



# Participatory tool to improve knowledge, management and protection of the karstic chalk aquifer system in Eastern Normandy

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# Participatory tool to improve knowledge, management and protection of the karstic chalk aquifer system in Eastern Normandy

*Pierre-Yann DAVID, Didier PENNEQUIN, BRGM Regional Direction of Normandy*

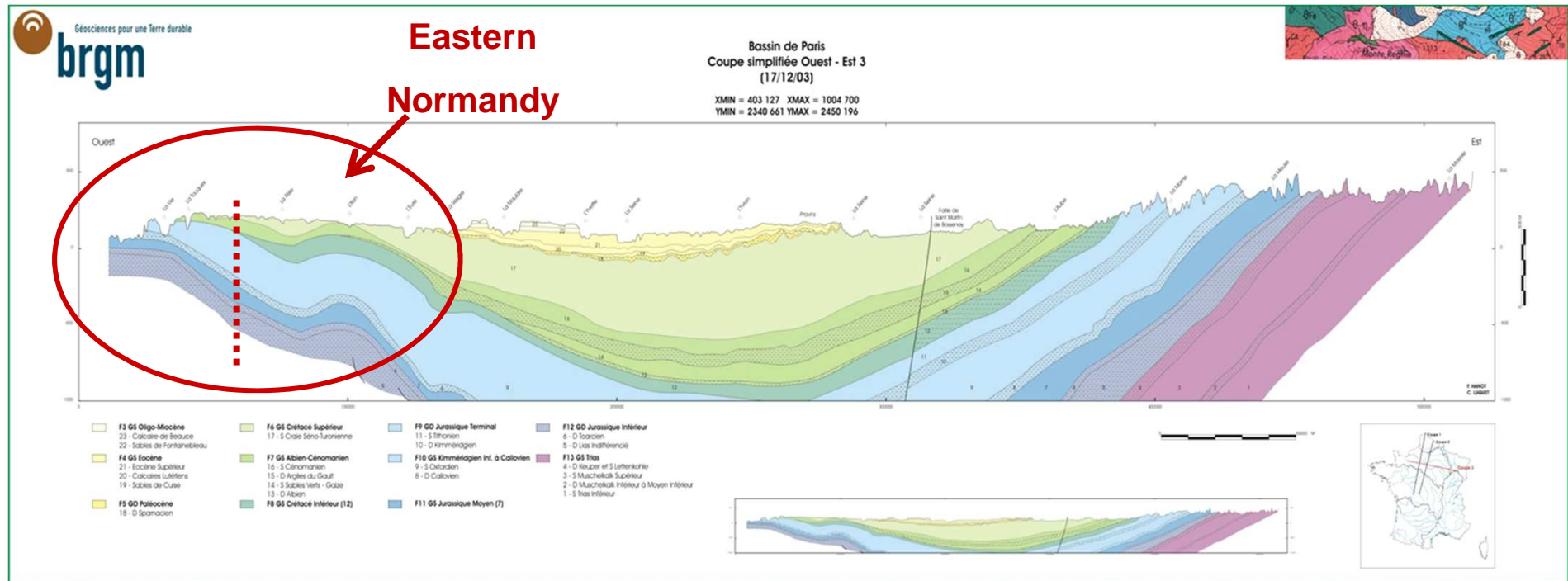
*24<sup>th</sup> of June 2015, KG@B*



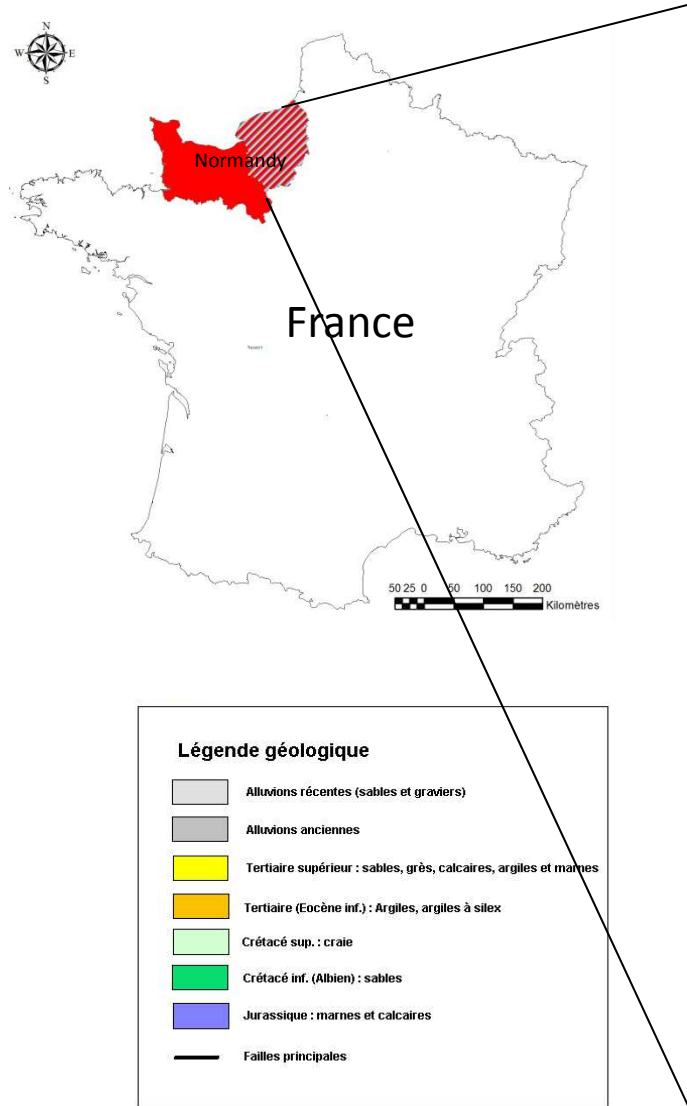
*BRGM, Regional Direction of Normandy, 14 route d'Houpeville 76130 Mont-Saint-Aignan, France  
py.david@brgm.fr ; d.pennequin@brgm.fr*



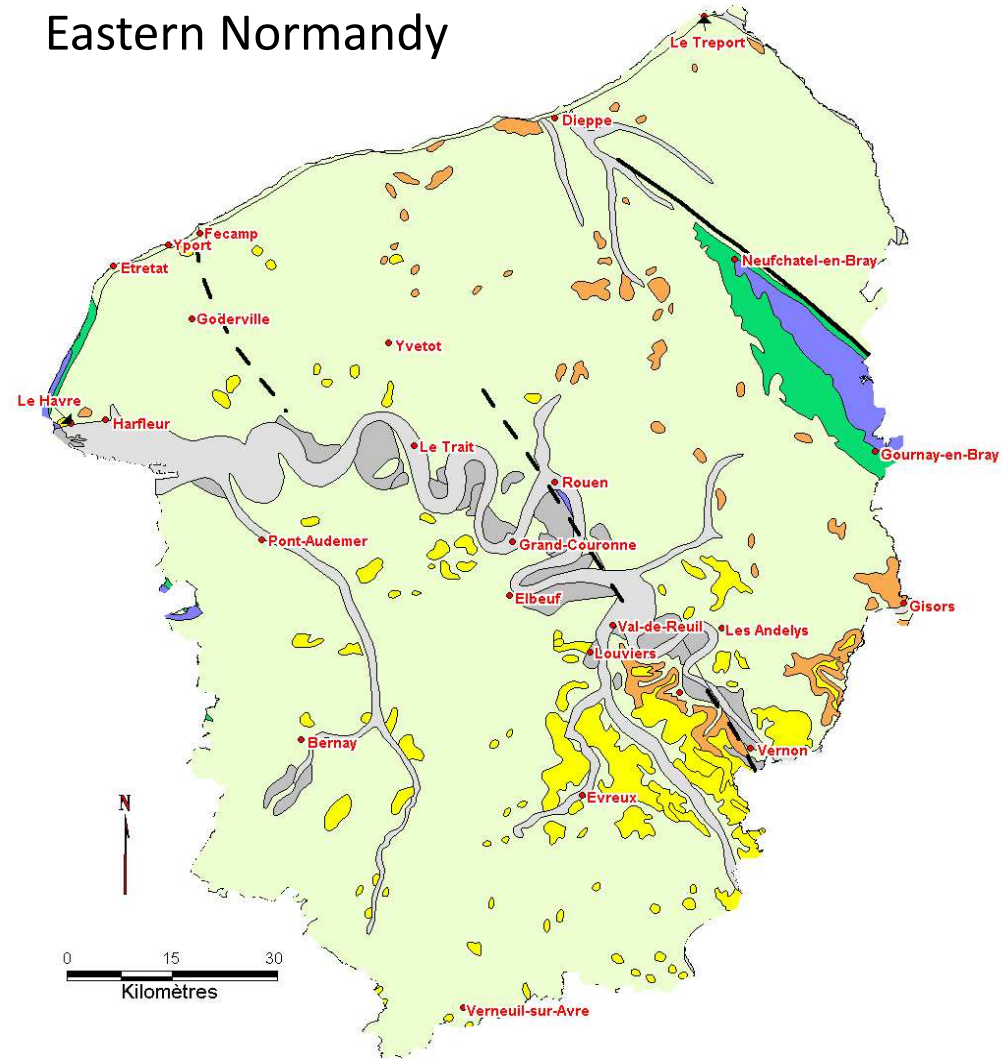
# Eastern Normandy karstic context



# Eastern Normandy karstic context



## Eastern Normandy

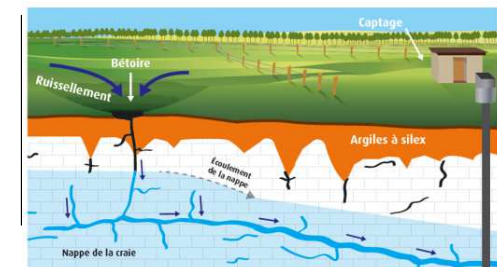
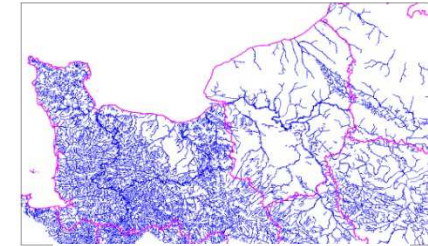


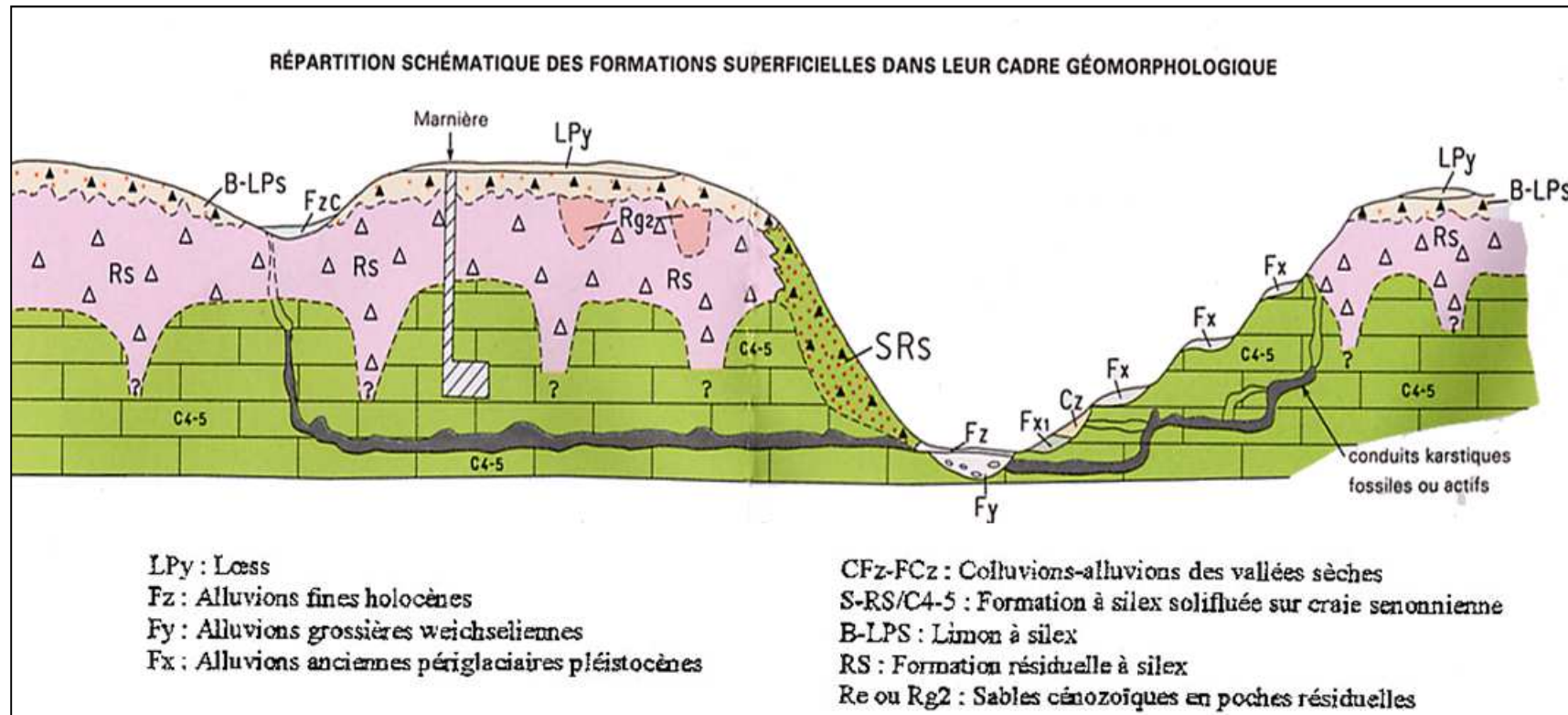


# Eastern Normandy karstic context



- Low density river network : rain water mostly infiltrates and some catchments don't have any permanent river
- Karst generates natural collapse structures at the ground surface (locally called « bétoires ») which constitute entrance points for rain and surface water into the chalk aquifer system
- During intense rainfall episodes, sinkholes represent preferential transport vectors for suspended solids (SS) coming from erosion processes, as well as for pollutants including those issued from plant healthcare products, such as fertilizers and pesticides
- Sinkholes are also sometimes, either deliberately or accidentally, outlet points for drained agricultural land, road wastewater networks and wastewater treatment plants
- Karst conduits connected to the sinkholes, rapidly transfer particles and pollutants to the chalk aquifer system and thereby to the well fields used for drinking water purpose.
- 100% of drinking water comes from groundwater





Typical cross-section of Chalk and upper formations in Eastern Normandy  
(QUESNEL F., 1997)

# Eastern Normandy karstic context



Different sinkhole morphologies can be observed in the landscape :



**toire n°10129** : béttoire fraîchement ouverte – mottes d'herbes effondrées encore visibles dans la toire (observation BRGM du 26/11/2009)



**Doline béttoire n°10867** : doline béttoire de grande dimension : profondeur 6m et diamètre 10m environ (observation BRGM du 27/11/2009)



2 béttoires nouvellement formées dans l'axe d'un talweg dans le secteur de Fontaine-le-Dun le lendemain de fortes précipitations (observation BRGM de janvier 2009)



**Doline béttoire n°8098** : observation de ravinements et de ruissellements s'engouffrant dans la béttoire (observation BRGM du 27/11/2009)





# Eastern Normandy karstic context



Sometimes with strange use !!!





# Sinkholes and the stakeholders...



**This karst context forces many watershed stakeholders to act on « betoires » (sinkholes):**

- **Some tend to clog out or mud off sinkholes :**



Sinkhole  
Under a Road



Sinkhole  
appeared  
in an infiltration  
pond

- Authorities in charge of road maintenance to prevent road from collapsing

- Communities in charge of drinking water resources management, to prevent groundwater from being polluted

- Communities in charge of wastewater treatment when a sinkholes appear in the bottom of treated wastewater infiltration ponds

- Farmers when sinkholes appear in the middle of their fields

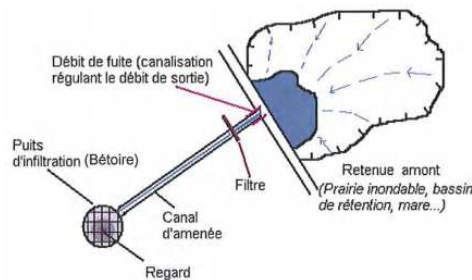


# Sinkholes and the stakeholders...



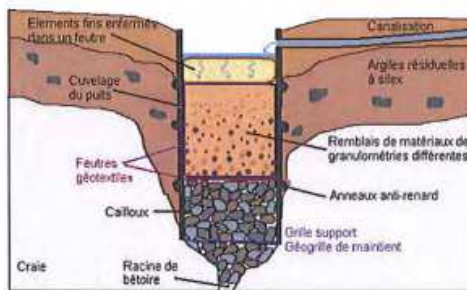
This karst context forces many watershed stakeholders to act on « betoires » (sinkholes):

- Some act to keep the sinkholes infiltration capacity :

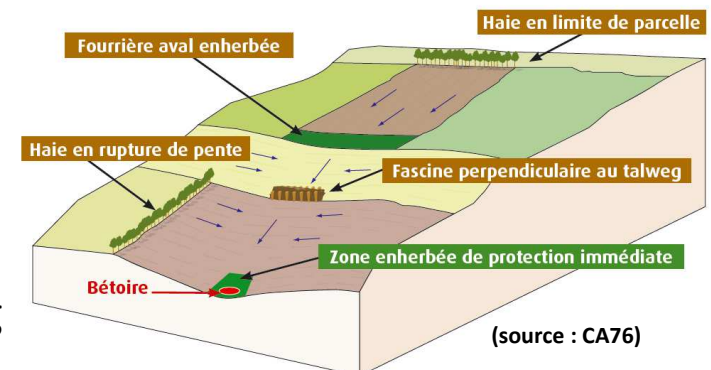


■ Inhabitants of villages or communities facing flooding threats

■ authorities in charge of flooding problems



■ Authorities and communities in charge of water resources management to ensure recharge capacity and enhance run off water quality (use of : hedge, fascine, grass strips,...)



(source : SMBV Pointe de caux)

# Sinkholes and the stakeholders...



**But sometimes acting on sinkholes can have negative impacts downstream and lead to « messy » situations. For example :**

- > Clogging out or mudding off sinkhole often increases run off and tends to enhance flooding downstream (many examples of litigation)**
- > Using sinkhole as an effluent outlet point (fields or road run off, drained agricultural land outlet) often impacts drinking water quality downstream**

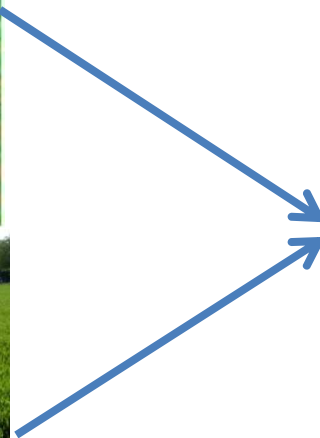
**Up to recent times, stakeholders tended to solve individual problems without having an overall vision of the sinkhole role in the whole hydrosystem (geotechnical risk, sanitary risk, flooding risk, reducing recharge,...)**



# Sinkholes and the stakeholders...



- Many organisms (communities, local authorities, etc.) carry out field investigations : sinkholes census, tracer tests, sinkholes impact on groundwater quality,...
- **Surveys results are dispersed and not easily available for management purpose**



# A regional karst data base



- > **Purpose** : to centralize in a common tool the knowledge of karst characteristics and transfer processes in order to improve the management and protection of groundwater resources
- > A regional data base has been developed by BRGM and includes information about : (1) exokarst (sinkholes) characteristic and location, (2) karstic springs and (3) karst conduit connections highlighted by tracer tests
- > **Data base, development and initialization** : from 2008 to 2012, a 4-year program of intensive work of consulting historical archives and carrying out field investigations;
- > **Project financially supported by** Seine-Normandie Water Agency, the three Eastern-Normandy Councils and BRGM

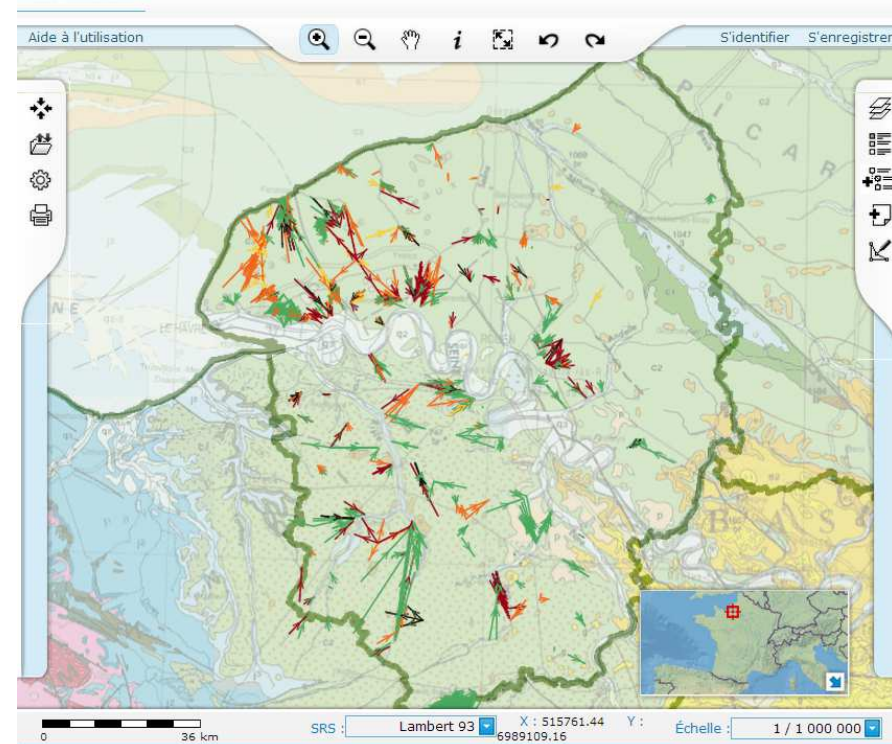
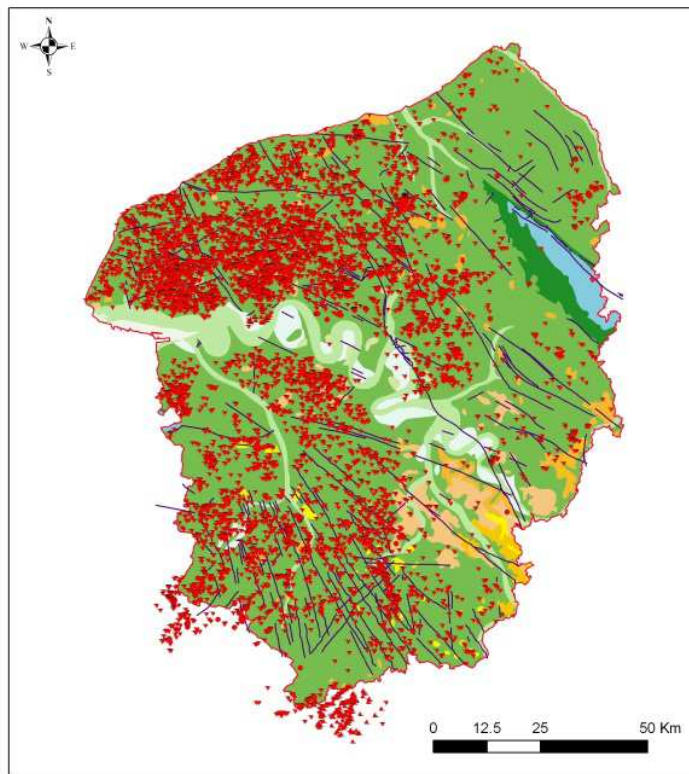


# A few numbers...



**At the end of 2012, introduced in the data base :**

- 1170 reports (7830 historical reports reviewed),
- 14921 sinkholes (around 9000 sinkholes and 6000 sinkhole index)
- 2049 springs
- 2425 karst connections tested by tracer tests (670 injection processes)





# Participatory tool



- > Designed, developed and initialized by BRGM from 2008 to 2012
- > Now taken forward in a participatory way involving all watershed stakeholders, including agricultural organizations and civil society
- > A participatory tool has been developed for that purpose, including **2 Websites interfaces** :
  - > A first one through which data can be introduced into the data base
  - > A second one, from which data can be retrieved in different ways (GIS format, files with various format, ...) free of charge

## DATA INPUT

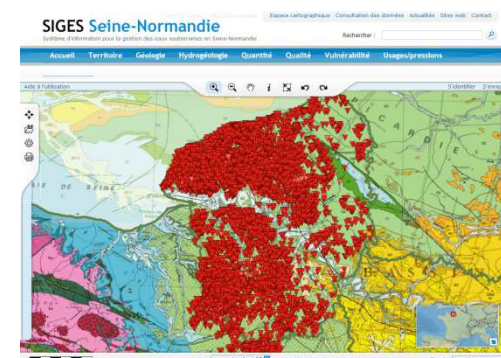


<https://tracages.brgm.fr/>

Data base  
(oracle)

Sinkholes  
Tracer tests  
Springs

## DATA OUTPUT



<http://sigessn.brgm.fr>

# Participatory tool



## > The input Data WEB site interface (secured access)

The left screenshot shows the login page titled "Base de Données BETOIRES - TRACAGES - EXUTOIRES". It features a login form with fields for "Identifiant" (username: py.david@brgm.fr) and "Mot de passe" (password: [masked]). Below the form is a "Se connecter" button. To the left of the form are logos for "REGION HAUTE NORMANDIE", "eau seine normandie", "Seine-Maritime", and "Le Département de l'Eure". To the right of the form is a text block explaining the site's purpose and providing contact information for the BRGM.

The right screenshot shows the "Etape 1 : Visualisation d'un point" page for "Betoire n°B8146". It displays a list of observation dates on the left and a detailed form for "Caractéristique de la perte" on the right. The form includes sections for "Aménagement réalisé dans les règles de l'art" and "Aménagements 'artisanaux'", each with several checkboxes. At the bottom, there are buttons for "Supprimer le point", "Enregistrer les modifications", "Retour", and "Invalider le point".

## > It allows watershed stakeholders to store, update and share data about :

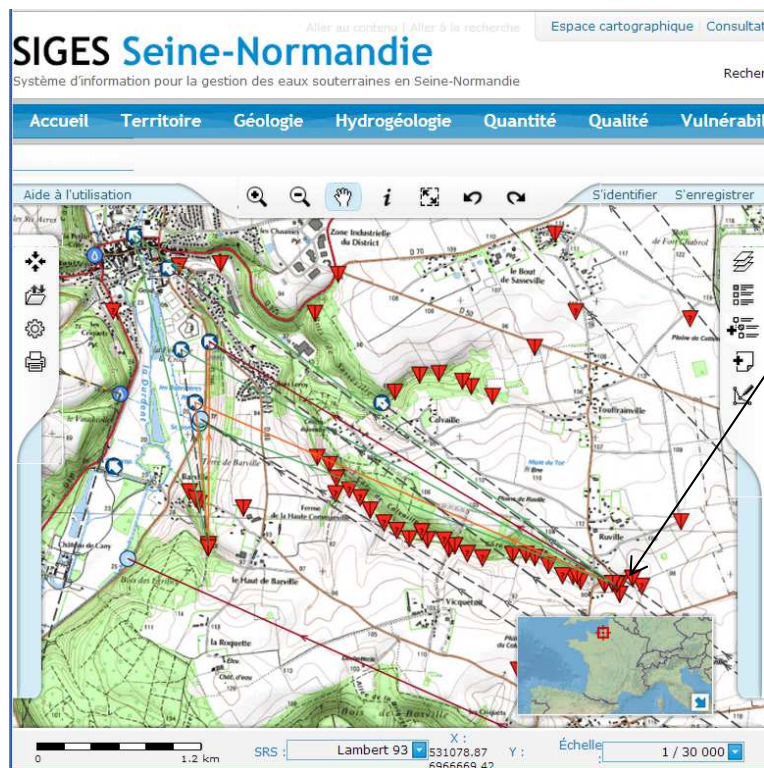
- Sinkhole characteristics : more than 20 sets of criteria describe sinkholes such as geometry, down flow variation over time, impluvium, geomorphology context, chalk stratigraphy, water quality,...)
- Sinkhole management (clogging out, conversion into infiltration well, watershed management,... )
- Tracer tests results

In addition, photos and reports can be uploaded

## Participatory tool

The output data WEBSITE allows to :

- > consult on-line data
- > download data on GIS or CSV format, free of charge





# Sinkhole data sheet

# Sinkhole data sheet

# Participatory tool



## Fiche Traçage

Identifiant : T384

Nature du point d'injection : Sédiments  
Identifiant d'injection : 00147  
Date de l'injection : 28/02/2007  
Nombre de points de suivi : 4  
Objet du traçage :

### 1. Identification du point d'injection

Nature du point : Sédiments  
Identifiant : 00147  
Désignation locale :  
Commune : 76202 - GOUVERNILLE  
Lieu-dit :  
Point de repère :  
Coordonnées : X : 495657.001 Y : 4917400.000  
X Lambert 93 : 800046.107 Y Lambert 93 : 6051903.102  
Précision des coordonnées : +/- 25.0 mètres  
Méthode d'obtention : coordonnées précises dans un rapport  
Altitude : 100.0m NGF  
Précision : +/- 0.0 mètres  
Cote IGN m : 18100 804500  
Bassin versant hydrographique : Sèvrain  
Bassin versant hydrologique : Trypt  
Masse d'eau Nomenclature : 3202 - Crée artificielle du littoral ouest  
Méthode d'obtention : SIG (Masse d'eau au droit du point)  
Entité hydrologique : 006 - PAYS DE CAUX / DRAE  
Méthode d'obtention : SIG (Masse d'eau au droit du point)

### 2. Conditions de réalisation de l'injection

Date d'injection : 28/02/2007 Heure d'injection : 09:00  
Durée d'observation : 30  
Sujet réalisé par : SARSCS  
Nature du traceur : Isotopes de potassium  
Injection : Directe Durée (en heure) :  
Quantité injectée : 7.0 Unité : kg  
Volume de chasse : 12.0 Unité : m3  
Chasse par écoulement naturel : Non  
Conditions climatiques : Période pluvieuse  
Cote hydrologique : Basses eaux  
Commentaires : 7 KG (TRACER) : Observation du 27/02 au 23/03, VOLUME DE CHASSE DE 12m3 à 12.4m3, renouvellement continu suite aux précipitations.

## Tracer test data sheet

### 3. Résultats du traçage

ID Pt de suivi	Nature du point	Résultat	Vitesse l'ère arrivée	Résultats	Profilé résultat (x1 à 10)
0701	Sédiments	Négatif	--	> DÉTAILS RÉSULTAT	0
0702	Point de suivi	Négatif	--	> DÉTAILS RÉSULTAT	0
0703	Point de suivi	Négatif	--	> DÉTAILS RÉSULTAT	0
0704	Point de suivi	Positif	212.0 m/h	> DÉTAILS RÉSULTAT	0

### 4. Sources d'information

ID Ref. 2006	Nature	Date	Titre	Auteurs	Organisme	Relevance	Lieu d'archivage
001	2	2007	ETUDE DE LA CIRCULATION KARSTIQUE DES EAUX DE RUSSOILLONNEN : SITUATION DE L'INJECTION - SYNTHÈSE DES OPÉRATIONS DE TRAÇAGE 2	ASSILIN L. / POISSAULT G.	SARSCS	FAITS-VERBES-TRAÇAGE	ORFÈVRE (CHIFFRE INFORMATIQUE)

### 5. Documents numériques disponibles (0)

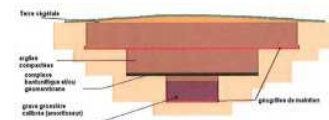
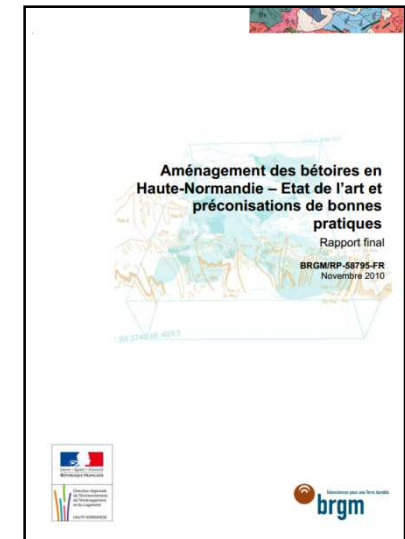
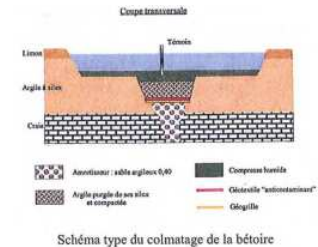
> Retour en haut de la page

# Participatory tool



## This participatory tool also includes :

- > A guide for « béttoire » (sinkholes) management including :
    - State of the art on current practices WRT sinkhole management + classification of the sinkhole managements + critical assessment
    - Elaboration of « good practice » guide for sinkhole management according to 2 criteria :
      1. identified risk for on site and downstream « at stake structures » (sanitary, hydraulic works, geotechnical, flood, recharge deficiency...)
      2. Physical and geological setting
    - Recommendation concerning administrative aspects (water legislation dossier content, investigation fields to be carried out before acting on sinkholes....)
- report on-line : <http://sigessn.brgm.fr/IMG/pdf/rp-58795-fr.pdf>



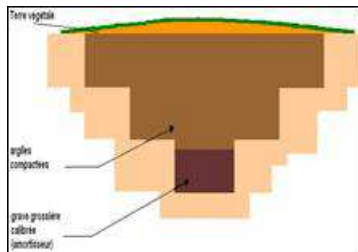
- > Training sessions for catchment stakeholders to help them to deal with sinkhole management



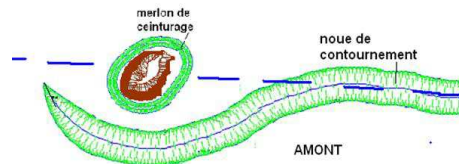
# CLASSIFICATION OF THE EXISTING TECHNIQUES OF SINKHOLES MANAGEMENT

## IMPERMEABLE

Clogging out the sinkhole



Diverting runoff away from the sinkhole

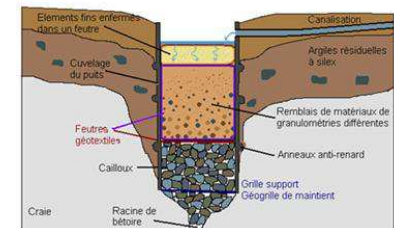


## INFILTRATING

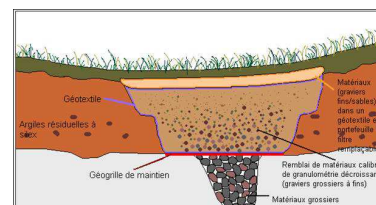
Filling up with permeable (non filtrating) material



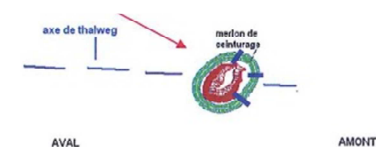
Conversion into infiltration well



Filling up with filtrating materials



Diverting runoff partially and controlling infiltration flow



# Participatory tool



## This participatory tool also includes :

- > **A tracer test declaration form** centralized by the regional environment authority (DREAL)
- > **3 purposes :**
  1. to inform authorities in charge of drinking water supply and other actors of the basins
  2. to register tracing test activities and avoid interferences between 2 tests
  3. to control the kind of tracer that are being used (to avoid the use of ecotoxic tracers)

RESERVE A LA DREAL      Déclaration reçue le : \_\_\_\_\_ N° de déclaration : \_\_\_\_\_

**FICHE DE DÉCLARATION PRÉALABLE D'UN TRAÇAGE EN RÉGION HAUTE-NORMANDIE**

L'objectif de ce formulaire de déclaration préalable des opérations de traçage est de :

- prévenir les organismes chargés de la distribution d'eau potable ainsi que les services de la police de l'eau afin qu'ils puissent gérer au mieux les problèmes liés à ces essais (pollution de l'eau, etc.)
- tenir un registre des opérations de traçages réalisées en Haute-Normandie afin :
  - > d'éviter les interférences et erreurs d'interprétation lorsque plusieurs opérateurs réalisent des traçages simultanément dans un même périmètre,
  - > de garder trace des opérations de traçages y compris celles non bancairiales dans la base de données régionale des traçages
- contrôler le type de traceur injecté dans les eaux souterraines

Prestateur responsable des essais :

<b>Personne responsable :</b>	Nom :	Tel :	E-mail :
Intitulé de l'étude :			
Date :		Signature :	

A renvoyer au moins 15 jours avant le début de l'essai de traçage :

- par mail aux destinataires suivants :
  - Bureau de la police de l'eau de la DDTM : [ddtm@ddtm.haut-normandie.fr](mailto:ddtm@ddtm.haut-normandie.fr) (04 94 77 71)
  - DREAL Service ressources : [service.ressources@drh.haut-normandie.fr](mailto:service.ressources@drh.haut-normandie.fr) (04 94 77 71)
  - ARS Haute-Normandie : [ars.haut-normandie@ars.haut-normandie.fr](mailto:ars.haut-normandie@ars.haut-normandie.fr) (04 94 77 71)
  - Collectivités AEP concernées<sup>1</sup> : [collectivites.aep@drh.haut-normandie.fr](mailto:collectivites.aep@drh.haut-normandie.fr) (04 94 77 71)
  - BRPD : [brpd@drh.haut-normandie.fr](mailto:brpd@drh.haut-normandie.fr) (04 94 77 71)
  - Cellule opérationnelle de la Gendarmerie : [cellule.operationnelle@drh.haut-normandie.fr](mailto:cellule.operationnelle@drh.haut-normandie.fr) (04 94 77 71)

<sup>1</sup> A charge aux collectivités AEP qui reçoivent cette déclaration de garantir leur éventuel distributeur d'eau si la distribution ne se fait pas en régie

**ET**

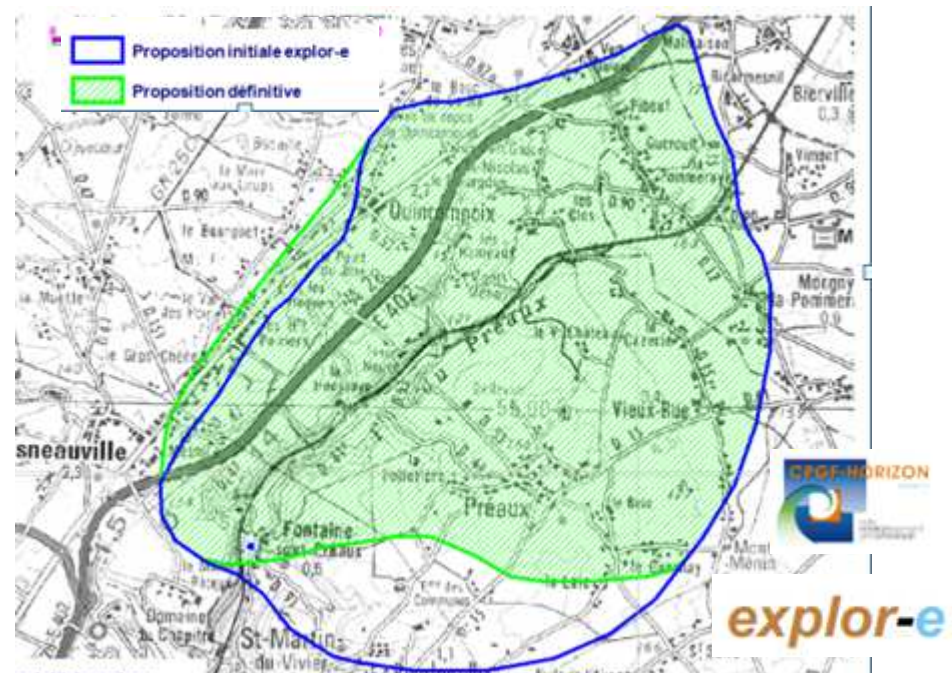
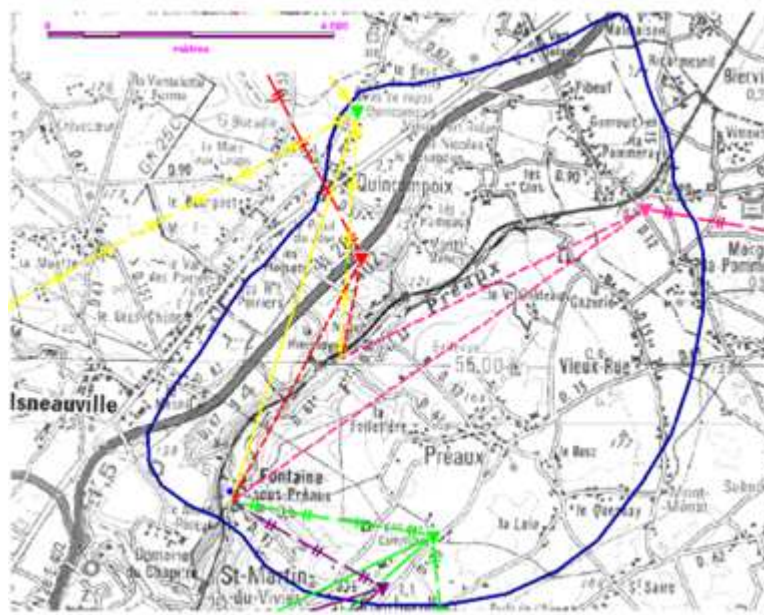
par courrier à : DREAL Haute-Normandie / SRE / BEMA- 2 rue saint sever 76032 rouen cedex

Situation des essais				Traceur		Date prévue pour l'opération
Injection		Suivi		Traceur utilisé	Quantité / Unité	
Commune (département)	Y Pointe d'injection : - 01. Distance, m de source - 04. 000, m de source - 05. 000, m de source	X Pointe de suivi : - 01. 000, m de source - 02. 000, m de source - 03. 000, m de source	Y Pointe de suivi : - 01. 000, m de source - 02. 000, m de source - 03. 000, m de source			

# Example of use (1)



- This participatory tool allows for better management and protection of the chalk aquifer system and prevents it from quality degradation (turbidity, nitrates, pesticides, ...) :
  - Sinkholes connected to the drinking water wells are better known
  - Drinking water supply organisms benefit from improve active water resources management (specific watershed and sinkhole management : herb strips, fascines, dams, infiltration...)
  - Water abstraction benefits from optimally designed protection zone

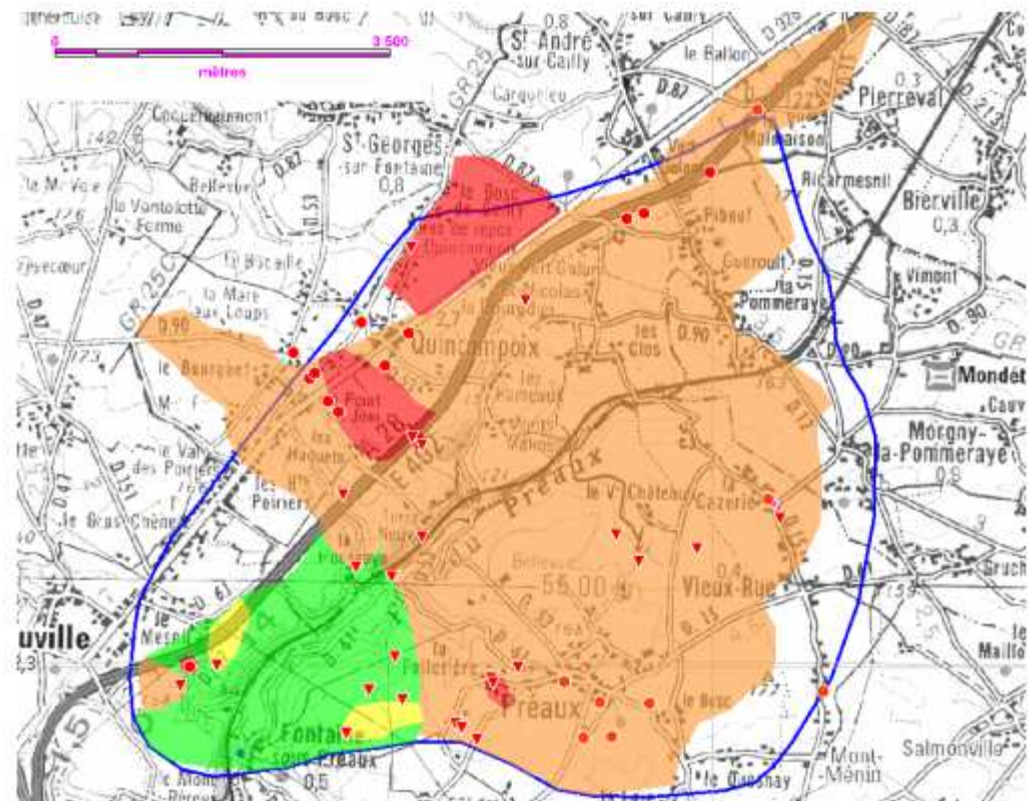
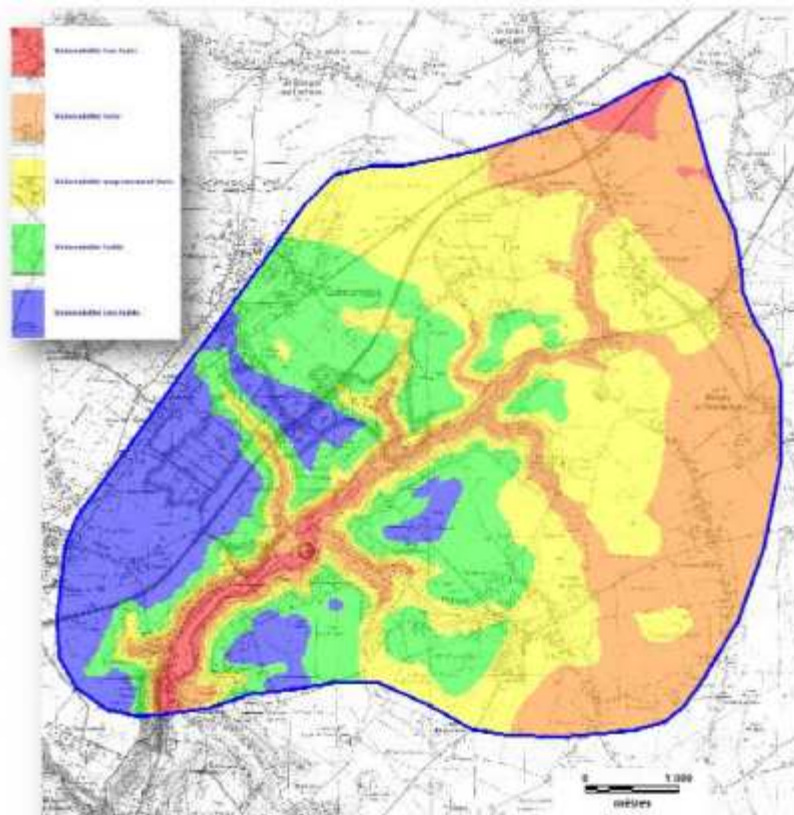




## Example of use (2)



- Improved definition of groundwater vulnerability : both karstic and matricial (elaborated with the consolidated data from the participatory tool)



# A better understanding of exokarst spatial distribution



In addition with helping in karst problem management, it also greatly enhances understanding of the effects of recharge, lithology and geological structures on karst developments in the chalk aquifer system

- > As part of the development of this data base, BRGM co-funded and co-directed a thesis carried out by Sanae El Janyani (Rouen University) from 2009 to 2012. The Young Karst Researcher Prize 2012 were awarded to her for this work

- > Thesis on line : <https://tel.archives-ouvertes.fr/tel-00920267/document>

*S. El Janyani. Incidence des bétoires et de la karstogénèse des plateaux crayeux de la Haute-Normandie sur le fonctionnement hydrologique de l'aquifère de la craie Modélisation hydrogéologique des influences climatiques à différentes échelles spatio-temporelles.. Continental interfaces, environment. Université de Rouen, 2013. French*

# A better understanding of exokarst spatial distribution



- The surface of the chalk plateaus in the western Paris Basin is covered with Quaternary loesses and clay-with-flints
- Preliminary results show correlation between thickness of surface layers and sinkholes density

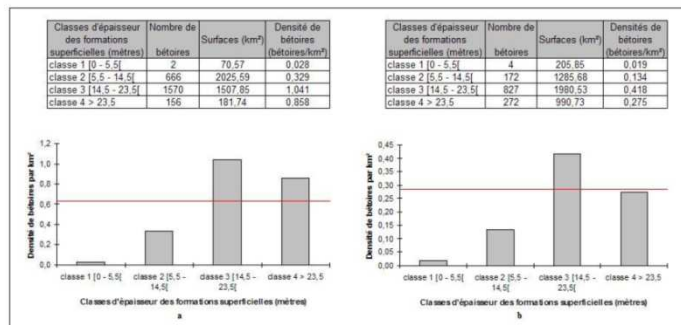
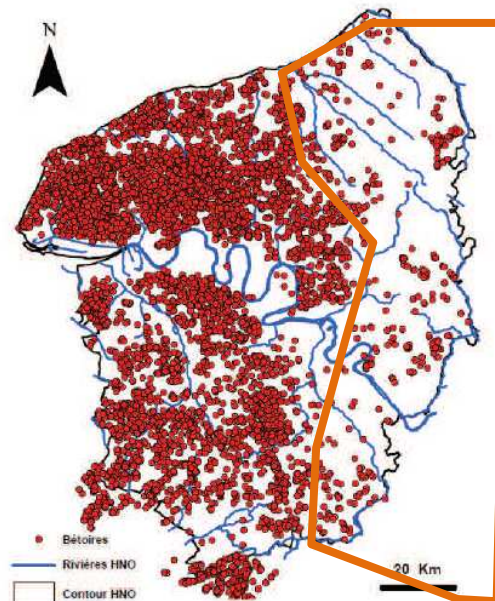
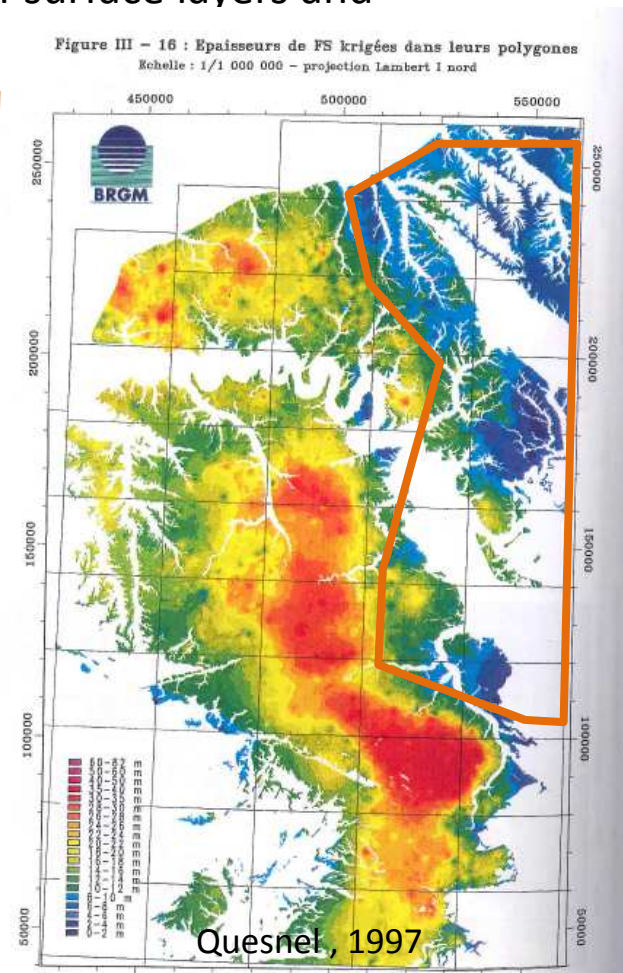


Figure 27 : Résultats des densités de bêttoires selon l'épaisseur des formations superficielles a) en Seine-Maritime, b) dans l'Eure

Seidel and David, 2010



El Janyani, 2012



Quesnel, 1997

- Very few sinkholes in chalk covered by thin surface layers (<5m)



# A better understanding of exokarst spatial distribution



- > Spatial modelling was also carried out based on the topographic index of Beven and Kirkby, « IBK » (also known as TWI). This index was developed by Beven and Kirkby (1979) based on the TOPMODEL runoff model
- > The application of this index to the digital elevation model (DEM) produced a map of the potential wetland sectors. Results were compared with the location of the sinkholes
- > Sinkholes are mainly located in the theoretical wet areas (thalweg on plateaus, dry valleys) (drainage system)

*Illustration of the Cailly river watershed,  
But this characteristic has been observed in all  
Upper Normandy watersheds, except in the areas  
affected by the presence of Tertiary deposits and  
by the absence of the clay-with-flints layer*

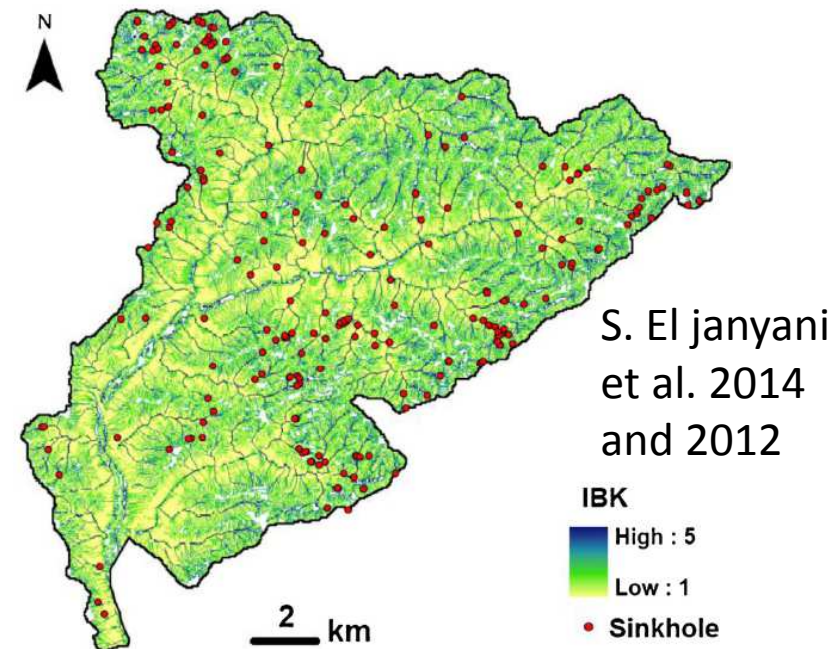
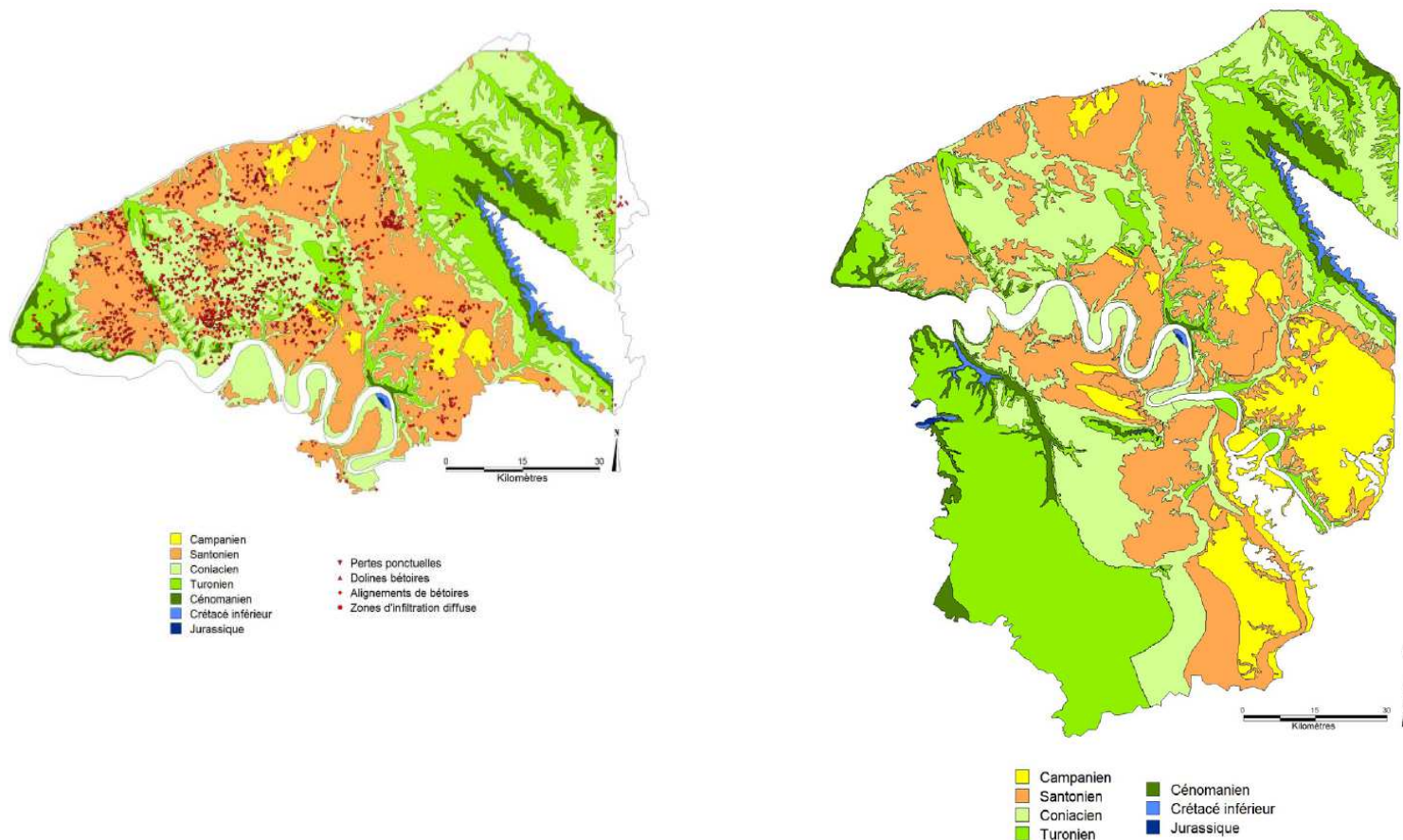


Fig. 4 Validated sinkholes located on the spatial modelling map of the topographic wetness index (IBK) of the index value indicates a high probability of wetlands present on the site

# A better understanding of exokarst spatial distribution



- Other correlations are being studied by BRGM (ex : sinkhole density vs. chalk stratigraphy, sinkhole density vs. geological structures,...)





# Thank you for your attention

