Mem. Descr. Carta Geol. d'It.
XC (2010), pp. 181-208,
figg. 26, tabb. 3

A comprehensive hydrogeological view of the Friuli alluvial plain by means of a multi-annual quantitative and qualitative research survey

Quadro idrogeologico generale della Pianura alluvionale friulana sulla base di indagini quantitative e qualitative pluriannuali

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Abstract - In order to define a global hydrogeological model of the Friuli alluvial plain, the present work investigates the relationships between the regional unconfined and multilayered aquifer systems integrating geological, hydrogeological, geochemical and isotope data.

The Neogenic and Quaternary mostly clastic sediments of both continental and marine origin, locally more than 1000 meters thick, gave rise to a sequence of megafan-shaped progradated sedimentary bodies, both lenghtwise and crosswise granulometrically differentiated.

The geometry of the relating saturated zone has been reconstructed by both deterministic and stochastic methods.

By means of the isophreatic map of the High Plain (APF), the active recharge to the confined system of the Low Plain (BPF) has been calculated. The groundwater flow conditioning by means of the regional tecto-dynamics is showed.

The hydrogeological model, integrated with hydrogeochemical and isotope data collected from wells, springs and rivers, allowed some considerations about recharge provenience and hydraulic connection within the confined aquifer system.

Key words: Friuli Plain, hydraulic connection, multilayered aquifer, recharge, water-table aquifer.

Riassunto - Lo scopo del presente lavoro è stato quello di definire un modello di circolazione idrica sotterranea della pianura friulana studiando le relazioni fra i due sistemi acquiferi presenti nell'area (falda freatica dell'Alta Pianura e sistema multistrato della Bassa pianura) attraverso l'interpretazione integrata di dati geologici, idrogeologici, idrochimici e isotopici. Le elaborazioni dei dati piezometrici, le carte di distribuzione dei macrocostituenti e l'analisi dei dati isotopici sui campioni esaminati hanno consentito, per il sistema acquifero multistrato della Bassa Pianura, di trarre delle conclusioni sulle caratteristiche della ricarica e sui fenomeni di drenanza.

Parole chiave: acquifero multistrato, drenanza, falda libera, pianura friulana, ricarica.

1. - INTRODUCTION

More and more often, the use of research techniques and elaboration methodologies that are peculiar to geological, geophysical, geochemical and geostatistical fields turns out the necessity and suitability of assuming an integrated multi-disciplinary approach within hydrogeological surveys addressed to detailed tridimensional characterizations of geological structures, to descriptions of recharge mechanisms and groundwater flow paths as well as to spatial distribution settlements of the hydraulic properties of aquifers associated to complex depositional systems (i.e. alluvial plains). As a rule, the cognitive bases of hydrogeological researches are quantitatively and qualitatively heterogeneous and tipically scattered both in space and in time dimension.

The aim of the present work is to syntesize, as an integration of the foregoing knowledge, the results attained by the Authors within the over seven-year surveys hinged on geometric, hydrodinamic and hydrochemical features of the indifferentiated and multi-layered aquifers of the Friuli Plain eastward of Tagliamento River.

The outstanding issues of hydraulic head and qualitative measurements carried out within a local experimental monitoring network (Martelli *et alii,* 2007a), together with the hypotheses concerning the recharge and circulation patterns of the regional groundwaters (supported by geostatistical elaborations of piezometric, pluviometric and cli-

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mate data, as well as chemical and isotopic analyses), will be exposed and discussed. In every respect, the aquifer reservoirs of the southern sector of the Friuli - Venezia Giulia region represent a strategic resource at a regional scale.

2. - THE FRIULI PLAIN AND ITS AQUIFERS

The Friuli Plain (fig. 1) on the left side of the Tagliamento River represents the extreme eastern part of the Po Plain, to whom it preserves some of the most peculiar hydrogeological patterns (ANTONELLI & STEFANINI, 1982; DAL PRÀ *et alii,* 1989; REGIONE EMILIA-ROMAGNA, ENI-AGIP, 1998; REGIONE LOMBARDIA, ENI-AGIP, 2002). The depositional processes that occurred in the Upper Pleistocene, conditioned by both the geological-structural evolution of the area and the sea level fluctuations following from the climatic events of Quaternary glaciations (FLORINETH & SCHLUCHTER, 2000; OROMBELLI & RAVAZZI, 1996), produced the sedimentation of clastic materials (of fluvio-glacial, marine, lagoon and marshy origin) progradating in size, along a N-S direction, within a coalescent system of alluvial mega-fans (FONTANA, 2006). Such detrital materials lie over, in order, (a) terrigenous-carbonatic marine deposits of the Miocene transgression (outcropping at the southern boundary of the Carnic Pre-Alps and to the S of Udine), (b) the Grivò (Upper Palaeocene – Lower Eocene) and the Cormons (Ypresian) arenaceous-marly Flysch, as an evidence of an active mountain chain foredeep system in motion from

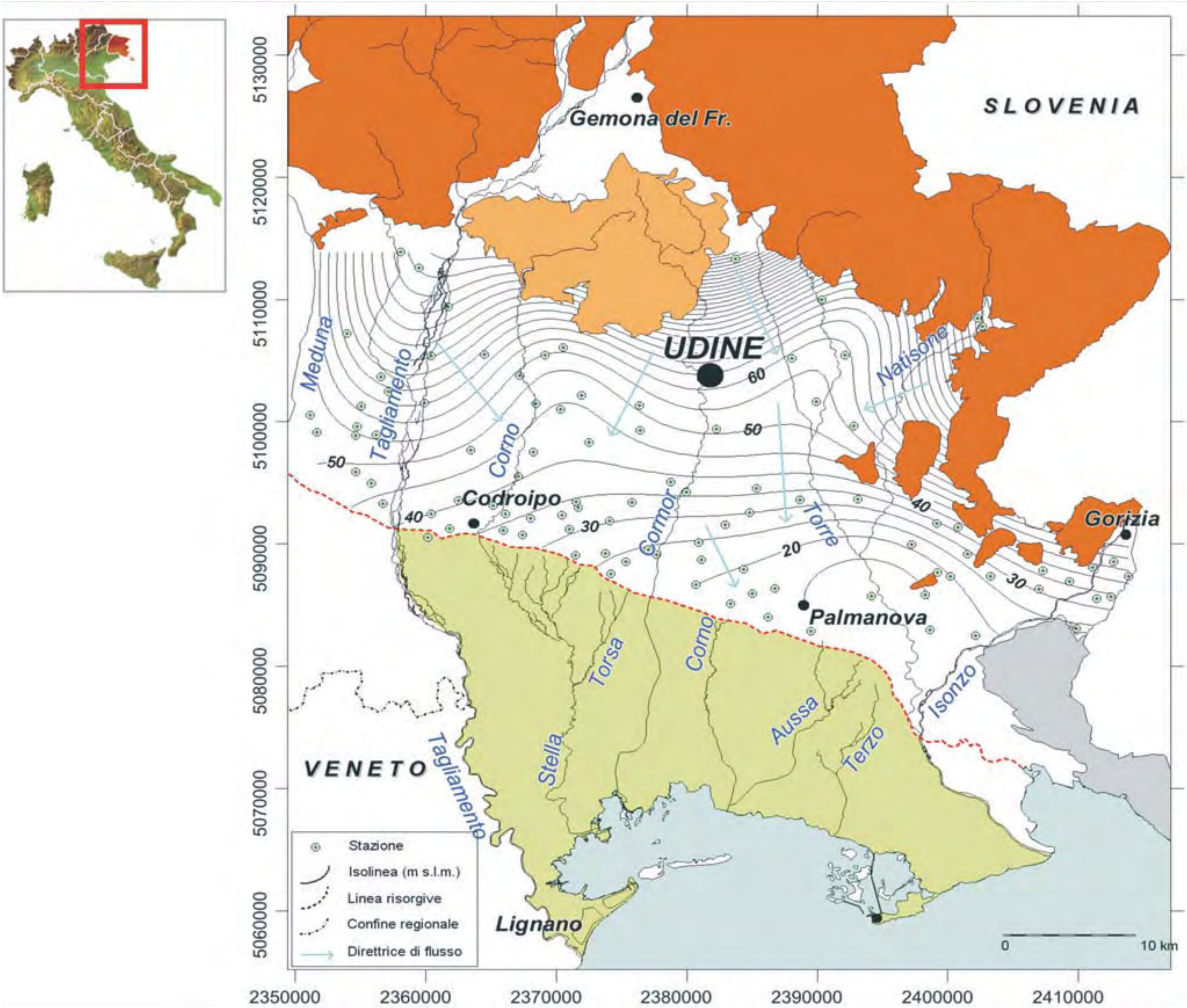

Fig. 1 – Isophreatimetric map of the High Plain unconfined aquifer system (from MARTELLI & GRANATI, 2007a). Dot symbols indicate the location of the piezometric gauge network , while arrows mark the main groundwater flow directions.
– Carta, in proiezione Gauss-Boaga, dell'andamento freatimetrico (m slm) della falda dell'Alta Pianura friulana (da MARTELLI & GRANATI*, 2007a). I simboli indicano i singoli pozzi della rete di rilevamento regionale, mentre le frecce individuano le principali direzioni di deflusso idrico sotterraneo.*

the western sector of the Slovenian basin to the eastern sector of the Veneto basin, and (c) the Mesozoic carbonate platform, over 6.000 meters thick and conditioned by buried and sometimes seismically active overthrust fronts, oriented in a Dinaric direction and overlapping towards SW (BURRATO *et alii,* 2008; CALORE *et alii,* 1995; CASTELLARIN & CANTELLI, 2000; CATI *et alii,* 1989a, 1989b; GALADINI *et alii,* 2005). The thickness of the Neogenic and Quaternary deposits increases from NE (about 50 meters at the foot of the moraine hills) towards SW (over 900 meters at the western border of the plain) (REGIONE AUTONOMA FRIULI-VENEZIA GIULIA, 2004). The pre-Quaternary substratum behaves as a permeability boundary for groundwaters circulating within the alluvial materials.

The geometric pattern of the Quaternary deposits has been conditioned by both the geological-structural evolution of the area and the Pleistocene glacial-eustatic fluctuations, that worked together in order to outline the main hydrogeological subdivision of the Friuli Plain in two distinct sectors.

In the High Plain (area of about 1150 km^2, stretching between the Tagliamento moraines, the central and eastern Pre-Alps and the spring belt), the thick coarse-grained detrital body of fluvioglacial origin (gravels irregularly cemented in conglomerate horizons and intercalated with layers of sand and, less frequently, of clay) holds, owing to its marked high permeability characteristics, a wide and continuous water-table aquifer, whose depth-to-water decreases from the moraines foot (about 75 meters to the N of Udine) to the most southern sector near the spring belt (MARTELLI & GRANATI, 2007b). The springs, extending for about 40 kilometers in the E-W direction, discharge about 80 m^3/s (CONSORZIO DI BONIFICA LEDRA-TAGLIAMENTO, 1982).

Southward from springs, the hydrogeological behaviour of the Low Plain (about 740 km^2) is a direct consequence of the presence of a complex and articulated sequence of wide and continuous silty-clayey deposits, sandy and subordinately gravelly horizons: within such multi-layered system, at least eight confined and variously branched superimposed aquifer horizons are recognisable. Owing to the strict hydraulic link existing between High and Low Plain, the confined aquifers are fed by groundwaters coming from the phreatic system (about 820 millions of m^3/year) (MARTELLI *et alii,* 2003; MARTELLI & GRANATI, 2007b). This connection assures a common feeding area, located to the north of the spring belt (MOSETTI, 1983; STEFANINI, 1978), to both of the aquifer systems: the 25% of the whole recharge contributions is due to effective meteoric infiltration and the remaining 75% to relevant seepage from losing rivers of the High Plain hydrographic network (MARTELLI & GRANATI, 2007b).

The annual groundwater volume drawn from the Low Plain confined aquifers, representing the main regional reservoir for drinking and domestic uses, has been estimated at 526 millions of m^3/year (GRANATI *et alii,* 2000; MARTELLI *et alii,* 2004; MARTELLI & GRANATI, 2007b). About 84% of withdrawals concerns the most shallow aquifer horizons (till 112 m bsl): a progressive loss in both pressure and natural productivity is evidenced by a large number of wells in the northern sector of the Low Plain (MARTELLI & GRANATI, 2007b).

3. - THE GEOLOGICAL-STRUCTURAL FRAME OF THE STUDIED AREA

The involvement of multi-disciplinary approaches and operative methodologies representatively marks the studies, undertaken in the last decades and refined in the most recent past, whose aim can be singled out in the hydrogeological characterisation of the site of interest; such studies are propaedeutic to quantitative groundwater flow and transport modelling calibrated to a suitable use scale (GRANATI, 2007; DRIUTTI, 2009).

The knowledge of the Friuli Plain deep structure follows from deep boreholes and geophysical surveys (AGIP, 1972; CALORE *et alii,* 1995; CASSANO *et alii,* 1986; CATI *et alii,* 1989a, 1989b; MARTINIS, 1971) that started in the fifties by ENI-AGIP for hydrocarbon research and that have been recently synthesized and improved by Trieste University (REGIONE AUTONOMA FRIULI-VENEZIA GIULIA, 2004) even through a new deep drilling project in the Grado lagoon (DELLA VEDOVA *et alii,* 2009; FANTONI *et alii*, 2003; REGIONE AUTONOMA FRIULI-VENEZIA GIULIA, 2004).

The lithostratigraphical data coming from water-wells closely spread in the area of interest (GRANATI *et alii,* 1999, 2000), from a few to over 500 meters deep, represent the main survey tool for the Neogenic and Quaternary alluvial body and its aquifer systems (GIOVANNELLI *et alii,* 1985; MAROCCO, 1988; MAROCCO *et alii,* 1988; MARTELLI & GRANATI, 2007a, 2007b; MARTELLI & RODA, 1998).

The conceptualisation and characterisation of the aquifers' spatial structure (MARTELLI & GRANATI, 2006) started off from lithostratigraphical evidences associated to over a thousand water-wells gathered among (a) the regional archive of water-wells and drillings realised in the Quaternary alluvial horizon and in the unfastened deposits of the Friuli region (REGIONE AUTONOMA FRIULI-

VENEZIA GIULIA, 1990), (b) technical reports in applications for large (Udine Civil Engineers Office) and small (Provincial Direction of Regional Technical Services) supplies of drinking water, trout breeding, industrial and agricultural groundwater drawings, and (c) technical reports in applications for deep geothermal groundwater drawings (Industrial Regional Direction).

Beginning with class codification processes (on the basis of hydrogeological criteria) of the materials defined by the drilling operators and pursuing with correlations between productive aquifer horizons and lithologically similar layers characterised by the same average depth, it has been possible to reconstruct in detail (MARTELLI & GRANATI, 2006) the geometry of the Low Plain confined aquifer system: the existence of eight artesian layers, identified with a capital letter (from A to H in the increasing depth direction) accordingly with the past scientific literature conventions (MARTELLI *et alii,* 2004; STEFANINI & CUCCHI, 1977), has been confirmed between 19 m bsl and over 500 m bsl.

4. - THE HIGH PLAIN WATER-TABLE AQUIFER BEHAVIOUR

The annual averaged phreatimetric pattern of the High Plain aquifer system came out from geostatistical elaboration of data collected within the regional water-table monitoring network (MARTELLI & GRANATI, 2007b): 96 hydraulic head measurement stations, supplied with data coming from 20 or more observation years in the period 1967-2004, have been taken into account.

At a regional scale, the main groundwater flow directions (fig.1), as evidenced by the drainage axes in correspondence of the Corno River and the Torre – Natisone – Isonzo hydrographic network, single out a fan-shaped arrangement, with a NW-SE flow direction in the western sector and a NE-SW direction in the eastern one, with a SE deflection near the spring area. The groundwater recharge from the Tagliamento River is particularly evident in the left river side.

The groundwater flow conditioning by the regional tecto-dynamic pattern comes out (fig. 2) from overlaying the above-mentioned isophreatimetric map and the Friuli Plain structural map (POLI *et alii,* 2008). The Palmanova line, active until the Palaeogene and whose trace can be seen in the lower right corner of the map, represents the buried front of the Dinaric belt under the Miocene and Quaternary deposits. The Pozzuolo, Udine and Medea faults show deformation evidences in the Upper Pleistocene (BURRATO *et alii,* 2008; GALADINI *et alii,* 2005): in particular, the former one causes a Miocene molasse outcrop along the left side of the Cormor river to the SW of Udine and consequently a resulting thickness lowering of the Quaternary alluvial body (less than 75 meters) near the tectonic displacement (REGIONE AUTONOMA FRIULI-VENEZIA GIULIA, 2004). The whole tectonic lines act as a water divide between the western and the eastern sectors, tied to the Tagliamento River and the Torre – Natisone hydrographic network dynamics respectively. The drainage axes, shown by the water table map, also appear strictly connected to the dinaric and south-alpine paleogeography.

The map of the annual averaged water table excursion (fig. 3) shows the link between hydrographic network and groundwaters. It has been drawn through data of 132 water-wells collected in the period 1998-2007. The greatest values are located in correspondence with the Tagliamento (14 meters) and the upper Torre (9 meters) rivers, as well as radial decreasing values can be observed moving both towards the northern moraines and the southern spring belt (about 1 meter).

5. - HYDROCHEMICAL CHARACTERISATION OF THE HIGH PLAIN UNCONFINED AQUIFER

The improvement of the knowledge concerning the High Plain groundwater flow system could not leave the analysis of the main chemical-physical features (main dissolved ions, pH, temperature, conductivity) out of consideration. The elaborations involved time series of data (tab. 1 and fig. 4) as follows:

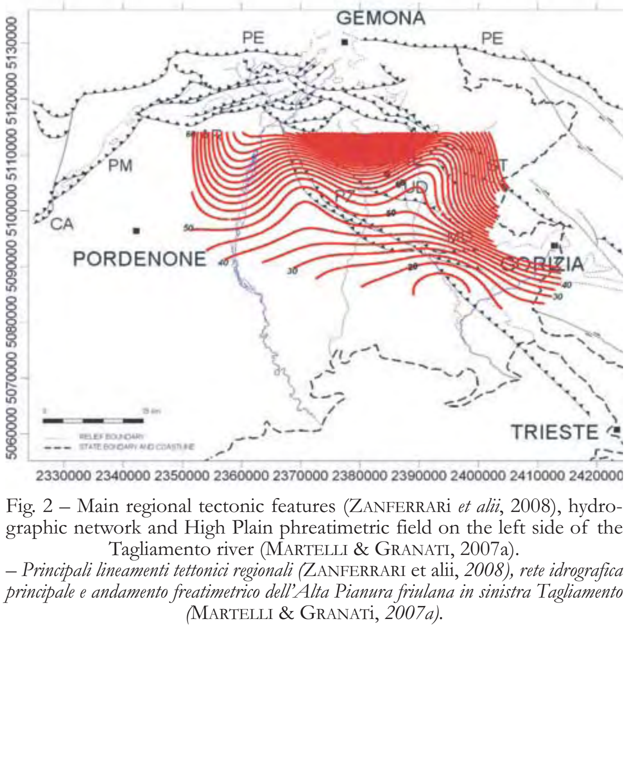

Fig. 2 – Main regional tectonic features (ZANFERRARI *et alii*, 2008), hydrographic network and High Plain phreatimetric field on the left side of the Tagliamento river (MARTELLI & GRANATI, 2007a).
– *Principali lineamenti tettonici regionali (*ZANFERRARI et alii, *2008), rete idrografica principale e andamento freatimetrico dell'Alta Pianura friulana in sinistra Tagliamento (*MARTELLI & GRANATI, *2007a).*

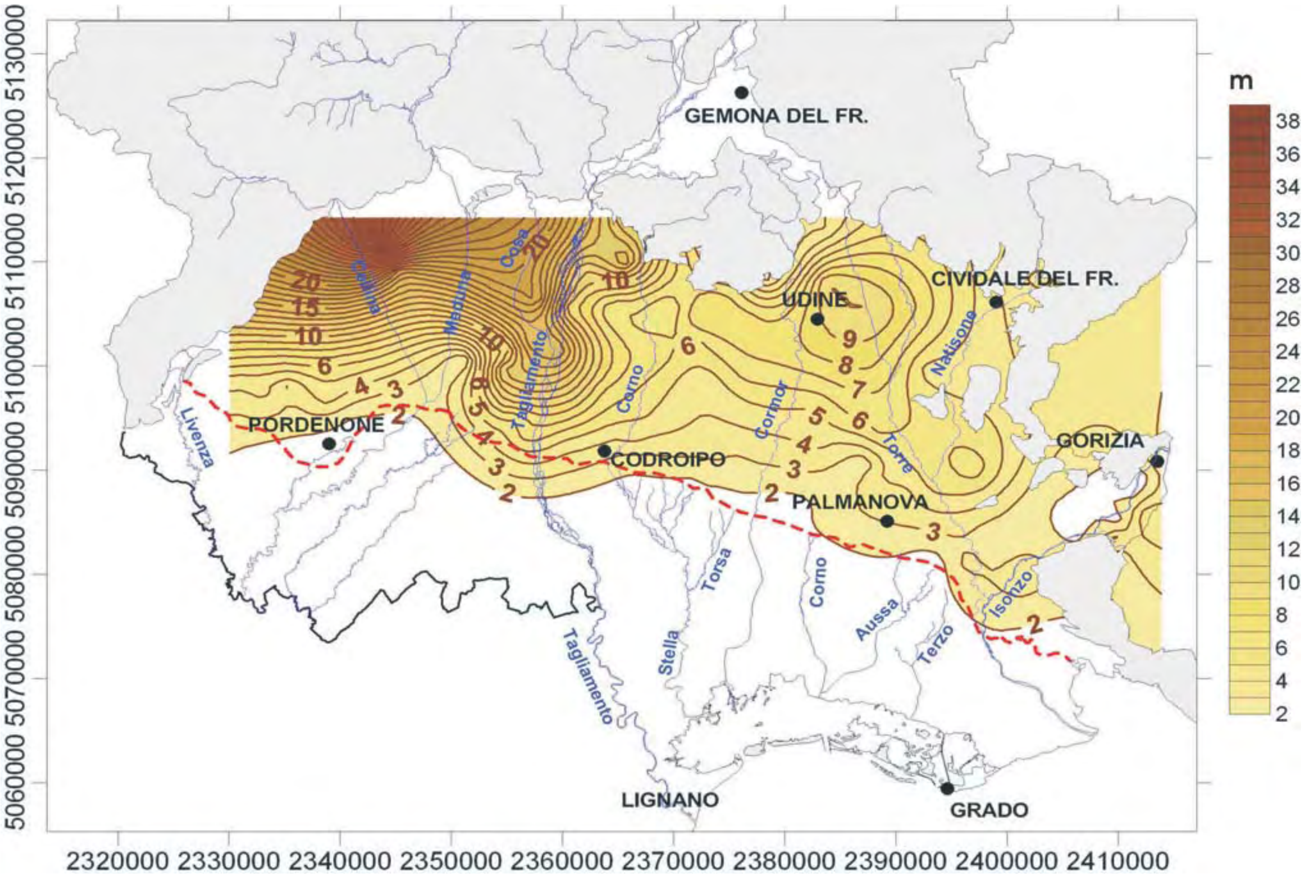

Fig. 3 – Annual averaged (1998-2007) phreatimetric excursion (in metres) of the High Plain unconfined aquifer. The regional border is marked by the black bold line; the red dotted line shows the average position of the spring alignment.

– Mappa dell'escursione freatimetrica media annua (1998 – 2007), in metri, dell'acquifero indifferenziato dell'Alta Pianura friulana. In grassetto è rappresentato il confine regionale; con tratteggio rosso, è indicata la posizione media dell'allineamento delle risorgive.

- observations collected in 34 sampling points of the regional qualitative monitoring network for the period 1982- 1992;
- measurements carried out (project PRIN 2005) in correspondence of 17 springs, 1 phreatic well and the 4 main rivers of the sector (Tagliamento, Torre, Natisone and Isonzo) for the period 2003-2007 (MARTELLI & GRANATI, 2008a; BORTOLAN PIRONA, 2008).

As evidenced by the Schoeller diagram (fig. 5), both river waters and groundwaters of the northern sector of the Friuli Plain show a Ca-HCO_3 hydrochemical facies. Limestones, dolomitic limestones and dolomites are widely present in both the mountain basins of the Friuli rivers and the Quaternary alluvial deposits.

According to the hydraulic head outputs, that put in evidence a remarkable groundwater recharge action by the Tagliamento River in the most western sector of the studied plain, both groundwaters and spring waters of such area belong to a Ca-SO_4 facies: the relevant $SO_4^{=}$ amount that characterises the Tagliamento waters is due to the dissolution of Permian gypsum (Bellerophon formation) that outcrops in the Carnic Alps (STEFANINI, 1978). The same waters are relatively poor in HCO_3^- owing to the interfering action of calcium coming from sulphates (STEFANINI, 1972). Starting from the area close to the Tagliamento River, where $SO_4^{=}$ ranges from 80 to 130 mg/l (fig. 6), the concentration of such anion in High Plain groundwaters decreases moving eastward accordingly with the increasing distance from the river and it becomes close to zero in the most eastern sector pertaining to the recharge contributions of the Torre – Natisone hydrographic system: the sulphate concentration in the upper Torre waters ranges between 2 and 16 mg/l, while calcium joins values of about 60 mg/l. The seepage waters of the Tagliamento River, although progressively diluted, preserve their distinctive chemical character according to the regional tectonic pattern.

The map of the calcium spatial distribution (fig. 7) shows the lowest concentrations in correspondence of a central sector stretched between the Cormor and the Torre rivers, as a divide, according to the phreatimetric evidences, of the western area from the eastern one (pertaining re-

Tab. 1 – *Main physical-chemical parameters determined for sampled groundwaters of the Friuli High Plain, spring waters and rivers.*
– Valori dei principali parametri chimico-fisici rilevati in campioni idrici prelevati da 35 pozzi della falda freatica dell'Alta Pianura friulana, da 17 affioramenti di risorgiva e da 4 corsi d'acqua.

Codice	**Temp.** (°C)	**pH**	**Cond.** (µS/cm)	**Ca^{++}** (mg/l)	**Mg^{++}** (mg/l)	**Na^{+}** (mg/l)	**K^{+}** (mg/l)	**Cl^{-}** (mg/l)	**$SO^{4=}$** (mg/l)	**Sr^{-}** (mg/l)	**NO^{3-}** (mg/l)	**HCO^{3-}** (mg/l)
213	12,8	7,4	545	82,1	26,9	3,2	1,0	5,0	81,3	0,4	19,6	304,0
214	12,8	7,4	554	84,8	27,1	3,5	0,7	4,0	83,8	0,4	22,4	
215	10,3	7,4	544	78,9	28,1	4,0	1,3	5,1	59,2	0,3	26,3	
216	13,3	7,4	564	84,3	29,8	3,6	0,8	5,0	49,9	0,3	26,2	351,0
217	13,3	7,4	600	82,2	28,7	16,1	1,3	20,7	52,9	0,3	24,4	
219	13,1	7,3	583	86,3	29,2	4,5	1,4	5,9	52,4	0,3	26,8	360,0
220	13,1	7,4	530	78,3	25,3	3,5	2,0	7,1	43,8	0,3	74,7	
253	13,7	7,6	482	74,8	22,1	3,1	1,2	4,7	21,4	0,2	20,5	
255	14,5	7,4	551	90,9	20,7	3,4	1,2	5,2	15,7	0,2	23,9	386,0
256	14,5	7,4	581	90,8	27,4	3,8	1,9	6,7	28,0	0,2	29,0	
234	13,0	7,5	532	87,6	22,9	3,1	1,5	4,9	18,6	0,2	23,0	351,0
235	13,4	7,8	350	61,3	9,5	4,1	1,9	4,2	9,5	0,1	9,5	222,0
245	12,1	7,6	418	68,7	13,9	3,0	1,5	4,8	10,4	0,2	18,1	
246	14,5	7,6	551	83,0	21,1	6,2	5,6	7,5	19,0	0,1	32,3	310,0
247	12,9	7,8	345	60,0	9,9	2,9	1,1	3,4	7,7	0,2	7,5	
248	14,3	7,2	662	104,1	17,4	23,8	1,9	16,9	26,4	0,3	3,6	
254	14,2	7,6	403	62,6	17,9	3,1	1,2	3,5	10,1	0,1	18,2	
236	12,2	7,7	472	79,8	19,6	3,4	1,0	3,2	122,3	0,9	3,7	199,0
238	13,2	7,7	498	76,7	23,5	4,1	1,3	5,0	74,9	0,4	14,7	
242	12,5	8,0	474	71,4	20,4	6,3	8,2	5,8	76,4	0,5	11,0	
218	12,5	7,4	516	72,5	27,4	5,3	1,0	7,6	42,7	0,2	18,7	309,0
228	12,9	7,7	432	64,0	18,9	2,9	1,2	5,3	24,5	0,2	14,6	
232	12,1	7,6	453	73,9	22,4	4,3	2,1	5,5	34,4	0,3	13,5	
233	13,9	7,8	340	51,4	17,0	2,4	0,8	4,8	10,2	0,1	13,3	234,0
237	12,8	7,9	433	64,9	19,6	4,2	4,3	5,9	71,3	0,5	6,7	258,0
239	13,2	7,6	629	90,6	35,0	12,3	8,3	17,7	28,2	0,1	62,9	
240	13,1	7,7	450	64,6	25,0	3,2	0,8	4,9	27,1	0,1	14,0	286,0
241	12,3	7,5	544	79,3	28,2	4,5	1,3	6,1	52,3	0,2	31,6	
243	13,4	7,7	367	53,8	18,4	3,1	0,8	4,3	18,1	0,1	12,8	
244	12,8	7,6	439	61,1	23,7	4,8	0,9	5,3	21,9	0,1	21,4	
249	12,8	7,7	383	58,6	20,0	3,3	0,8	4,0	16,2	0,1	13,5	
250	13,1	7,6	490	71,6	25,7	5,5	1,0	8,2	32,8	0,2	17,6	310,0
251	13,3	7,8	382	55,8	18,0	3,3	0,7	4,8	15,2	0,1	15,9	
252	15,1	7,9	277	48,7	9,0	2,1	1,1	2,8	7,2	0,2	56,1	177,0
37	12,0	7,8	340	42,1	24,2	3,8	0,8	8,1	32,0		16,2	
TAG	19,9	7,5	435	72,3	18,8	3,2	0,4	5,1	127,3		2,8	151,2
TOR	16,7	7,6	191	34,6	9,3	1,5	0,4	4,0	3,7		2,9	132,2
NAT	22,7	7,7	247	42,6	5,2	1,9	0,4	4,0	4,4		2,6	145,5
ISO	20,8	7,6	216	38,4	6,9	1,3	0,2	3,7	3,3		2,0	140,7
RIS1	10,0	7,8	543	65,4	21,1	3,1	1,0	4,2	48,1	0,2	7,0	240,9
RIS2	12,3	7,8	644	88,9	25,1	6,2	1,5	10,1	67,6	0,8	10,8	341,6
RIS3	12,2	7,7	640	77,9	26,7	7,2	2,0	10,1	63,2	0,9	15,1	317,2
RIS4	10,6	7,9	685	81,2	26,4	2,8	1,0	6,7	67,1	0,8	19,4	311,9
RIS5	12,1	7,8	589	77,4	25,4	2,6	0,6	5,8	69,2	0,9	17,6	292,8
RIS6	12,6	7,9	668	87,6	27,5	3,5	1,5	8,0	44,8	0,7	20,9	366,0
RIS7	11,7	7,6	661	89,6	29,4	3,4	0,9	8,4	64,7	0,7	22,3	353,8
RIS8	10,3	7,6	619	85,1	29,5	2,9	0,7	5,6	87,6	0,7	11,5	324,5
RIS9	11,9	7,3	786	105,6	34,9	3,0	0,7	9,6	130,1	1,2	13,6	361,1
RIS10	14,8	7,6	532	73,2	25,1	2,2	0,5	4,2	81,2	< 0,01	10,9	258,6
RIS11	14,0	7,9	575	74,9	27,8	3,5	0,8	5,8	47,8	0,4	16,2	329,4
RIS12	13,5	7,5	722	97,7	31,3	7,3	1,5	16,7	30,4	< 0,01	37,5	400,2
RIS13	14,4	7,4	624	83,3	29,3	5,6	0,9	8,8	38,4	< 0,01	25,3	363,6
RIS14	14,3	7,2	748	98,9	33,0	6,6	1,0	11,8	45,3	< 0,01	28,7	407,5
RIS15	13,5	7,2	649	98,5	28,7	5,6	1,6	13,4	21,1	< 0,01	26,1	412,4
RIS16	12,0	7,7	448	68,6	20,0	2,9	0,9	3,8	9,4	< 0,01	11,6	288,0
RIS17	12,8	7,2	513	80,5	20,8	3,2	1,5	4,7	14,0	< 0,01	12,6	333,7

Fig. 4 – Physical-chemical sampling sites in the High Friuli Plain (APF). Legend: a) spring belt; b) sampling wells to the South of main regional tectonic features; c) sampling wells to the North of main regional tectonic features; d) sampled springs; e) sampled rivers.
- *Ubicazione dei punti di campionamento chimico-fisico nell'Alta Pianura Friulana (APF). Legenda: a) allineamento medio degli affioramenti di risorgiva; b) pozzi posti a Sud dei principali elementi tettonici regionali; c) pozzi posti a Nord dei principali elementi tettonici regionali; d) risorgive; e) corsi d'acqua superficiali.*

spectively to the Tagliamento and the Torre-Natisone system recharge contributions). The higher calcium values in the western sector are due to the sulphate contribution, as well as the ones pertaining to the spring area, accordingly with the main groundwater flow directions.

The thematic maps that describe the spatial variability of chlorine, sodium and nitrate content (figg. 8-10) show maximum concentrations in the same areas. High nitrates are connected to local pollution phenomena of agricultural origin. Peak concentrations of chlorine and sodium close to the Cormor River, also supported by past documentary evidences (STEFANINI, 1972), need further investigations.

Spring waters, whose alignment marks in surface the transition between the two Friuli Plain hydrogeological systems, show chemical patterns that are similar to the ones proper to western phreatic groundwaters: they are characterised by a Ca-HCO_3 facies, with a sulphate content decreasing from W to E accordingly with an increasing distance from the Tagliamento River (fig. 11).

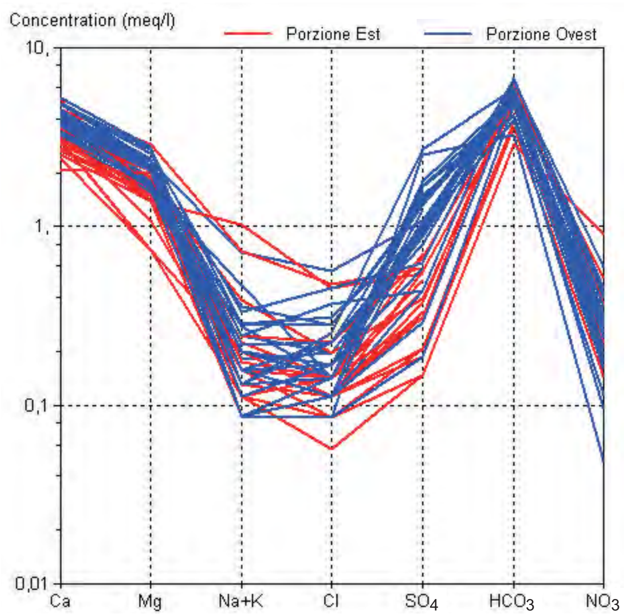

Fig. 5 – Schoeller diagram for Friuli High Plain groundwaters sampled to the South (red lines) and to the North (blue lines) of the main regional tectonic features.
- *Diagramma di Schoeller relativo alle acque freatiche dell'Alta Pianura friulana, differenziate in base alla localizzazione rispetto ai principali lineamenti tettonici regionali.*

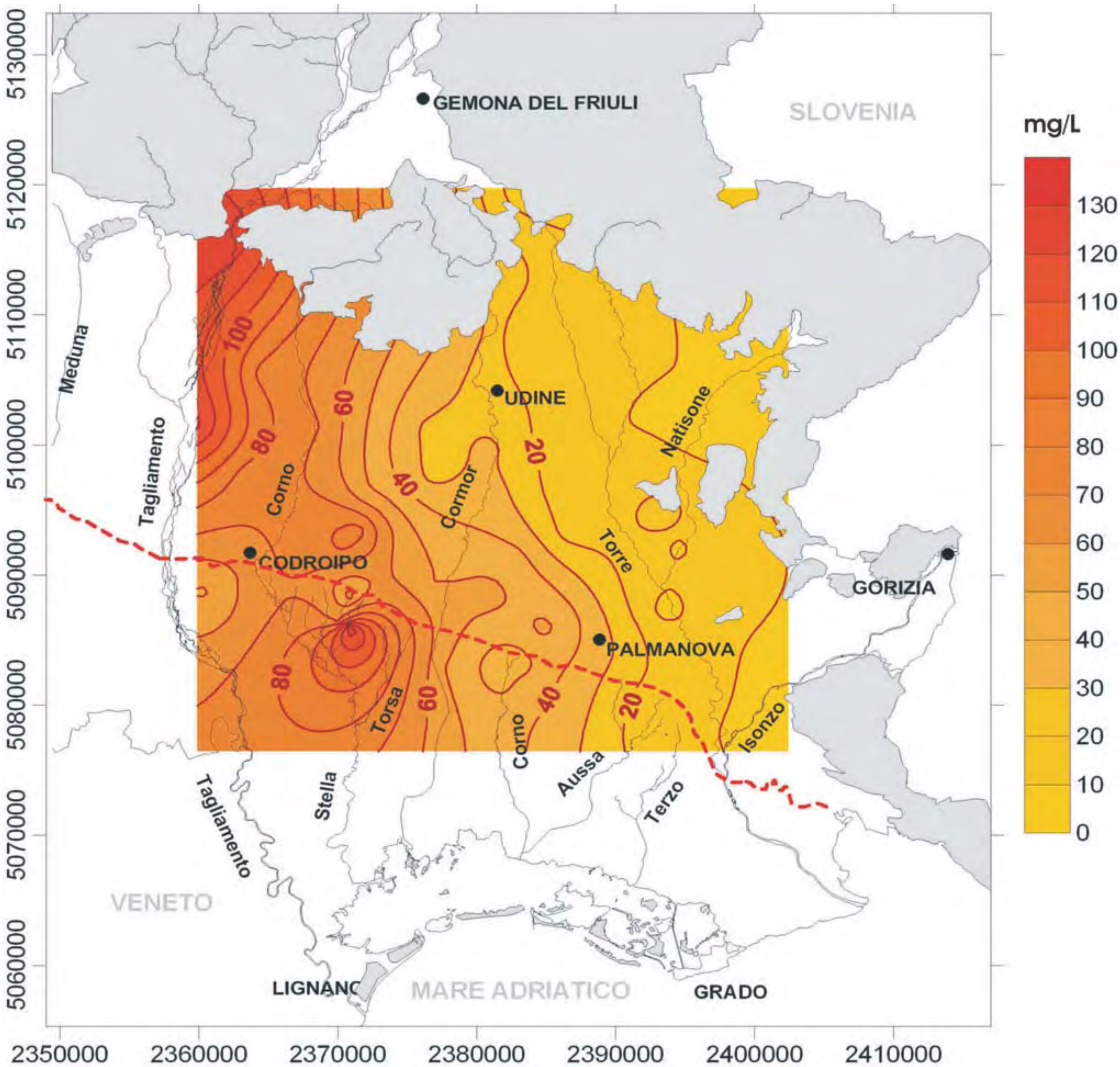

Fig. 6 – Sulphates distribution in High Plain groundwaters, surficial and spring wters.
- *Carta della distribuzione dei solfati nelle acque sotterranee, superficiali e di risorgiva dell'Alta Pianura friulana.*

6. - PIEZOMETRIC CHARACTERISTICS OF THE LOW PLAIN AQUIFER SYSTEM

The quantitative piezometric survey related to the sequence of confined aquifer levels that can be found in the Friuli Low Plain between 19 and more than 500 m bsl required the arrangement, together with ex APAT – Italian Geological Service (MARTELLI *et alii,* 2007a), of an experimental monitoring network involving 134 water-wells within the studied area. The hydraulic head data collected in the period 2003-2007 allowed (MARTELLI & GRANATI, 2006, 2007b; MARTELLI & GRANATI, 2007a), by means of geostatistical methods of variographic analysis, to reconstruct the groundwater flow fields pertaining to the single aquifer levels, mapping out (fig.12) the annual averaged spatial distribution of piezometric head. Except Aquifer E (179/216 m bsl), for which no isomaps have been drawn owing to the small available measurement points, and the deepest Aquifer H (over 276 m bsl), marked by complex and peculiar flow circuits (as confirmed by the after-mentioned geochemical and isotopic results), a main NW-SE flow direction is recognisable for the remaining aquifers (MARTELLI *et alii,* 2007a). The most shallow Aquifer A (19/80 m bsl), whose average hydraulic gradient is about $1{,}0 \cdot 10^{-3}$, shows a rather articulated piezometric topology. The similar piezometric distributions that are appraisable for Aquifer B (80/112 m bsl) and Aquifer C (112/148 m bsl), whose hydraulic gradients are about $1{,}8 \cdot 10^{-3}$ e $1{,}9 \cdot 10^{-3}$ respectively, let foresee, together with the qualitative evidences, a possible mutual hydraulic connection (MARTELLI & GRANATI, 2006, 2007b). Analogous considerations pertain Aquifer D (148/179 m bsl) and Aquifer F (216/262 m bsl), characterised by an average hydraulic gradient of about $2{,}0 \cdot 10^{-3}$ e $8{,}2 \cdot 10^{-3}$ respectively. An hydraulic head increase with depth is recognisable as a general trend, in spite of the wide variability range evinced at the same depth by the inner pressures within Aquifers C, D, E.

As regards the piezometric excursions, the isomaps, however conditioned by the inhomogeneous measurement sites' spatial distribution, show the highest values close to the spring belt till 200 m bsl. The extreme variations concerning Aquifers A (average excursion 1,4 meters) and B (average excursion 2,0 meters) are located near the Aussa-Corno hydrographic system, while the corresponding maxima in Aquifers C (average excursion 2,0 meters), D (average excursion 2,7 meters) and E (average excursion 2,4 meters) are recognisable close to the upper

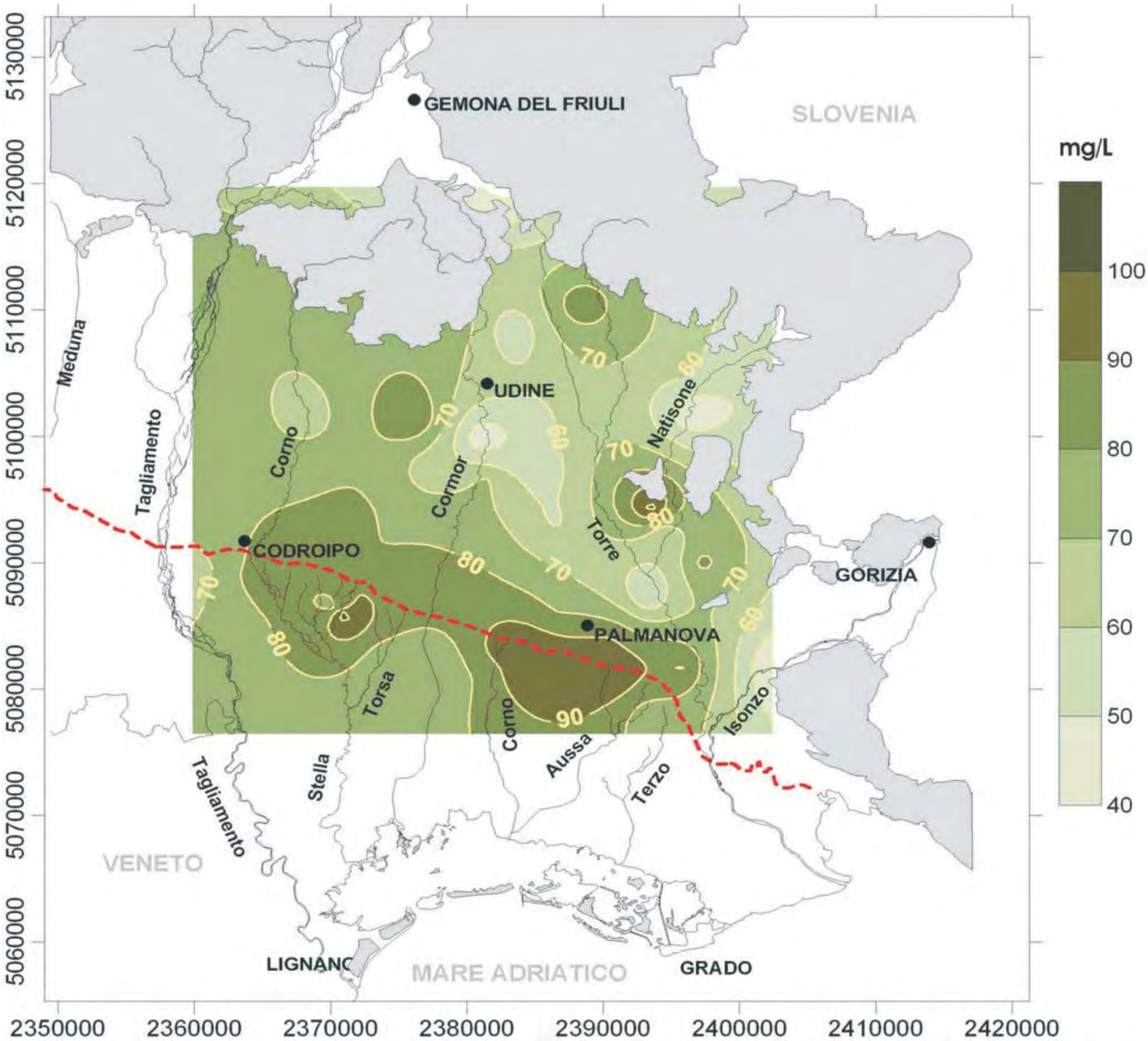

Fig. 7 – Calcium distribution in High Plain groundwaters, surficial and spring waters.
– Carta della distribuzione del calcio nelle acque sotterranee, superficiali e di risorgiva dell'Alta Pianura friulana.

Torsa-Stella hydrographic system. Within Aquifer F (average excursion 2,6 meters), the excursion decrease develops radially starting from a maximum located in the central sector near the middle Cormor River.

The highest piezometric variability of Aquifer H (average excursion 1,3 meters) characterises the sector close to the lower Tagliamento River. Figure 13 shows the excursion patterns for Aquifers A and D.

7. - HYDROCHEMICAL CHARACTERISATION OF THE LOW PLAIN CONFINED AQUIFERS

Geochemical surveys, turned to improve both the main groundwater circuits' definition and the recharge areas of the Low Plain confined aquifers on the left side of the Tagliamento River (PRIN 2005), have been recently carried out on the basis of the data (major ions, pH, temperature, conduc-

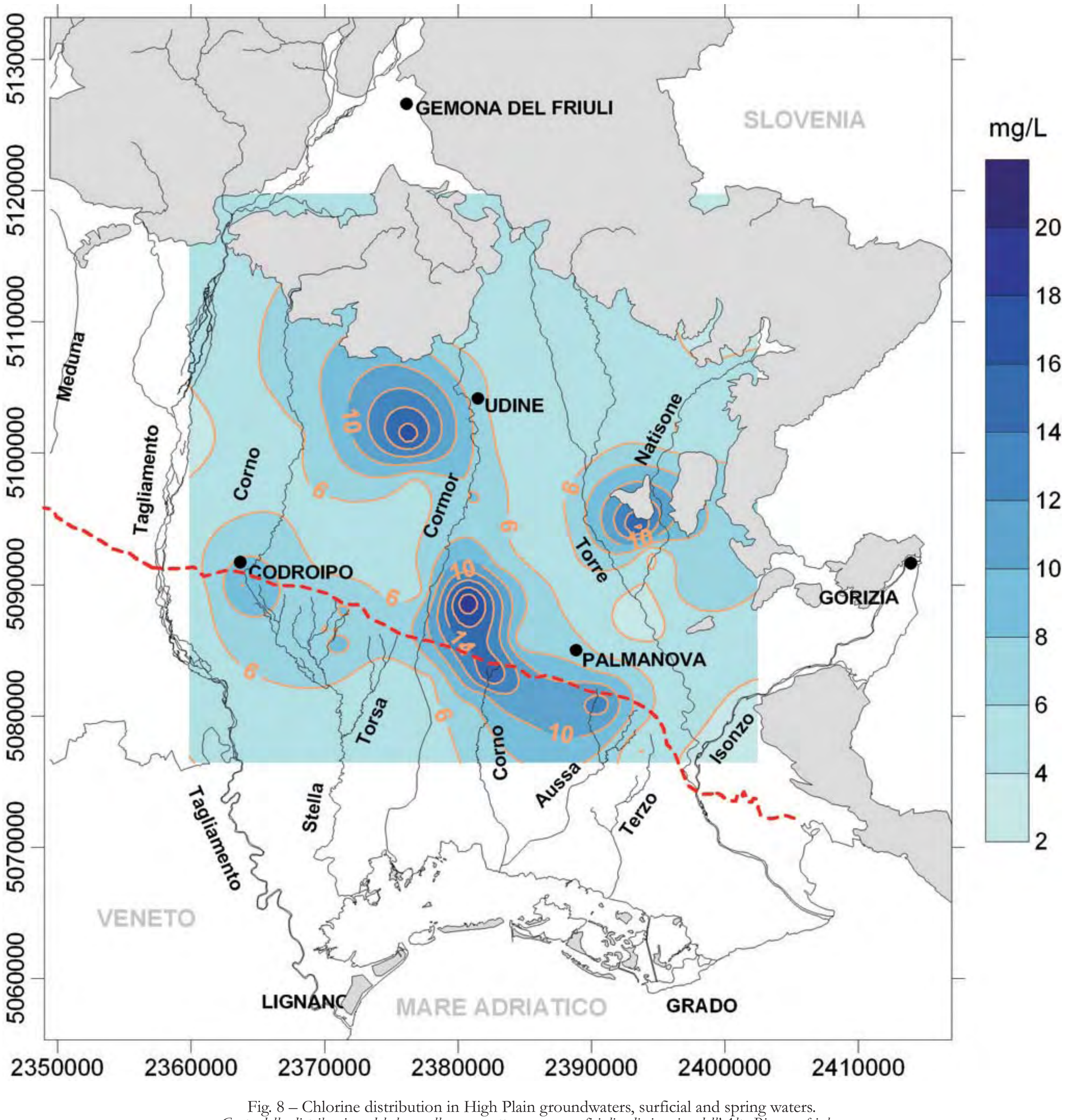

Fig. 8 – Chlorine distribution in High Plain groundwaters, surficial and spring waters.
- Carta della distribuzione del cloro nelle acque sotterranee, superficiali e di risorgiva dell'Alta Pianura friulana.

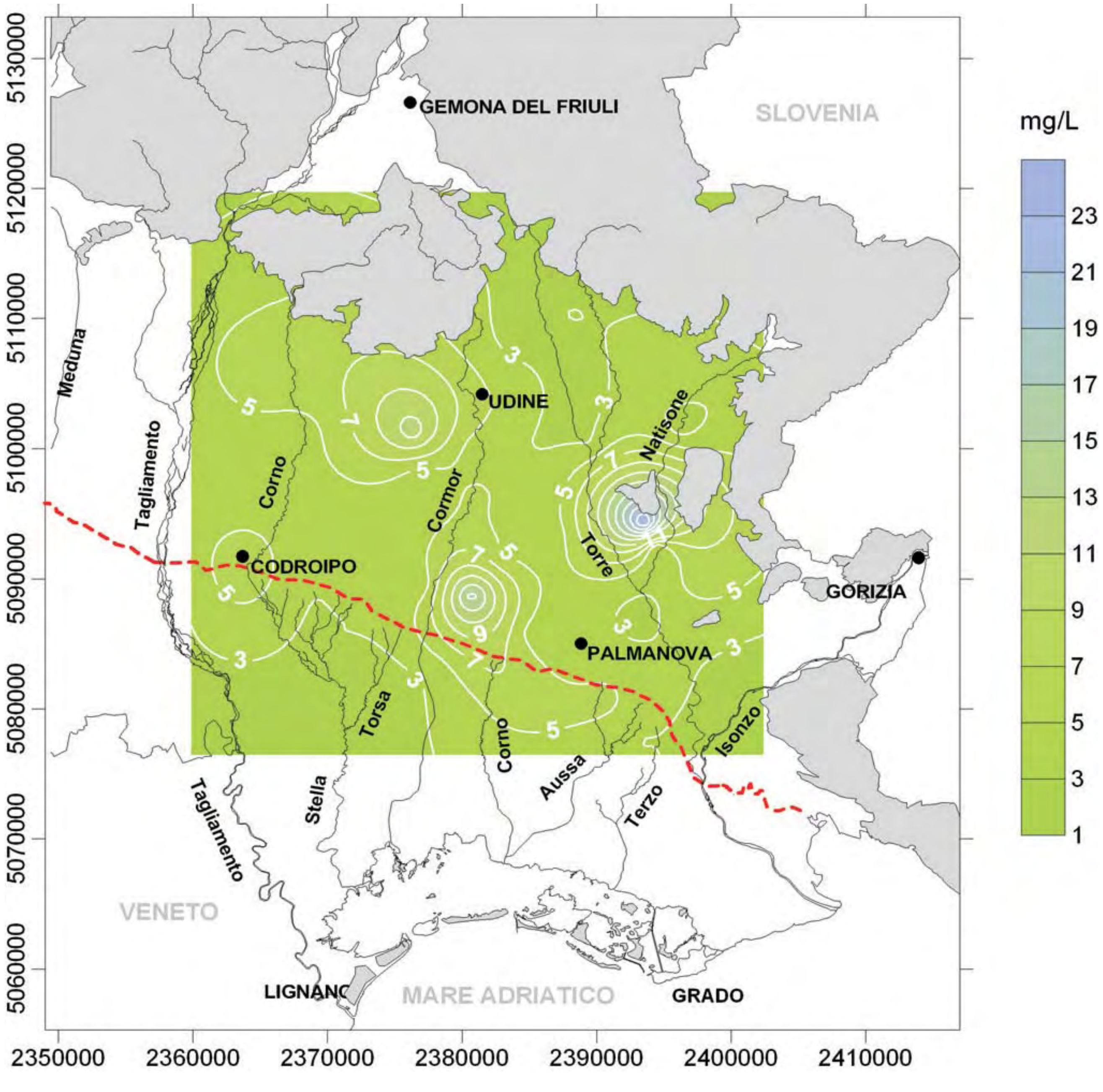

Fig. 9 – Sodium distribution in High Plain groundwaters, surficial and spring waters.
– *Carta della distribuzione del sodio nelle acque sotterranee, superficiali e di risorgiva dell'Alta Pianura friulana.*

tivity) collected in April, July, October 2006 and March 2007 through qualitative measurements on 36 artesian wells reaching aquifer levels more than 180 m bsl deep (1 well for Aquifer D, 6 for Aquifer E, 6 for Aquifer F, 4 for Aquifer G, 19 for Aquifer H). The interest for the deep flow patterns is strictly connected to the effects of the increasing groundwater withdrawals, owing to both the quali-quantitative impoverishment of the most shallow confined levels and the increasing geothermal exploitation of the deep thermal waters (over 300 m bsl), that can be found along the coastal area in correspondence of the Cesarolo structural high (Barnaba, 1990; Calore *et alii*, 1995; Martelli & Granati, 2008a, 2009). The collected data have been compared and completed with the ones coming from:

- 23 wells reaching the confined aquifer levels less than 180 m bsl deep (14 wells in Aquifer A, 5 in Aquifer B, 1 in Aquifer C, 3 in Aquifer D), moni-

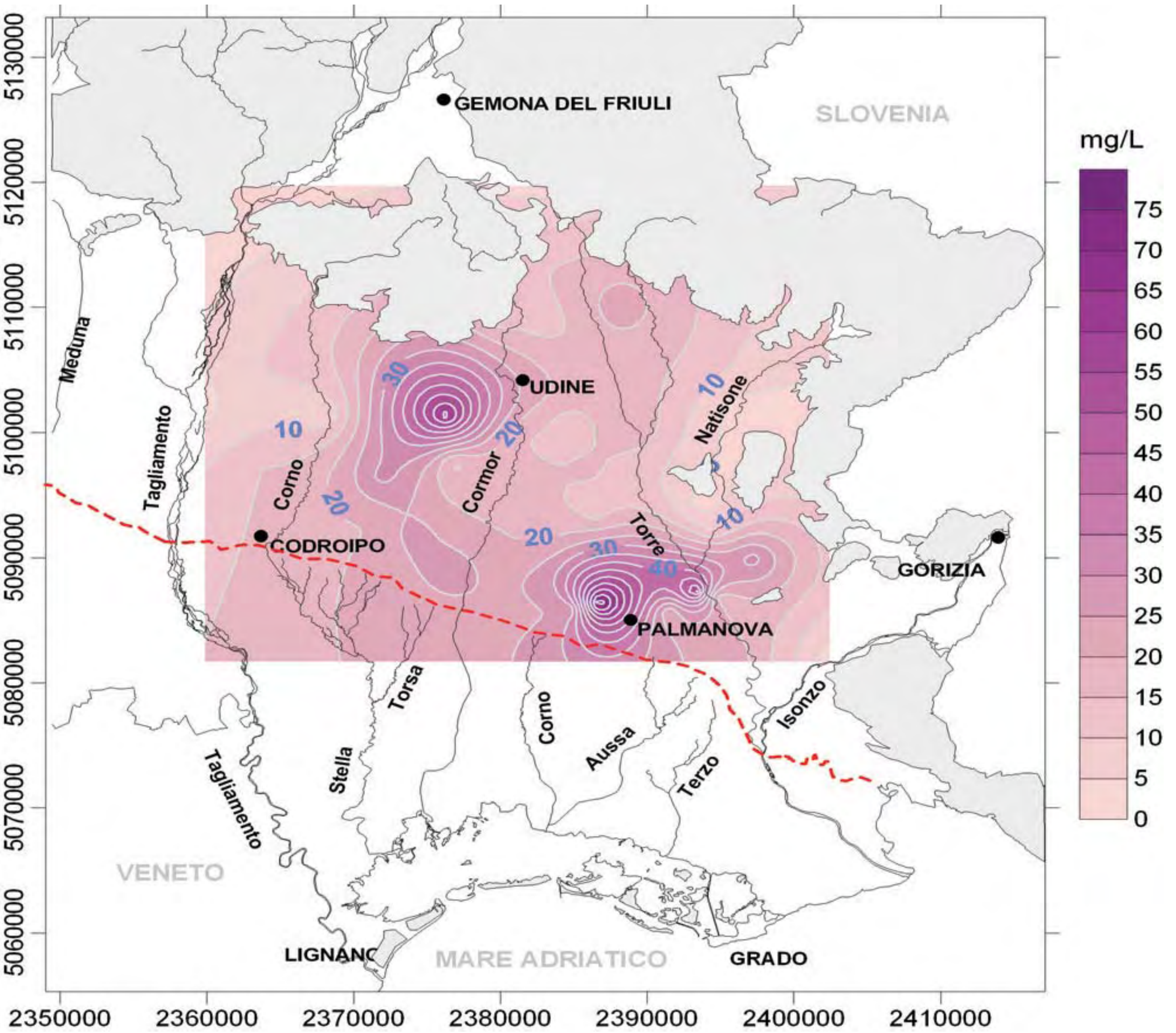

Fig. 10 – Nitrate distribution in High Plain groundwaters, surficial and spring waters.
– Carta della distribuzione dei nitrati nelle acque sotterranee, superficiali e di risorgiva dell'Alta Pianura friulana.

tored by ARPA in June-July-August and October-November-December 2006 (BORTOLAN PIRONA, 2008; MARTELLI & GRANATI, 2009);

- 255 wells of the regional archive (REGIONE AUTONOMA FRIULI-VENEZIA GIULIA, 1990), reaching the whole recognised aquifer levels (44 wells in Aquifer A, 32 in Aquifer B, 11 in Aquifer C, 40 in Aquifer D, 7 in Aquifer E, 53 in Aquifer F, 10 in Aquifer G, 59 in Aquifer H), analysed by OGS in 1989 within the regional geothermal anomalies surveys (OSSERVATORIO GEOFISICO SPERIMENTALE DI TRIESTE, 1989).

Table 2 displays the values, sometimes averaged on the available measurements for each water-well, of the main determined chemical-physical parameters (fig. 14).

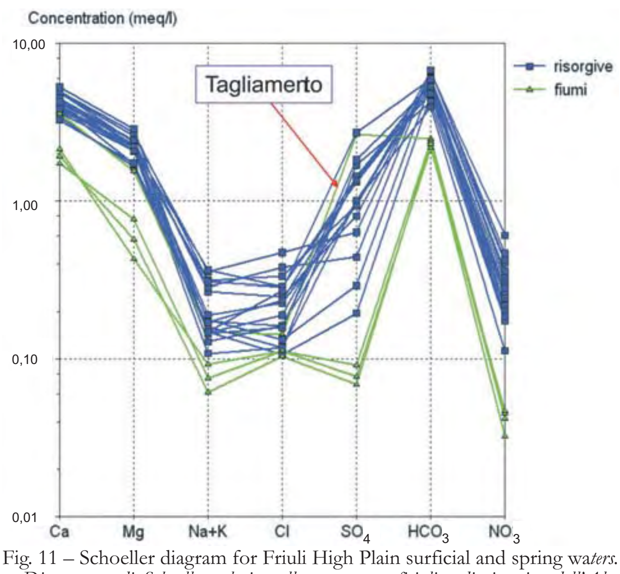

Fig. 11 – Schoeller diagram for Friuli High Plain surficial and spring waters.
– Diagramma di Schoeller relativo alle acque superficiali e di risorgiva dell'Alta Pianura friulana.

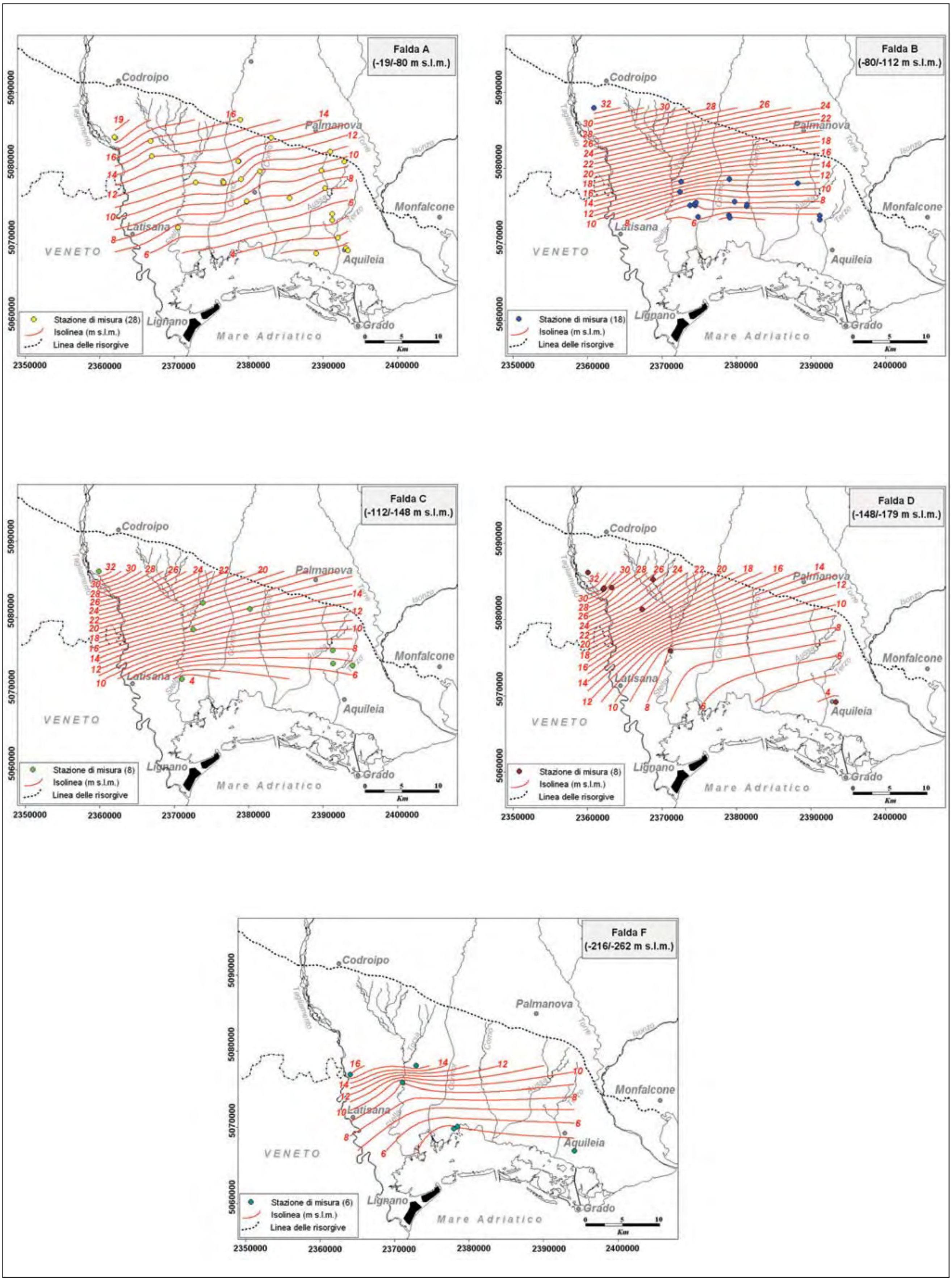

Fig. 12 – Aquifers A, B, C, D, F: hydraulic head contour lines (September-October 2003) (from MARTELLI & GRANATI, 2007a).
– Falde A, B, C, D, F: ricostruzioni piezometriche relative a misure effettuate nel periodo settembre-ottobre 2003 (da MARTELLI & GRANATI, *2007a).*

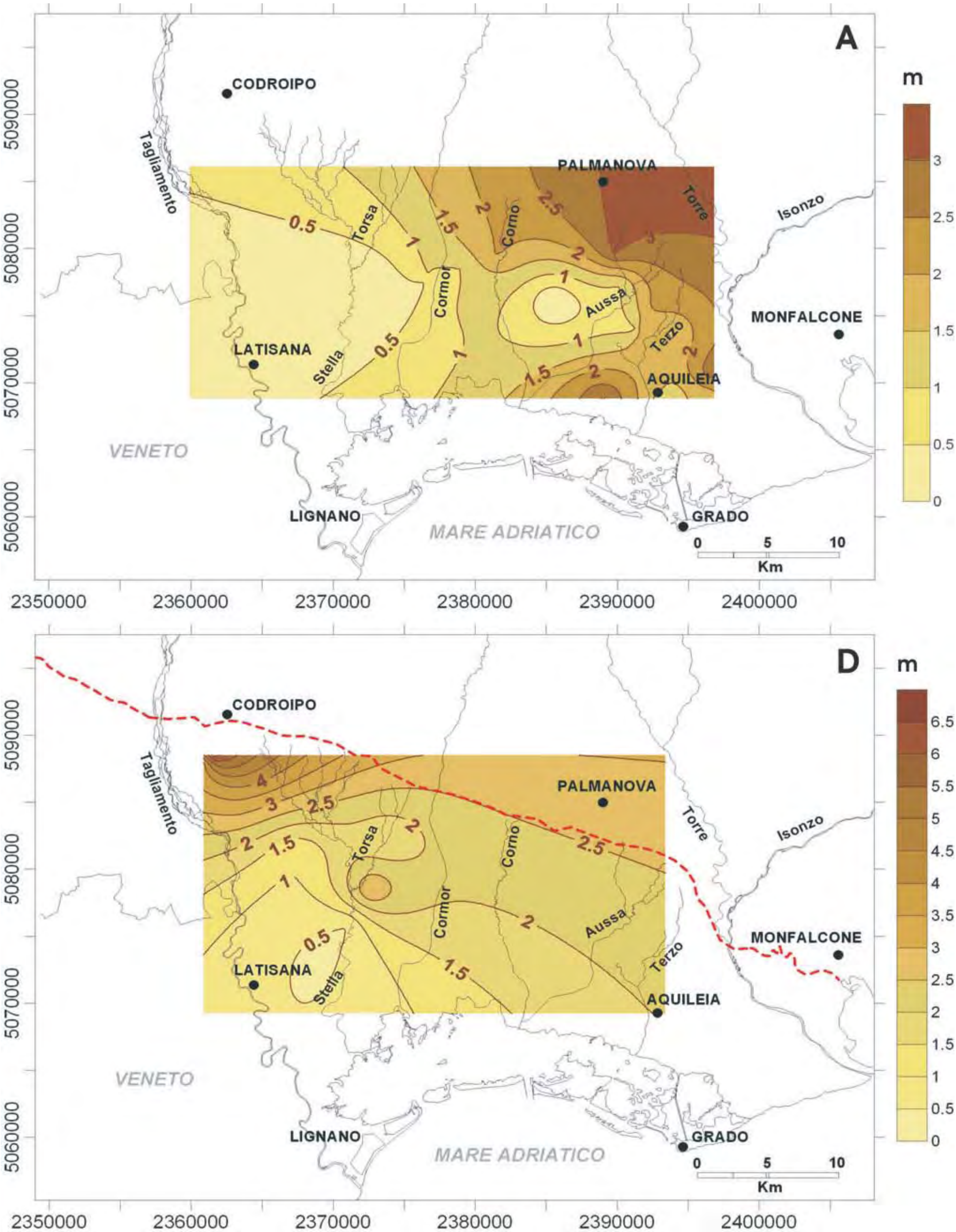

Fig. 13 – Annual averaged phreatimetric excursions (in m) of the Low Plain confined aquifers A,D.
– Mappe dell'escursione piezometrica media annua (in m) dei livelli acquiferi A e D della Bassa Pianura friulana.

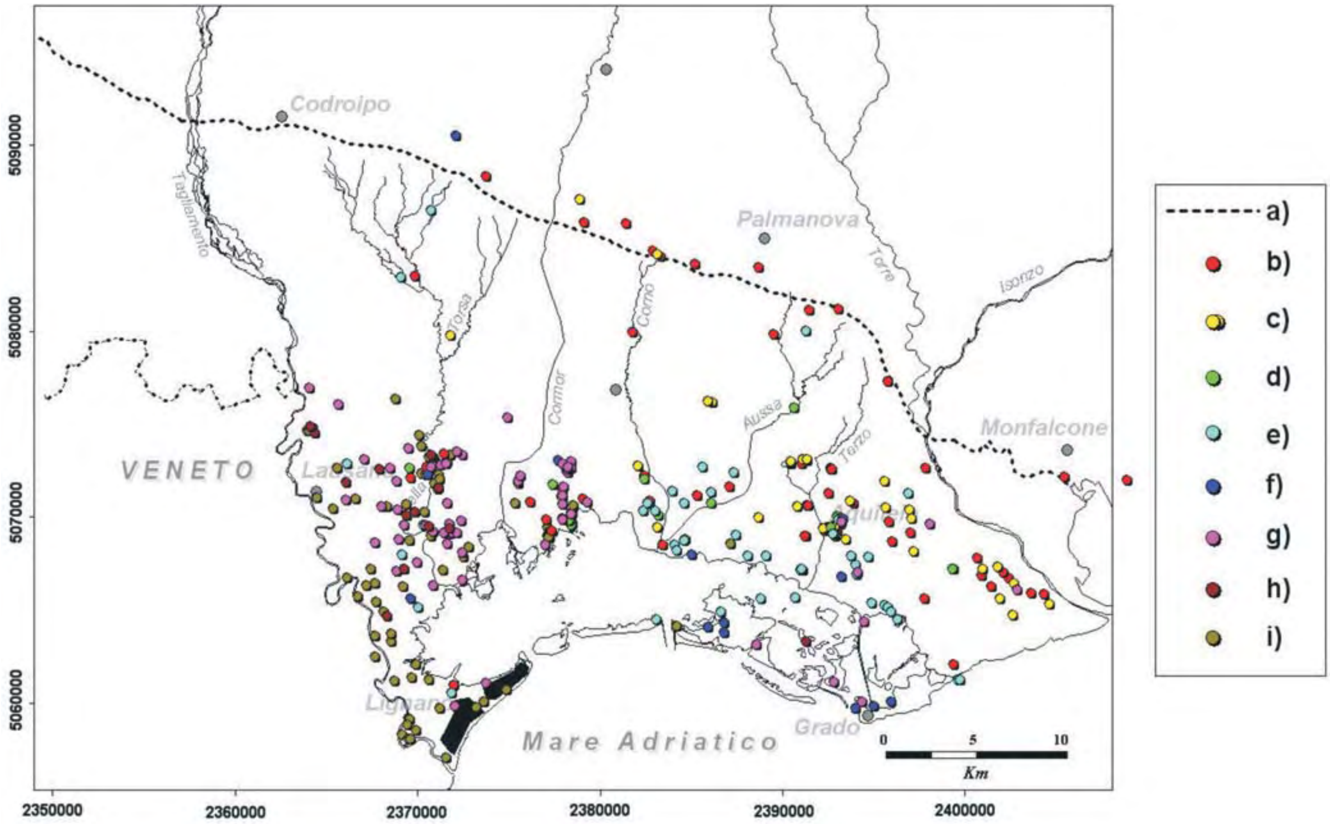

Fig. 14 – Hydrochemical sampling sites in the Low Friuli Plain. Legend: a) spring line; b) Aquifer A; c) Aquifer B; d) Aquifer C; e) Aquifer D; f) Aquifer E; g) Aquifer F; h) Aquifer G; i) Aquifer H.
– *Distribuzione dei punti di campionamento idrochimico negli acquiferi confinati della Bassa Pianura Friulana. Legenda: a) linea delle risorgive; b) Falda A; c) Falda B; d) Falda C; e) Falda D; f) Falda E; g) Falda F; h) Falda G; i) Falda H.*

The Ca-HCO_3 facies (figg. 15-16), that can be associated to a flow circulation totally developing within the Quaternary clastic carbonate sediments, marks groundwaters till 150 m bsl (Aquifers A, B, C). Groundwaters of the lower Aquifers D and E show transition characteristics towards the Na-HCO_3 facies, which becomes predominant in the deeper Aquifers F, G, H. Over 300 m bsl (Aquifer H), the Na-Cl facies can also be recognised (Martelli & Granati, 2009).

Within the most shallow Aquifers A, B, C, D (till 200 m bsl), the spatial distribution of sulphate content displays, although with a rather complex behaviour, a decreasing trend in the NW-SE direction according to the recharge origin (fig. 17); the highest concentrations can be distinguished between the Stella and the Aussa-Corno rivers. Topologically different sulphate distributions characterise groundwaters of the deeper Aquifers F, G, H (over 200 m bsl).

Analyzing the main chemical-physical data vs. depth (Martelli & Granati, 2009), a water temperature increase (fig. 18), according to a gradient of about 4°C/100 m higher than the conventional one, can be singled out.

The conductivity (fig. 19) displays an increasing trend under 300 m bsl, consistently with deep groundwater flow patterns characterised by long residence times (Martelli & Granati, 2008a) leading to high contents of dissolved salts of geochemical origin.

Calcium and magnesium solute concentrations (fig. 20) decrease in a similar way; the values related to water samples coming from aquifer levels between 200 and 400 m bsl are clearly scattered (Martelli & Granati, 2009).

The alkaline metals (sodium, potassium) dissolved contents also show a similar increase with depth (fig. 21), together with a remarkable scattering of concentration values within the deepest confined levels (Martelli & Granati, 2009).

Unlike the Cl^- ion (fig. 22), that undergoes an increasing concentration under 400 m bsl, and the HCO_3^- ion (fig. 23), that shows a clear spread of values, the sulphate amounts (fig. 24) are remarkably scattered till 300 m bsl, accor-

Tab. 2 – *Main physical-chemical parameters determined for sampled groundwaters of the Friuli Low Plain multi-layered aquifer system.*
– Valori dei principali parametri chimico-fisici rilevati in campioni idrici prelevati da pozzi attingenti ai livelli confinati del sistema acquifero multifalda della Bassa Pianura friulana.

ID	**Fonte**	**Quota filtri** (-m slm)	**Conduc** (µS/cm)	**pH**	**TDS** (mg/l)	**Ca^{2+}** (mg/l)	**Mg^{2+}** (mg/l)	**Na+** (mg/l)	**K+** (mg/l)	**Cl^{-}** (mg/l)	**HCO^{3-}** (mg/l)	**SO_4^{2-}** (mg/l)	**NO^{3-}** (mg/l)	**Sr^{-}** (mg/l)	**SiO^{2}** (mg/l)
Falda A															
463	ARPA	50,0	512	7,7		81,5	21,5	5,5	2,0	8,0	311,0	36,6	16,5		
608	ARPA	63,0	638	7,3		94,5	30,5	6,0	2,0	11,0	381,0	32,6	38,4		
609	ARPA	63,0	651	7,5		96,0	31,0	5,5	2,0	10,0	363,0	40,8	49,7		
614	ARPA	61,0	556	7,5		77,0	27,5	5,5	1,0	10,5	308,0	40,1	38,3		
618	ARPA	48,0	591	7,4		85,0	30,0	8,5	2,0	13,0	341,5	39,1	35,9		
619	ARPA	67,0	613	7,6		89,0	31,0	8,0	1,5	12,5	335,5	52,4	42,8		
620	ARPA	62,0	506	7,7		71,0	26,5	2,0	1,0	4,5	220,5	104,9	17,2		
1293	ARPA	70,0	469	7,4		79,5	17,0	3,5	1,5	5,5	296,0	12,4	23,2		
1295	ARPA	54,0	610	7,4		97,5	27,0	4,5	1,0	11,0	363,0	26,9	33,3		
1300	ARPA	40,0	463	7,6		67,0	24,5	2,5	1,0	6,0	271,5	19,9	23,1		
1303	ARPA	40,0	663	7,2		104,5	32,0	6,5	1,5	11,5	354,0	53,8	51,1		
1312	ARPA	37,0	480	7,6		68,5	26,5	3,0	1,0	4,0	293,0	28,6	15,3		
1316	ARPA	40,0	423	7,8		59,5	24,5	3,0	1,0	3,5	174,0	112,0	3,7		
1320	ARPA	40,0	546	7,8		79,0	28,0	10,0	2,0	15,0	317,0	26,0	24,0		
0050010	OGS	29,5	375			57,3	19,4	3,8	0,9	8,4	200,0	13,5		0,4	10,5
0050013	OGS	29,9	370			58,1	19,7	2,9	0,7	3,4	200,0	13,5		0,3	7,5
0050024	OGS	70,8	350			53,3	20,4	7,1	0,9	2,6	200,0	0,5		0,3	12,7
0050025	OGS	70,9	330			51,7	21,9	7,2	1,0	1,7	202,0	29,0		0,3	12,7
0050028	OGS	60,4	395			59,3	21,9	2,6	0,6	2,8	210,0	15,3		0,2	6,6
0050056	OGS	65,2	390			54,5	23,8	5,4	1,4	2,5	220,0	20,7		0,4	11,5
0050069	OGS	28,0	370			52,1	21,9	3,3	1,0	2,7	214,0	19,8		0,3	11,2
0280012	OGS	78,8	440			64,1	20,9	6,8	1,1	2,6	240,0	38,4		0,4	15,9
0280030	OGS	79,5	370			32,0	8,0	43,0	1,4	1,7	228,0	0,5		0,1	17,8
0280036	OGS	77,5	375			53,7	23,3	7,9	1,1	1,3	198,0	48,6		0,4	17,3
0280061	OGS	59,7	375			41,7	17,5	20,0	1,5	0,7	230,0	0,4		0,3	16,6
0650012	OGS	59,0	360			56,9	17,7	1,9	0,7	4,7	206,0	11,9		0,1	5,2
0650014	OGS	27,7	395			62,5	19,9	2,9	0,5	2,3	230,0	24,7		0,2	8,1
0650017	OGS	62,5	360			57,3	15,6	4,8	0,9	1,9	214,0	15,7		0,4	12,1
0650023	OGS	16,9	450			82,6	15,6	2,8	1,2	5,5	248,0	19,3		0,2	3,7
0780007	OGS	72,2	390			43,7	21,1	7,2	4,1	3,4	224,0	0,8		0,2	13,8
0780013	OGS	64,7	370			45,7	22,1	4,6	1,7	3,1	218,0	15,3		0,2	8,3
0780014	OGS	54,3	400			52,1	19,2	10,0	1,9	1,5	250,0	3,1		0,2	13,3
0780015	OGS	50,2	370			48,1	20,9	4,8	1,7	2,7	215,0	16,0		0,2	7,4
0780019	OGS	72,0	360			50,1	18,5	2,9	0,7	5,7	192,0	11,7		0,2	7,7
0780021	OGS	67,0	365			44,1	20,7	8,4	2,1	2,3	217,0	6,3		0,2	11,6
0780026	OGS	72,2	400			49,7	19,7	10,8	2,3	2,1	243,0	0,5		0,2	16,7
0780043	OGS	76,1	415			57,7	19,0	8,4	1,3	2,3	212,0	22,1		0,3	15,0
0780069	OGS	68,5	425			50,1	20,7	7,8	2,1	3,3	216,0	11,9		0,2	7,4
0830045	OGS	26,2	565			25,3	13,4	61,0	5,6	26,8	316,0	0,5		0,3	10,4
0910010	OGS	78,6	500			75,8	23,6	2,5	0,6	5,3	174,0	115,0		0,7	3,3
0910027	OGS	73,5	455			42,9	18,7	35,0	3,6	0,9	250,0	1,0		0,3	15,4
0990041	OGS	24,6	375			52,1	12,1	14,8	0,8	22,1	163,0	14,0		0,2	3,8
0990054	OGS	37,7	430			76,1	13,8	3,3	1,7	5,0	235,0	16,2		0,1	3,0
1140013	OGS	66,2	390			47,7	21,6	8,4	0,9	1,0	190,0	54,7		0,3	13,9
1340010	OGS	42,3	445			50,9	19,7	20,8	1,7	1,8	276,0	1,0		0,3	17,0
1340016	OGS	50,8	380			47,7	16,5	13,6	1,2	0,4	198,0	30,6		0,3	14,6
1610039	OGS	74,5	435			48,5	21,1	7,4	1,7	1,2	202,0	33,8		0,3	14,8
1610050	OGS	76,8	505			60,1	27,2	4,7	0,9	6,2	214,0	59,9		0,4	13,2
1920002	OGS	79,8	405			45,3	18,2	12,0	1,7	0,3	216,0	7,9		0,3	16,8
1920022	OGS	28,0	400			66,1	20,2	2,2	0,7	4,0	222,0	14,8		0,1	4,9
1920023	OGS	30,0	400			65,7	20,7	2,3	0,7	4,3	215,0	14,4		0,1	4,6
1920024	OGS	30,5	395			68,1	18,0	2,2	0,7	4,3	220,0	15,9		0,1	4,5
1920025	OGS	27,5	390			64,1	19,9	2,2	0,7	4,1	216,0	13,0		0,1	4,9
1920043	OGS	63,0	405			65,7	20,4	2,4	0,6	3,2	226,0	13,5		0,2	7,3
1920045	OGS	60,6	360			52,9	21,9	2,9	0,6	2,4	200,0	13,5		0,4	9,4
1920046	OGS	63,6	365			54,9	20,9	2,9	0,6	2,8	200,0	23,0		0,4	9,4
1950032	OGS	49,6	370			52,1	20,9	4,8	0,8	0,6	192,0	44,5		0,4	11,7
1950048	OGS	56,8	380			56,5	20,2	4,6	0,9	2,3	214,0	34,9		0,4	13,8

next page

Falda B															
637	ARPA	85,0	664	7,2		99,0	42,0	6,0	1,0	11,0	439,0	65,2	0,3		
1304	ARPA	90,0	544	7,5		81,0	29,5	6,5	1,0	10,0	311,0	36,2	31,6		
1310	ARPA	90,0	371	7,8		50,5	23,5	5,5	1,0	1,0	204,0	66,0	0,8		
1325	ARPA	86,0	505	7,4		72,0	27,0	7,0	1,0	13,0	299,0	31,3	26,9		
1328	ARPA	93,0	470	7,4		70,5	25,5	3,5	1,0	4,0	242,0	70,3	12,7		
0050030	OGS	99,0	365			53,7	21,4	2,8	0,6	3,0	196,0	19,8		0,2	7,2
0050036	OGS	98,0	380			58,9	21,6	3,5	1,0	6,7	201,0	13,5		0,2	5,7
0050054	OGS	109,0	370			56,1	19,9	2,6	0,6	3,3	204,0	16,2		0,3	7,8
0050058	OGS	100,0	375			55,7	21,6	3,6	0,8	5,2	198,0	13,1		0,4	10,0
0050059	OGS	99,2	385			54,5	22,4	3,6	0,8	5,5	210,0	31,9		0,4	9,9
0050060	OGS	100,0	325			50,9	22,6	4,0	0,8	2,7	215,0	12,0		0,4	11,5
0050061	OGS	99,0	375			60,5	22,8	4,4	1,1	2,0	228,0	29,0		0,3	9,4
0050062	OGS	89,0	355			50,5	21,9	3,8	0,7	3,0	200,0	23,4		0,4	11,0
0280037	OGS	83,2	370			54,5	20,2	8,6	1,2	1,6	200,0	47,0		0,3	17,3
0280060	OGS	89,0	370			34,5	13,1	30,8	1,4	1,6	228,0	0,9		0,2	16,9
0650006	OGS	96,6	385			56,1	21,4	3,2	0,7	2,6	214,0	36,7		0,3	7,3
0650008	OGS	99,7	380			56,1	20,9	2,4	0,6	3,4	218,0	18,9		0,2	7,3
0650020	OGS	97,7	365			50,1	20,4	5,4	0,8	1,9	216,0	21,8		0,4	11,4
0650022	OGS	98,0	370			59,3	17,5	1,7	0,8	3,5	208,0	12,2		0,2	4,4
0650026	OGS	95,9	400			62,9	19,9	2,8	0,8	7,1	209,0	14,4		0,2	5,8
0650030	OGS	100,4	345			46,1	19,2	4,1	0,8	3,7	191,0	8,6		0,2	10,4
0780003	OGS	100,0	365			44,1	19,9	8,0	1,5	2,4	212,0	3,2		0,2	13,7
0780010	OGS	99,9	350			48,5	17,3	5,6	1,1	1,5	208,0	9,9		0,2	10,8
0780012	OGS	100,5	360			48,9	18,7	6,2	1,2	1,3	214,0	7,6		0,2	12,0
0780016	OGS	95,3	370			46,1	21,9	5,0	1,7	2,2	210,0	14,6		0,2	10,4
0780018	OGS	95,6	360			49,7	19,7	2,9	0,7	5,1	193,0	11,7		0,2	7,7
0780027	OGS	90,9	400			50,1	19,7	10,4	2,2	3,7	240,0	0,9		0,2	17,9
1610003	OGS	92,7	535			60,1	30,6	4,2	1,0	7,4	236,0	46,6		0,5	9,1
1610042	OGS	99,2	405			46,9	20,2	6,3	0,9	1,3	164,0	54,9		0,4	12,8
1920014	OGS	89,8	365			36,1	28,7	4,6	0,9	0,8	200,0	35,3		0,3	16,5
1920026	OGS	102,6	350			52,1	20,9	2,5	0,5	2,7	190,0	13,5		0,2	6,7
1920027	OGS	103,6	350			53,7	19,7	2,8	0,6	2,8	200,0	13,5		0,2	7,4
1920029	OGS	83,6	350			52,5	21,6	2,5	0,8	3,0	197,0	13,5		0,2	6,7
1920032	OGS	97,6	400			62,1	22,9	2,4	0,6	4,1	218,0	13,7		0,1	6,8
1920033	OGS	87,8	390			60,5	22,8	2,6	0,5	3,3	222,0	16,7		0,2	7,3
1920042	OGS	95,8	390			54,5	25,0	2,3	0,5	3,7	218,0	13,5		0,1	6,4
1920047	OGS	109,8	350			52,9	21,1	3,0	0,6	2,5	202,0	13,5		0,3	9,2
Falda C															
1299	ARPA	141,0	477	7,5		70,0	24,5	3,0	1,0	6,0	289,5	16,1	21,9		
0050027	OGS	126,5	345			50,9	20,7	6,6	1,2	1,6	207,0	15,0		0,3	13,2
0050044	OGS	126,8	365			52,1	21,9	3,1	0,6	2,5	200,0	16,7		0,2	6,2
0050063	OGS	118,0	395			56,1	24,3	2,7	0,6	3,1	214,0	14,9		0,3	9,1
0280029	OGS	133,8	325			42,5	17,5	15,6	1,4	1,0	217,0	11,0		0,3	17,8
0650018	OGS	148,7	345			46,1	20,2	5,2	0,8	3,0	154,0	7,4		0,2	10,9
0910013	OGS	140,4	375			29,3	12,4	38,0	1,4	0,7	234,0	0,8		0,2	16,7
0910016	OGS	141,5	400			40,1	16,0	28,4	2,4	2,3	244,0	2,2		0,3	13,7
1340014	OGS	147,6	355			38,9	16,5	17,2	1,3	1,0	212,0	9,2		0,2	15,1
1610038	OGS	127,0	555			64,1	30,1	4,6	1,0	10,3	232,0	58,0		0,5	12,0
1610044	OGS	126,6	405			46,5	20,4	6,4	0,9	0,8	164,0	55,6		0,4	12,0
1950046	OGS	122,7	350			47,7	17,5	11,4	1,2	2,6	200,0	21,0		0,4	16,9
Falda D															
1294	ARPA	169,0	433	7,6		60,5	24,5	3,5	1,0	5,5	253,0	26,7	14,2		
1317	ARPA	152,0	410	7,8		55,5	25,0	2,0	1,0	2,0	155,5	114,0	2,1		
1330	ARPA	170,0	390	7,8		54,0	22,5	2,0	0,5	7,0	174,0	93,0	2,1		
29	DGT	179,0	509	8,5	305	15,6	5,9	81,1	5,0	4,8	292,8	0,1	0,0		
0050003	OGS	162,0	335			49,7	22,1	8,8	1,4	2,6	225,0	20,0		0,3	15,8
0050004	OGS	170,7	385			48,9	25,3	4,7	1,2	3,1	206,0	27,0		0,4	12,0
0050005	OGS	163,7	380			53,3	22,4	4,7	1,2	3,7	210,0	28,3		0,4	11,9
0050006	OGS	170,0	385			52,9	23,1	4,7	1,2	3,8	208,0	28,3		0,4	11,9
0050009	OGS	170,0	380			52,9	20,9	10,3	1,3	3,1	222,0	17,1		0,4	13,3
0050016	OGS	169,1	340			47,7	18,0	10,7	1,9	1,8	205,0	11,0		0,3	16,0
0050018	OGS	171,1	365			32,0	11,2	44,4	3,4	2,7	220,0	9,0		0,2	15,0
0050019	OGS	171,1	445			48,1	19,4	13,6	1,8	4,7	212,0	22,7		0,3	15,8
0050020	OGS	171,1	440			44,1	22,9	10,0	1,2	3,3	182,0	48,4		0,3	11,8
0050038	OGS	155,5	340			52,1	21,9	3,0	0,6	3,0	190,0	16,0		0,1	8,9
0050043	OGS	151,5	395			58,1	22,1	3,7	0,8	7,4	212,0	21,6		0,3	7,5
0050046	OGS	176,3	410			55,3	19,4	15,3	2,0	9,9	212,0	33,3		0,4	13,6
0050047	OGS	170,2	340			55,7	15,3	2,2	0,8	3,7	180,0	12,6		0,1	5,7
0050050	OGS	168,0	400			62,1	20,7	2,9	0,8	5,9	207,0	14,6		0,2	5,7
0050052	OGS	149,4	370			56,9	16,5	3,3	0,6	4,7	210,0	8,8		0,4	12,6
0050065	OGS	159,5	380			56,5	21,6	3,2	0,7	2,8	210,0	15,7		0,4	10,0
0650005	OGS	160,5	385			56,9	20,7	3,2	0,6	3,4	212,0	27,0		0,3	7,3

next page

0780039	OGS	169,9	540			27,6	15,1	66,0	8,9	30,0	283,0	3,1		0,2	14,5
0780047	OGS	171,3	450			32,5	13,9	44,0	4,3	12,0	224,0	11,0		0,2	18,3
0780048	OGS	165,6	590			28,8	11,2	80,0	6,4	43,0	245,0	11,7		0,2	14,6
0780071	OGS	167,5	410			45,7	18,5	11,2	1,2	0,9	174,0	46,8		0,3	16,2
0780080	OGS	167,7	525			28,8	14,3	66,0	9,1	29,0	287,0	2,7		0,2	14,6
0800011	OGS	178,2	340			38,5	17,3	15,4	1,2	1,6	194,0	16,0		0,3	14,9
0830017	OGS	179,0	615			18,0	10,2	86,0	4,4	7,4	388,0	0,5		0,2	17,7
0910024	OGS	164,0	420			41,7	20,4	12,8	1,4	1,1	176,0	46,8		0,3	16,8
1140043	OGS	178,4	350			36,1	14,1	22,4	1,4	1,9	214,0	1,8		0,2	16,0
1340041	OGS	159,9	365			37,3	13,9	30,4	2,0	1,3	238,0	1,4		0,2	16,6
1340048	OGS	149,9	430			41,7	18,2	33,2	3,5	2,1	284,0	1,1		0,2	14,3
1610045	OGS	167,3	405			47,7	19,7	6,6	0,9	0,8	158,0	56,2		0,4	12,6
1610046	OGS	164,1	405			46,5	20,4	6,6	0,9	0,8	170,0	54,7		0,3	10,4
1610048	OGS	164,0	505			61,7	26,3	4,8	0,9	6,5	208,0	58,9		0,4	12,6
1920001	OGS	168,2	410			45,3	20,2	6,6	0,9	1,7	160,0	56,0		0,4	13,9
1920015	OGS	169,1	415			47,3	19,9	6,8	0,9	1,3	160,0	59,6		0,3	13,0
1920018	OGS	179,0	415			46,5	19,9	6,4	0,9	1,3	158,0	59,6		0,4	12,9
1920055	OGS	158,8	365			46,5	22,4	4,1	0,8	1,4	204,0	28,1		0,4	13,6
1950028	OGS	155,7	385			56,1	19,9	4,3	0,8	3,7	196,0	47,3		0,4	12,4
1950030	OGS	153,7	350			49,7	19,9	3,5	0,7	2,4	172,0	49,8		0,5	10,4
1950031	OGS	164,1	345			47,3	20,4	3,9	0,7	1,7	168,0	50,6		0,4	11,1
1950045	OGS	161,8	365			50,5	21,9	3,2	0,6	2,4	200,0	26,1		0,4	10,8
1950049	OGS	159,7	355			71,7	19,7	5,4	0,9	2,0	198,0	28,1		0,4	11,3
Falda E															
10	DGT	215,0	384	7,2	293	41,7	20,1	5,7	1,4	4,7	234,2	15,5	0,0		
25	DGT	198,0	392	6,8	270	41,3	20,9	10,7	1,1	1,1	219,4	34,7	0,0		
27	DGT	202,0	318	8,6	258	44,7	21,8	2,8	0,6	1,4	158,5	75,7	1,9		
33	DGT	215,0	428	7,5	289	25,9	11,8	57,2	8,2	15,5	232,4	3,8	50,8		
34	DGT	213,0	434	7,4	297	23,6	11,1	61,2	8,9	26,1	235,5	3,8	0,2		
36	DGT	216,0	243	6,9	204	37,5	13,1	6,6	0,7	11,4	163,9	8,8	6,1		
0050039	OGS	195,0	345			54,1	20,9	3,3	0,6	2,6	198,0	17,0		0,1	8,9
0280028	OGS	185,2	385			56,5	23,3	8,3	1,0	1,4	198,0	63,9		0,3	17,4
0780072	OGS	187,0	425			42,9	18,2	20,4	4,6	2,4	214,0	17,6		0,3	15,6
0780073	OGS	188,3	685			16,8	6,6	129,0	6,5	34,8	264,0	1,4		0,1	13,1
0780074	OGS	188,9	410			44,9	17,3	16,4	1,7	0,7	180,0	43,8		0,3	16,9
1340008	OGS	209,2	360			36,1	13,9	30,0	1,9	0,8	134,0	0,7		0,2	16,5
1920016	OGS	200,9	415			44,5	21,1	8,0	1,1	0,7	170,0	51,1		0,3	13,9
Falda F															
2	DGT	218,0	371	8,2	269	32,2	16,6	18,8	2,5	3,4	213,7	16,1	0,6		
9	DGT	220,0	379	7,4	284	46,1	21,3	5,8	0,7	1,1	204,4	50,3	0,0		
14	DGT	238,0	370	8,6	258	25,7	12,9	37,8	1,2	1,2	248,3	0,1	0,1		
26	DGT	233,0	368	8,0	265	36,8	21,2	11,5	0,9	1,3	200,4	42,7	0,9		
31	DGT	220,0	449	9,4	300	22,9	11,1	63,6	5,9	7,5	288,5	0,2	0,0		
35	DGT	218,0	422	7,5	289	26,5	12,5	51,1	7,5	13,7	248,9	3,3	2,8		
0050017	OGS	218,0	360			51,7	22,4	7,6	1,7	2,5	212,0	24,0		0,3	16,8
0050040	OGS	236,0	340			20,8	8,0	70,0	3,8	4,5	215,0	0,9		0,1	14,7
0280010	OGS	257,2	325			32,8	13,4	26,0	1,3	0,8	210,0	0,9		0,2	18,5
0280013	OGS	230,0	370			36,9	11,7	28,8	1,3	1,3	220,0	0,5		0,2	17,4
0280018	OGS	227,2	300			32,5	14,1	31,0	1,3	1,5	200,0	2,2		0,2	17,9
0280019	OGS	233,0	325			33,7	14,8	29,4	1,3	1,1	210,0	0,5		0,2	20,6
0280021	OGS	237,4	399			57,7	24,8	6,8	1,0	1,6	205,0	49,5		0,4	17,9
0280022	OGS	237,4	315			31,7	15,1	30,0	1,2	0,9	210,0	0,7		0,2	20,1
0280023	OGS	238,1	320			32,1	14,8	31,0	1,3	1,0	210,0	1,8		0,2	19,8
0280024	OGS	258,3	310			32,9	14,1	30,0	1,3	1,0	208,0	5,0		0,2	19,9
0280025	OGS	232,0	315			34,5	14,6	30,0	1,2	0,8	210,0	3,1		0,2	19,9
0280031	OGS	258,7	370			38,5	10,7	32,5	1,5	0,7	222,0	0,5		0,2	17,0
0280032	OGS	218,1	370			32,1	13,9	33,0	1,4	2,1	226,0	0,5		0,2	16,1
0280034	OGS	237,6	325			31,2	14,6	32,0	1,3	0,7	212,0	0,9		0,2	20,1
0280038	OGS	238,8	325			31,3	15,1	34,5	1,3	1,4	223,0	0,7		0,2	20,3
0280039	OGS	239,4	370			34,5	11,4	35,5	1,3	0,8	228,0	0,5		0,2	16,9
0280040	OGS	238,5	370			32,1	11,7	35,0	1,3	1,3	232,0	0,5		0,2	16,9
0780009	OGS	219,0	370			48,9	19,0	6,2	1,2	2,0	216,0	7,6		0,2	12,4
0780044	OGS	234,3	462			19,6	8,5	80,0	3,7	1,1	266,0	2,0		0,1	17,9
0800046	OGS	246,0	350			30,9	12,6	34,0	1,1	1,9	222,0	0,7		0,2	16,3
0800048	OGS	259,3	370			26,9	10,5	33,6	1,4	0,6	236,0	0,7		0,2	17,3
0830020	OGS	219,3	540			26,9	10,7	66,0	4,7	3,0	342,0	0,5		0,3	15,3

next page

0830030	OGS	249,1	470			75,4	22,4	2,0	0,6	3,7	166,0	115,0		0,8	3,9
0910011	OGS	239,4	375			29,3	12,2	40,0	1,4	1,8	234,0	0,7		0,2	15,6
1140002	OGS	247,0	360			32,5	15,3	27,2	1,4	0,6	220,0	0,8		0,2	16,7
1140004	OGS	246,2	360			35,3	14,1	26,8	1,4	1,1	218,0	0,5		0,2	16,3
1140034	OGS	259,4	345			24,2	11,2	55,0	1,6	1,1	237,0	1,0		0,1	18,0
1140037	OGS	249,5	375			26,5	9,5	47,0	1,4	0,7	234,0	0,5		0,1	17,3
1140038	OGS	240,3	365			28,5	12,4	37,6	1,3	0,4	238,0	0,8		0,2	15,8
1140039	OGS	240,8	360			28,1	12,9	36,0	1,4	0,8	234,0	0,9		0,2	15,8
1140040	OGS	247,5	435			43,3	19,2	26,5	2,7	0,9	272,0	0,7		0,3	15,4
1140046	OGS	244,6	370			28,3	10,9	38,5	1,3	0,9	230,0	1,1		0,1	17,2
1140047	OGS	243,0	350			35,7	14,8	21,2	1,4	0,3	212,0	1,1		0,2	15,6
1140048	OGS	240,1	430			43,7	18,5	26,5	2,4	0,4	270,0	0,9		0,3	15,7
1140050	OGS	242,7	355			29,3	13,4	31,2	1,3	1,0	224,0	0,5		0,2	14,3
1140052	OGS	240,0	355			29,3	13,6	31,0	1,2	1,0	220,0	0,9		0,2	16,6
1140053	OGS	238,8	355			31,7	14,3	28,5	1,1	1,1	222,0	0,6		0,2	16,9
1140058	OGS	260,0	325			28,8	13,6	38,0	1,3	1,0	218,0	1,0		0,2	18,1
1140060	OGS	247,6	380			32,9	12,2	35,0	1,4	1,5	240,0	0,9		0,2	17,3
1340001	OGS	258,3	360			21,8	11,2	66,0	1,8	0,9	240,0	1,0		0,1	15,2
1340003	OGS	258,0	365			26,9	10,7	48,0	1,4	0,6	232,0	1,6		0,1	17,3
1340005	OGS	258,2	345			28,5	12,9	40,4	1,5	0,7	230,0	1,6		0,2	17,4
1340011	OGS	237,3	370			29,7	11,7	39,0	1,3	0,9	228,0	1,0		0,2	16,8
1340013	OGS	257,3	350			37,7	15,3	20,0	1,1	1,0	202,0	8,1		0,2	16,5
1340022	OGS	260,0	370			32,1	14,1	32,5	1,3	0,9	230,0	0,8		0,2	16,7
1340026	OGS	255,8	305			31,4	14,0	29,0	1,2	0,9	208,0	1,0		0,2	17,7
1340027	OGS	260,5	330			40,1	15,8	17,4	1,1	1,4	196,0	17,7		0,2	15,6
1340032	OGS	252,0	360			26,5	10,2	48,0	1,5	2,0	240,0	1,5		0,1	16,6
1340039	OGS	258,4	345			44,1	14,3	17,8	1,2	2,0	198,0	29,5		0,2	18,9
1340045	OGS	239,2	370			25,7	10,0	48,4	1,5	0,4	244,0	1,4		0,1	16,5
1340049	OGS	255,0	370			26,1	10,9	50,5	1,6	1,0	246,0	1,4		0,1	16,7
1510019	OGS	251,2	300			37,7	16,5	19,0	1,0	0,9	192,0	11,0		0,2	18,8
1560011	OGS	219,2	355			52,9	19,9	3,0	0,6	2,5	206,0	21,1		0,2	6,8
Falda G															
4	DGT	267,0	460	8,1	283	23,7	12,6	38,0	1,7	3,7	245,2	0,3	0,0		
6	DGT	263,0	467	7,2	342	63,3	20,5	3,5	0,6	4,9	168,9	111,5	7,7		
23	DGT	269,0	413	7,0	288	24,3	11,7	59,7	1,9	1,4	310,1	0,7	0,1		
30	DGT	269,0	517	6,9	369	25,4	12,3	79,2	5,5	30,7	297,7	4,1	1,6		
0800038	OGS	266,3	325			39,3	15,3	16,0	1,1	1,2	200,0	15,3		0,2	16,8
1140045	OGS	266,7	340			24,7	11,2	51,0	1,4	1,3	225,0	1,0		0,1	18,6
1140049	OGS	269,8	355			30,5	13,4	30,5	1,2	1,8	212,0	0,9		0,2	16,4
1140055	OGS	267,8	300			30,9	13,8	30,0	1,3	1,0	207,0	1,0		0,1	17,5
1340012	OGS	262,7	350			36,9	16,0	18,0	1,1	0,7	204,0	12,1		0,2	16,4
1340024	OGS	267,4	380			31,7	13,6	36,0	1,3	1,3	234,0	0,8		0,2	17,2
1340025	OGS	268,5	430			54,9	18,7	14,8	1,4	0,9	262,0	0,8		0,3	17,4
1340033	OGS	267,3	320			35,7	15,1	21,2	1,3	1,3	208,0	10,3		0,2	15,3
1340034	OGS	262,8	325			36,1	14,6	21,2	1,3	1,4	206,0	10,1		0,2	14,9
1340050	OGS	269,4	365			24,2	10,4	62,0	1,8	0,9	250,0	1,0		0,1	16,3
Falda H															
1	DGT	325,0	370	8,4	256	22,0	10,3	36,1	1,5	1,6	218,9	5,6	0,5		
3	DGT	500,0	556	8,4	339	23,9	13,2	39,1	1,7	3,4	254,3	0,1	0,0		
5	DGT	492,0	510	8,8	334	24,2	13,3	38,3	1,7	3,8	247,3	0,1	0,0		
7	DGT	281,0	370	7,1	243	38,8	18,5	9,8	0,8	1,6	211,5	24,7	0,0		
8	DGT	494,0	557	8,6	351	25,3	13,0	38,5	1,7	3,6	255,6	0,1	0,8		
11	DGT	362,0	493	7,9	359	42,3	21,0	5,6	0,7	1,0	188,8	53,9	0,0		
12	DGT	346,0	436	8,3	286	25,6	15,8	15,3	1,0	1,6	207,6	0,2	0,8		
13	DGT	298,0	353	8,2	247	26,7	13,5	29,4	1,4	3,5	234,1	0,1	0,0		
15	DGT	359,0	401	8,2	266	22,3	10,1	45,6	1,3	1,6	252,6	0,0	0,7		
16	DGT	358,0	366	8,4	254	23,0	10,4	45,7	1,4	1,2	250,8	0,3	0,1		
17	DGT	359,0	353	7,3	240	25,0	12,7	33,1	1,7	2,4	237,5	0,0	0,0		
18	DGT	359,0	419	7,9	270	24,1	12,4	49,7	2,4	9,3	263,4	0,3	0,0		
19	DGT	359,0	404	6,7	271	25,9	12,8	33,3	1,6	2,5	240,4	0,2	1,2		
20	DGT	507,0	2538	8,7	1292	6,3	4,3	380,7	17,5	346,4	490,1	0,7	6,6		

next page

21	DGT	495,0	1289	9,0	740	6,7	2,7	200,8	20,8	145,5	358,5	0,0	1,0		
22	DGT	575,0	2094	8,3	1138	10,7	5,5	304,2	13,4	265,3	473,4	0,2	2,8		
24	DGT	524,0	663	8,6	404	15,3	8,1	111,8	4,9	11,5	325,8	0,1	0,9		
28	DGT	414,0	389	8,1	250	24,7	11,9	40,7	1,8	2,2	236,1	0,4	0,0		
32	DGT	598,0	9420	7,4	4819	82,1	48,5	1326,8	63,4	2233,4	272,3	92,0	20,9		
0280011	OGS	436,0	280			28,9	13,4	21,0	1,4	1,2	182,0	0,9		0,1	21,3
0280042	OGS	351,6	340			31,7	11,9	27,5	1,7	1,6	210,0	0,7		0,1	16,0
0280059	OGS	308,5	365			36,9	13,9	28,0	1,4	0,8	228,0	0,7		0,2	17,2
0780070	OGS	281,3	425			27,6	11,7	5,1	2,5	1,8	224,0	12,6		0,2	15,1
0800004	OGS	604,6	4475			40,9	22,6	813,0	51,0	1451,0	480,0	6,4		0,4	26,4
0800009	OGS	429,6	770			19,2	9,2	138,0	6,8	44,2	426,0	0,5		0,1	16,1
0800012	OGS	457,0	600			14,4	7,3	108,0	5,0	18,0	370,0	0,5		0,1	16,1
0800021	OGS	523,1	555			19,2	7,5	86,0	4,4	14,6	336,0	0,5		0,1	14,6
0800024	OGS	488,3	695			15,6	7,5	135,0	6,3	24,8	402,0	0,5		0,1	16,5
0800025	OGS	279,6	415			24,8	10,9	59,5	2,1	1,3	270,0	1,1		0,1	17,5
0800026	OGS	574,7	1540			7,6	4,3	360,0	20,0	326,0	478,0	4,5		0,0	23,1
0800028	OGS	451,8	430			22,0	7,3	64,0	3,6	12,4	260,0	0,5		0,1	15,4
0800031	OGS	467,1	400			28,1	10,2	50,0	2,7	4,3	266,0	0,7		0,1	18,0
0800039	OGS	445,9	640			20,4	8,5	114,0	5,3	24,2	374,0	1,8		0,1	17,5
0800040	OGS	473,2	760			12,0	5,3	143,0	8,7	29,3	450,0	0,5		0,0	18,1
0800043	OGS	450,0	690			14,0	5,1	143,0	7,5	29,9	394,0	1,1		0,0	17,1
0800050	OGS	495,5	1040			6,4	2,4	144,0	16,9	143,0	428,0	0,9		0,1	21,5
0800052	OGS	366,3	390			27,7	9,7	48,0	1,7	1,6	252,0	0,7		0,1	16,9
0800059	OGS	495,5	985			6,8	2,7	130,0	15,4	152,0	360,0	1,4		0,1	19,1
0800063	OGS	299,4	710			20,0	6,8	130,0	5,0	8,9	456,0	1,3		0,1	19,6
0800064	OGS	499,0	780			12,4	2,7	155,0	8,5	19,2	476,0	0,9		0,0	18,3
0800065	OGS	565,0	990			5,9	3,0	260,0	13,4	97,0	538,0	1,0		0,0	21,0
0830001	OGS	416,4	735			4,0	1,0	122,0	14,0	26,8	424,0	0,9		0,0	20,2
0830003	OGS	414,6	695			4,4	1,5	98,0	16,3	36,5	382,0	0,9		0,0	19,1
0830007	OGS	568,0	44200			230,0	1430,0	6400,0	424,0	19785,0	154,0	2745,0		7,4	0,1
0830008	OGS	499,2	3900			60,1	12,6	413,0	55,5	1239,0	240,0	5,4		0,8	19,6
0830009	OGS	486,4	970			7,2	2,7	138,0	12,4	143,0	372,0	0,5		0,1	16,0
0830016	OGS	498,0	860			5,6	2,9	118,0	14,6	68,5	412,0	0,7		0,0	13,8
0830019	OGS	395,5	845			5,2	2,2	126,0	14,4	71,1	408,0	0,9		0,0	14,0
0830023	OGS	558,4	435			32,1	12,2	32,8	4,0	1,6	274,0	0,9		0,3	15,5
0830037	OGS	532,4	900			6,4	2,7	114,0	21,5	123,5	340,0	0,4		0,1	19,3
0830038	OGS	498,9	700			4,0	1,9	100,0	17,0	35,3	384,0	2,9		0,0	19,8
0830047	OGS	459,0	645			4,8	1,9	94,0	14,0	8,8	404,0	0,6		0,0	14,0
0830048	OGS	475,3	945			3,6	1,5	140,0	16,5	97,1	426,0	0,6		0,0	20,4
0910005	OGS	357,8	365			28,5	13,4	34,5	1,9	3,7	216,0	0,4		0,1	17,9
0910006	OGS	357,9	365			30,1	12,6	33,0	1,9	3,7	216,0	0,4		0,1	17,8
0910007	OGS	357,7	360			31,3	11,7	32,5	1,9	2,5	216,0	0,4		0,1	17,8
0910008	OGS	359,0	365			31,7	11,7	33,0	1,9	3,3	214,0	0,7		0,1	17,9
0910014	OGS	299,2	400			40,9	16,0	26,4	2,3	1,3	244,0	0,9		0,3	15,8
1140031	OGS	282,9	395			25,7	9,0	51,5	1,5	0,7	252,0	1,1		0,1	17,2
1140033	OGS	296,4	405			39,3	14,8	30,5	2,1	0,9	252,0	0,7		0,3	17,3
1140035	OGS	329,9	400			25,7	10,2	50,0	1,6	0,6	246,0	0,7		0,1	17,3
1140036	OGS	330,2	380			33,7	13,1	33,5	1,6	0,6	230,0	0,7		0,2	16,9
1140042	OGS	299,3	375			27,3	11,4	40,0	1,4	1,2	234,0	1,1		0,2	16,3
1140054	OGS	497,1	275			28,9	14,8	10,0	0,7	1,3	166,0	0,9		0,1	11,9
1140056	OGS	296,0	370			31,3	12,6	35,5	1,3	1,0	230,0	0,8		0,2	17,4
1140059	OGS	277,8	310			30,3	14,4	29,0	1,2	0,7	207,0	1,0		0,1	18,0
1140071	OGS	408,1	305			30,5	17,3	12,8	1,5	2,7	194,0	0,7		0,1	13,6
1140076	OGS	511,3	400			26,5	17,6	59,0	2,3	9,3	258,0	1,0		0,1	20,1
1170014	OGS	289,2	270			26,5	15,3	11,6	1,0	1,9	184,0	0,5		0,1	12,8
1340002	OGS	279,2	330			34,5	13,1	24,4	1,5	1,6	206,0	7,5		0,2	15,9
1340020	OGS	515,7	370			28,1	11,4	39,0	2,9	2,4	220,0	1,4		0,1	17,9
1340021	OGS	298,0	380			42,5	20,4	12,8	1,2	1,0	200,0	32,3		0,3	14,8
1340023	OGS	277,0	380			32,1	12,6	35,0	1,3	0,3	230,0	0,8		0,2	17,2
1340029	OGS	477,0	530			15,6	8,5	85,0	4,7	3,2	344,0	0,9		0,0	16,2
1340035	OGS	417,8	315			22,0	11,7	36,0	2,3	3,5	214,0	0,5		0,1	14,5
1340037	OGS	404,5	505			22,0	8,0	84,0	3,3	5,8	320,0	0,5		0,1	17,7
1340038	OGS	298,9	345			44,1	14,1	17,8	1,1	0,4	192,0	28,1		0,2	18,9
1340051	OGS	279,9	330			33,9	14,4	29,0	1,7	0,9	215,0	1,0		0,2	18,1

ding to the recharge coming from the High Plain unconfined aquifer. At greater depths (MARTELLI & GRANATI, 2008a, 2008b), the sulphate contents are low and almost uncorrelated with depth.

8. - ISOTOPE REMARKS

In order to improve the knowledge about the flow and recharge patterns of the Friuli Plain aquifers, isotope analyses (^{18}O, ^{2}H, ^{14}C) have been carried out (MARTELLI *et alii,* 2007b) on the basis of water samples collected, during the period April 2003 – March 2007, from:

56 wells reaching each confined aquifer level of the Low Plain multi-layered system and 1 well pertaining to the High Plain unconfined aquifer system;

- 17 surfacing spring waters between the Tagliamento and Torre rivers;
- 4 main local rivers (Tagliamento, Torre, Natisone, Isonzo).

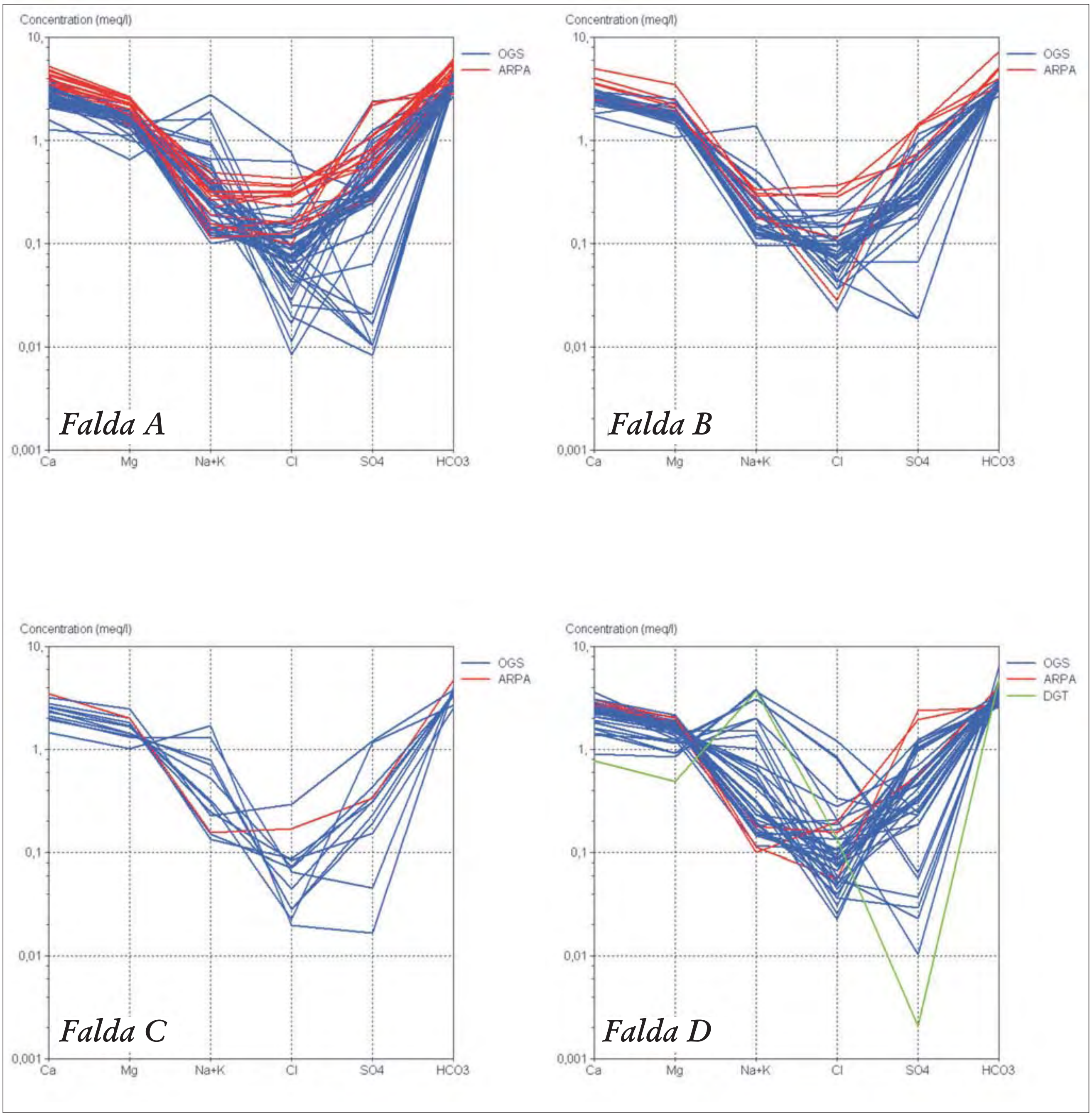

Fig. 15 – Schoeller diagrams concerning groundwaters of Low Plain Aquifers A, B, C, D.
– *Diagrammi di Schoeller relativi alle acque delle Falde A, B, C, D della Bassa Pianura friulana.*

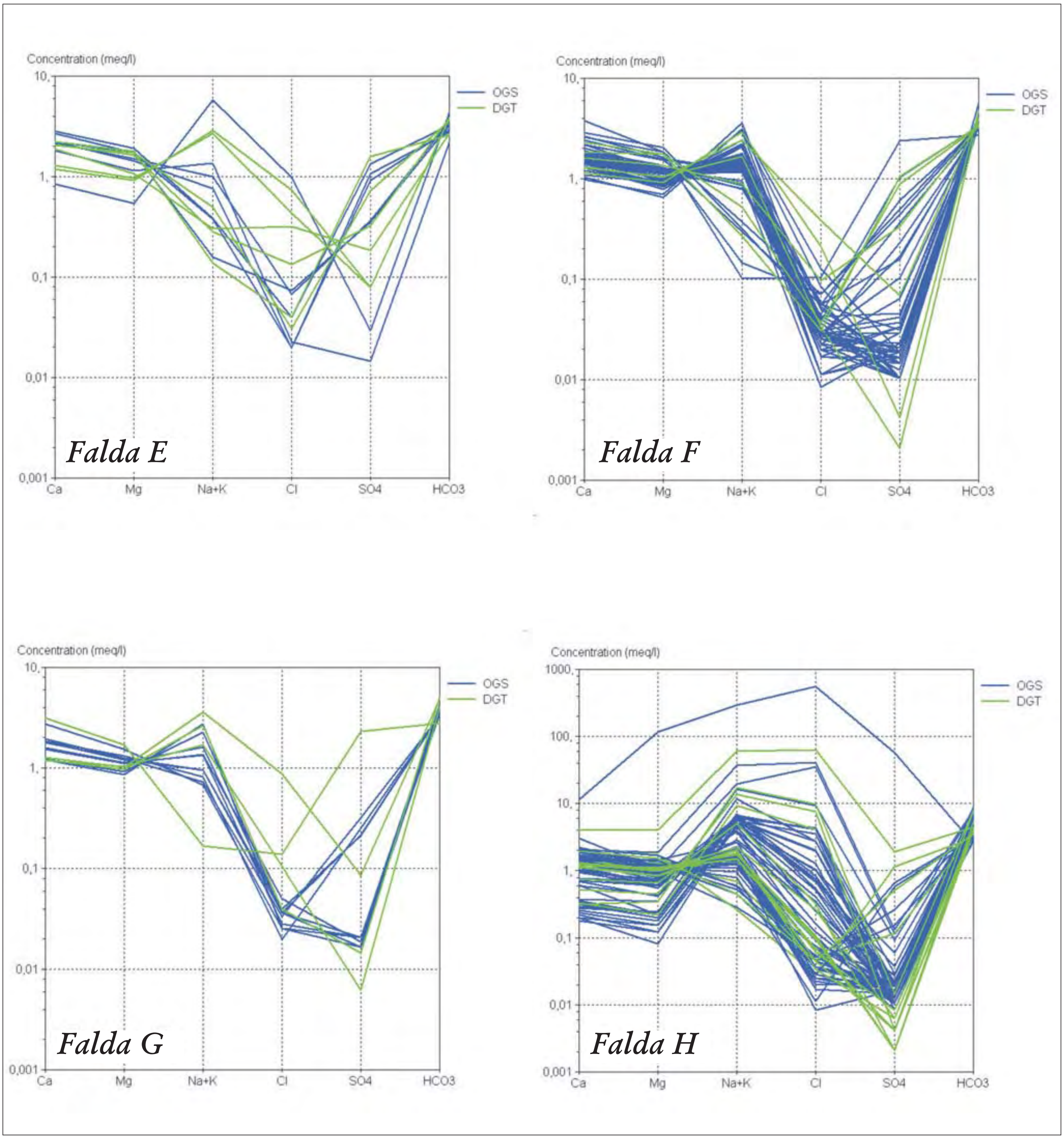

Fig. 16 – Schoeller diagrams concerning groundwaters of Low Plain Aquifers E, F, G, H.
– Diagrammi di Schoeller relativi alle acque delle Falde E, F, G, H della Bassa Pianura friulana.

Data related to the hydrogen and oxygen isotope composition have been evaluated (MARTELLI & GRANATI, 2008b), together with the age calculated from the ^{14}C contents, for water samples coming (March – November 2007) from 19 artesian wells of the Low Plain (3 new-acquired and 16 already involved in heavier isotopes determinations) and from the above-mentioned phreatic well of the High Plain (tab. 3). The δ^2D and $\delta^{18}O$ analyses were performed on a FINNIGAN GLF 1086 automatic equilibration device and a DELTA PLUS FINNIGAN mass-spectrometer (Department of Earth Sciences, University of Parma); the ^{14}C content was analysed at the Hydroisotop GmbH Laboratory in Schweitenkirchen (D).

Preliminary analyses (MARTELLI *et alii,* 2007b) outlined as most of deep groundwaters does not

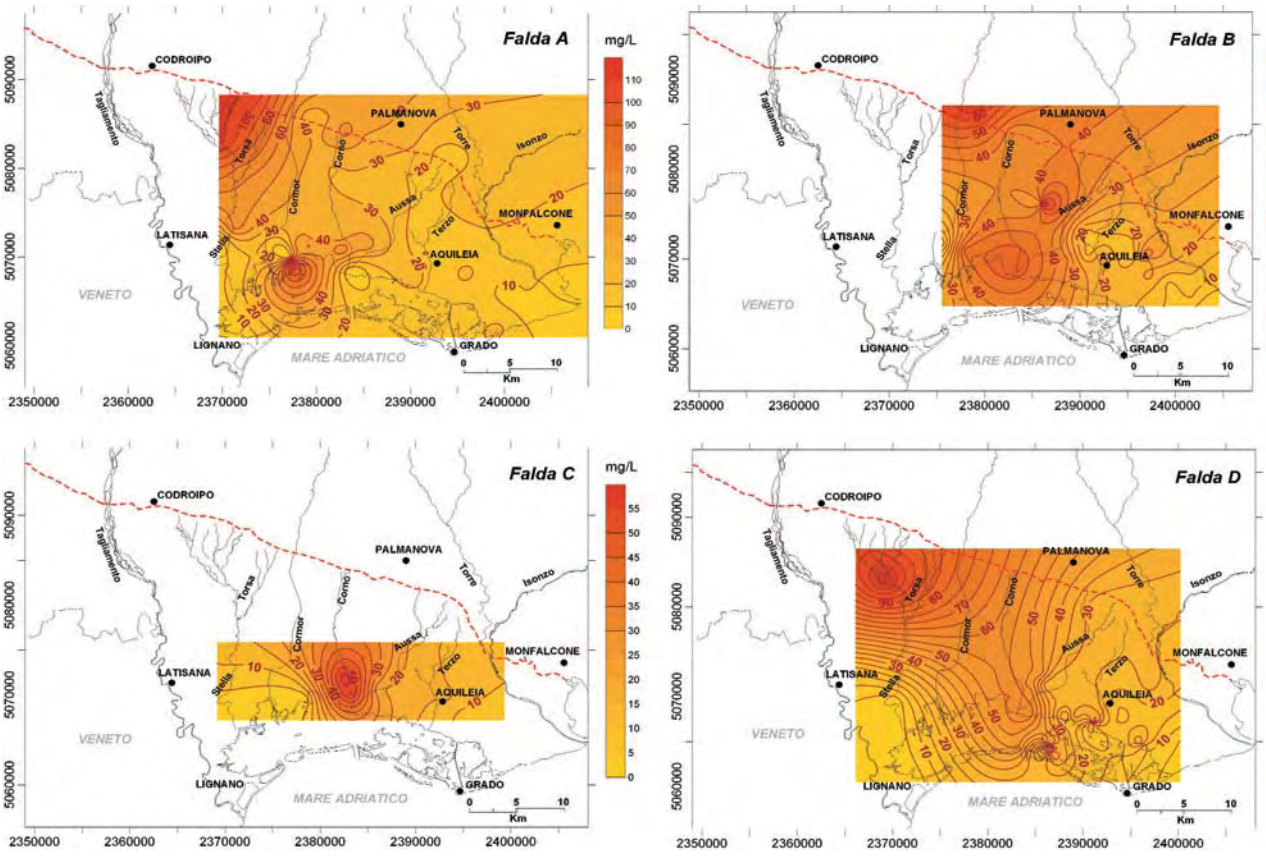

Fig. 17 – Sulphate distribution in groundwaters of Low Plain Aquifers A, B, C, D.
– *Carte della distribuzione dei solfati nelle acque delle Falde A, B, C, D della Bassa Pianura friulana.*

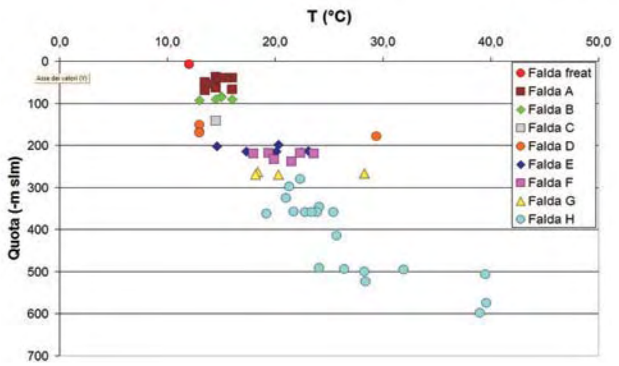

Fig. 18 – Temperature (°C) versus withdrawal depth in the Low Plain confined aquifers.
– *Variazione della temperatura (°C) con la quota di attingimento idrico sotterraneo dei pozzi campionati nella Bassa Pianura friulana.*

reveal remarkable seasonal fluctuations in the $\delta^{18}O$ and δD contents, pointing out permeability and flow conditions in the relative aquifer horizons such as to allow a recharge contribution mixing. With regard to the $\delta^{18}O$ spatial variability, the water samples of the most shallow confined aquifer levels (A, B, C, D) become increasingly more negative towards NW, while spring waters show progressively less negative values moving eastward; the deepest groundwaters (F, G, H) are isotopically lighter towards the coastal sector, according to greater flow depths, higher recharge areas and/or old recharge contributions. Tagliamento and Isonzo rivers are characterised by negative $\delta^{18}O$ values owing to their high mountain basins.

The diagram in figure 25 displays the relationship between $\delta^{18}O$ and δD contents in river, spring and groundwater samples. Groundwater radiocarbon datings are also reported. The similar out-

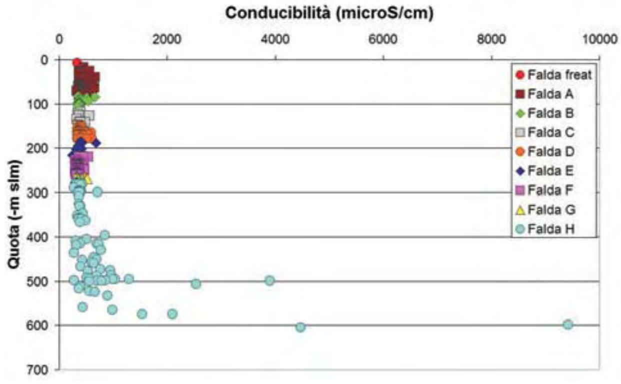

Fig. 19 – Conductivity (µS/cm) versus withdrawal depth in the Low Plain confined aquifers.
– *Variazione della conducibilità (µS/cm) con la quota di attingimento idrico sotterraneo dei pozzi campionati nella Bassa Pianura friulana.*

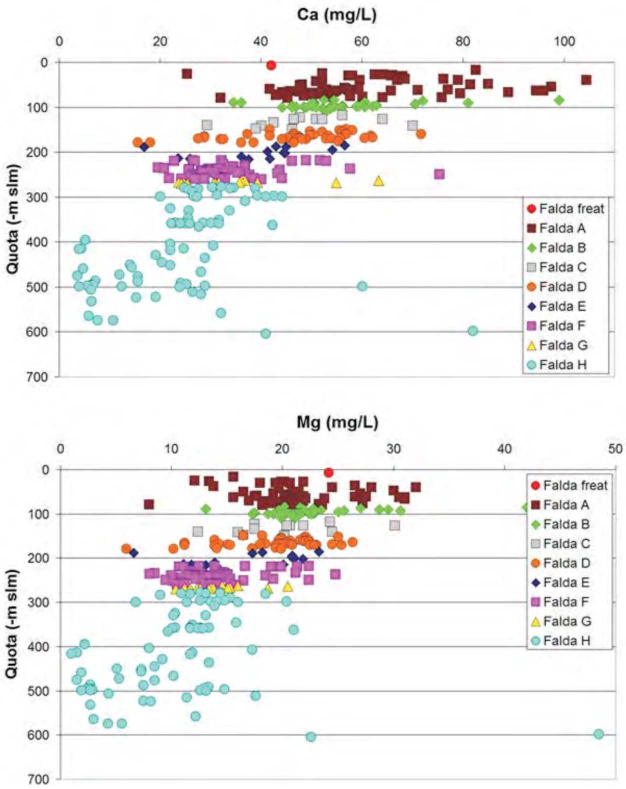

Fig. 20 – Ca^{++} (mg/l) and Mg^{++} (mg/l) contents versus withdrawal depth in the Low Plain confined aquifers.
– *Variazione dei parametri Ca^{+} (mg/l) e Mg^{++} (mg/l) con la quota di attingimento idrico sotterraneo dei pozzi campionati nella Bassa Pianura friulana.*

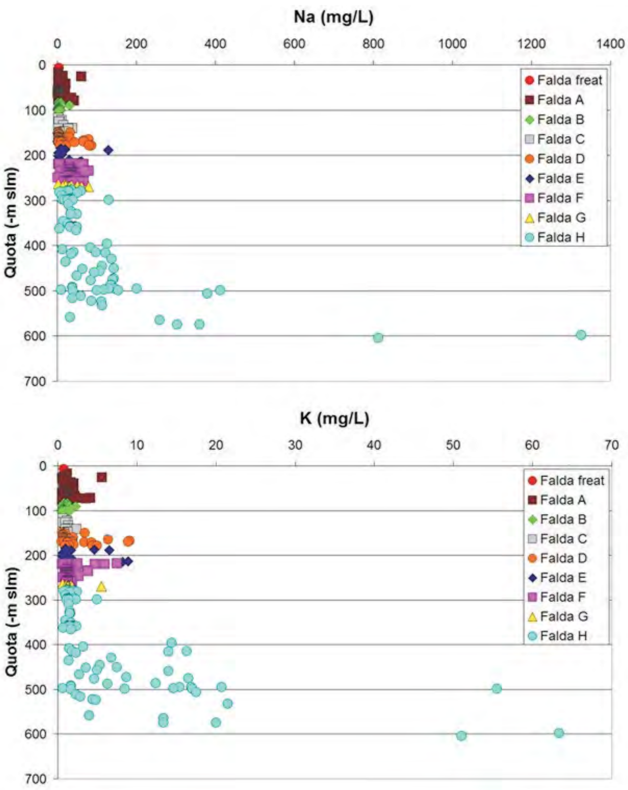

Fig. 21 – Na^{+} (mg/l) and K^{+} (mg/l) contents versus withdrawal depth in the Low Plain confined aquifers.
– *Variazione dei parametri Na^{+} (mg/l) e K^{+} (mg/l) con la quota di attingimento idrico sotterraneo dei pozzi campionati nella Bassa Pianura friulana.*

coming isotope ratios that characterise surface, phreatic, spring and meteoric waters regarding MWL_S (Northern Italy Meteoric Water Line: *$\delta D = 7{,}7094\ \delta^{18}O + 9{,}4034$*) and GMWL (Global Meteoric Water Line: *$\delta D = 8{,}20\ \delta^{18}O + 11{,}27$*) (Longinelli & Selmo, 2003; Longinelli *et alii*, 2006) support both the meteoric origin of recent aged waters (Martelli *et alii*, 2007b) and their hydraulic connection.

Groundwaters coming from Aquifers A, B, C (till 150 m bsl) show an isotope signal consistent with the one determined for phreatic and spring waters, that means present or recent recharge.

The most isotopically negative groundwaters ($\delta^{18}O$ = 9,5 – 10,5‰) are almost exclusively associated to aquifer levels more than 270 m bsl deep and are undoubtedly old (up to 36000 years).

Mixing processes characterise groundwaters with an isotope signal between -8 and -9‰, coming from aquifer levels more than 180 m bsl deep and pointing out really different ages.

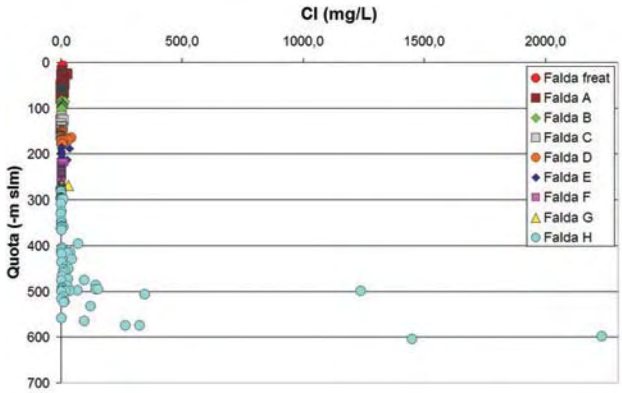

Fig. 22 – Cl^{-} (mg/l) content versus withdrawal depth in the Low Plain's confined aquifers.
– *Variazione del parametro Cl^{-} (mg/l) con la quota di attingimento idrico sotterraneo dei pozzi campionati nella Bassa Pianura friulana.*

The diagram $\delta^{18}O$ vs. Cl (fig. 26) shows some of the most remarkable mixing phenomena, especially as far as the deepest confined levels are concerned:

- the red arrow marks deep fresh-waters moving towards shallow levels, with a mixing between old and recent fresh-waters;

- the blue arrow displays a mixing between old recharged fresh-waters and saline paleo-waters;

- the green arrow is indicative of a mixing between fresh and saline old waters.

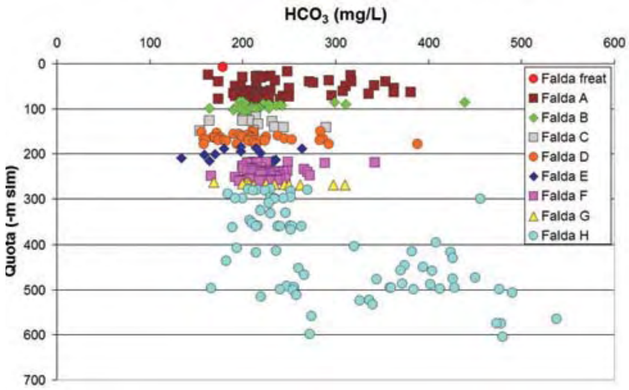

Fig. 23 – HCO^{3-} (mg/l) content versus withdrawal depth in the Low Plain confined aquifers.
– *Variazione del parametro HCO^{3-} (mg/l) con la quota di attingimento idrico sotterraneo dei pozzi campionati nella Bassa Pianura friulana.*

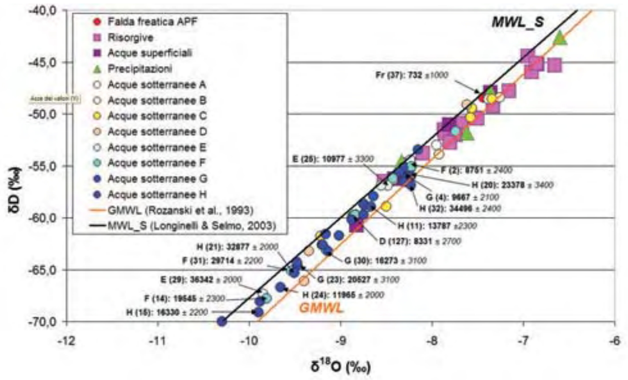

Fig. 25 – Relationship between $\delta^{18}O$ and δD of groundwaters, surface waters, spring waters and meteoric waters, together with ^{14}C dating results (mean of corrected ages by INGERSON & PEARSON, 1964, and MOOK, 1980).
– *Relazione tra $\delta^{18}O$ e δD per acque sotterranee, superficiali, di risorgiva e di precipitazione, con indicazione dei risultati di datazioni con radiocarbonio. Le età indicate derivano dalla media delle età corrette secondo* INGERSON & PEARSON *(1964) e* MOOK *(1980).*

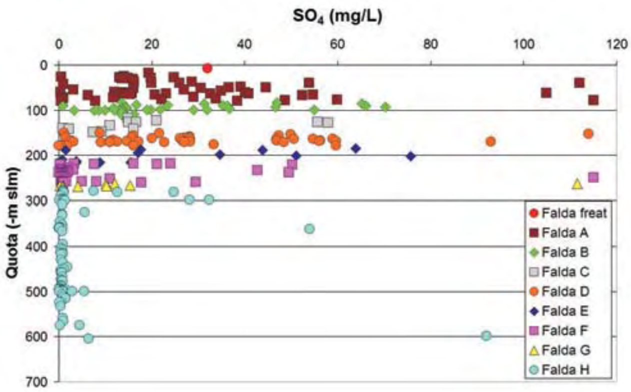

Fig. 24 – $SO_4^{=}$ (mg/l) content versus withdrawal depth in the Low Plain confined aquifers.
– *Variazione del parametro $SO_4^{=}$ (mg/l) con la quota di attingimento idrico sotterraneo dei pozzi campionati nella Bassa Pianura friulana.*

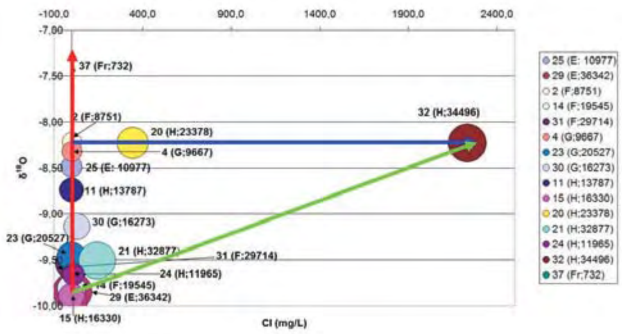

Fig. 26 - $\delta^{18}O$ (‰) versus Cl- (mg/l) in Friuli Plain groundwaters; ^{14}C dating results are also indicated.
– *Relazione tra $\delta^{18}O$ (‰), Cl- (mg/l) ed età determinate mediante analisi al radiocarbonio delle acque sotterranee della Pianura Friulana.*

9. - CONCLUSIONS

Owing to the above-mentioned surveys and elaborations, the following considerations can be pointed out:

- the local geological and structural patterns played a determinant role in conditioning the High Plain groundwater flow circulation; the divide between western and eastern groundwaters is evidenced in terms of both hydraulic head and chemistry; the same data also confirm the strict connection between the main regional hydrographic systems and the High Plain unconfined aquifer;
- the Low Plain confined aquifer levels till 300 m bsl are fed by groundwaters coming from the High Plain water-table aquifer;
- the Low Plain confined aquifer system exhibits mutual connections between its levels, in terms both of pressure (as supposed on the basis of the similar hydraulic head distributions in the Aquifers B-C and Aquifers D-F) and of mass transport (as evidenced by geochemical and isotopical outputs about deep and shallow groundwater mixings).

On account of such statements, a sustainable exploitation of the Low Plain aquifer system needs the assumption of two distinct withdrawal approaches, connected to the recharge origin and speed features. In fact, the confined levels till 300 m bsl are fed by the High Plain groundwaters, while the deepest productive horizons, whose present exploitation is valued at about 5 millions of m^3/year (MARTELLI & GRANATI, 2006, 2007a, 2007b), are involved in complex and low flow circuits, related to prealpine/alpine recharge areas.

Acknowledgements

The Authors are grateful to the Referees for their thoughtful suggestions and constructive reviews.

Tab. 3 – *Isotopic data and* ^{14}C *dating results (mean of corrected ages by* INGERSON & PEARSON*, 1964, and* MOOK*, 1980) concerning Friuli Plain's groundwaters, spring waters and surficial waters.*
– Sintesi dei campionamenti isotopici effettuati su acque di falda, superficiali e di risorgiva della Pianura friulana, con indicazione dei risultati delle datazioni con radiocarbonio; l'età riportata deriva dalla media delle età corrette secondo INGERSON & PEARSON (1964) e MOOK (1980).

ID	$\delta^{18}O$-VSMOW (‰)	dD	Età (^{14}C)	ID	$\delta^{18}O$-VSMOW (‰)	dD	Età (^{14}C)
Falda freatica				23	-9,47	-64,61	20527
37	-7,44	-48,41	732	30	-9,14	-63,27	16273
Falda A				*Falda H*			
128			11739	1	-9,48	-64,34	
152	-8,30	-56,12		3	-8,35	-55,55	
84	-7,95	-52,99		5	-8,31	-55,19	
85	-7,38	-48,56		7	-8,15	-53,47	
Falda B				8	-8,29	-56,13	
130	-7,26	-48,41		11	-8,74	-58,78	13787
150	-8,42	-56,35		12	-8,31	-56,57	
64			6953	13	-8,74	-59,72	
74	-7,92	-53,87		15	-9,90	-69,13	16330
Falda C				16	-9,88	-68,08	
131	-7,58	-50,33		17	-8,88	-60,21	
146	-9,22	-61,76		18	-9,16	-61,55	
151	-8,50	-58,91		19	-9,01	-61,73	
72	-7,56	-49,48		20	-8,23	-56,03	23378
96	-7,34	-48,55		21	-9,51	-65,30	32877
Falda D				22	-8,67	-58,90	
29	-9,85	-67,35	36342	24	-9,66	-66,69	11965
127	-8,87	-59,83		28	-9,20	-62,63	
162	-9,40	-66,10		32	-8,23	-56,86	34496
127			8331	125	-9,49	-64,01	
138	-9,20	-62,60		*Risorgive*			
159	-9,35	-63,21		RIS1	-8,52	-56,52	
58	-7,62	-49,12		RIS2	-8,10	-53,78	
Falda E				RIS3	-7,86	-51,55	
25	-8,49	-56,90	10977	RIS4	-7,67	-50,90	
33	-8,83	-59,71		RIS5	-7,85	-51,85	
34	-8,56	-56,92		RIS6	-7,33	-49,25	
36	-8,23	-54,43		RIS7	-7,74	-52,00	
124	-10,30	-69,98		RIS8	-7,53	-50,42	
Falda F				RIS9	-7,51	-50,47	
2	-8,22	-55,05	8751	RIS10	-8,26	-54,87	
9	-8,43	-56,19		RIS11	-7,80	-52,76	
10	-7,74	-51,68		RIS12	-6,85	-45,21	
14	-9,81	-67,78	19545	RIS13	-7,16	-47,76	
26	-8,75	-58,60		RIS14	-6,91	-45,98	
27	-8,86	-59,78		RIS15	-6,66	-45,34	
31	-9,54	-65,14	29714	RIS16	-6,95	-44,45	
35	-8,72	-59,03		RIS17	-6,86	-45,13	
111	-8,84	-59,74		*Corsi d'acqua*			
126	-9,16	-63,08		TAG	-8,83	-60,72	
Falda G				TOR	-7,81	-51,05	
4	-8,32	-55,64	9667	ISO	-8,41	-56,25	
6	-8,64	-57,92		NAT	-7,36	-47,94	

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