Demonstrating Managed Aquifer Recharge as
a Solution to Water Scarcity and Drought
An EU FP7 Project

Monitoring and Investigation Technologies Workshop
Athens 16-18 March 2016

Monitoring system at the Sant'Alessio Induced RiverBank Filtration plant (Lucca, Italy)

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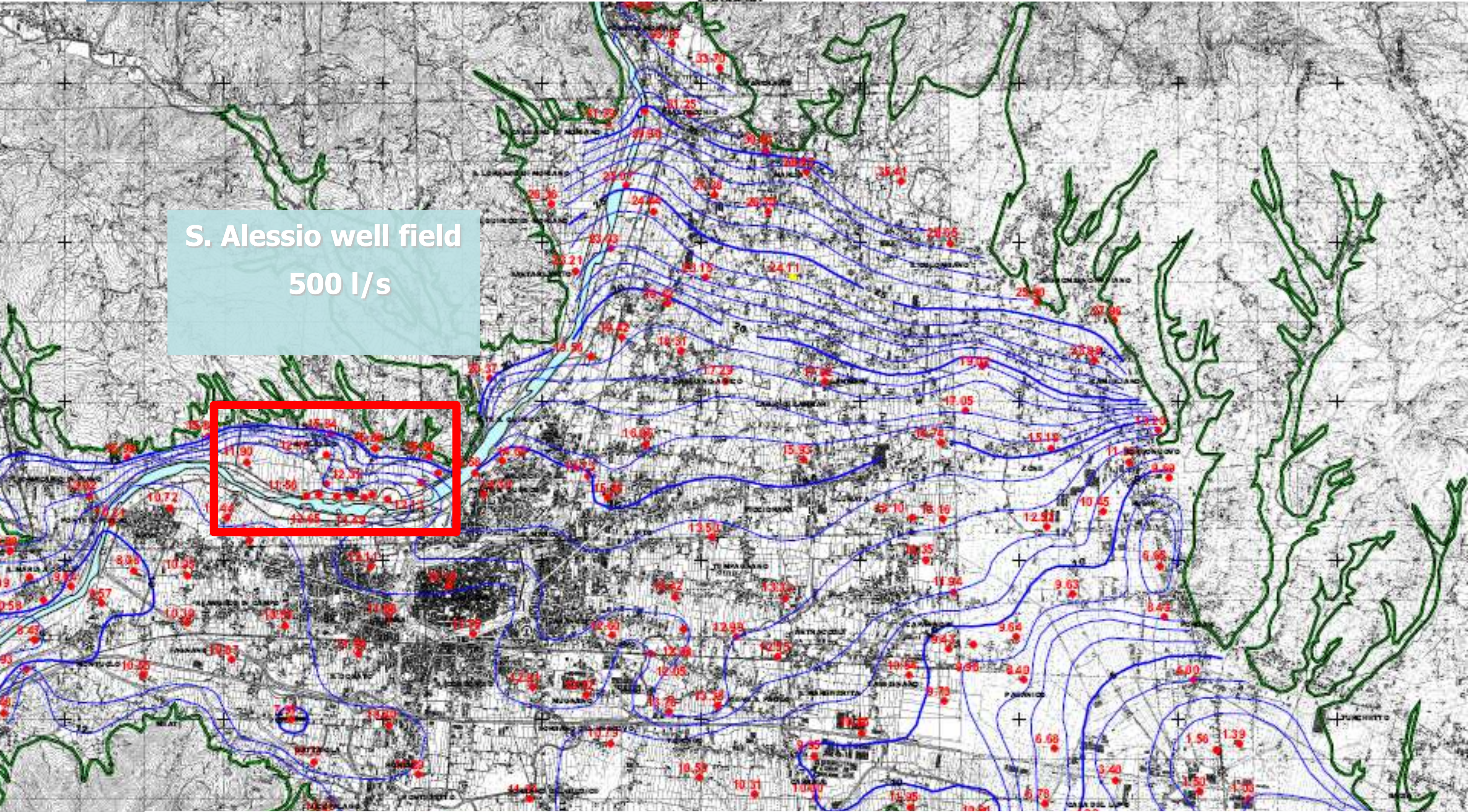
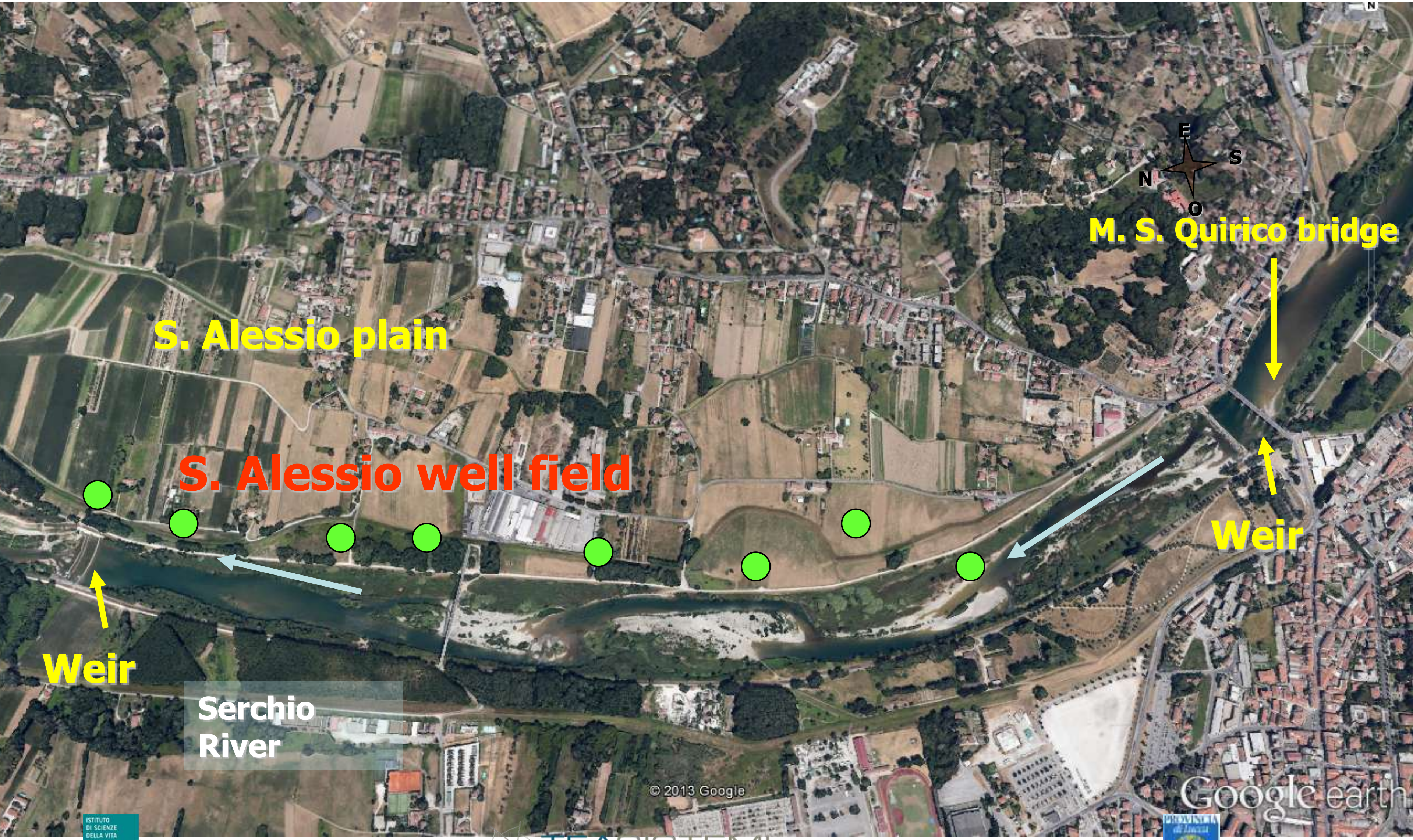
Background

The Lucca plain hosts the most important aquifer of Tuscany providing supply to Pisa, Lucca and Livorno and to a large paper mill industrial hub. The Serchio River, hydraulically connected, greatly recharges the aquifer.

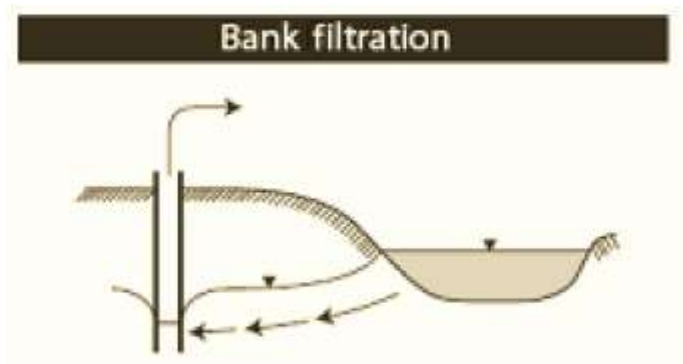


Along the Serchio River groundwater is pumped enhancing riverbank filtration into the sand and gravel aquifer. At Sant’Alessio, River head is artificially raised and 20 pumping wells withdraw about 600 l/s.

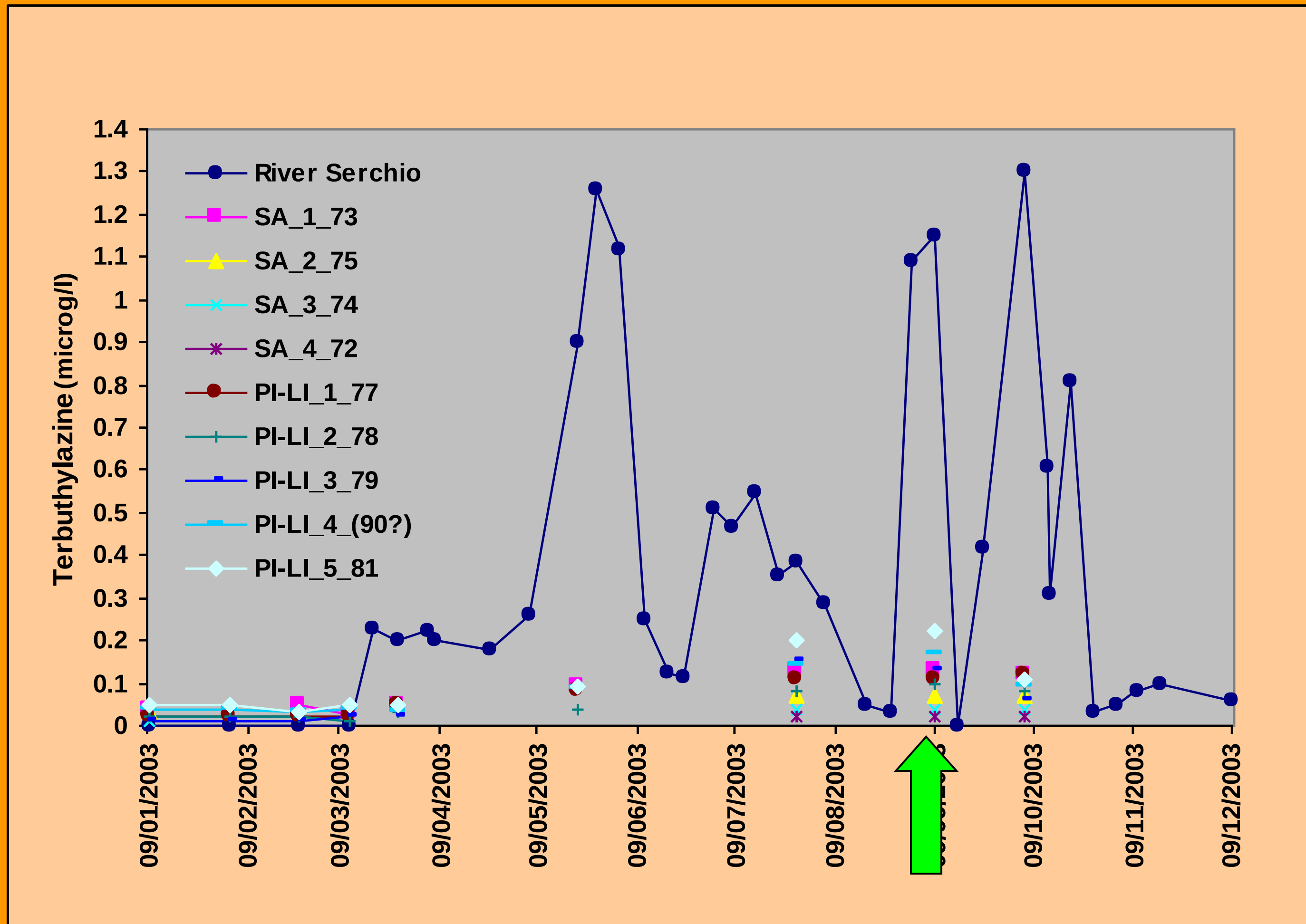
IRBF MAR system



IRBF MAR system



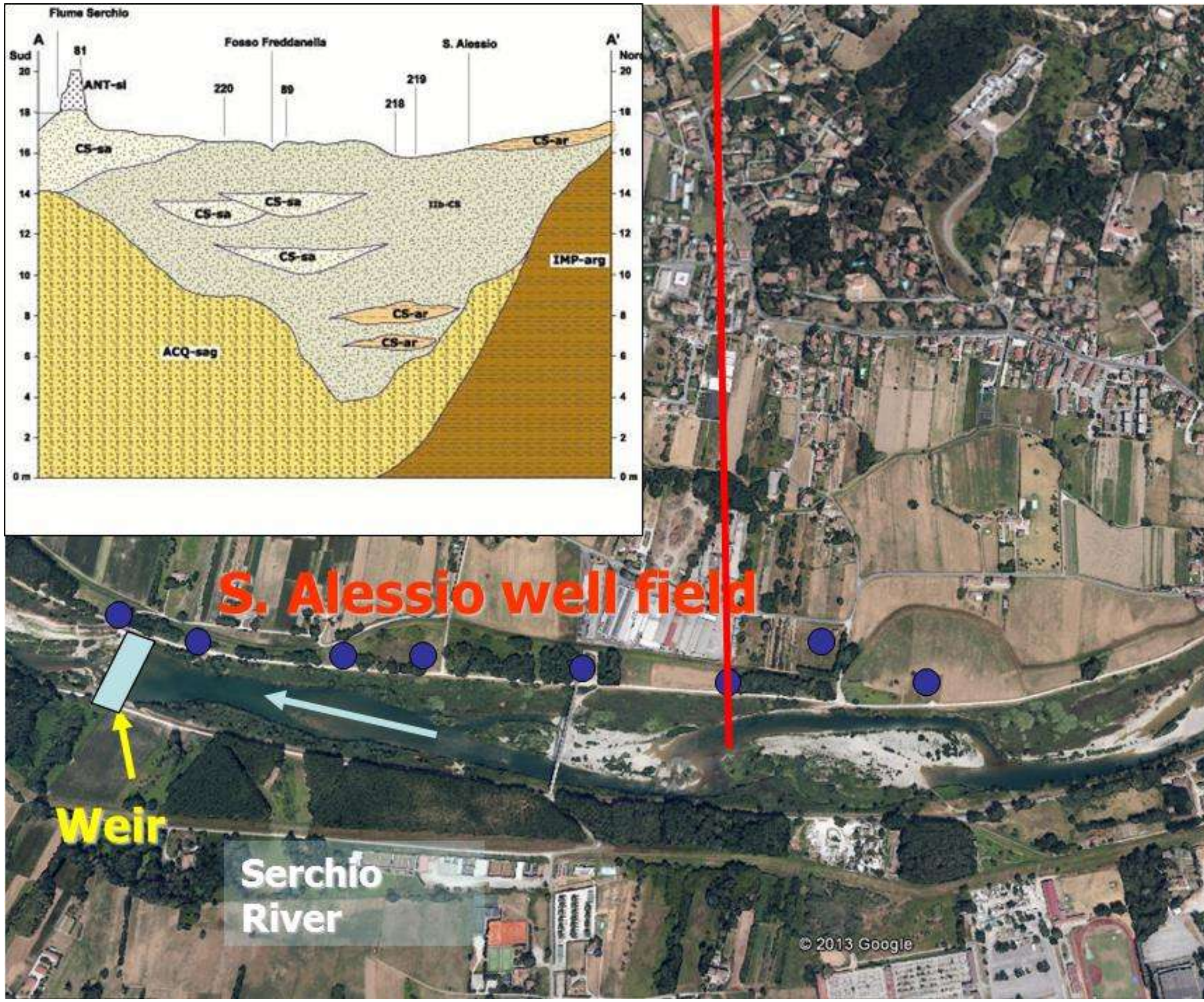
Pesticides in surface water and in groundwater

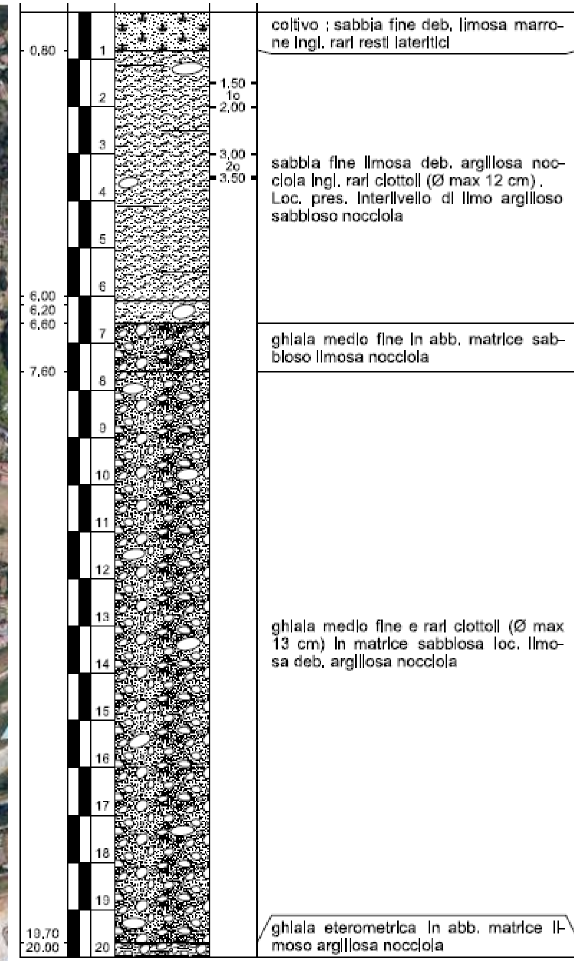


The MAR plant is not at present monitored on routinely basis.

Stratigraphy and IRBF MAR

MAR Solutions - Managed Aquifer Recharge Strategies and Actions (AG128)





WP8/Managing river bank filtration at the Serchio River well field

Objective> To merge existing and proved technologies to produce a Decision Support System (DSS) **based on remote data acquisition and transmission** and GIS physically-based fully distributed numerical modelling to continuously monitor and manage the well field.

The DSS, the installed sensors, data transmission and storage tools will constitute a prototype whose potential market exploitation will be tested.

Deliver contingency measures plan (mixing options…???)

Task 8.1: **Installing and operating the monitoring system** (SSSA, Lucca, TEA)

Task 8.2: **Demo site analysis** (UFZ, SSSA, Lucca)

Task 8.3: **Decision Support System development and testing** (TEA, SSSA)

Task 8.4: **Model implementation and calibration** (SSSA, Lucca)

Task 8.5: **Application of the DSS at the Serchio IRF well field** (SSSA, TEA, Lucca)

Task 8.1: **Installing and operating the monitoring system** (SSSA, Lucca, TEA)

Objective

To provide the IRBF plant with a monitoring system to control:

- *Safety of the MAR plant (water quality)*

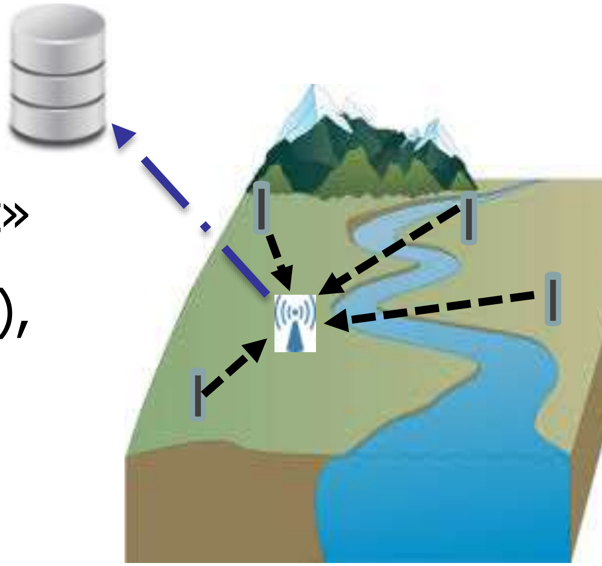
A Wireless Sensor Network (WSN) to monitor:

- Surface water and groundwater T, EC & hydraulic head

Additional, Surface and groundwater quality monitoring by means of onsite spectrometer

Water temperature & water EC to be used as natural tracer
As derived information: sw/gw interaction behavior

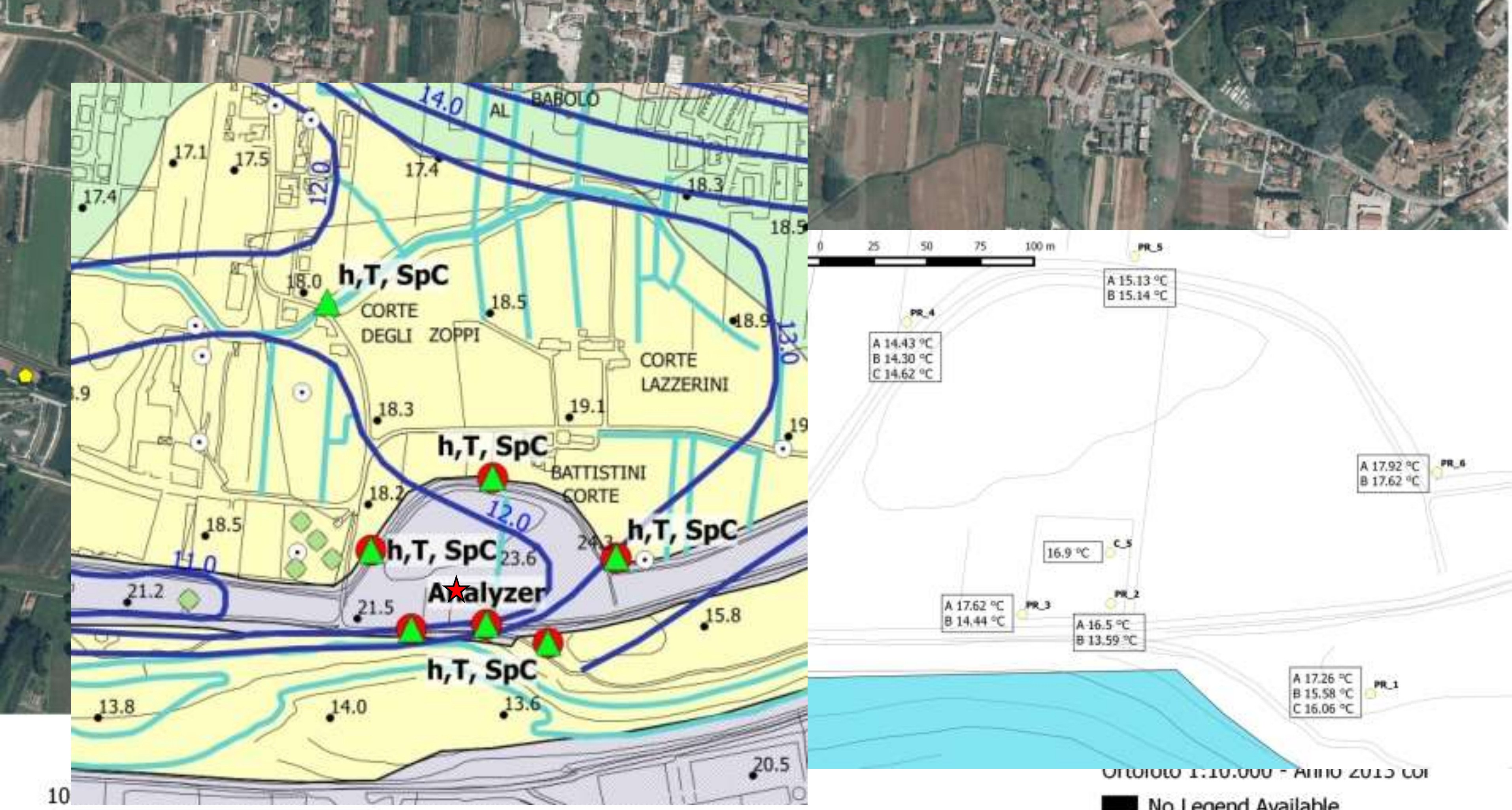
The WSN is based on several data loggers «client» connected via radio to 1 server point (Gateway), transmitting to the Database DB via GSM-GPRS



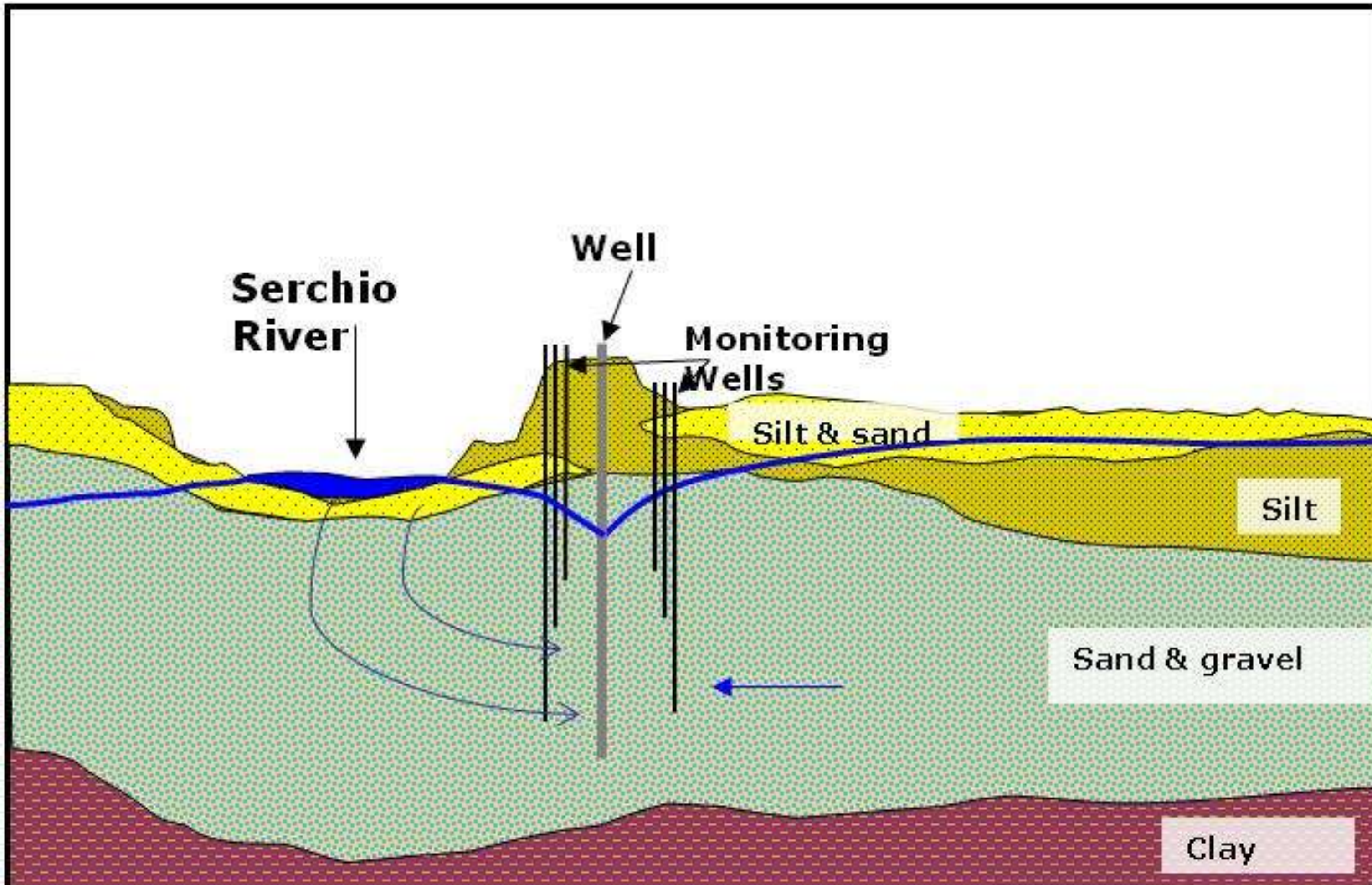
Monitoring design (SSSA, Lucca)

6 borehole clusters were finally set in place at:

- 12 m / 15m / 20m depth (15 & 20 m 2 inches)

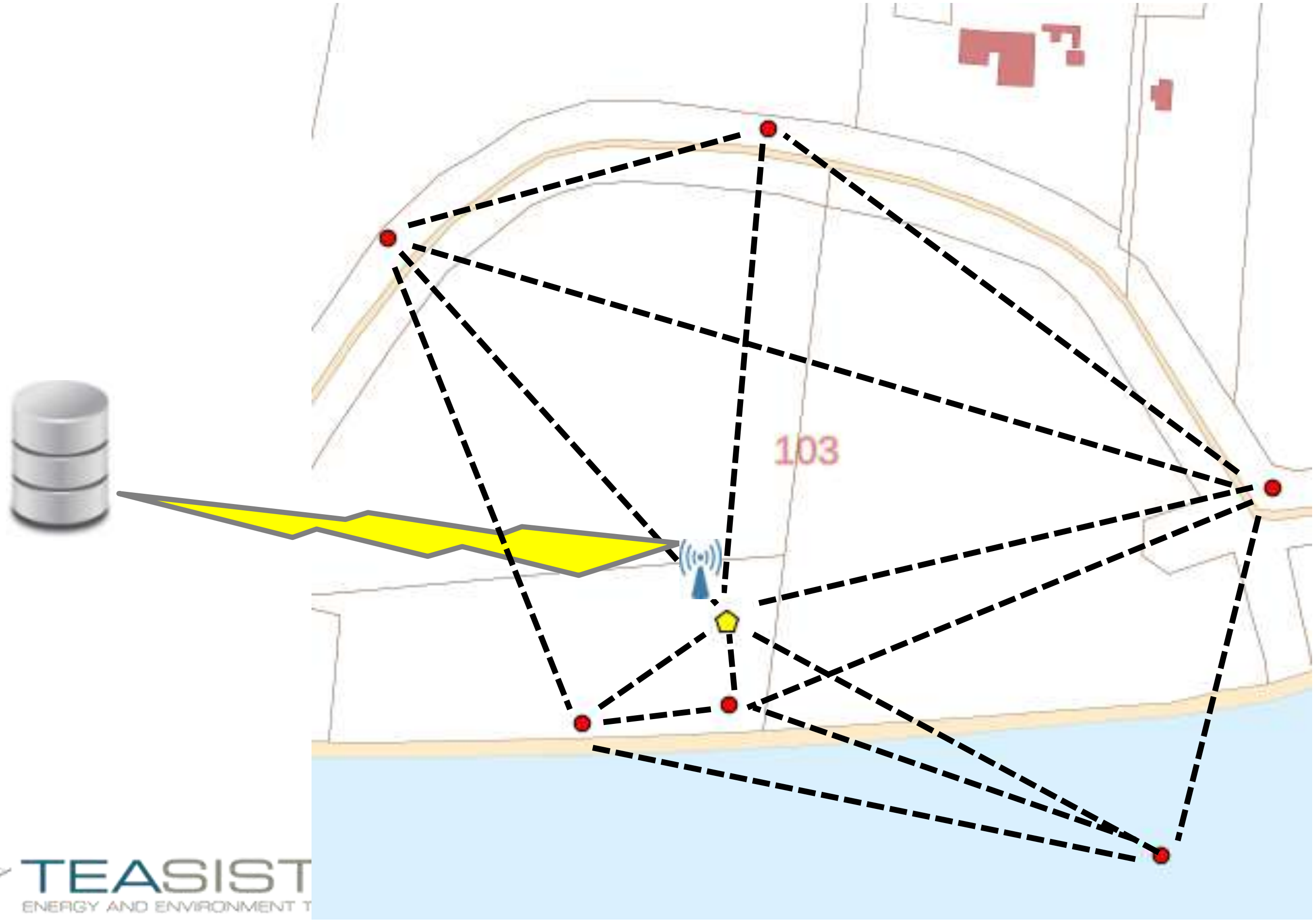


Piezometer cluster



GW Monitoring

This part of WSN is based on several data loggers connected via **RF** within a *mesh*. 1 central point is included in the mesh (**Gateway**), transmitting via GSM/GPRS to DB



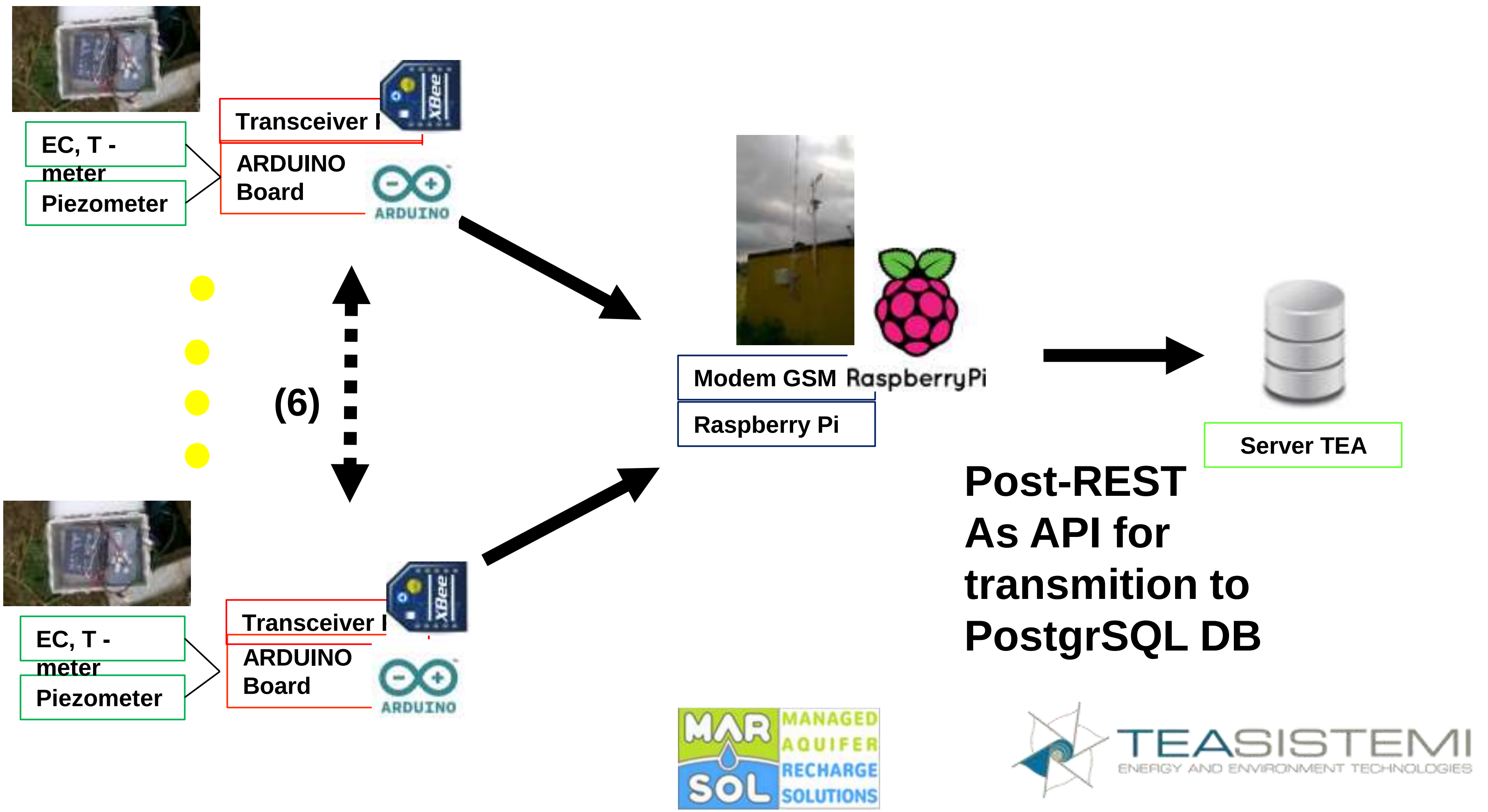
A *low cost* and *open source* (=customized) approach

A mesh-type WSN: any **mesh node (n.6)** transmits to others via **radio modem** (**XBEE** PRO 868).

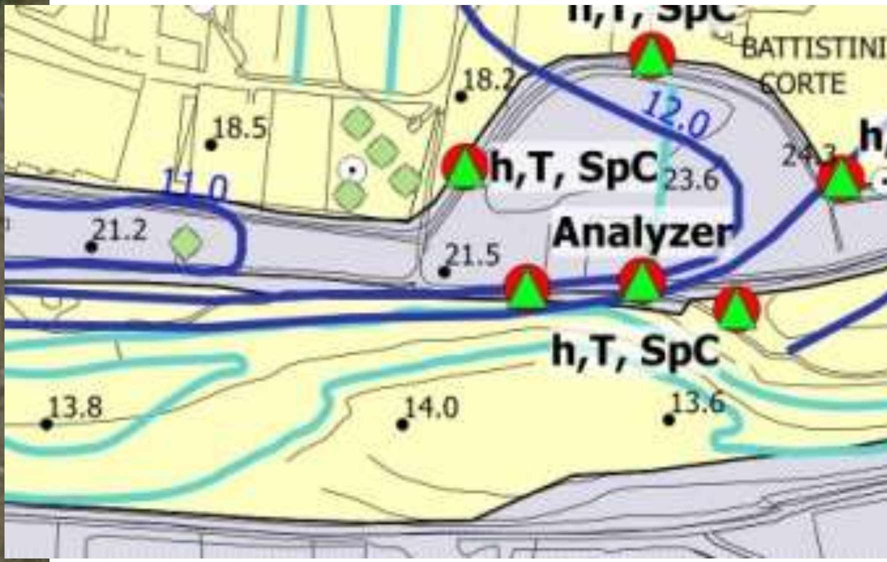
1 point in the mesh serves as **GATEWAY,** transmitting via **GSM/GPRS** to a **GeoDatabase**.

In-house assembled, low cost data logging system: based on **ARDUINO BOARD**

Data transmission is implemented within a **RaspberryPI**



Task 8.1: **Installing and operating the monitoring system** (SSSA, Lucca, TEA)



Actions		idsgw_1	date	time	level	temperature	ph	ces
Edit	Delete	4968	2015-04-22	09:26:24	8.01714	9.68442	1	489.071
Edit	Delete	4969	2015-04-22	09:41:25	8.02453	9.74725	1	478.441
Edit	Delete	4970	2015-04-22	09:56:26	8.06199	9.69709	1	491.116
Edit	Delete	4971	2015-04-22	10:11:26	7.96673	9.76323	1	484.021
Edit	Delete	4972	2015-04-22	10:26:27	8.06777	9.70175	1	492.287
Edit	Delete	4973	2015-04-22	10:41:27	8.00311	9.68582	1	491.066
Edit	Delete	4974	2015-04-22	10:56:28	8.06094	9.76796	1	492.797
Edit	Delete	4975	2015-04-22	11:11:29	7.94177	9.75494	1	483.606
Edit	Delete	4976	2015-04-22	11:26:30	7.94677	9.63806	1	478.603
Edit	Delete	4977	2015-04-22	11:41:30	7.9409	9.60817	1	478.644
Edit	Delete	4978	2015-04-22	11:56:30	7.94111	9.72637	1	477.618
Edit	Delete	4979	2015-04-22	12:11:31	8.05931	9.7782	1	484.018
Edit	Delete	4980	2015-04-22	12:26:31	8.00855	9.718	1	477.45
Edit	Delete	4981	2015-04-22	12:41:33	7.99031	9.69059	1	483.874

Actions		idsgw_2	date	time	level	temperature	ph	ces
Edit	Delete	42	2015-04-22	09:26:24	6.95355	11.1557	1	436.743
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Edit	Delete	44	2015-04-22	09:56:26	7.05875	11.2638	1	424.809
Edit	Delete	45	2015-04-22	10:11:26	6.96377	11.2878	1	430.4
Edit	Delete	46	2015-04-22	10:26:27	7.02084	11.2455	1	430.012
Edit	Delete	47	2015-04-22	10:41:27	6.95691	11.1726	1	435.679
Edit	Delete	48	2015-04-22	10:56:28	7.00977	11.2364	1	428.885
Edit	Delete	49	2015-04-22	11:11:29	6.99195	11.2129	1	431.92
Edit	Delete	50	2015-04-22	11:26:30	6.98902	11.1175	1	421.518
Edit	Delete	51	2015-04-22	11:41:30	6.99128	11.1176	1	425.408
Edit	Delete	52	2015-04-22	11:56:30	7.06064	11.2059	1	428.455

Acquisition and transmission frequency

- Data acquired 6 times per hour (every 10 min.)
  - Every 10 minutes: a time window of 30 sec. for acquisition. Then data are averaged and the average value is saved and sent to the central node via RF.
- Every hour, data are sent from the central node to the server, and then fed to GeoDB

WSN: examples of recorded data

Data recorded at probe 1 (temperature, EC, water table level)

Edit Data - MarsolPublic (93.145.196.238:5432) - dbmarsol - gw_monitor_1

File Edit View Tools Help

No limit

	idsgw_1 integer	date date	time time without	temperature real	ces real	level real
408	5440	2016-03-13	11:51:12	16.3063	414.294	11.5112
409	5441	2016-03-13	12:01:13	17.7752	423.277	11.869
410	5442	2016-03-13	12:11:13	16.8628	417.428	11.6018
411	5443	2016-03-13	12:21:13	17.2345	419.935	11.72
412	5444	2016-03-13	12:31:13	18.0625	424.949	11.9819
413	5445	2016-03-13	12:41:13	17.1331	419.099	11.6947
414	5446	2016-03-13	12:51:13	17.9611	424.113	11.9481
415	5447	2016-03-13	13:01:14	17.5758	421.625	11.7794
416	5448	2016-03-13	13:11:14	18.3949	426.65	12.0415
417	5449	2016-03-13	13:21:14	17.0298	418.276	11.6187
418	5450	2016-03-13	13:31:14	17.8659	423.3	11.8724
419	5451	2016-03-13	13:41:14	16.9445	417.857	11.5849
420	5452	2016-03-13	13:51:14	17.3199	419.951	11.7033
421	5469	2016-03-14	10:05:56	14.2352	401.93	11.1696
422	5470	2016-03-14	10:15:56	15.2432	408.472	11.5207
423	5471	2016-03-14	10:25:56	15.1516	408.064	11.4872
424	5472	2016-03-14	10:35:56	14.1893	401.521	11.1612
425	5473	2016-03-14	10:45:56	15.6862	411.335	11.6628
426	5474	2016-03-14	10:55:56	16.2818	415.423	11.8717
427	5475	2016-03-14	10:06:08	14.2199	401.521	11.1696

GW temperature (in °C)

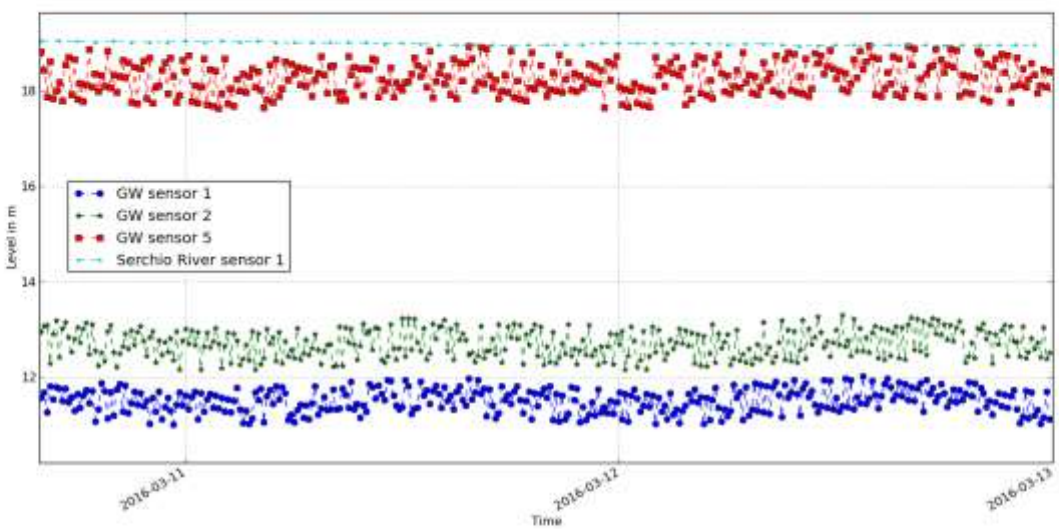
Edit Data - MarsolPublic (93.145.196.238:5432) - dbmarsol - temperature_gw

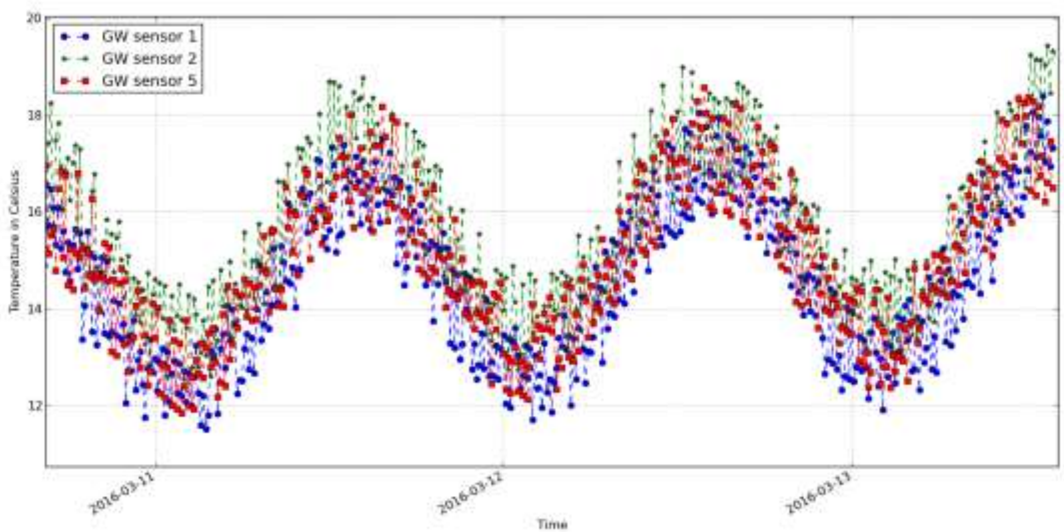
File Edit View Tools Help

No limit

	date date	time time without	temperature_1 real	temperature_2 real	temperature_3 real	te re	temperature_5 real	temperature_6 real
408	2016-03-13	11:51:12	16.3063	18.2817	18.2447		16.6532	18.9734
409	2016-03-13	12:01:13	17.7752	16.4909	17.9824		19.2063	17.6178
410	2016-03-13	12:11:13	16.8628	18.3847	18.3635		17.212	18.0372
411	2016-03-13	12:21:13	17.2345	19.2423	16.4406		19.1164	18.9126
412	2016-03-13	12:31:13	18.0625	18.2775	18.2769		17.1042	17.9278
413	2016-03-13	12:41:13	17.1331	19.153	16.3366		17.4995	18.3473
414	2016-03-13	12:51:13	17.9611	16.6874	18.173		18.3798	19.2227
415	2016-03-13	13:01:14	17.5758	19.1305	16.7544		17.9493	18.7879
416	2016-03-13	13:11:14	18.3949	17.1291	17.1566		18.3482	17.7942
417	2016-03-13	13:21:14	17.0298	19.0403	16.2122		17.3691	18.199
418	2016-03-13	13:31:14	17.8659	19.437	16.597		19.2909	19.1007
419	2016-03-13	13:41:14	16.9445	18.4633	17.4539		17.2603	18.107
420	2016-03-13	13:51:14	17.3199	19.3288	16.4921		17.6773	17.1133
421	2016-03-14	10:05:56	14.2352	16.8163	15.0777		17.2001	16.3133
422	2016-03-14	10:06:08	14.2199	16.7998	15.5538		17.2664	16.3808
423	2016-03-14	10:15:56	15.2432	16.2069	15.6967		17.8629	16.9712
424	2016-03-14	10:16:08	16.1902	16.2728	15.4586		16.2225	18.0172
425	2016-03-14	10:25:56	15.1516	15.1693	15.1095		17.2498	16.8869
426	2016-03-14	10:26:08	15.6251	16.9316	15.1888		17.3161	17.393

WSN: examples of recorded data



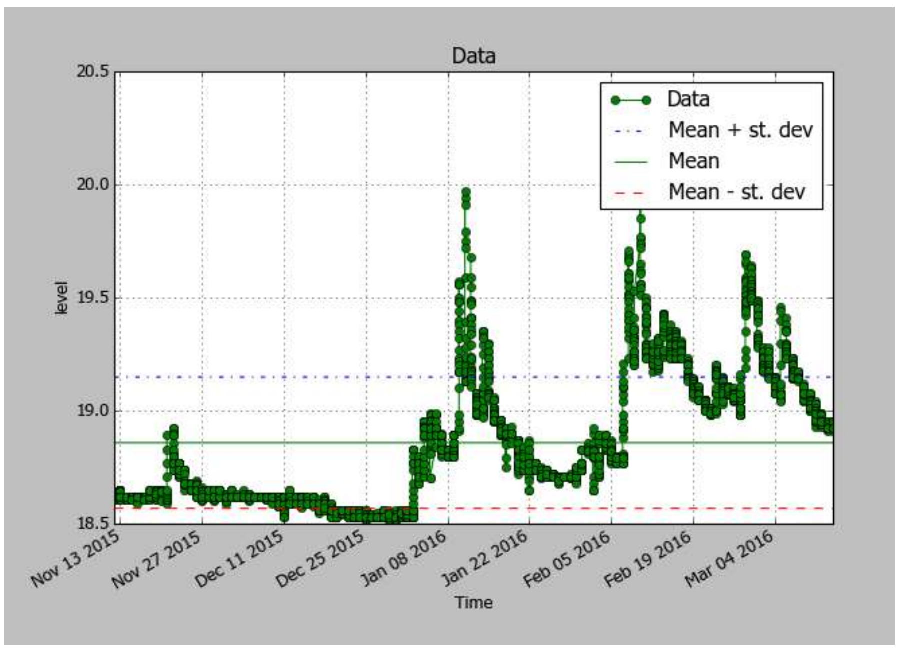


SW Monitoring

GeoDB is connected to the regional Service for Hydrology (a sensor for automated detection of hydrometric level)

Hourly-based data

Data are automatically retrieved and saved in our GeoDB



Edit Data - MarsolPublic (93.145.196.238:5432) - dbmarsol - sw_level_1

File Edit View Tools Help

No limit

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2901	2901	2016-03-12	21:00:06	18.95
2902	2902	2016-03-12	22:00:05	18.95
2903	2903	2016-03-12	23:00:05	18.95
2904	2904	2016-03-13	00:00:06	18.94
2905	2905	2016-03-13	01:00:05	18.94
2906	2906	2016-03-13	02:00:07	18.95
2907	2907	2016-03-13	03:00:06	18.94
2908	2908	2016-03-13	04:00:05	18.93
2909	2909	2016-03-13	05:00:07	18.92
2910	2910	2016-03-13	06:00:06	18.93
2911	2911	2016-03-13	07:00:05	18.95
2912	2912	2016-03-13	08:00:05	18.94
2913	2913	2016-03-13	09:00:06	18.93
2914	2914	2016-03-13	10:00:06	18.92
2915	2915	2016-03-13	11:00:07	18.92
2916	2916	2016-03-13	12:00:05	18.92
2917	2917	2016-03-13	13:00:05	18.91
2918	2918	2016-03-13	14:00:06	18.92
2919	2919	2016-03-13	15:00:06	18.92
2920	2920	2016-03-13	16:00:05	18.92
2921	2921	2016-03-13	17:00:05	18.92
2922	2922	2016-03-13	18:00:05	18.92
2923	2923	2016-03-13	19:00:07	18.92
2924	2924	2016-03-13	20:00:06	18.92
2925	2925	2016-03-13	21:00:05	18.92
2926	2926	2016-03-13	22:00:05	18.92
2927	2927	2016-03-13	23:00:05	18.92
2928	2928	2016-03-14	00:00:05	18.94
2929	2929	2016-03-14	01:00:05	18.95
2930	2930	2016-03-14	02:00:06	18.95
2931	2931	2016-03-14	03:00:06	18.95
2932	2932	2016-03-14	04:00:05	18.94
2933	2933	2016-03-14	05:00:07	18.93
2934	2934	2016-03-14	06:00:06	18.92
2935	2935	2016-03-14	07:00:05	18.94
2936	2936	2016-03-14	08:00:07	18.94
2937	2937	2016-03-14	09:00:06	18.94
2938	2938	2016-03-14	10:00:06	18.93
2939	2939	2016-03-14	11:00:06	18.92
2940	2940	2016-03-14	12:00:05	18.91
2941	2941	2016-03-14	13:00:05	18.95

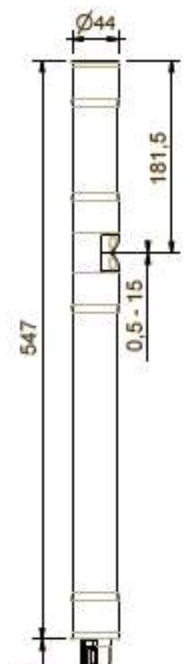
Water quality

Two points to be installed –one gw –one sw using S::CAN SPECTRO::LYSER probe

spectro::lyser™

spectro::lyser™ UV monitors depending on the application an individual selection of: NO_3-N, COD, BOD, TOC, DOC, UV254, NO_2-N, BTX, fingerprints and spectral alarms, temperature and pressure

spectro::lyser™ UV-Vis monitors depending on the application an individual selection of TSS, turbidity, NO_3-N, COD, BOD, TOC, DOC, UV254, color, BTX, O_3, H_2S, AOC, fingerprints and spectral alarms, temperature and pressure



These two (expensive) probes will be used to calibrate the low-data and low-expensive monitoring system and to finalise the alarm system …

However … how to cope with supply in case of pollution accident? NEXT TO COME

Monitoring: critical points, and solutions

An *exciting* but *tough* experience:

we experienced several problems, here summarized.

- Initial WSN Concept was simpler: a *mesh* without a dedicated central point (the Gateway was only 1 simple point in the mesh).
  - Advantage was a lower power consumption
  - Weakness: lower transmission power

However…. It was not possible to implement such a design.

Actually, the main criticality… vandalism!!!

Electronics and Antenna have to be protected, and hidden inside a concrete manhole

→

This implied to find a more powerful scheme for the WSN

… and also a long delay on WSN installation and test

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MAR SOL MANAGED AQUIFER RECHARGE SOLUTIONS

LIMITATIONS

Vandalism

Loss of signals between the sensor and the antenna due to:

- cable connection's;
- concrete or other materials to protect the installations if the antenna is inside the piezometer box – need for lower frequency transmission;

The use of antennas is regulated: population fears

Landowners resistance to allow the installation

Obstacles may require you to use SIM cards

Monitoring: critical points, and solutions

Additional problems experienced, which caused the delay on running the WSN.

- Some problem with moisture/water infiltration, even in manholes
  - ➢ All points have been revised, with exception of Point 4, which has been eliminated from the WSN
- An event of electricity overloading occurred at the central node
  - ➢ Electronics were destroyed and a completely new installation of central node was necessary
- Some problems in the electricity switching system at nodes
  - ➢ This device allows to switch off/on the electronics, to save battery.
  - ➢ The devices broke down (probably they were not suitable for outdoor conditions) and this caused an abrupt consumption of batteries.
  - ➢ In turn, data logging system was compromised, requiring a long additional assistance.
  - ➢ The switching devices have been completely substituted

Monitoring: lesson learned

WSN design and installation have to face (possible) power consumption problems:

- Vandalism problems imply that if solar panels can not be used, another source of energy is needed.
- Car battery is now the solution, but is quite demanding in terms of maintenance

The OPEN solution has great advantages (as stated before).

In the meantime, the *in-house* installation implies a lot of manpower and management of some criticalities, at list for the current stage of prototype.

- It is envisaged that with an industrialized solution a lot of problems may be avoided

WSN: a comparison of costs

Our solution

Single node (datalogger, transimission)	Cost (~ €)
Xbee 2.4 Ghz 1.5 Km 63mW	30
Shield Arduino for Xbee	17
Antenna 1.8 dBi	17
Arduino Leonardo	22
Arduino Proto	7
Relè to switch on/off electricity supply	35
DC Converter	50
Box IP66	34
Total for 1 node	**212**

Central node	Cost (~ €)
Xbee 2.4 Ghz 1.5 Km 63mW	30
Shield arduino for Xbee	17
Antenna 1.8 dBi	17
Arduino Leonardo	22
Arduino Proto	7
DC Converter	50
Box IP66	50
Raspberry Pi	53
SD Memory	10
Modem GPRS	30
Total	**286**

Total for a 6-point WSN	1558

Commercial solution

Single node (datalogger, transimission)	Cost (~ €)
Datalogger D200X client 3 inputs in box IP65.	408
Antenna 1.8 dBi	17
Modem GSM-GPRS for central datalogger	280
Total for 1 node	**705**

Central node	Cost (~ €)
Datalogger D2000X server in box IP65.	1190
Modem GSM-GPRS for central datalogger	280
Antenna 2.4 Ghz (with cable and connector)	190
Total	**1660**

Total for a 6-point WSN	5890

Remark. **In both cases:**

- **No cost for manpower is considered**
- **Batteries and probes are not included, since they do not differ**

- **the great advantage is the OPEN SOLUTION: you get data in XML format, which can be connected with any standard**
- **This is of great importance if dealing with interoperability and standardization, like WaterXML, for instance.**

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MAR SOL MANAGED AQUIFER RECHARGE SOLUTIONS

Task 8.3: **Decision Support System development and testing** (TEA, SSSA)

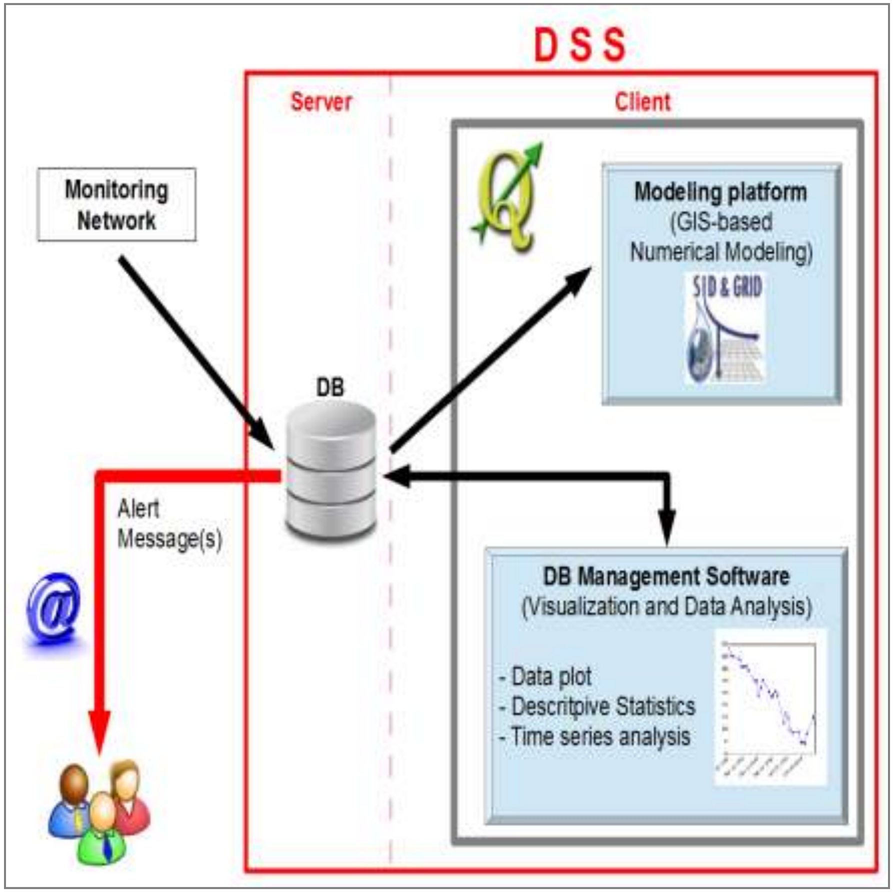
DSS (**Decision Support System**) aiming at:

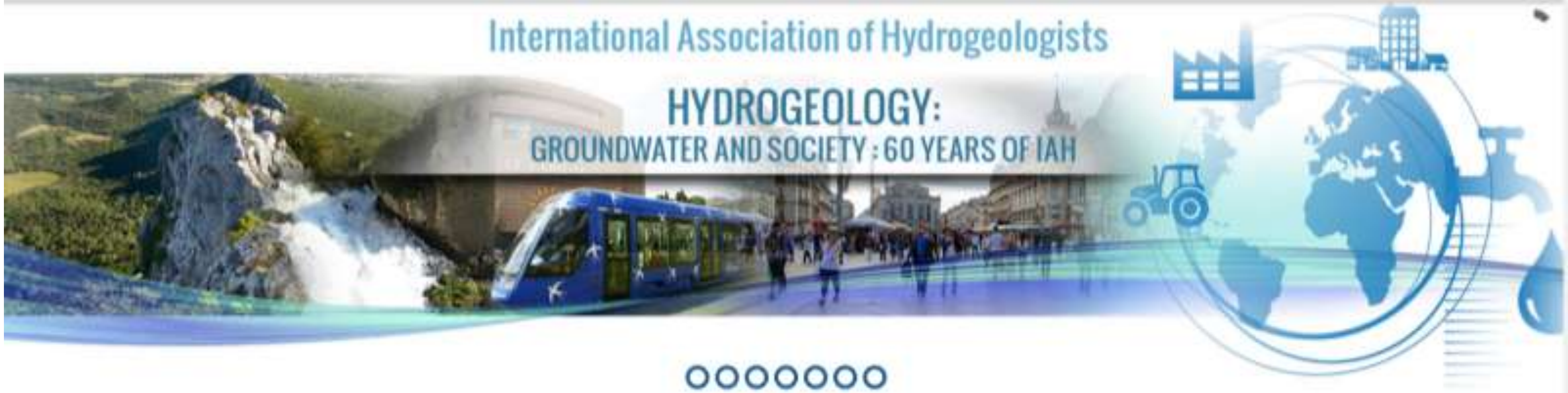
(a) Controlling and analyzing measured parameters

(b) Suggesting new scenarios for RBF plant

The DSS consists of 4 main pillars:

1) Alert system service
2) Short-cut modeling (directly included in DB, as stored procedures)
3) (GIS-embedded) statistical data analysis
4) (GIS-integrated) numerical modeling





Session 6.02 - Treated Waste water REUSE for groundwater recharge: addressing the challenge

Water scarcity and the overexploitation of conventional water resources are two of the main drivers to treated wastewater (TWW) REUSE. TWW groundwater recharge projects are blooming in the world especially in coastal areas and in the Mediterranean area where increasing pressures on the resource cause deep depletion and high salinization impacts. TWW can either be directly reinjected or indirectly through dedicated infiltration basins (Northern Gaza strip, Tunisia, ...). This practice enables to restore groundwater in terms of quantity and quality, but also to limit salt intrusion and mitigate climate change impacts. TWW could then be pumped from the groundwater for indirect surface reuse like agricultural irrigation. Ground properties are used and considered as a way to improve TWW quality (Korba in Tunisia) but most of the time much attention is often paid to TWW quality (pathogens, salinity, etc.) prior to recharge to avoid groundwater contamination.

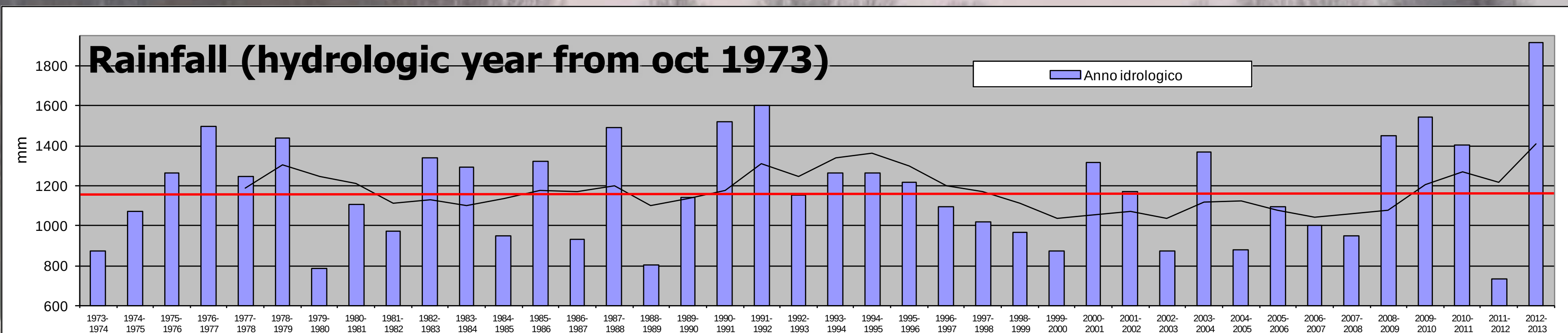
Thank you!

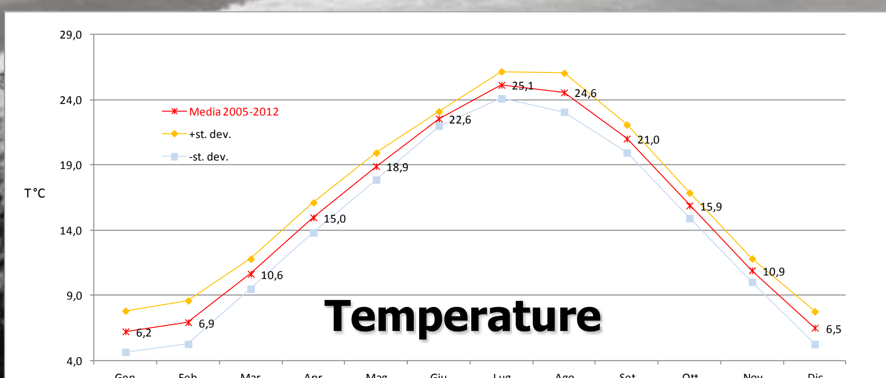
MAR SOL MANAGED AQUIFER RECHARGE SOLUTIONS

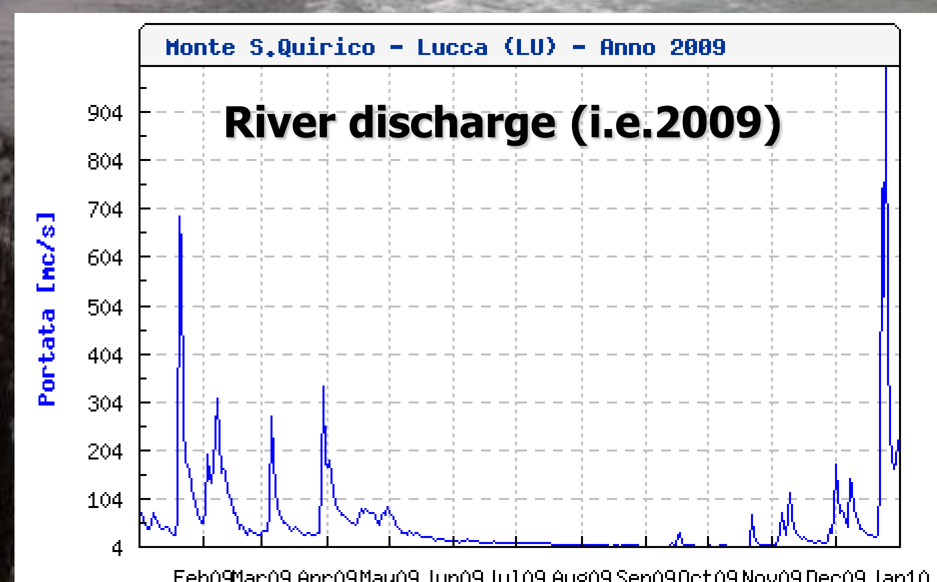
European Commission

EIP Water Online Market Place
Matchmaking for water Innovation
MAR Solutions - Managed Aquifer Recharge Strategies and Actions (AG128)

Some hydrological data







Task 8.2: **Demo site analysis** (UFZ, SSSA, Lucca) / to be completed, refined

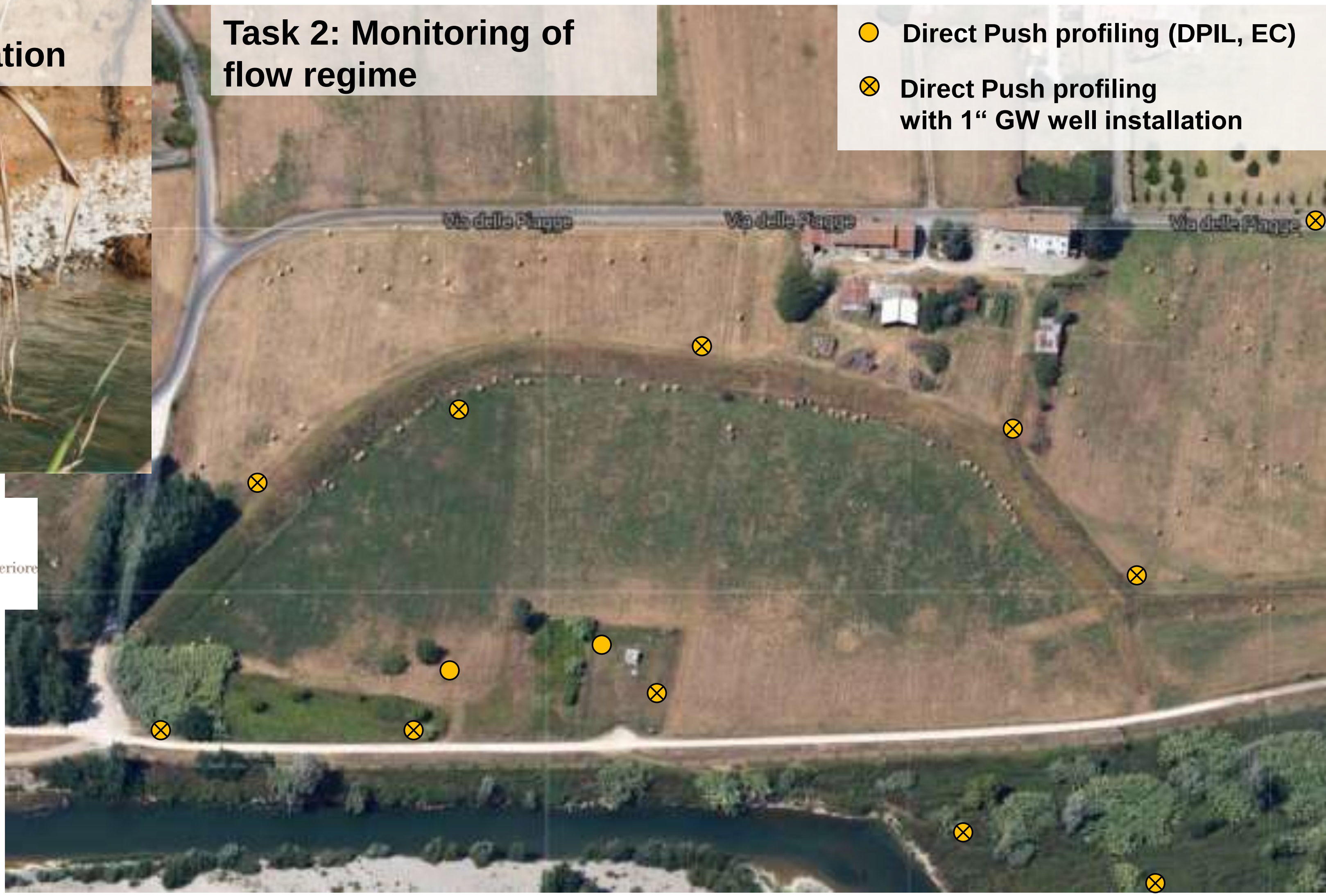
- Site investigation performed between May and September 2014
- Several preliminary issues to be dealt with:
    - UXO clearance
    - utility clearance
    - landowners resistance to collaborate due to results of a previous LIFE project

*great help from Lucca Province (not with landowners !) ://

Task 8.2: **Demo site analysis** (UFZ, SSSA, Lucca) / to be refined

Serchio River well field: Understanding well field hydraulics for Managed Aquifer Recharge

Task 1: Subsurface Characterization



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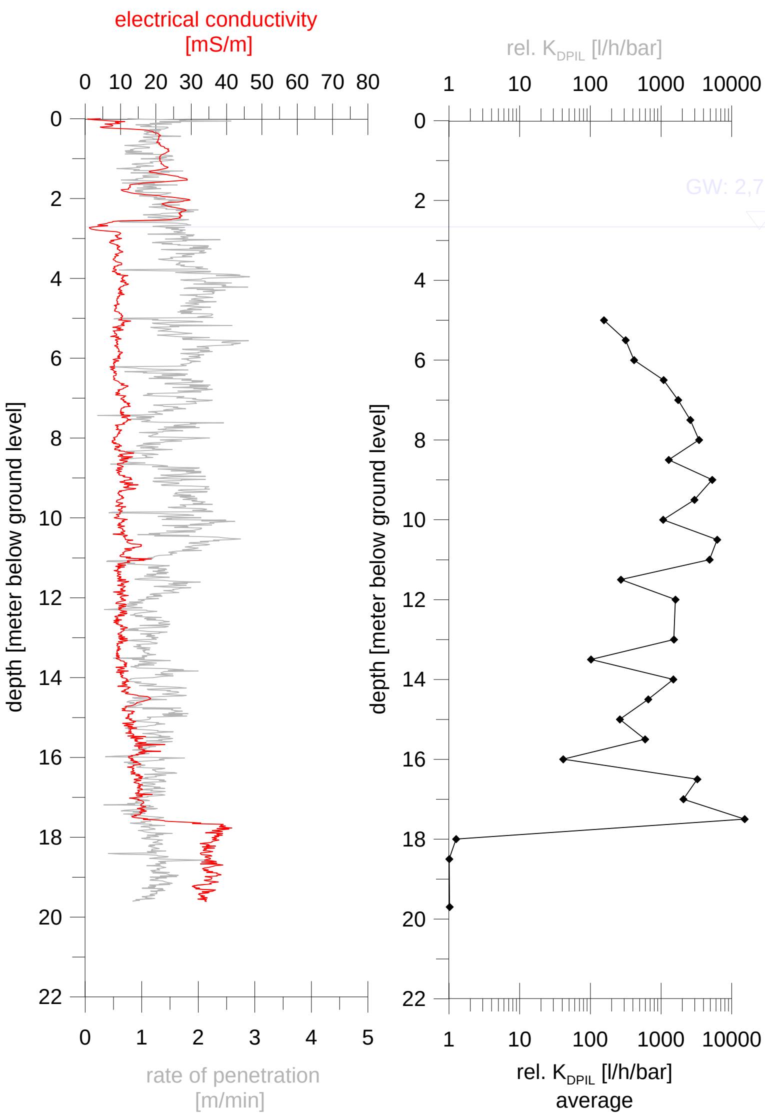
HELMHOLTZ CENTRE FOR ENVIRONMENTAL RESEARCH - UFZ

Serchio River well field: Understanding well field hydraulics for managed aquifer recharge



Direct Push Electrical Conductivity Logging

Direct Push Injection Logging