\ bed})$ – river lining

$C_3 = f(K_{river\ bed})$ – river bed with very low K



STRUCTURE OF THE SIMULATION MODEL:

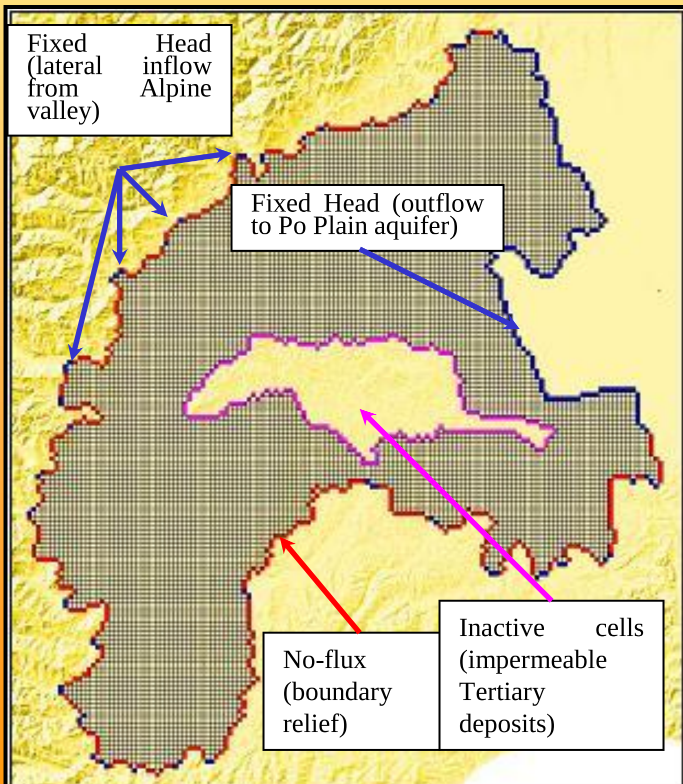
iii. Saturated zone *(a)*

✓ 3D deterministic, physically based, simulation model of groundwater flow with non-linear Boussinesq equation, solved numerically by an iterative implicit finite difference technique

Model grid:

cells 1km^2: 160 rows, 180 columns, 2 layers

9448 computation cells + 846 boundary cells

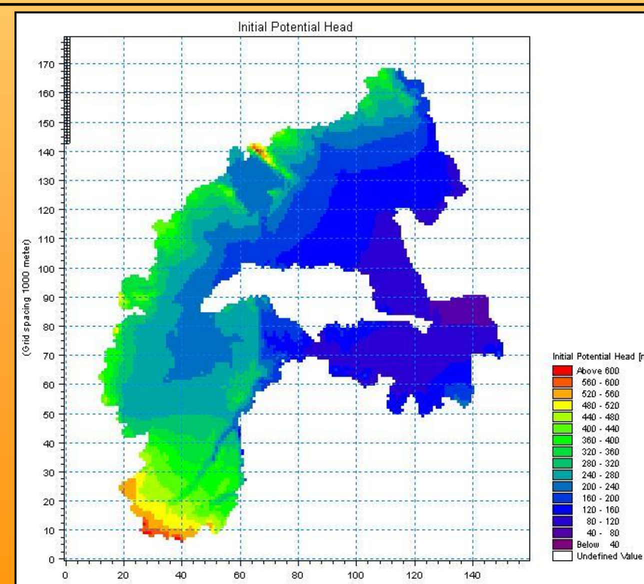


Initial conditions:

Piezometric head in 1st layer identified from

- 82 registration piezometers
- 430 measurement point in selected wells
- 1800 river bottom points

Piezometric head in 2nd layer identified from existing piezometric maps in AT district



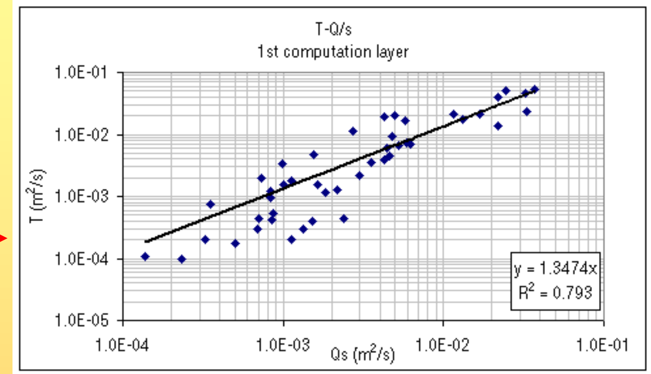
STRUCTURE OF THE SIMULATION MODEL:

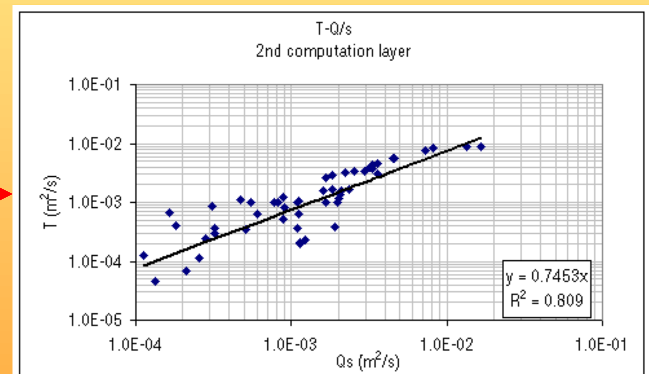
iii. Saturated zone *(b)*

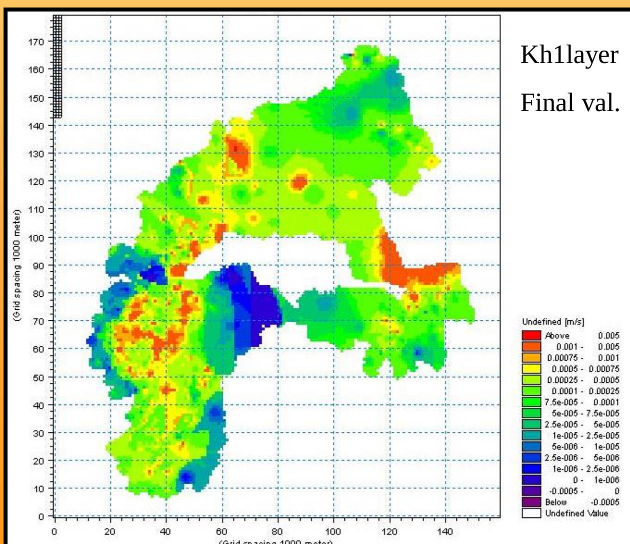
<u>Hydrodinamic parameters</u>:

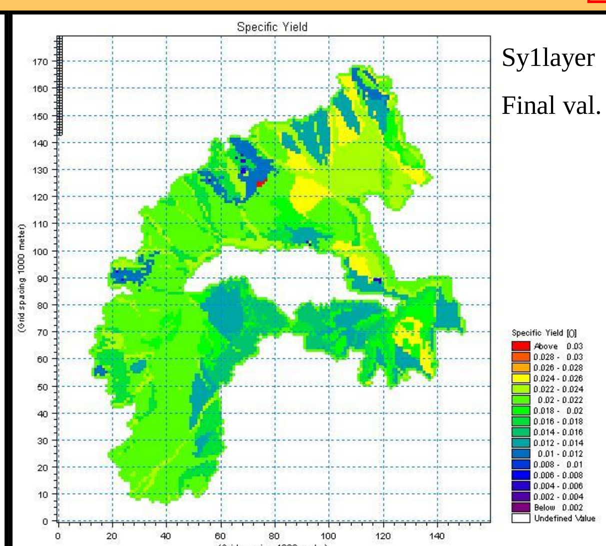
First estimation of K, T, S_y, S from

- 70 aquifer-test in 1st layer + 156 in 2nd layer
- analysis of T-Q/s relation
- estimation of T,K areal distribution using T-Q/s relation, applied to 1020 well-test in 1st layer + 435 in 2nd layer
- areal distribution of storage parameters obtained with interpolation related to granulometric facies distribution
- K_h/K_v, S = main calibration factors





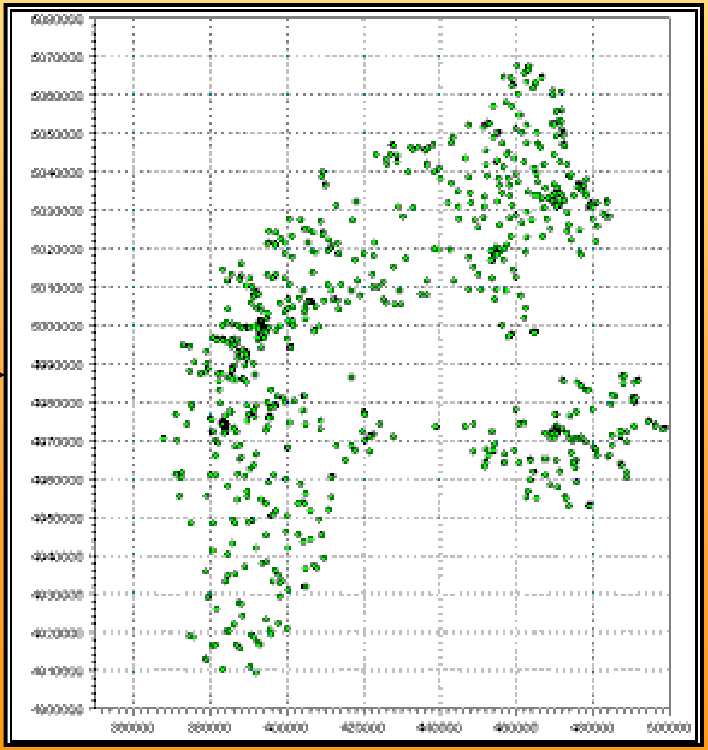


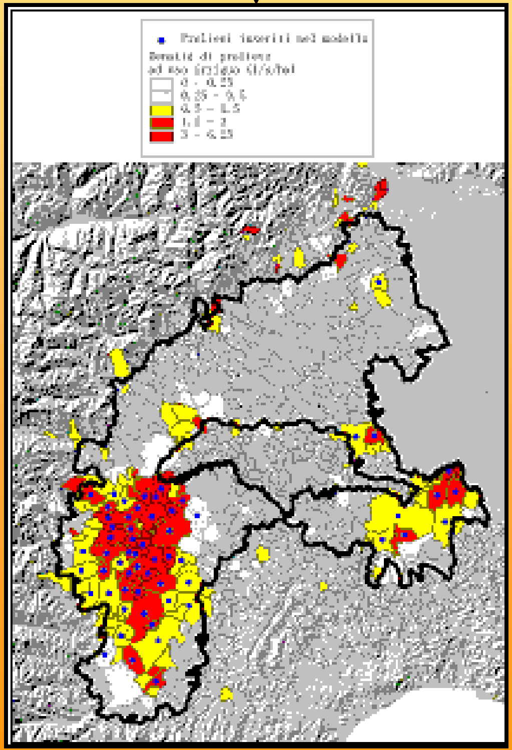


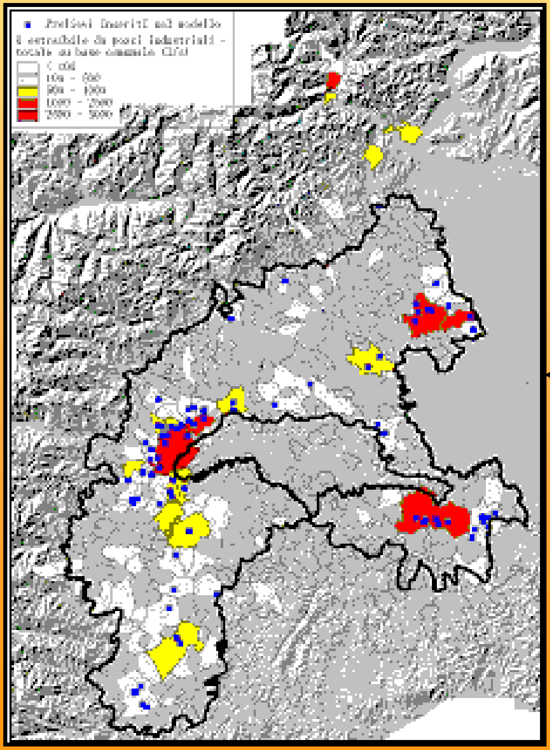
STRUCTURE OF THE SIMULATION MODEL:

iii. Saturated zone *(c)*

Abstraction	Abstraction rate ($10^6 m^3/y$)	Abstractions active into the model
Water supply for human use	≅290	923 (wells)
Irrigation (seasonal)	≅300	59 (pump.center)
Industrial production	≅250	79 (pump.center)
Total	≅ 840	1061







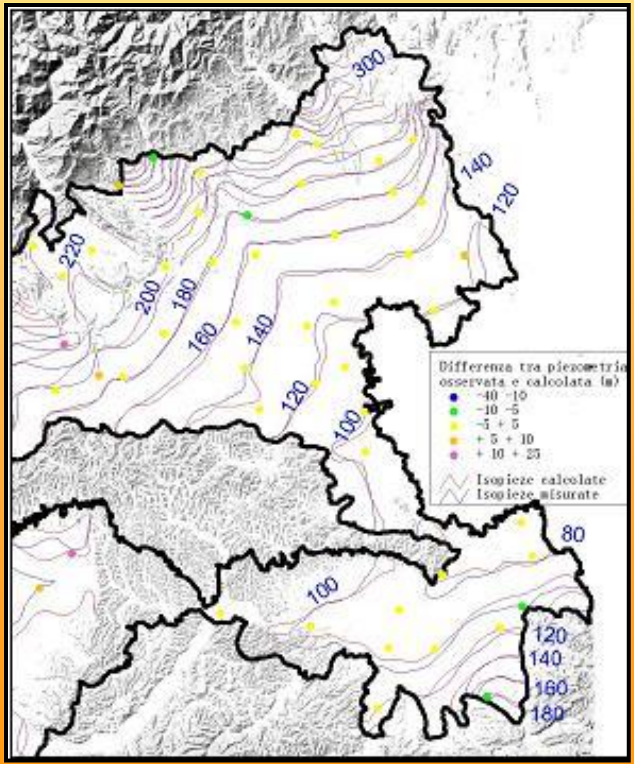
STRUCTURE OF THE SIMULATION MODEL:

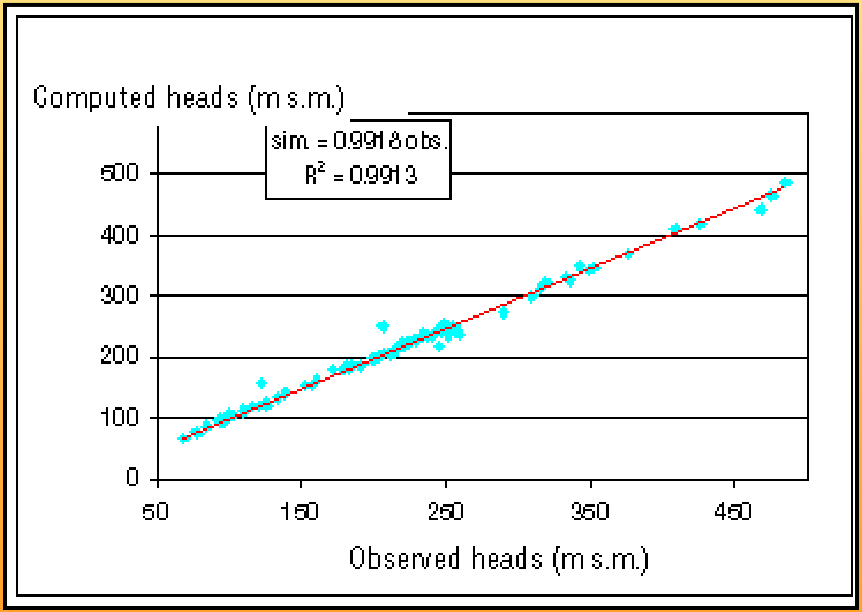
Procedures of calibration – observed/computed piezom.heads

<u>Comparison between computed/observed heads - maps</u>:

✓Best fit in low-hydraulic gradient areas (sim.- obs. << $DTM_{max-min}$)

✓Increasing discrepancy along relief boundary or hill morain areas (uncertainity linked to low-density of measured wells => optimization of monitoring network)



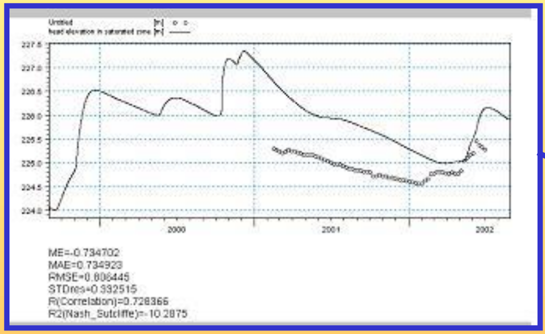


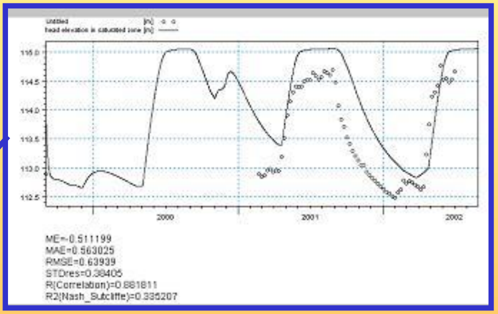
STRUCTURE OF THE SIMULATION MODEL:

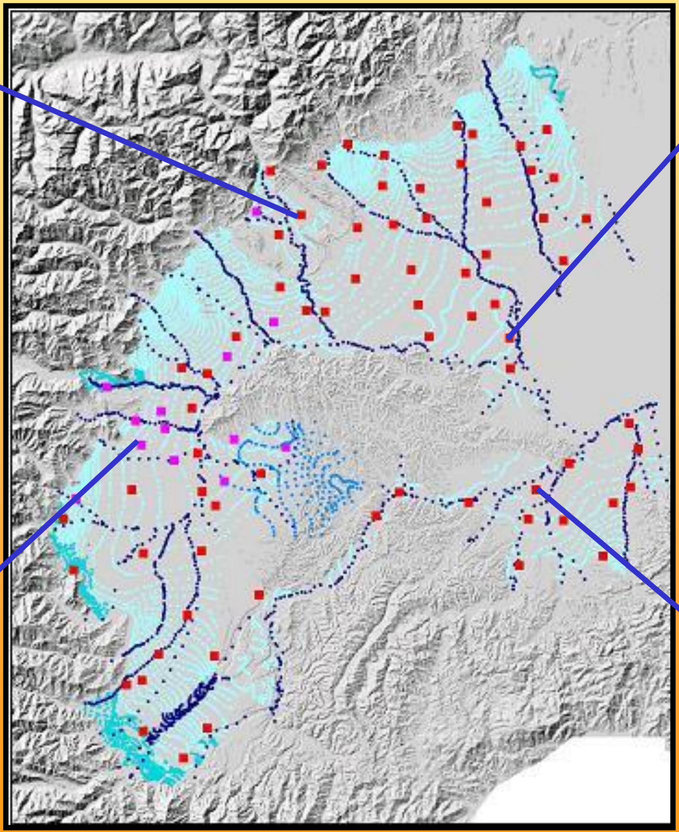
Procedures of calibration – time series in piezometric stations

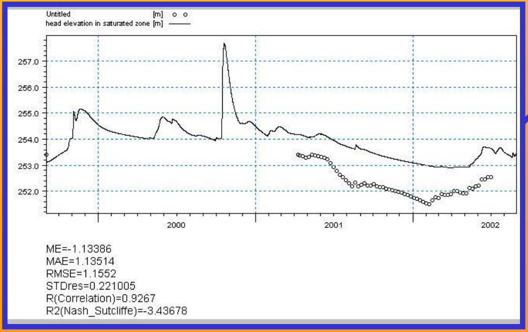
Comparison between computed/observed heads – time series:

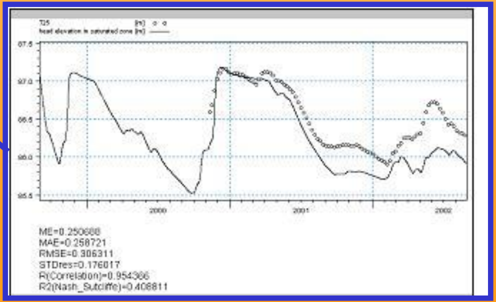
✓ 82 piezometric stations with daily data recorded during simulation period











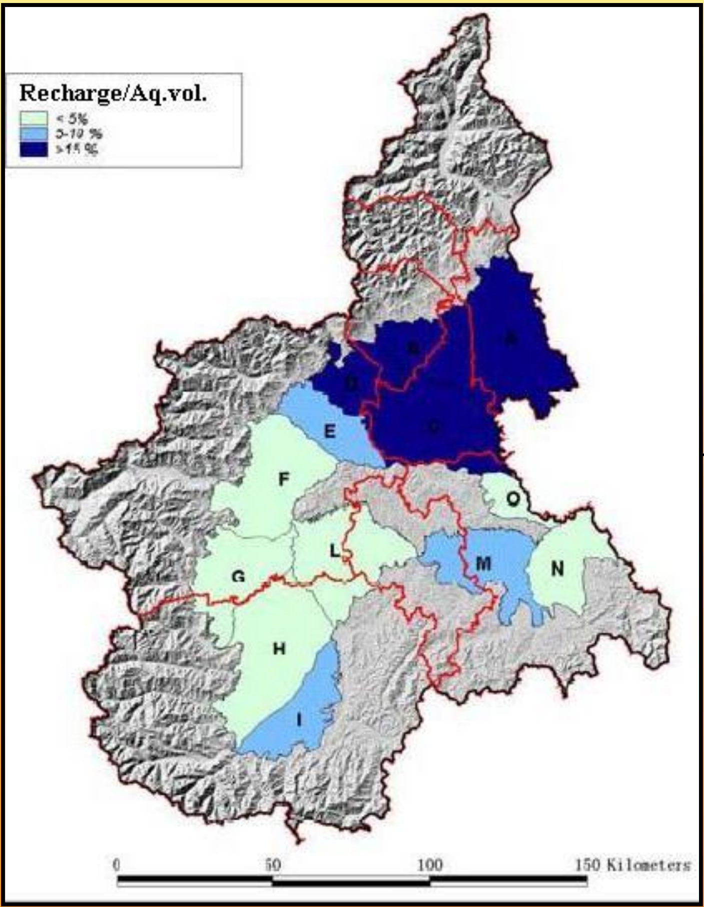
ANALYSIS OF RESULTS AND USE OF THE MODEL *(a)*

Evaluation of aquifer dynamic features with respect to different aggregation levels:

✓ Hydrographic unit (surface water)

✓ Aquifer complex/districts

Hydrographic unit	Recharge ($10^6 m^3/y$)	Abstractions volume ($10^6 m^3/y$)	Aquifer volume ($10^6 m^3/y$)	Infiltration rate ($10^6 m^3/y$)	Abstraction density ($10^6 m^3/km^2/y$)	Abstraction/Recharge ratio	Recharge/Aquifer Volume ratio
DORA BALTEA	245.18	16.48	873	0.61	0.041	7%	28%
CERVO	478.45	15.69	2127	0.78	0.026	3%	22%
AGOGNA	491.39	38.52	2524	0.97	0.076	8%	19%
SESIA	997.45	42.79	5151	1.07	0.046	4%	19%
TERDOPPIO	187.26	15.88	1041	0.90	0.076	8%	18%
TICINO	217.93	18.56	1216	0.89	0.076	9%	18%
ORCO	99.84	11.8	737	0.49	0.058	12%	14%
BANNA	105.95	41.84	792	0.23	0.092	39%	13%
BELBO	12.19	3.48	94	0.28	0.080	29%	13%
ALTO TANARO	118.62	15.91	919	0.37	0.050	13%	13%
GESSO	7.73	1.04	60	0.37	0.050	13%	13%
BORMIDA	36.28	10.39	294	0.28	0.080	29%	12%
MALONE	115.22	43.81	993	0.45	0.173	38%	12%
BORBORE	53.58	24.9	473	0.20	0.092	46%	11%
STURA DI LANZO	76.52	45.06	744	0.42	0.244	59%	10%
PO	647.39	155.01	6588	0.48	0.115	24%	10%
DORA RIPARIA	51.19	33.21	548	0.38	0.244	65%	9%
ORBA	20.16	5.87	217	0.28	0.081	29%	9%
SANGONE	48.79	33.46	552	0.36	0.244	69%	9%
TANARO	166.49	56.1	2098	0.24	0.082	34%	8%
CHISOLA	181.84	104.01	2489	0.44	0.254	57%	7%
CHISONE	11.69	6.26	165	0.48	0.258	54%	7%
PELLICE	39.23	21	555	0.48	0.258	54%	7%
STURA DI DEMONTE	117.16	32.24	1682	0.36	0.099	28%	7%
ALTO PO	164.24	78.94	2678	0.45	0.218	48%	6%
CURONE	10.76	3.11	185	0.29	0.083	29%	6%
SCRIVIA	52.89	15.72	937	0.28	0.083	30%	6%
VARAITA	63.99	25.27	1261	0.41	0.163	39%	5%
MAIRA	74.05	31.66	1579	0.38	0.163	43%	5%
GRANA-MELLEA	99.85	48.15	2402	0.34	0.163	48%	4%



ANALYSIS OF RESULTS AND USE OF THE MODEL *(b)*

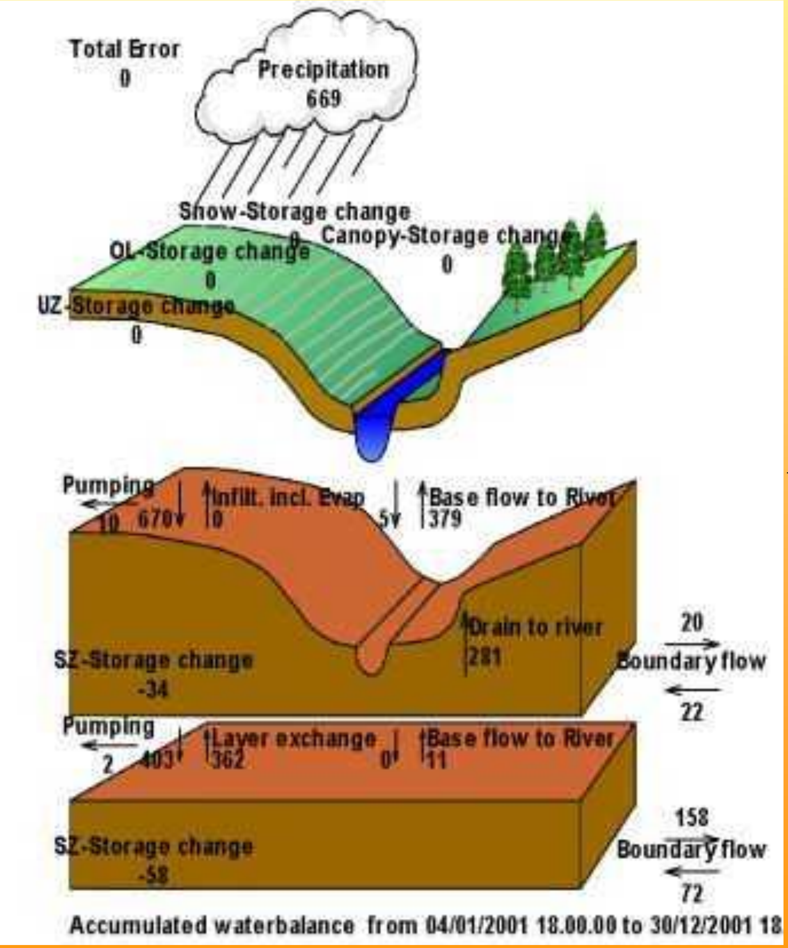
Systematic and dynamic approach to groundwater-balance evaluation

✓ Global scale (RP)

✓ Local (sub-regional) scale

1st AQUIFER			
INFLOW	$10^6 m^3/y$	m^3/s	%
Net recharge	5046	160	57%
Boundary inflow (horiz.)	946	30	11%
Flux from 2° to 1° layer (vert.)	2681	85	30%
River seepage	189	6	2%
Totale	8862	281	100%
OUTLOW			
Boundary outflow (horiz.)	284	9	3%
Flux from 1° to 2° layer (vert.)	2586	82	29%
Well abstraction	2681	85	30%
Baseflow to river	3185	101	36%
Drainage towards channels/springs	158	5	2%
Totale	8893	282	100%
Delta storage	-32	-1	0%

2nd AQUIFER			
INFLOW	$10^6 m^3/y$	m^3/s	%
River seepage	32	1	1%
Net recharge	0	0	0%
Boundary inflow (horiz.)	568	18	15%
Flux from 1° to 2° layer (vert.)	3185	101	85%
Totale	3753	119	100%
OUTLOW			
Boundary outflow (horiz.)	378	12	9%
Flux from 2° to 1° layer (vert.)	2681	85	66%
Well abstraction	442	14	11%
Baseflow to river	347	11	9%
Drainage towards channels/springs	189	6	5%
Totale	4037	128	100%
Delta storage	-284	-9	-7%



ANALYSIS OF RESULTS AND USE OF THE MODEL *(c)*

Evaluation of "quantitative status" according to national law (D.Lgs.152/99):

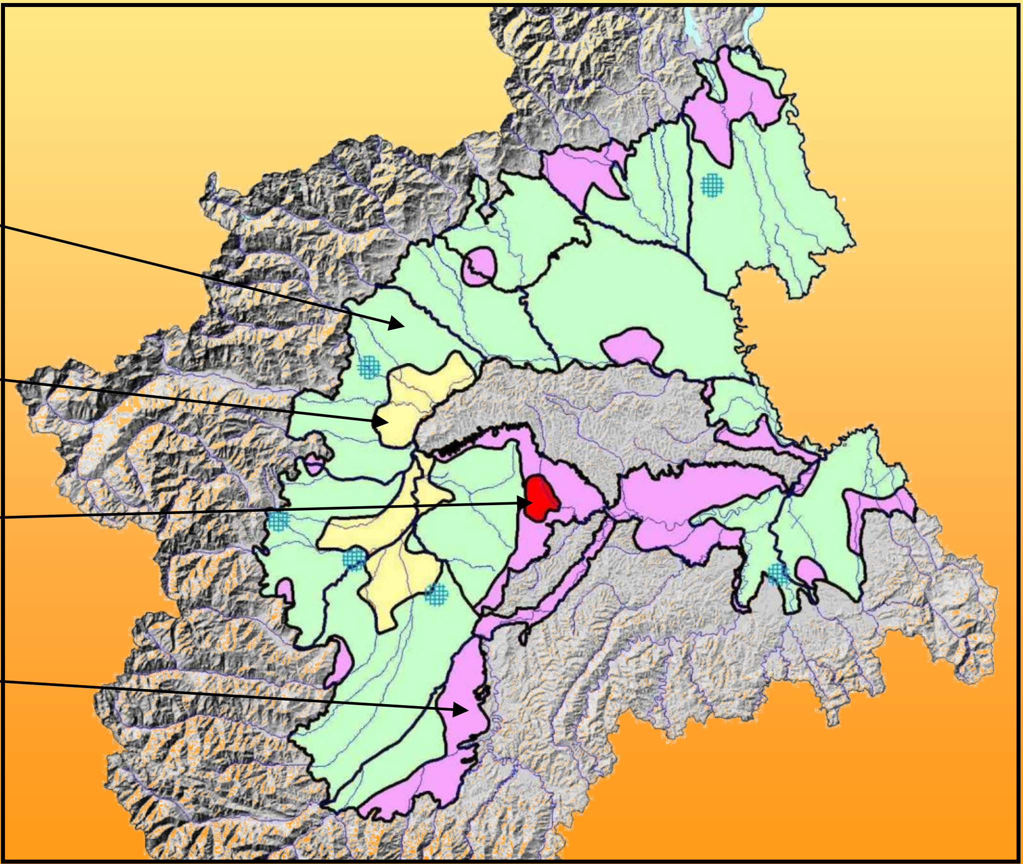
✓ Classification of aquifer complex with respect to productivity parameters, recharge rate and pumping impact

Low-moderate human impact, groundwater use is sustainable on a middle-long time period ("A" class)

Moderate impact of groundwater abstraction on aquifer balance ("B" class)

Significant changes on groundwater abstraction balance, as a consequence of very high abstraction rate ("C" class)

Low-moderate human impact, into aquifer complex with low productivity features ("D" class)



ANALYSIS OF RESULTS AND USE OF THE MODEL *(d)*

Decisions supporting of Minimum River Discharge:

✓ Identification of rivers branches on the amount of baseflow from the aquifer (or seepage loss)

Delineation of protection measures and identification of “potential water supply zone”:

✓ Identification of “recharge areas” of deep aquifers

✓ Preliminary evaluation of groundwater potential abstraction rate and impacts → “sustainable use”

✓ Location of new wellfield

Optimization of monitoring piezometric network

✓ In terms of position/density of the monitoring wells

✓ In terms of transmission of the data