



**HAL**  
open science

## Using high-resolution electrical resistivity maps in a watershed vulnerability study

Michel Dabas, Thomas Jubeau, Dominique Rouiller, Jean-Marie Larcher, Séverine Charriere, Thibault Constant

► **To cite this version:**

Michel Dabas, Thomas Jubeau, Dominique Rouiller, Jean-Marie Larcher, Séverine Charriere, et al.. Using high-resolution electrical resistivity maps in a watershed vulnerability study. *First Break*, 2012, 30 (8), pp.51-56. hal-02922141

**HAL Id: hal-02922141**

**<https://hal.science/hal-02922141>**

Submitted on 27 Aug 2020

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

**Title:**

**Using maps of high-resolution Electrical Resistivity in a Watershed Vulnerability Study**

**Authors:**

DABAS Michel<sup>1</sup>, JUBEAU Thomas<sup>1</sup>, ROUILLER Dominique<sup>2</sup>, LARCHER<sup>2</sup> Jean-Marie, CHARRIERE Séverine<sup>3</sup>, CONSTANT Thibault<sup>3</sup>

1: GEOCARTA,  
5 rue de la Banque, 75002 Paris,  
[dabas@geocarta.net](mailto:dabas@geocarta.net)

2: AXERREAL,  
Service Développement EPIS CENTRE, Domaine du Chaumoy  
18570 Le Subdray,  
[drl@episcentre.com](mailto:drl@episcentre.com)

3: IN VIVO AGROSOLUTIONS,  
83 avenue de la Grande Armée 75782 Paris Cedex 16,  
[scharriere@invivo-group.com](mailto:scharriere@invivo-group.com), [tconstant@invivo-group.com](mailto:tconstant@invivo-group.com)

Corresponding author: Michel Dabas

## **Keywords:**

geophysics, electrical resistivity, high spatial resolution, near-surface, soil science, diffuse pollution, contamination, catchment area, vulnerability, groundwater protection.

## **List of figure caption:**

Fig. 1 - ARP© in action

Fig. 2 - ER Map superposed on DEM

Fig. 3 - ER Map ARP© channel 2

Fig. 4 - Sorted resistivity map split into zones (white lines) and location of soil observations (pink dots)

Fig. 5- Scheme showing the improvement of data quality due to geophysics for Ambleville case study vulnerability

Fig. 6- Interpretative scheme of the method used on the CA of Ambleville

## **List of Tables:**

Table 1- Parameters of DRASTIC method for the estimation of groundwater vulnerability

## **Abstract:**

This paper illustrates the contribution of high-resolution geophysics and specifically apparent Electrical Resistivity (ER) at three depths of investigation (ARP(c) system) through the study of intrinsic vulnerability of a Catchment Area (CA). This CA is situated near Ambleville (Oise Valley, NE of Paris, France) and the study is carried out for *Conseil General* of the Oise Valley and *Agence de Bassin Seine Normandy*. This study made it possible to specify: topography; pedology (texture, clay content, permeability, depth of occurrence of basement (bedrock or parent material)) and geology (litho stratigraphy, faults) with a spatial resolution of the order of 12m using ER maps. Three apparent ER maps were aggregated in a single Composite Map which was further calibrated by auger borings. Knowing these elements, it was possible to inform the method of description of vulnerability (DRASTIC) with: conditions of refill of the basin; zones of outcrops; geological undulations; nature and thickness of protection layers and/or the unsaturated zone; permeability of the surface layers and to define their participation into the hydro-geologic processes within the basin. The final agro-pedological map of intrinsic vulnerability of the Catchment Area was carried out in a GIS with high-spatial-resolution (12m). The produced data will be used by farmers for intra-field modulation of the inputs.

## **Introduction:**

The EEC regulation 2000/60/CE lays down ambitious objectives as regards to the re-conquest of the quality of drinking water. The State Members must ensure the protection of water catchments area in order to prevent the deterioration of their quality and to reduce the degree of treatment necessary to the production of drinking water. For this purpose, they must establish protected areas for these water catchments.

In order to better define the action plans and to target and treat on a hierarchical basis the territories of action within the protection zones, it is also necessary to define within the catchment area the most vulnerable zones to diffuse pollution. Within the framework of Grenelle agreements for the environment, 507 water catchments were selected and defined as needing a protection in France.

In the case of the Catchment Area of Ambleville (Oise Valley) and for its nomination as a priority Catchment within the Grenelle, complementary studies were necessary to refine the understanding of his functioning. Local water catchments use springs of the Lutecian limestone and show a rate of high nitrate and pesticides. The close environment is characterized by both dwellings and arable lands. The arable surface is estimated at 382ha. The objective is to carry out agro-pedological maps and intrinsic vulnerability maps of the Catchment Area of Ambleville (450ha) in order to refine the comprehension of hydrogeologic/geological processes linked to the pedology of the basin. The originality of this study was the coupling between three partners: Geocarta for the establishment of the geophysical mapping with ARP© and WebSIG, EPIS CENTRE/AXERREAL in charge of the establishment of the agro-pedological maps and InVivo AgroSolutions in charge of hydrogeologic interpretations and the establishment of the intrinsic map of vulnerability of the water table.

### **Geophysical layer : the 3 ER Maps**

The intrinsic vulnerability is function of a certain number of parameters like: presence and thickness of the superficial layers, global pedology of the Catchment Area (CA), absolute values of the slopes and their lengths, position of the principal axes of fracturing. Obtaining these data quickly and at a reasonable price for feeding models is one of the most challenging questions in order to get accurate vulnerability maps. Spatial resolution of these data is also another point: variations in the subsurface parameters are often at very short wavelength (a few meters). Consequently the resolution of the input data to any prediction model should be of the same order.

These parameters were acquired indirectly by geophysical measurements using a new system for high resolution mapping of large areas (>100ha) designed primarily for Precision Farming (PF); the ARP© system (Dabas, 2009) (ARP stands for Automatic Electrical Profiling). This device was towed all over the free agricultural surfaces (475ha) within a few days. It makes possible to bring spatialized information (resolution down to 10m) all over the catchment area thanks to the mapping of apparent Electrical Resistivity (ER) with 3 depths of investigations together with acquiring the Digital Elevation Model (DEM).

It is established that geoelectrical mapping has proven to be useful in detecting soil spatial variations which often can be related to soil properties relevant for plant growth (Dabas et al., 1989). For instance, soil ER is linked to: soil salinity, soil texture, cation exchange capacity, soil moisture, organic carbon, pH, Bulk density, nitrate content, soil types (Gebbers et al., 2009). Whereas the influence of salinity normally plays a minor role under temperate conditions, clay content and water content are usually the most important factors causing spatial variation in ER.

ER is already used in specific topics like Precision Farming (definition of Homogenous Zones, prediction of Yield, Management of N input, etc.), Soil Science (optimized soil survey and guided sampling) and of course in 'standard' geophysics for finding water tables, stratigraphy mapping, detection of voids and buried structures, etc.

Its use for watershed studies is not yet developed and the aim of this study was to use the three maps of ER (and DEM) as an ancillary variable for the other variables needed in the vulnerability model.

In electrical methods, an electrical current is injected in the soil by means of a pair of electrodes. This current is either a D.C. current or a slow alternating current (several Hertz) to avoid polarization effects and/or eddy currents. The current flow in the whole volume of the soil and sub-soil and its spatial distribution is a function of the spatial distribution of the electrical resistivities.

As the soil is rarely uniform, geophysicists use the term apparent electrical resistivity to name the 'average' resistivity of the volume where the current is able to flow. This spatial distribution is measured by two or more electrodes on the ground surface, which measure the resulting voltage. The ratio of the voltage to the current, multiplied by a constant (the geometrical factor which takes into account the orientation of the 4 electrodes) is the apparent electrical resistivity. Because subsurface materials have generally different resistivities, measurements at the surface of the soil can characterize the vertical and horizontal distribution of underlying structures. Typical resistivities span from 2 Ohm.m (clay soils) to several hundreds Ohm.m or even thousand Ohm.m over crystalline or metamorphic areas. Generally, resistivity of subsurface materials is higher than soil resistivities in nearly all cases due to, broadly speaking, a lower amount of water.

These measurements are slow because operators should manually insert the four electrodes in the ground. As it is not possible by air-borne systems to measure correctly ER within the first two meters, we had to develop a new towed platform for measuring continuously the ER: the ARP© system. For this purpose, we have to:

- Design a resistivimeter which can cope high contact resistance, have the best time response and easy to operate in the field,
- Design a mechanics that can be used as rolling electrodes and towed by an all-terrain vehicle even in very harsh environments,
- Design a hardware and software to drive the instruments, help the operator while driving (auto-guidance) and also makes the real time Quality Check of ER and positioning parameters.

Consequently, the innovation lies in a continuous measurement of ER by a specific device (resistivimeter and spiked wheels acting as electrodes) towed by an all-terrain vehicle (Quad bike, 4x4, farm tractor). Positioning is ensured by GPS (differential or RTK). Measurements are taken every 10cm along the profiles with three depths of investigation (0 to 50cm, 1m and 2m). The final resolution of the cartography depends on the distance between two profiles.

The ARP © (Dabas, 2009) was commercially developed for agriculture by a spin-off from CNRS in 2001: Geocarta following previous work in CNRS (Dabas et al., 1997 and 1998). Several improvements were added like absolute positioning by a dGPS or RTK GPS, possibility to acquire 3 measurements at the same time corresponding to 3 depths of investigation ( 0 to 0.5; 0 to 1 and 0 to 1.7m) at a speed up to 6m/s with a spatial resolution of 10cm along the profiles (Fig 1).



*Fig. 1 - ARP© in action*

In open-field areas, up to 80 ha can be surveyed in a day. In standard conditions, number of measurements in one hectare is around 30 000 (inter-profile of 10m, measurement along profile every 10cm). The average velocity of data acquisition is around 4m/s (1ha = 5 minutes of survey!).

There are now seven generations of ARP systems working in the field. Most of them are built for specific applications.

Figure 2 shows the electrical image obtained for channel 2 (depth of investigation of the order of 1m) superposed on the DEM acquired at the same time as the resistivity (high resistivities in red corresponding to outcrops of limestone and/or very superficial soils and in blue low resistivity zones corresponding to clayey soils).

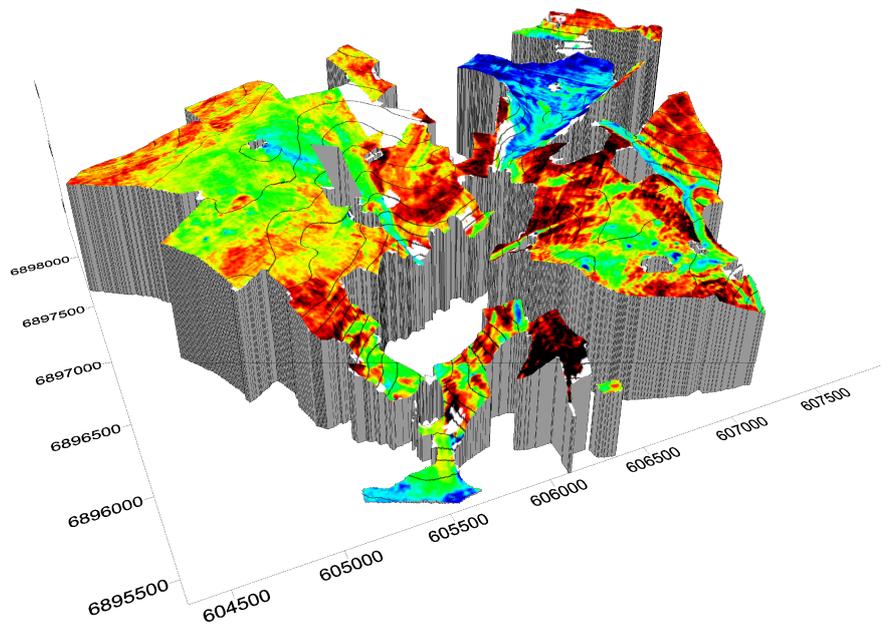


Fig. 2 - ER Map superposed on DEM

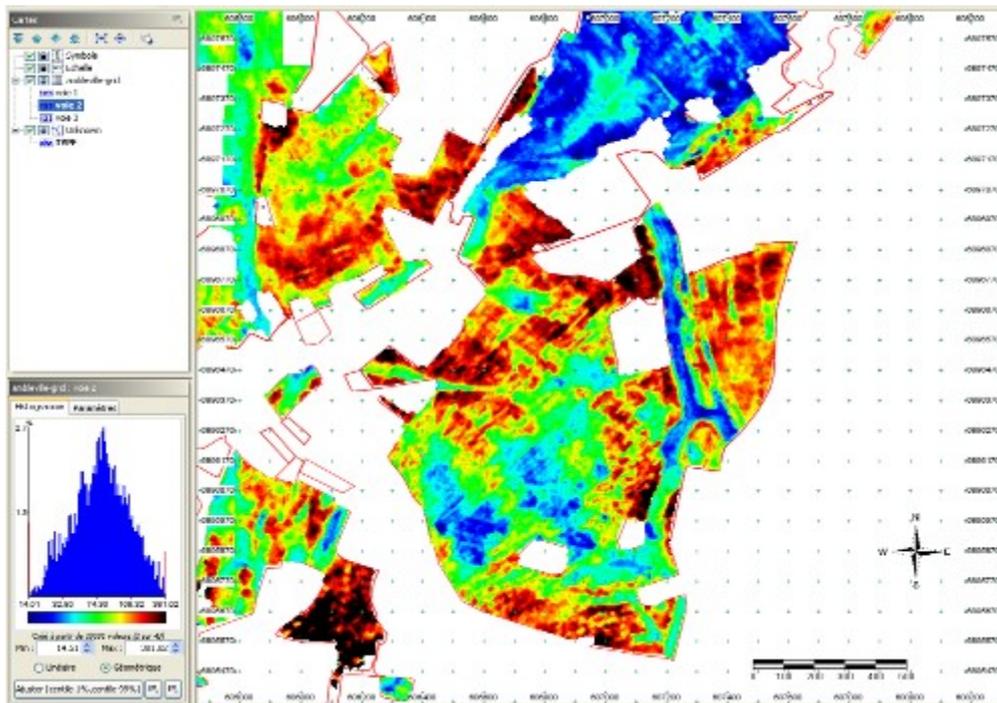


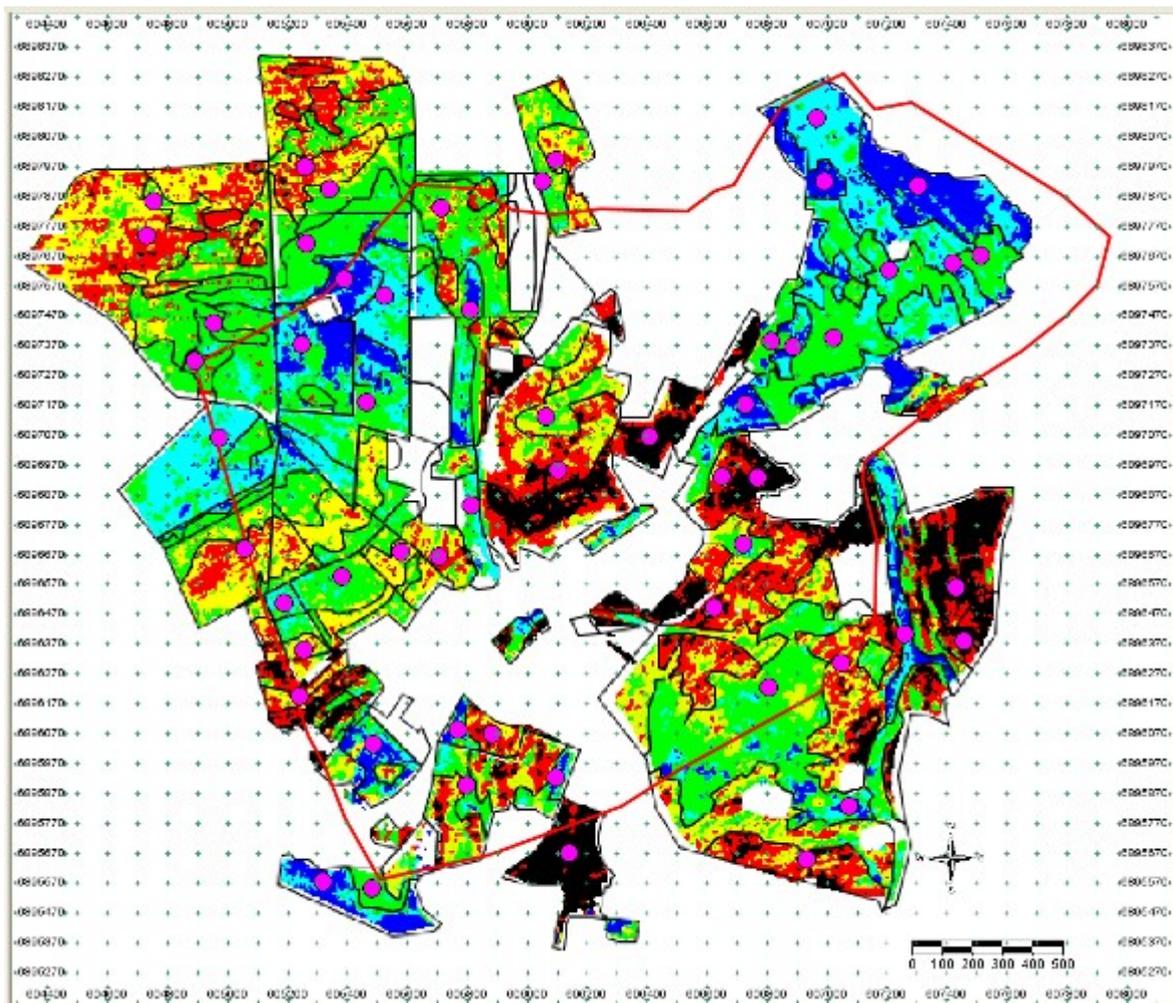
Fig. 3 - ER Map ARP© channel 2

Figure 3 shows the ER map (5m grid resolution) output of the GIS with resistivities spanning from 15 to 380 Ohm.m. For example distinctive anomalies show up clearly like Thalwegs (linear feature in blue), fracturation of the bedrock (direction N44 to the West and N0 to the East of the Thalweg), outcrops of limestone (in black-red), difference in clay content, etc...

The next step is now to transform this map into a pedological map.

### **From ER Maps to the Composite Map and Soil Map**

After the electrical survey, in order to characterise the soil units, a soil survey must be carried out. First the three apparent electrical data corresponding to the three depths of investigation are processed to synthesize it onto one single map. Unfortunately three points are not enough to carry a full inversion process in order to get the true ER. Consequently, we have developed a simple algorithm in order to merge the three apparent ER maps : for each depth of electrical measurements, the data is sorted into groups of equal resistivity. For the CA of Ambleville, the data were sorted into four classes for each depth of investigation: Low (L), Medium (M), High (H) and Very High (VH). The resulting composite map has potentially 64 Values but a clustering is done between similar classes so that at the end only 6 main classes remain. By agregation of the 3 depths of investigation, this composite map shows the area characterised with equivalent vertical electrical profiles. The result is shown on figure 4.



*Fig. 4 - Sorted resistivity map split into zones (white lines) and location of soil observations (pink dots)*

The colour code is as follow:

- Blue: L,L,L
- Sky blue: M,M,L
- Green: M,M,M
- Yellow: M,H,H
- Red: H,H,H
- Black: VH,VH,VH

The aim of the soil survey is now to convert this electrical profiles into soil profiles. Unfortunately, we have to describe the soils, in situ, with auger observations. For the 475ha, it required a three-day survey and 59 auger borings were carried out. Some of the borings proved unnecessary, but prudent to check the validity of the Composite Map, and to be certain that the same colour (class) in different areas corresponded to the same soil unit. The first analysis of the soil observations shows that 30 auger borings were sufficient to describe the CA, thus reducing the length of the survey to one and a half day.

Finally, three main soil units were observed: deep clayey soils (Low resistivity/blue), deep silty loam soils (medium and low resistivity after 40 cm/sky blue) and shallow depth calcareous soils (high resistivity/yellow, red and black). The green colour also corresponds to silty loam soils but the parent material (limestone bedrock), in this case, is never deeper than 80 cm.

Therefore, for each soil area, we were able to provide DRASTIC method with all the data required to establish computerised vulnerability maps, such as: soil layer texture and thickness, the range of stoniness (limestone flags), potential implanting depth and soil water potential.

#### **Interpretation in terms of vulnerability of groundwater to pollution**

The methodology used in the estimation of the vulnerability of the Catchment Area of Ambleville is DRASTIC, which incorporates seven parameters of vulnerability (Aller et al, 1987). Studies for similar agricultural environments have already been carried out (Barber et al., 1994).

Each of these seven parameters (see Table 5) is spatialized and represented under a GIS (Geographical Information System), then weighted and assembled into a final map with a vulnerability scale from 1 (low vulnerability) to 10 (high vulnerability). We show here only the final results.

Symbol	Parameters	Properties	Weight
D	Depth of the watertable	Over this depth, the higher the contaminant takes a long time to reach the water table.	5
R	Net recharge	Primary vehicle for the transport of the contaminant. Plus this refill, the greater the risk of contamination is high.	4
A	Lithology of the aquifer	Characterized by the size of the saturated soils or their degree of cracking. It is involved in the trapping of the pollutant that may escape the absorption capacity of the soil.	3
S	Soil	The more the soil is rich in clay and organic matter, the greater the absorption of metals and cations is important, and the protection of groundwater is high.	2
T	Topography	The steeper the terrain, the greater the runoff is important and therefore the groundwater contamination is low,	1
I	Unsaturated zone	Its impact is determined from the texture of the land within it. The percolation of the contaminant to the water table is all the greater that is favorable texture (gravel, coarse sand ...).	5
C	Permeability	The more this parameter is big, the greater the transfer of the pollutant is fast.	3

*Table 1- Parameters of DRASTIC method for the estimation of groundwater vulnerability*

The contribution of the geophysical surveys, soil interpretation and implementation of the DEM has provided :

- an increase of the accuracy of maps related to pedology (R, S) and geology (A, C),
- an increase of the accuracy of the topographical map of the area (T) and consequently the map of the depth of the aquifer (D), with the finest DEM

Finally, maps of parameters D, R, A, S, T and C are refined and we have computed that about 78% of the final result of the vulnerability map was refined (with the weights chosen).

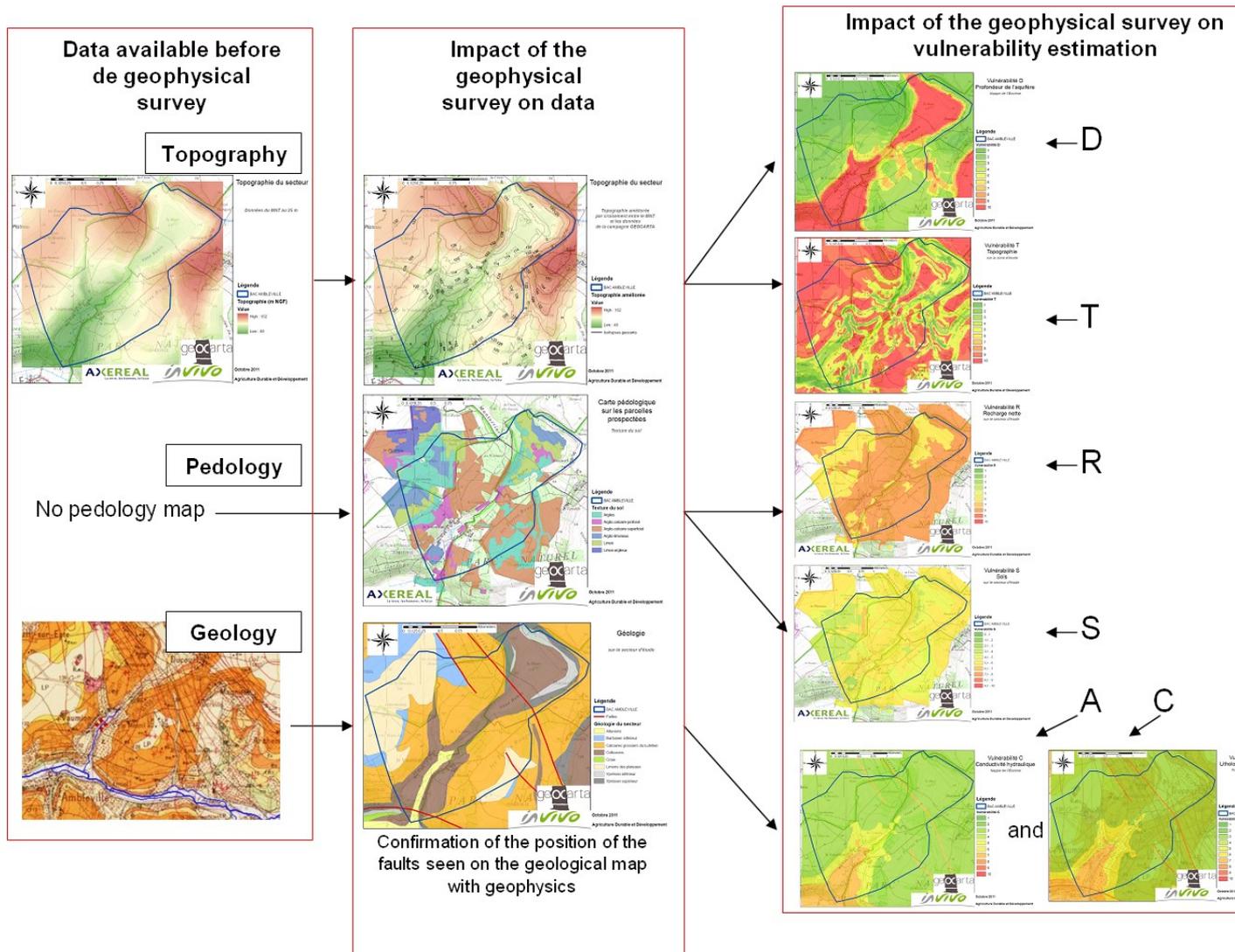


Fig. 5- Scheme showing the improvement of data quality due to geophysics for Ambleville case study

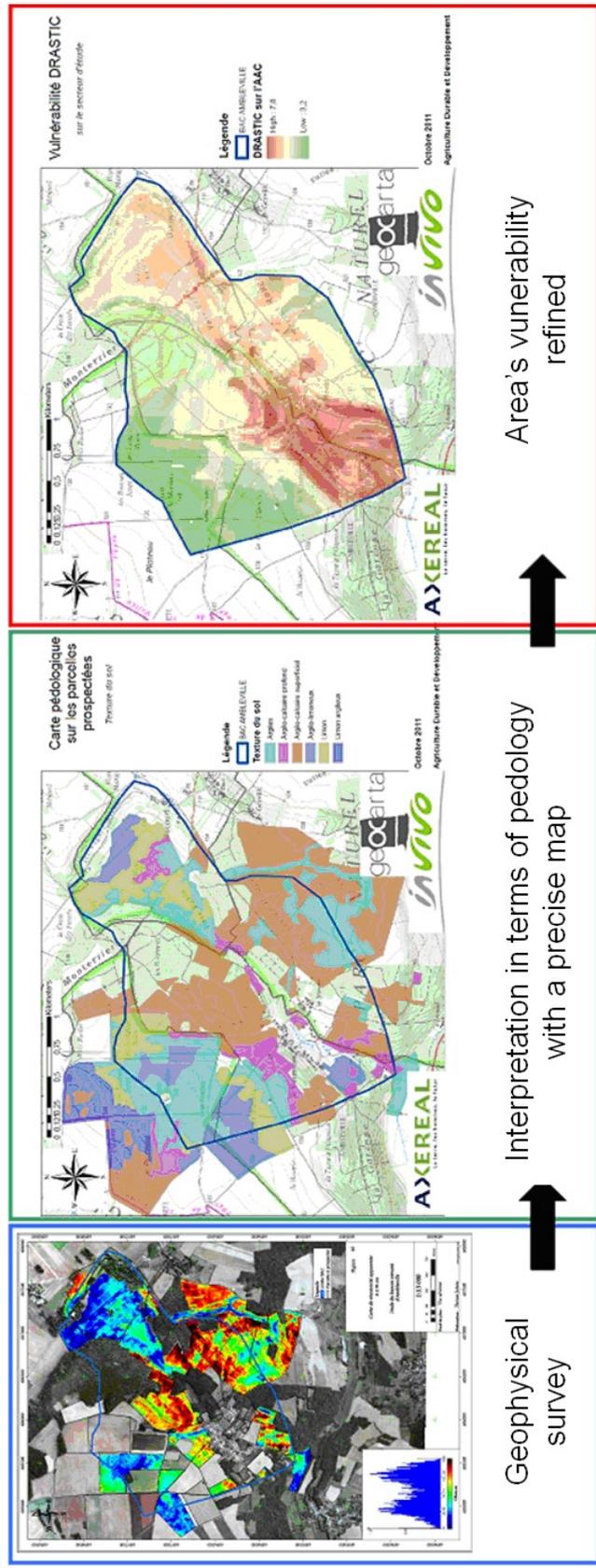


Fig. 6- Interpretative scheme of the method used on the CA of Ambleville

## Conclusion:

We have shown in a practical example over an agricultural area of 450ha that it was possible to better predict the vulnerability to diffuse agricultural pollutions. The method used was the DRASTIC model. The data of this model were refined through the use of an extensive geophysical survey with a very high spatial resolution of 12m. This electrical survey was carried out by an ARP(c) towed system within a week and a pedological survey in two days. These two surveys have brought several informations which are used by the DRASTIC model mainly DEM and soil units. The definition of the vulnerability zones is now done with a spatial resolution of the order of 10 meters and the increase of accuracy has been estimated of the order of 80%. The management of pollution in agricultural areas can be associated to the direction given by Precision Agriculture (Pag) in the management of fertilizers and phytosanitary products. Clearly the low cost acquisition of ER data developed for Agriculture in the context of Pag can benefit studies related to the hydrologic processes.

This study was conducted for *Conseil Général* of Val d'Oise and partially funded by *Agence de l'Eau Seine-Normandie*.

## References:

Aller, L., Bennet, T., Lehr, J. H. and Petty, R. J. [1987] DRASTIC: a standardized system for evaluating groundwater pollution potential using hydrogeologic settings. US EPA Report 600/2-85/018. US Environ. Protection Agency.

Barber, C, Bates, L. E., Barron, R. and Allison, H. [1994] Comparison of standardized and region-specific methods for assessment of the vulnerability of groundwater to pollution: a case study in an agricultural catchment. In *Proc. Water Down Under 1994 Conference*, Part I, 1, 2 7 9 - 2 8 3. National Conf. Publ., Inst. of Engineers, Australia.

Dabas, M., Hesse, A., Jolivet, A., Tabbagh, A., Ducomet, G. [1989] Intérêt de la cartographie de la résistivité électrique pour la connaissance du sol à grande échelle. *Science du Sol*, 27, 1, 65-68.

Dabas, M., Hesse, A., Jolivet, A., Panissod, C., Tabbagh, J., Tabbagh, A. [1998] Recent developments in shallow-depth electrical and electrostatic prospecting using mobile arrays. *Geophysics*, 63, 5, 1542-1550.

Dabas, M. [2009] Theory and practice of the new fast electrical imaging system ARP©, in *Seeing the Unseen*, Geophysics and Landscape Archaeology, Campana and Piro (Eds.), CRC Press, Taylor and Francis Group, 105-126.

Gebbers, R., Lück, E., Dabas, M., Domsch, H. [2009] Comparison of instruments for geoelectrical soil mapping at the field scale. *Near Surface Geophysics*, 7, 179-190.

Panissod, C., Dabas, M., Jolivet, A., Tabbagh, A. [1997] A novel mobile multipole system (MUCEP) for shallow (0-3m) geoelectrical investigation: the 'Vol-de-canards' array, *Geophysical prospecting*, 45, 983-1002.