Recharge areas of deep aquifers: a simplified approach for the assessment in Piedmont Region (NW Italy)

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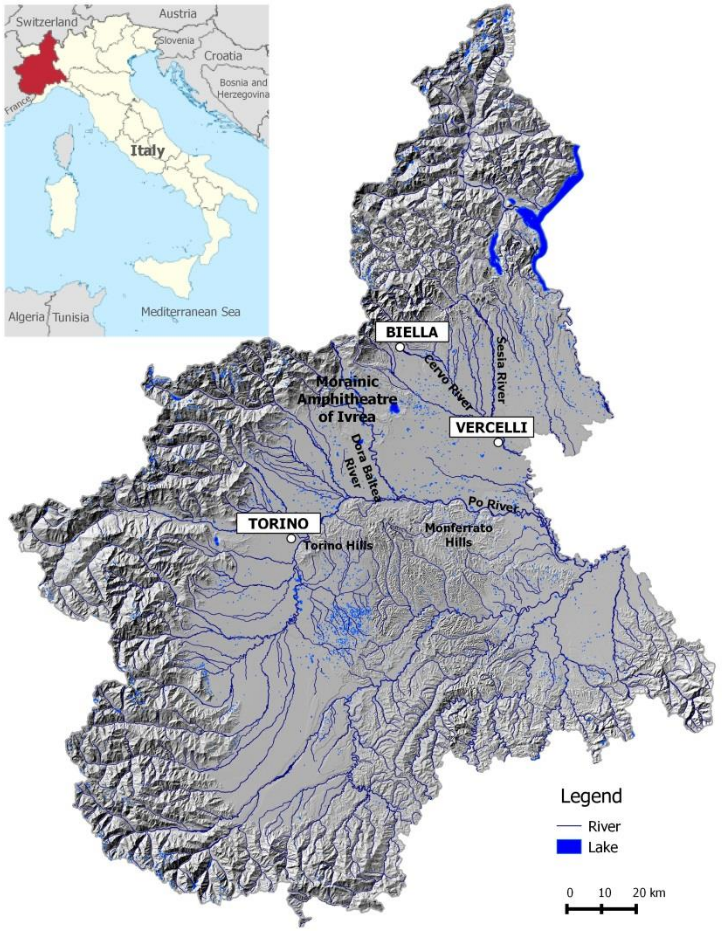
AIM OF THE STUDY

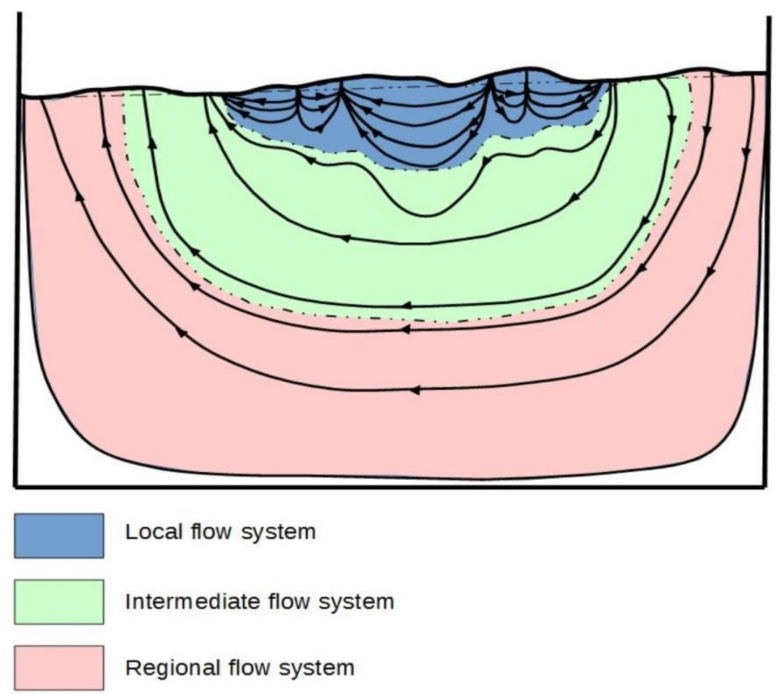


Identification and mapping of **recharge areas of deep aquifers (RADA)** at a regional scale in plain areas of **Piedmont Region (NW Italy)**

WHAT ARE RECHARGE AREAS OF DEEP AQUIFERS?

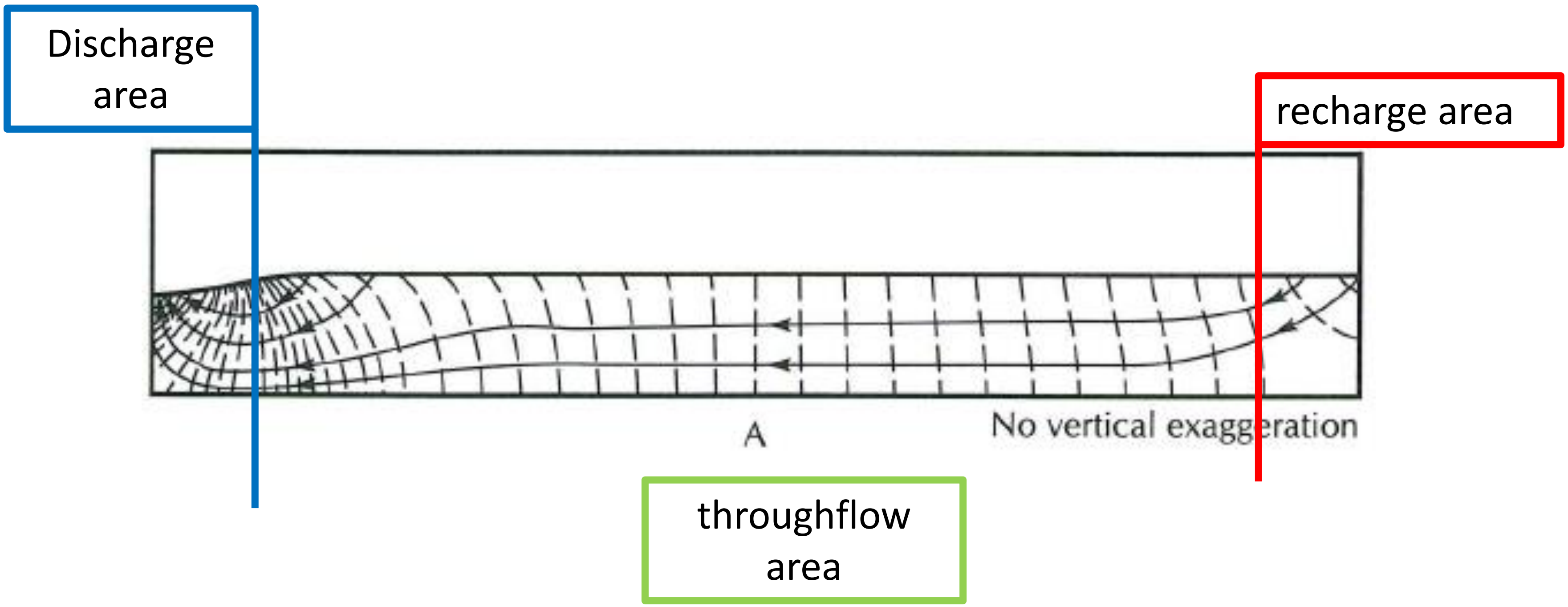
Toth (1963) defined a (groundwater) **flow system** as a set of flow lines in which any two lines adjacent at one point of the flow region remain adjacent through the whole region and that can be intersected anywhere by an uninterrupted surface across which flow takes place in one direction only.

Three different types of flow systems can occupy a basin: **local**, **intermediate** and **regional systems**.



(modified from Toth, 1963)

Water moves from the **recharge area**, where water flow is directed downward, to the **discharge area**, where it is directed upward. In between them, water passes through an area where water flows move horizontally and laterally (**throughflow areas**).

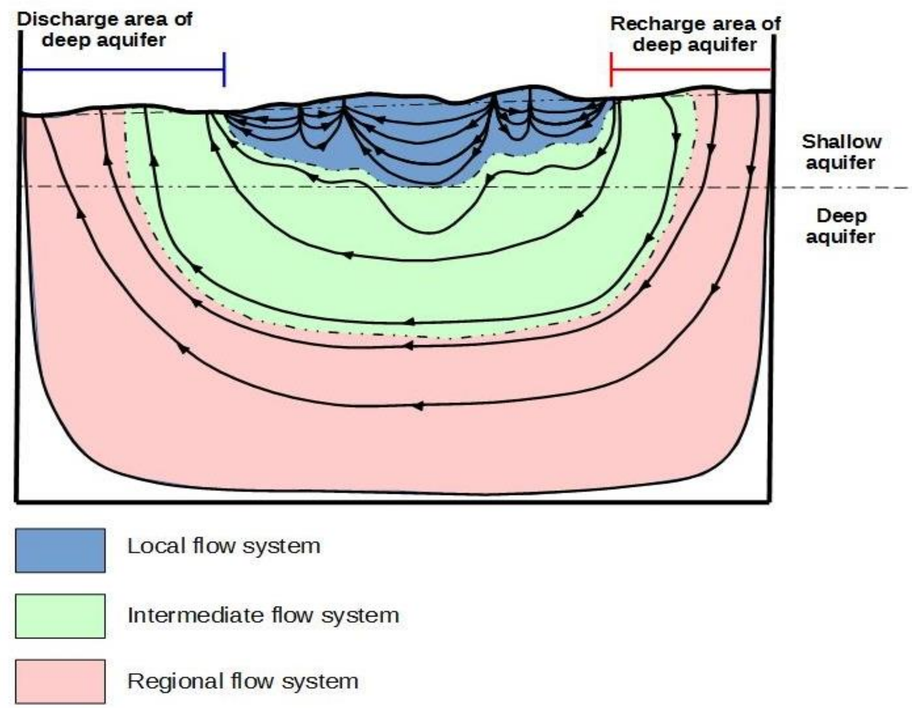


(modified from Freeze & Witherspoon, 1967)

A deep aquifer:

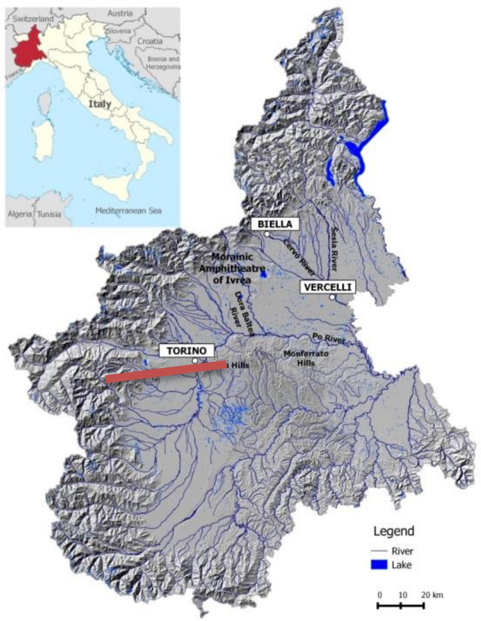
- is an aquifer located underneath a shallow aquifer
- is characterized by intermediate or regional flow systems,
- has a greater degree of confinement, lower flow velocities and longer water residence periods compared to shallow aquifers

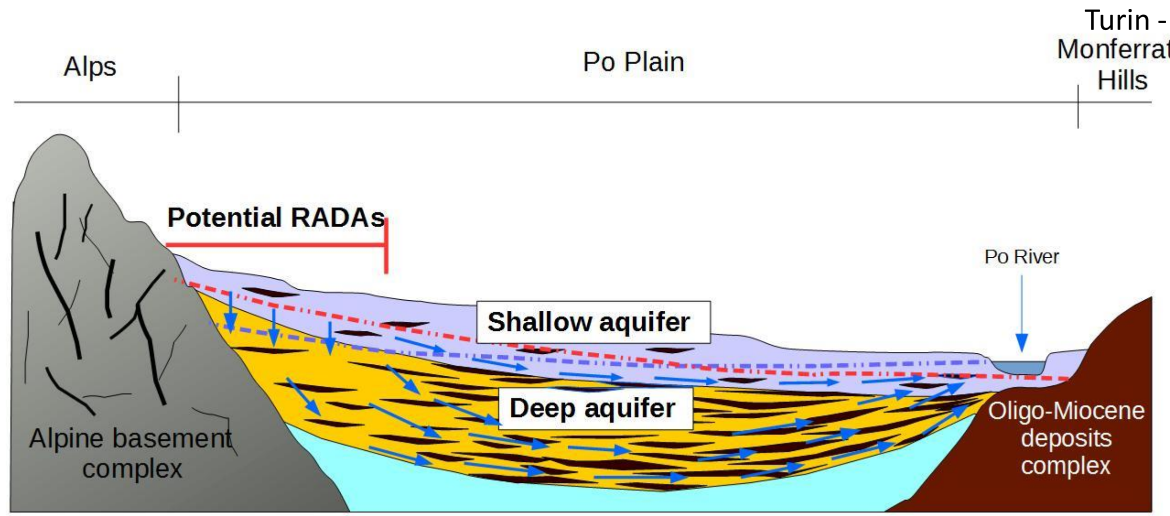
RECHARGE AREAS OF DEEP AQUIFERS (RADA) can be defined as limited areas along the ground surface where the water head difference between shallow and deep aquifers favours the downward flow of groundwater from the ground surface to deep aquifers through shallow aquifers.



Local, intermediate and regional flow systems and subdivisions for shallow and deep aquifers.

GENERAL SETTING OF PIEDMONT PLAIN





Fluvio and fluvio-glacial deposits complex

Multi-layered Villafranchian complex

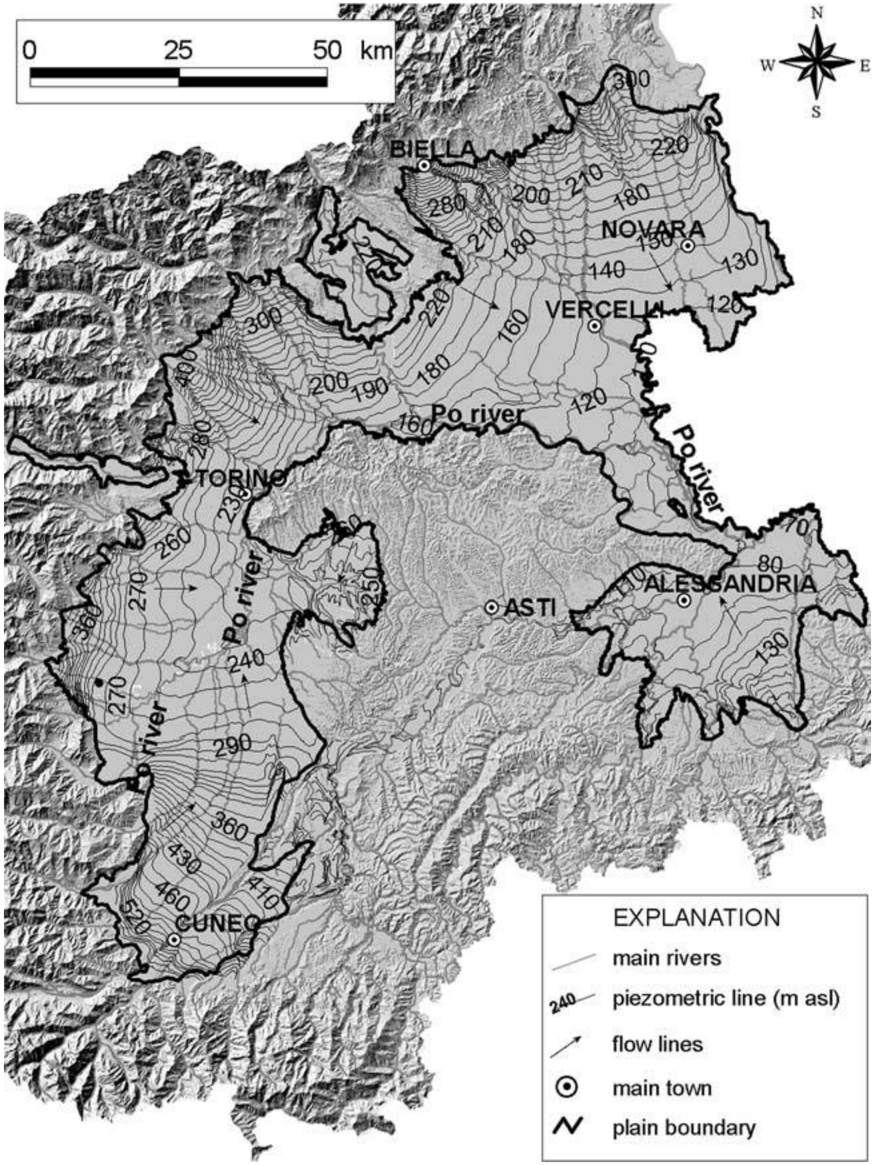
Pliocene marine sediments complex

Potentiometric surface of the shallow aquifer

Potentiometric surface of the deep aquifer

PIEZOMETRY OF SHALLOW AND DEEP AQUIFERS

- PIEZOMETRIC SURFACE OF THE SHALLOW AQUIFER normally follows the general topography of the land surface and the isopiezometric lines are generally placed parallel to the mountains.
- Generally PIEZOMETRIC SURFACE OF THE DEEP AQUIFERS have the same flow direction as shallow aquifer.



(Debernardi L., De Luca D.A., Lasagna M. (2008). Correlation between nitrate concentration in groundwater and parameter affecting aquifer intrinsic vulnerability. Environ. Geol. 55: 539-558)

WHY IS IMPORTANT TO IDENTIFY THE RADA IN PIEDMONT PLAIN?

- The deep aquifers represent one of the **most important supply of drinking water** in Piedmont plain.
- Their groundwater is constantly recharged in RADA, where groundwater flow is downward directed, from the topographic surface to the deep aquifer, passing through the shallow one. This flow is able to **transfer** not only **water** but also **pollutants** from the ground surface to the deep aquifer.
- The **identification and safeguard of RADA** represent one of the most **important prevention measure** against the damage of water quality.
- Legislative decree 152/2006 and Regional Law (Water protection plan) require to **protect groundwater** for drinking water supply, thus **identifying recharge areas of aquifers used for human consumption**.

PROBLEMS

The RADA identification on a regional scale is **not easy** because it requires **many hydrogeological an chemical data.**

These data are **lacking** in most of the Piedmont Region (NW Italy)

SOLUTION

An **expeditious method** for mapping RADA at a **regional scale** was proposed, based on easily available data.

This simplified approach involves three steps.

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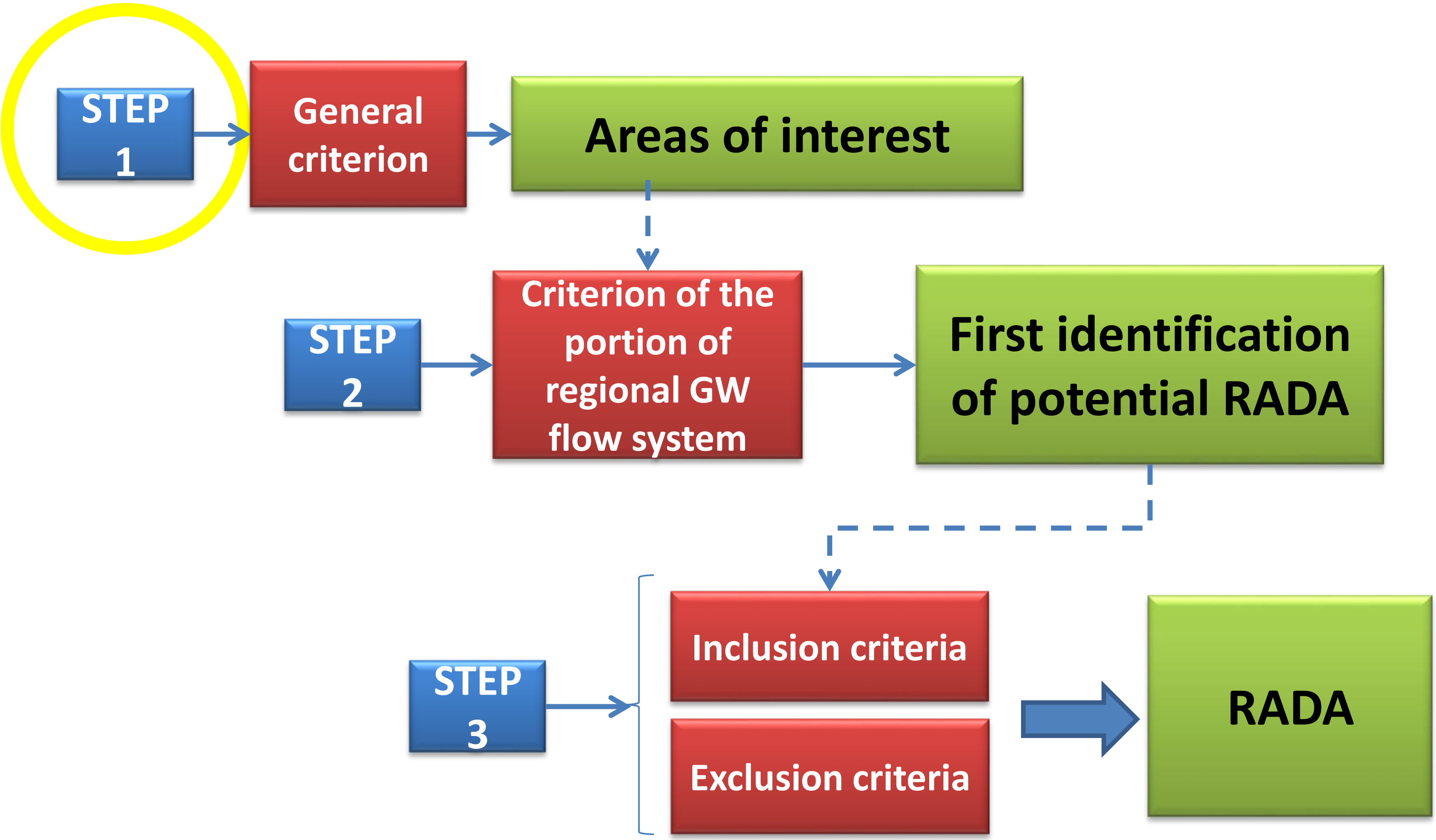
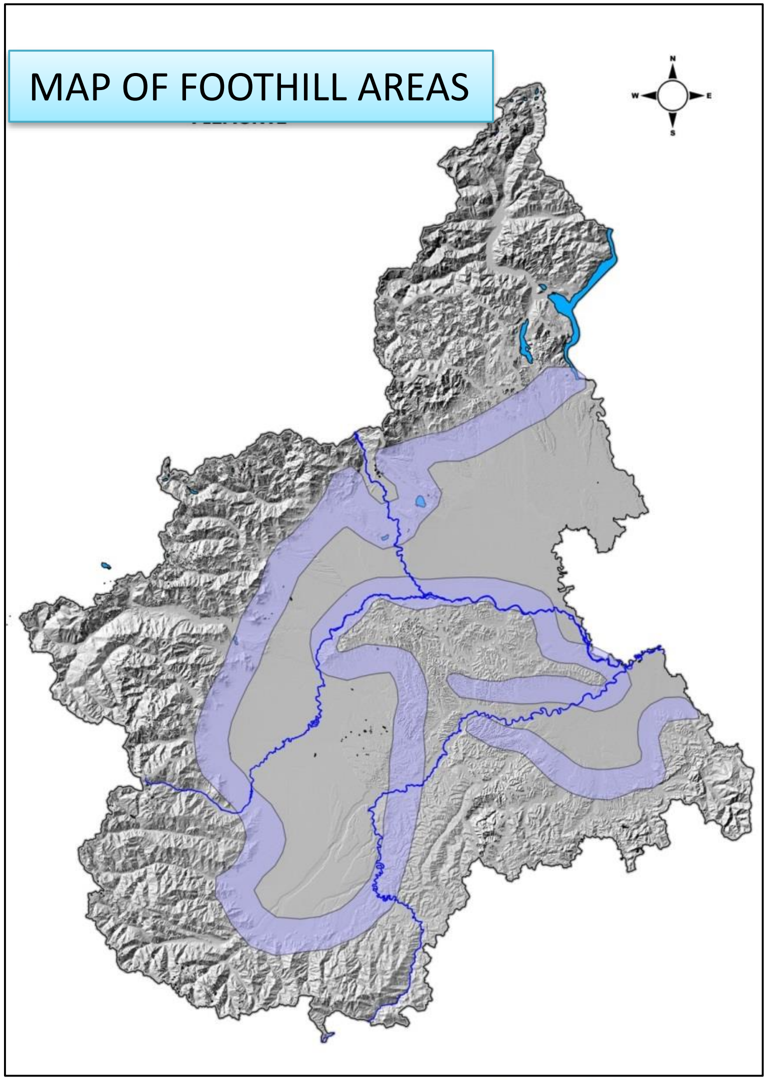
SIMPLIFIED APPROACH FOR RADA DELIMITATION



Step 1: GENERAL CRITERION

RADA must satisfy these conditions:

1) **THEY ARE FOOTHILL AREAS;**



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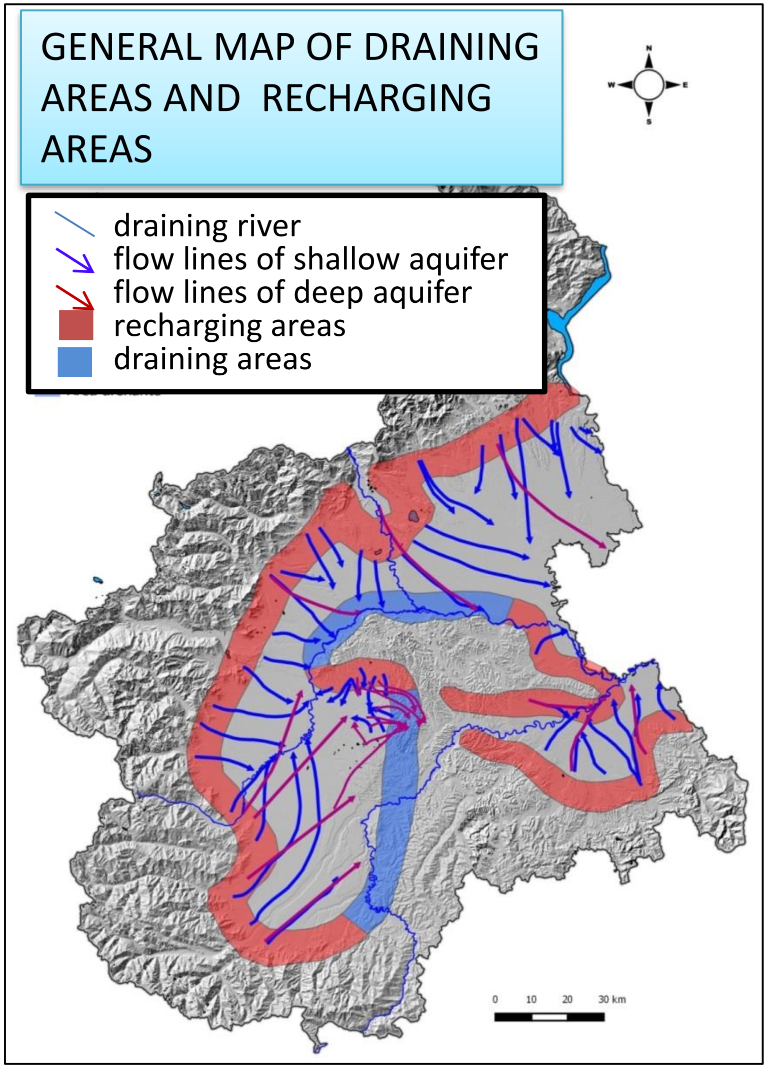
Step 1: GENERAL CRITERION

RADA must satisfy these conditions:

1) THEY ARE FOOTHILL AREAS;

2) **THEY ARE AREAS WHERE FLOW LINES OF DEEP AQUIFER START**



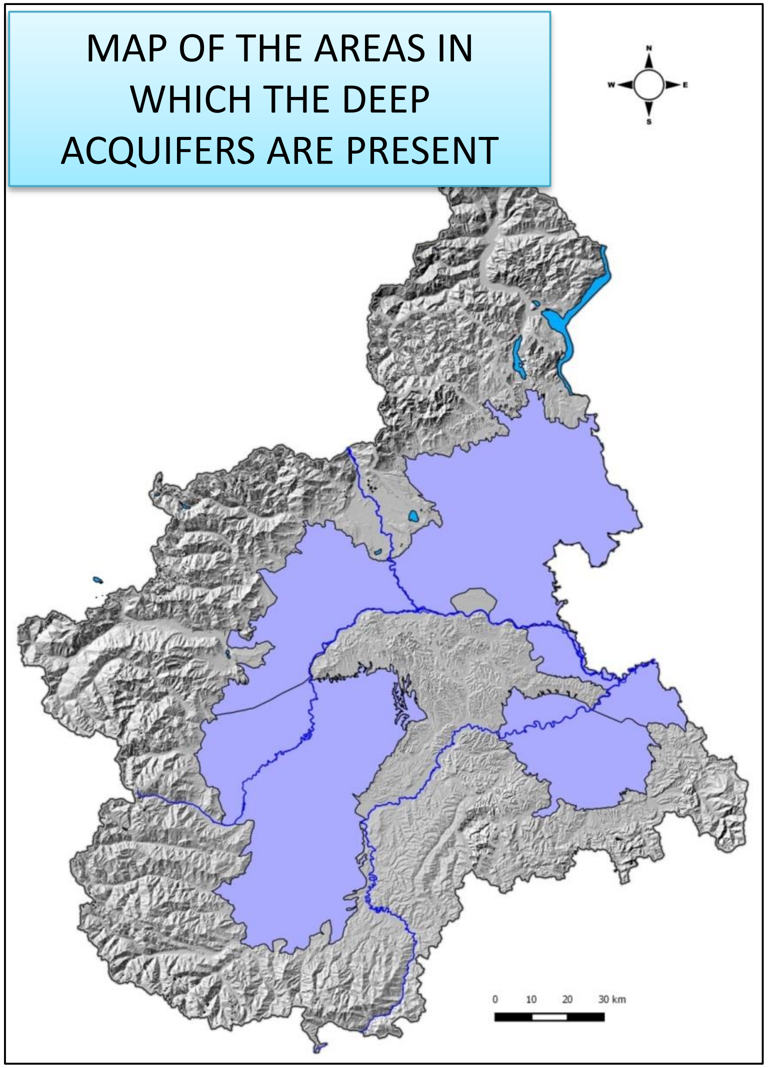
Step 1: GENERAL CRITERION

RADA must satisfy these conditions:

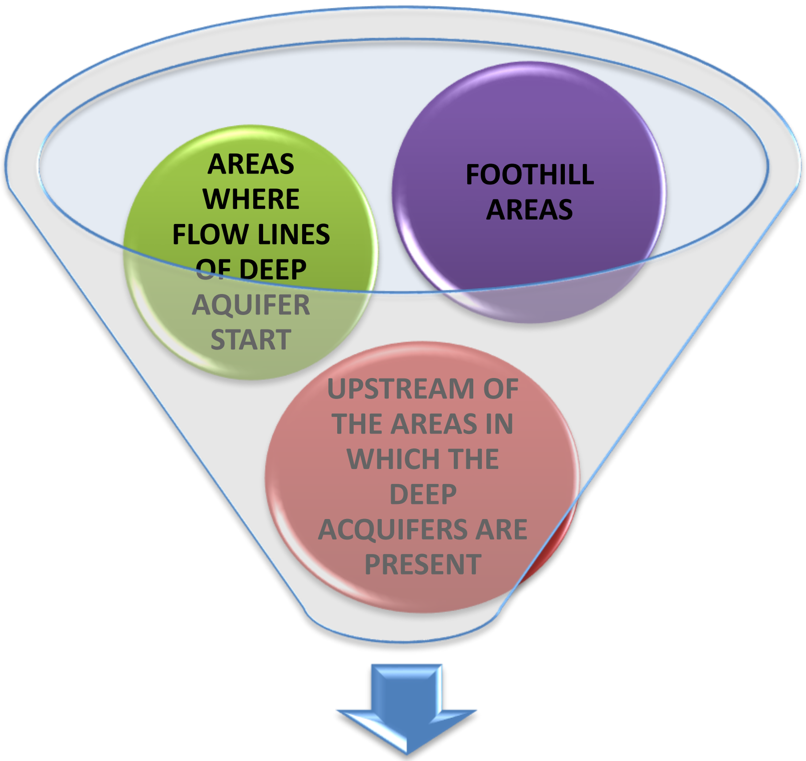
1) THEY ARE FOOTHILL AREAS;

2) THEY ARE AREAS WHERE FLOW LINES OF DEEP AQUIFER START

3) **THEY ARE UPSTREAM OF THE AREAS IN WHICH THE DEEP ACQUIFERS ARE PRESENT**

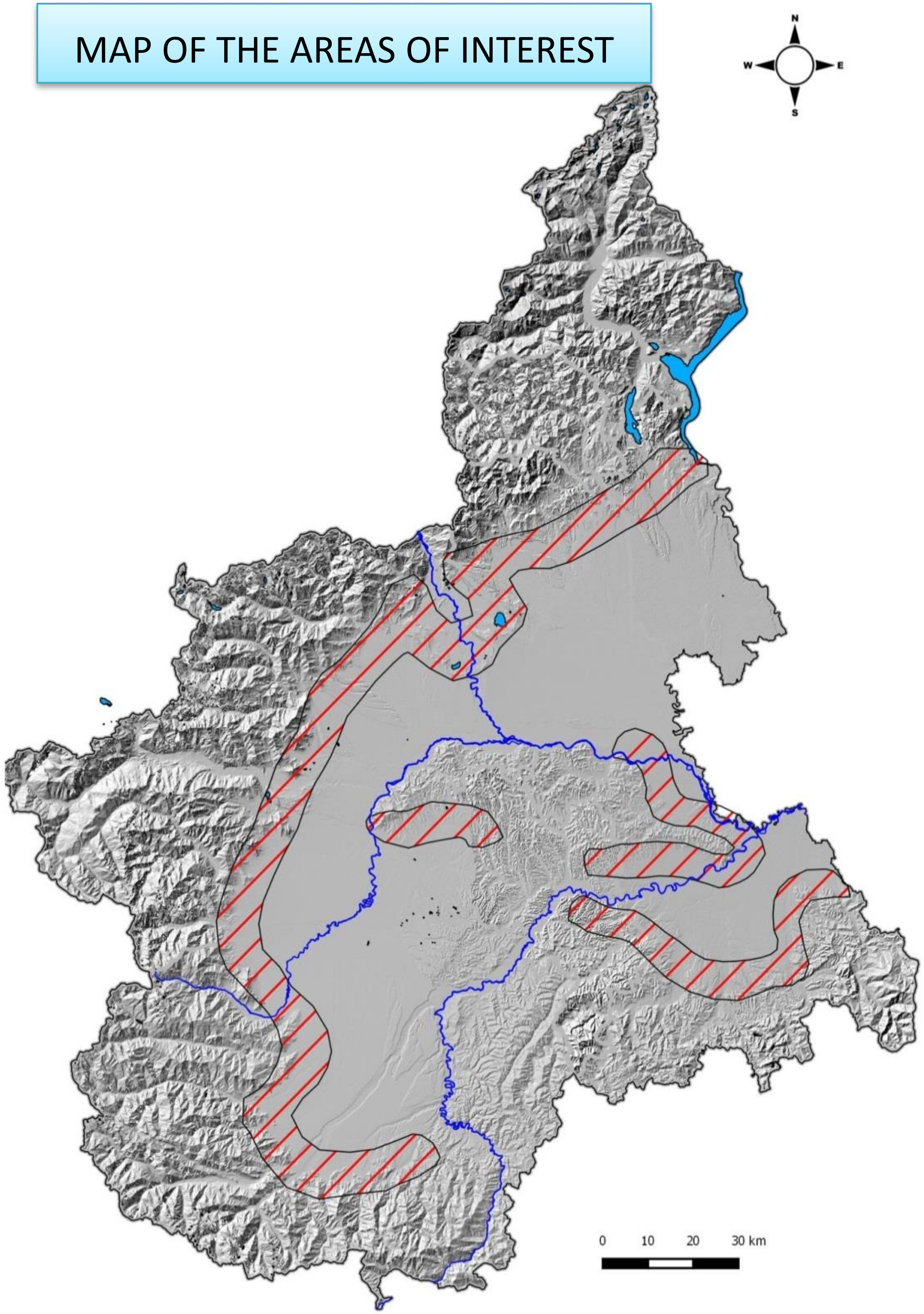


Step 1: GENERAL CRITERION

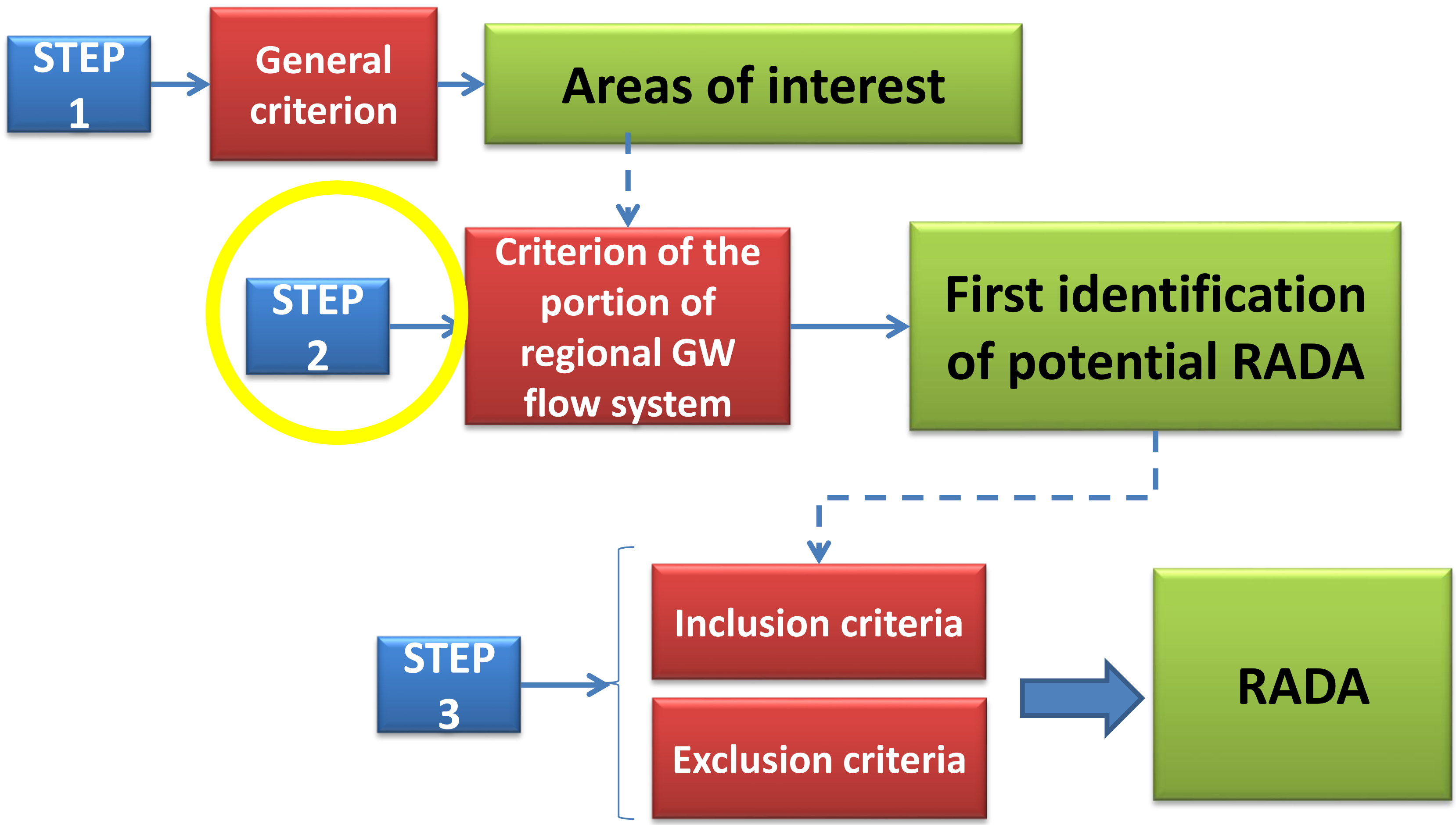


AREAS OF INTEREST

MAP OF THE AREAS OF INTEREST

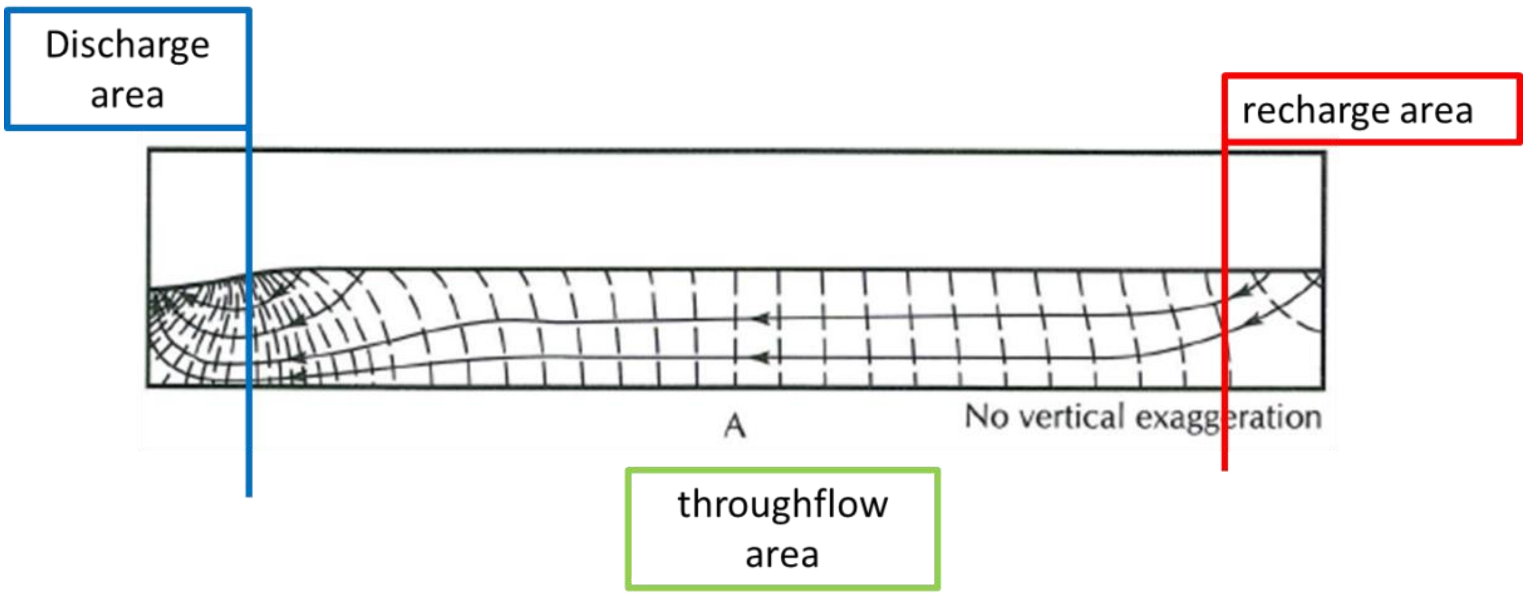


SIMPLIFIED APPROACH FOR RADA DELIMITATION



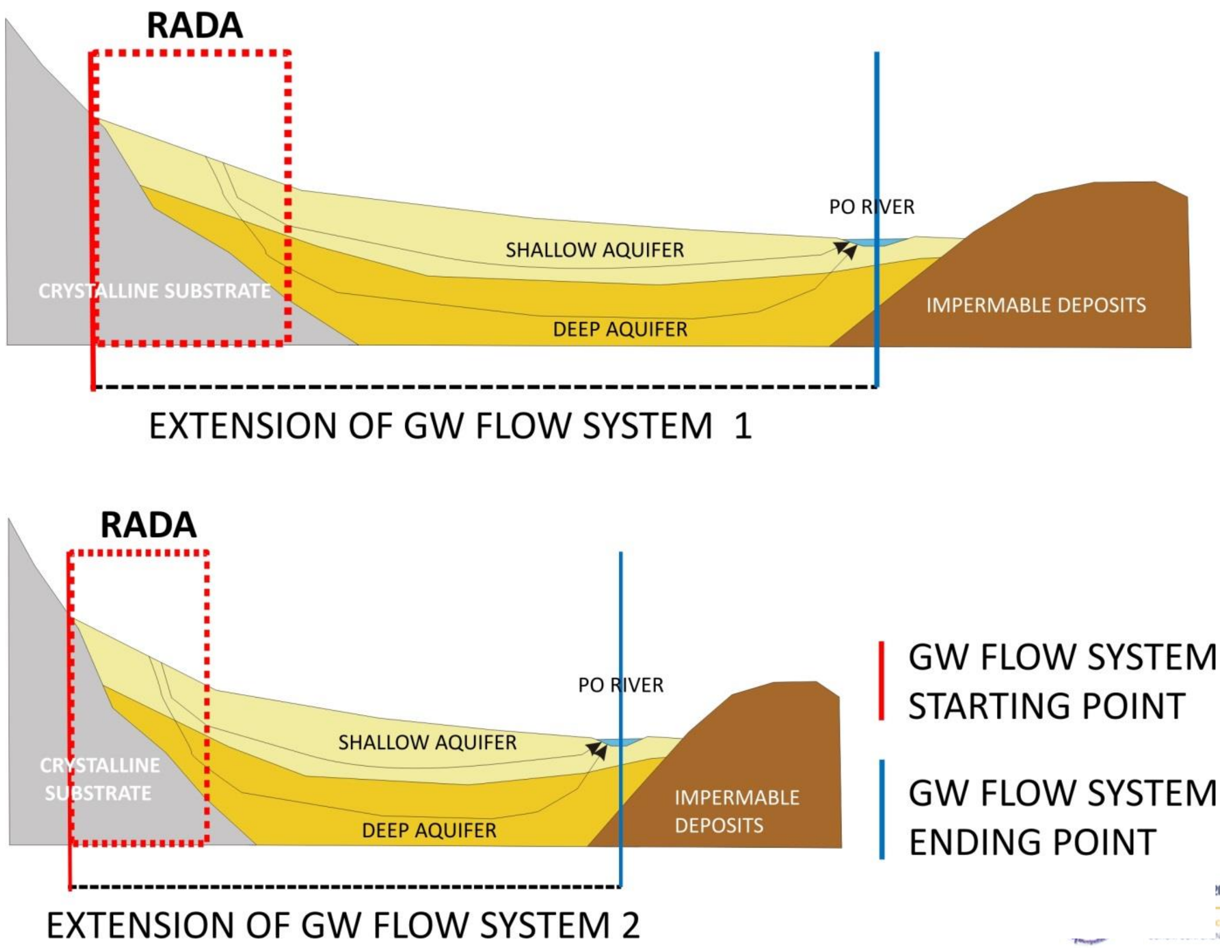
Step 2: CRITERION OF THE PORTION OF REGIONAL GW FLOW SYSTEM

RADA generally cover a limited portion of GW flow system, depending on hydrogeological features of the area.



Step 2: CRITERION OF THE PORTION OF REGIONAL GW FLOW SYSTEM

Short GW flow system have RADA with a smaller extension than long GW flow system .



Step 2: CRITERION OF THE PORTION OF REGIONAL GW FLOW SYSTEM

Main goals are:

1. **THE EVALUATION OF GW FLOW SYSTEM EXTENSION**

2. **THE DEFINITION OF POTENTIAL RADA EXTENSION, DEPENDING ON GW FLOW SYSTEM EXTENSION**

Step 2: CRITERION OF THE PORTION OF REGIONAL GW FLOW SYSTEM

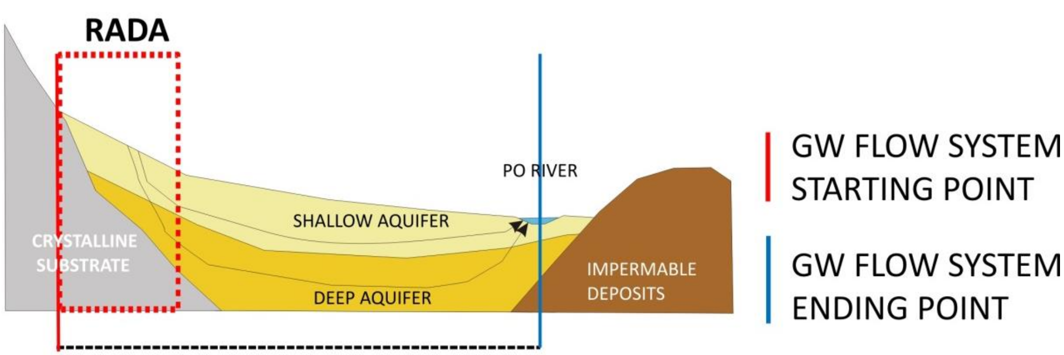
1. GW FLOW SYSTEM EXTENSION can be evaluated:

- **by defining GW flow system starting point**

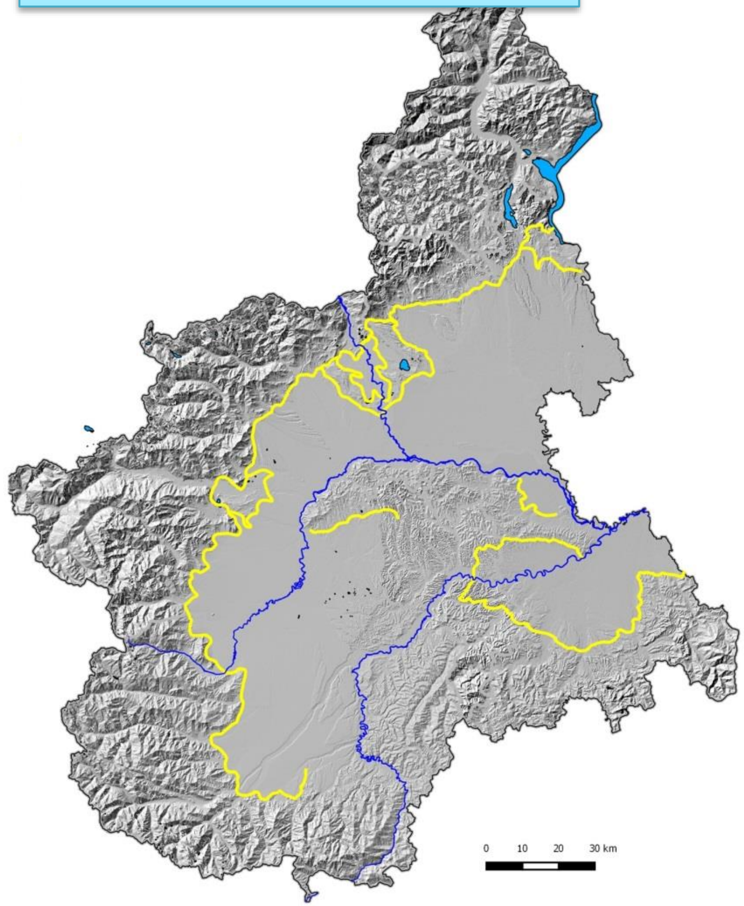
line that separate :

Permeable plain deposits and alpine cristalline substrate

Permeable plain deposits and hilly impermeable deposits



MAP OF GW FLOW SYSTEM STARTING POINT



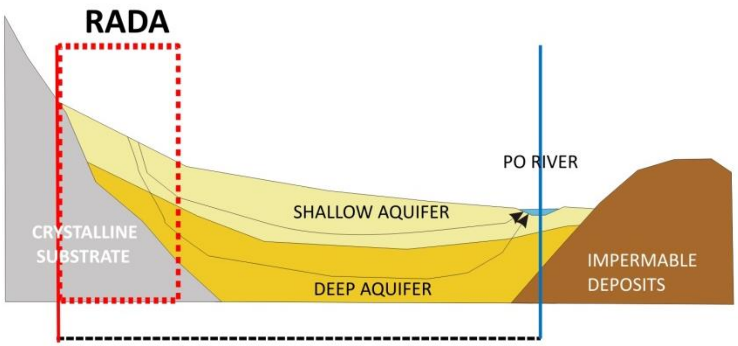
Step 2: CRITERION OF THE PORTION OF REGIONAL GW FLOW SYSTEM

1. GW FLOW SYSTEM EXTENSION can be evaluated:

- **by defining GW flow system ending point**

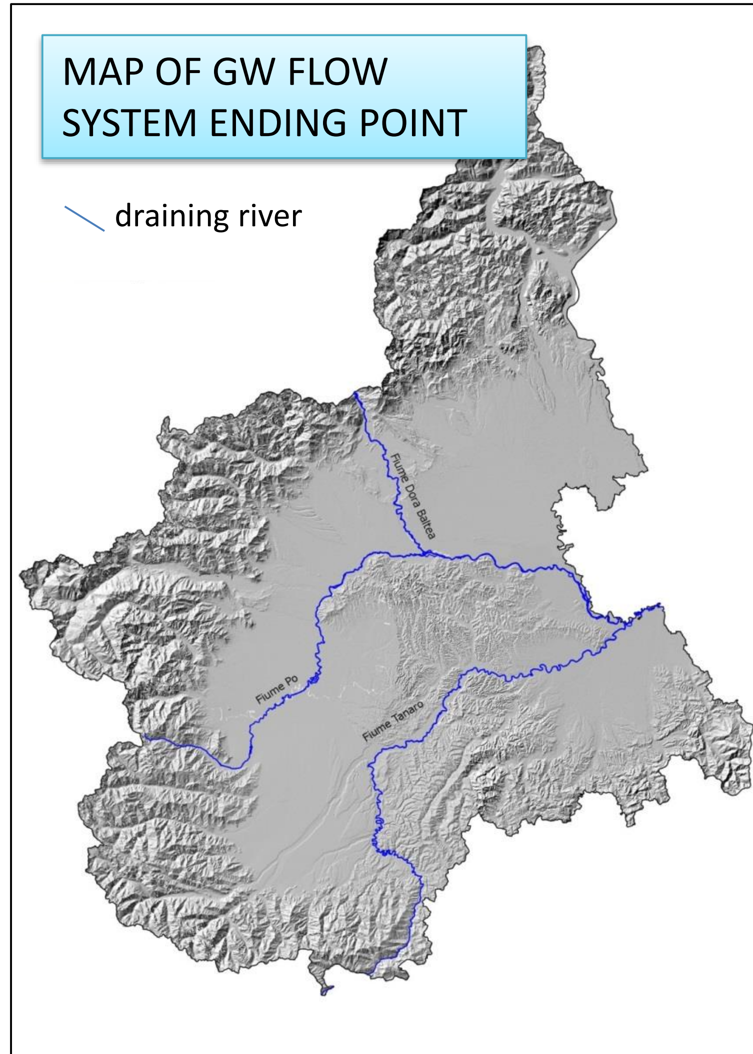
IDENTIFICATION OF THE MAIN DRAINAGE LINES

1) Po River
2) Tanaro River
3) Dora Baltea River
4) Artesian areas (Valle Maggiore)



GW FLOW SYSTEM STARTING POINT

GW FLOW SYSTEM ENDING POINT



Step 2: CRITERION OF THE PORTION OF REGIONAL GW FLOW SYSTEM

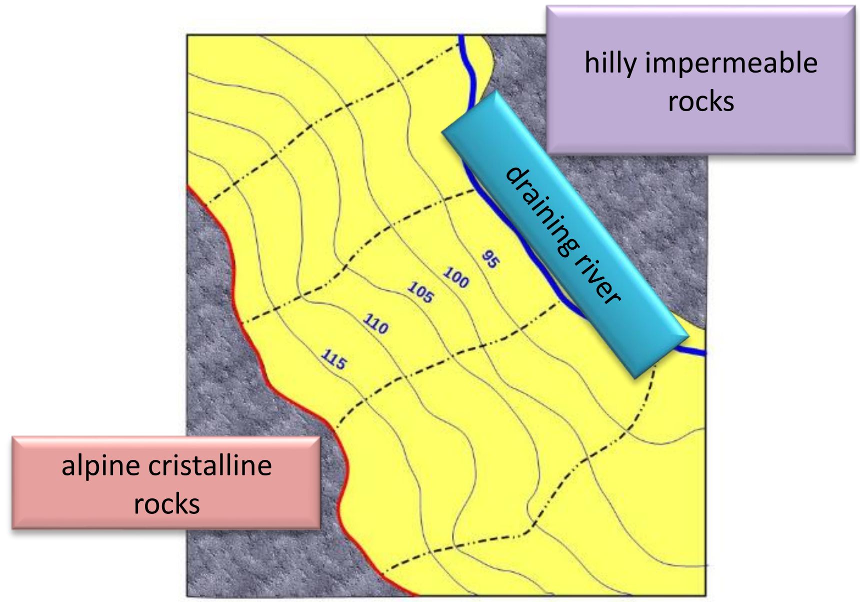
GW flow system starting point

+

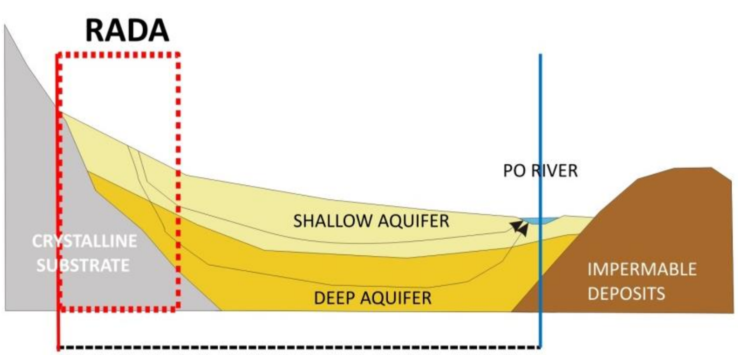
GW flow system ending point

→ **GW FLOW SYSTEM EXTENSION**

perpendicular to isopiezometric lines of deep aquifer



Isopiezometric lines
Extension of GW flow system
GW flow system starting point
GW flow system ending point



GW FLOW SYSTEM STARTING POINT

GW FLOW SYSTEM ENDING POINT

Step 2: CRITERION OF THE PORTION OF REGIONAL GW FLOW SYSTEM

2. DEFINITION OF POTENTIAL RADA EXTENSION, DEPENDING ON GW FLOW SYSTEM EXTENSION:

- **by setting a % of regional GW flow system extension**

Many authors (Thot 1963, Fetter 1994, Freeze & Cherry 1979 …) highlighted, in their hydrogeological models, RADA extension between **8% and 20%** of the total extension of regional GW flow system.
This percentage varies depending on geological and hydrogeological situation.

Step 2: CRITERION OF THE PORTION OF REGIONAL GW FLOW SYSTEM

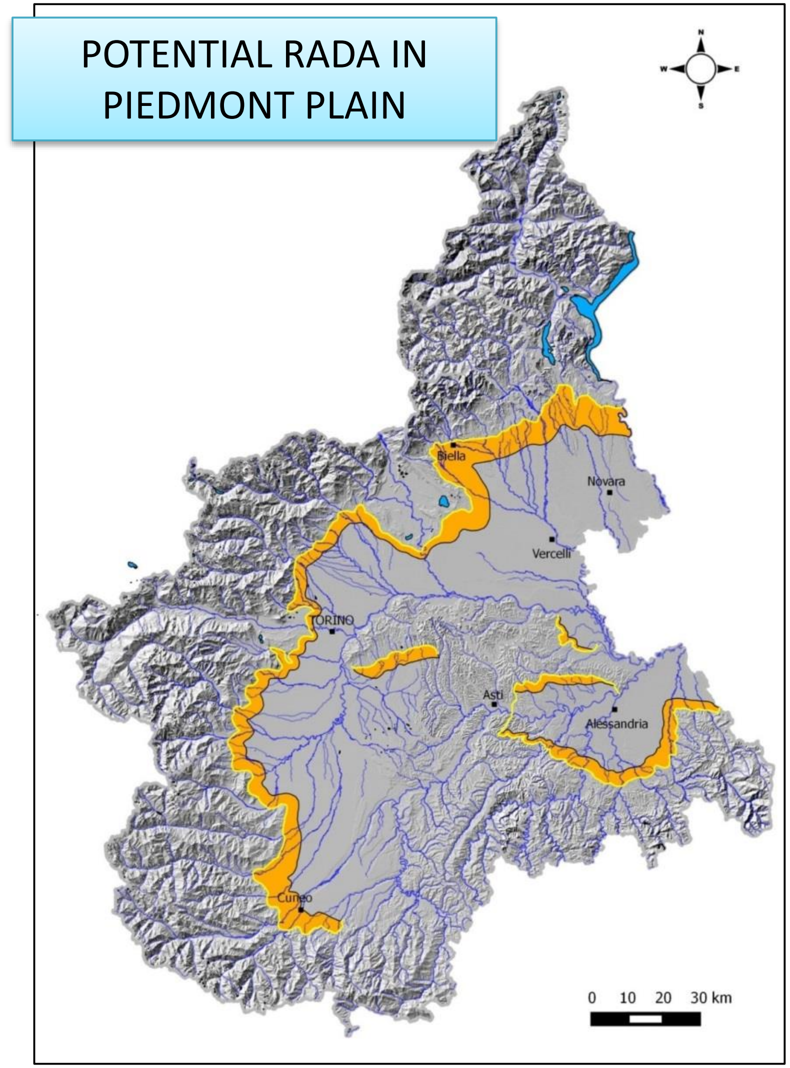
2. DEFINITION OF POTENTIAL RADA EXTENSION, DEPENDING ON GW FLOW SYSTEM EXTENSION:

REGIONAL GW FLOW SYSTEM EXTENSION		Potential RADA Extension (km)
Minimum (km)	Maximum (km)	
3	5	**0.5**
5	10	**1**
10	20	**2**
20	35	**3.5**
35	50	**5**
50	65	**6.5**
65	80	**8**
80	95	**9.5**
95	110	**11**

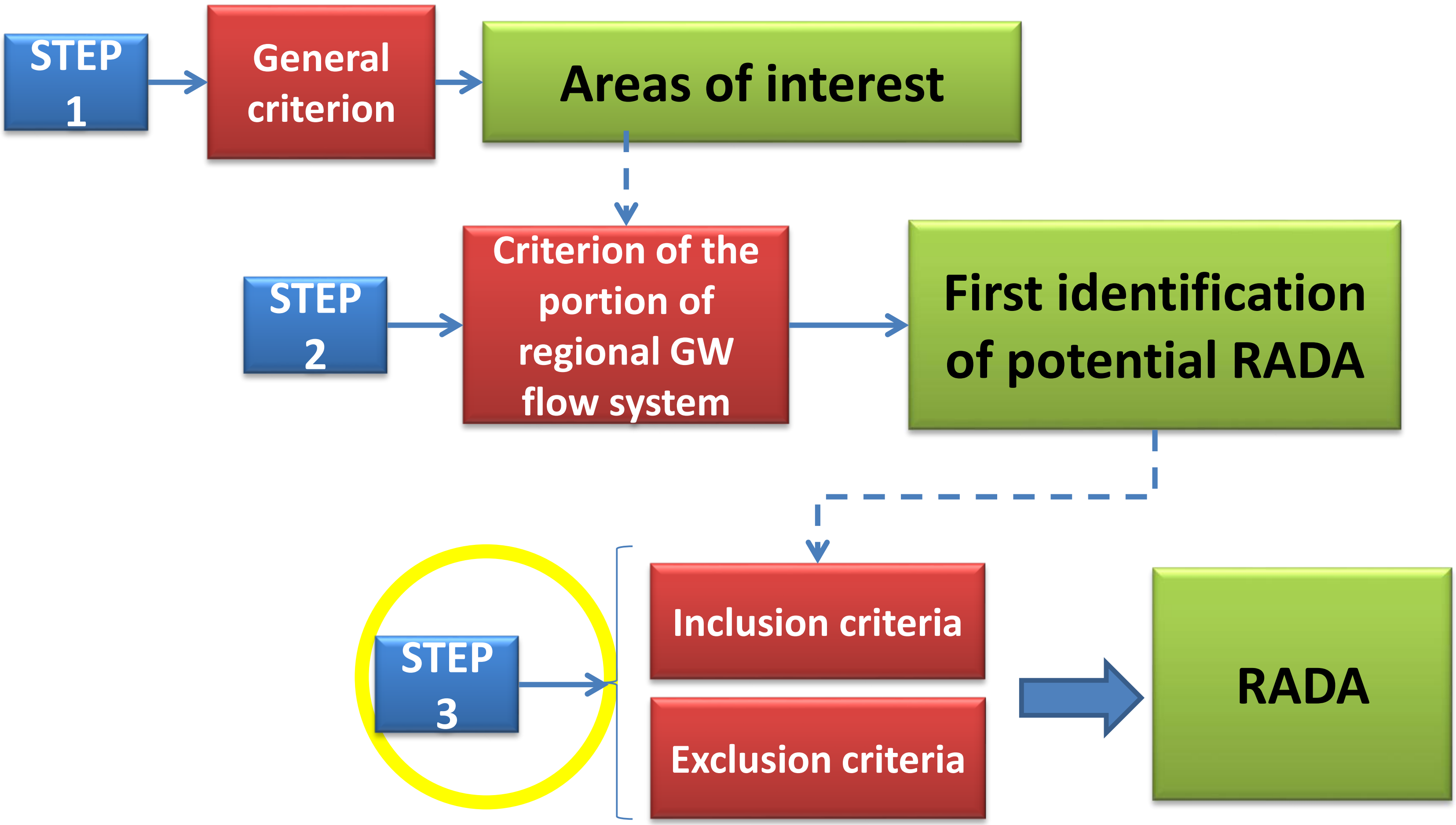
The potential RADA extension ranges between 10 % and 15% of the medium value of each class.

Step 2: CRITERION OF THE PORTION OF REGIONAL GW FLOW SYSTEM

First delimitation of potential RADA in Piedmont plain, according to the general criterion and the criterion of the portion of regional GW flow system.



SIMPLIFIED APPROACH FOR RADA DELIMITATION



Step 3: INCLUSION AND EXCLUSION CRITERIA

The potential RADA, delimited in step 1 and 2, could be **modify and detailed** using further geological and hydrogeological criteria:

- **INCLUSION CRITERIA**
- **EXCLUSION CRITERIA**

Step 3: INCLUSION AND EXCLUSION CRITERIA

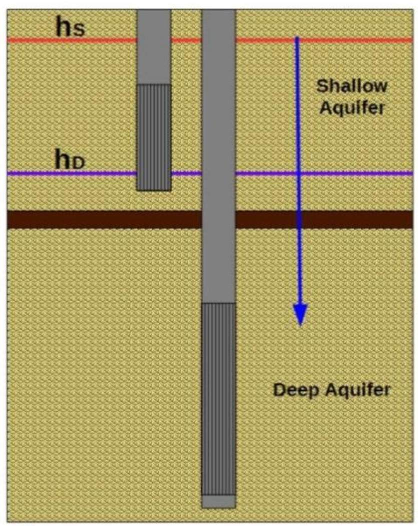
INCLUSION CRITERIA

1) Positive water head differences between aquifers (Δh):

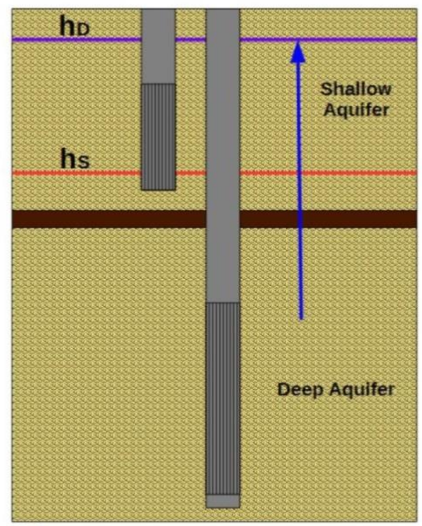
$$\Delta h = h_S - h_D$$

The positioning of potentiometric surfaces of shallow and deep aquifers influences the groundwater flow direction.

a) **Recharge areas** are positioned in areas where $h_S > h_D$ and thus where groundwater travels downward.



a)



b)

b) **Discharge areas** are positioned in areas where the $h_D > h_S$ and thus where groundwater travels upward.

Blue arrow: groundwater flow direction; h_S: shallow aquifer water level; h_D: deep aquifer water level.

All areas characterized by positive Δh values can be contoured and included into the RADA.

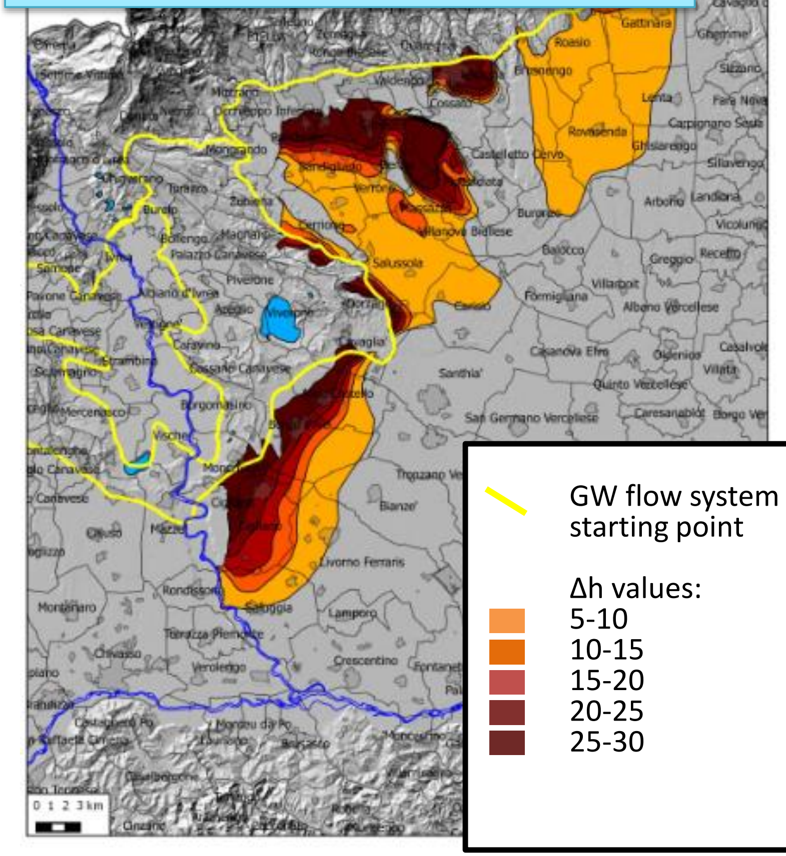
Step 3: INCLUSION AND EXCLUSION CRITERIA

INCLUSION CRITERIA

1) Positive water head differences between aquifers (Δh):

EXAMPLE

MAP OF WATER HEAD DIFFERENCES BETWEEN AQUIFERS (Δh) IN VERCELLI PLAIN



De Luca D.A., Gisolo A., Lasagna M., Morelli di Popolo e Ticineto A., Falco M., Cuzzi C. (submitted). Identifying recharge areas of deep aquifers: a simplified approach applied in the Vercelli-Biella Plain (NW Italy)

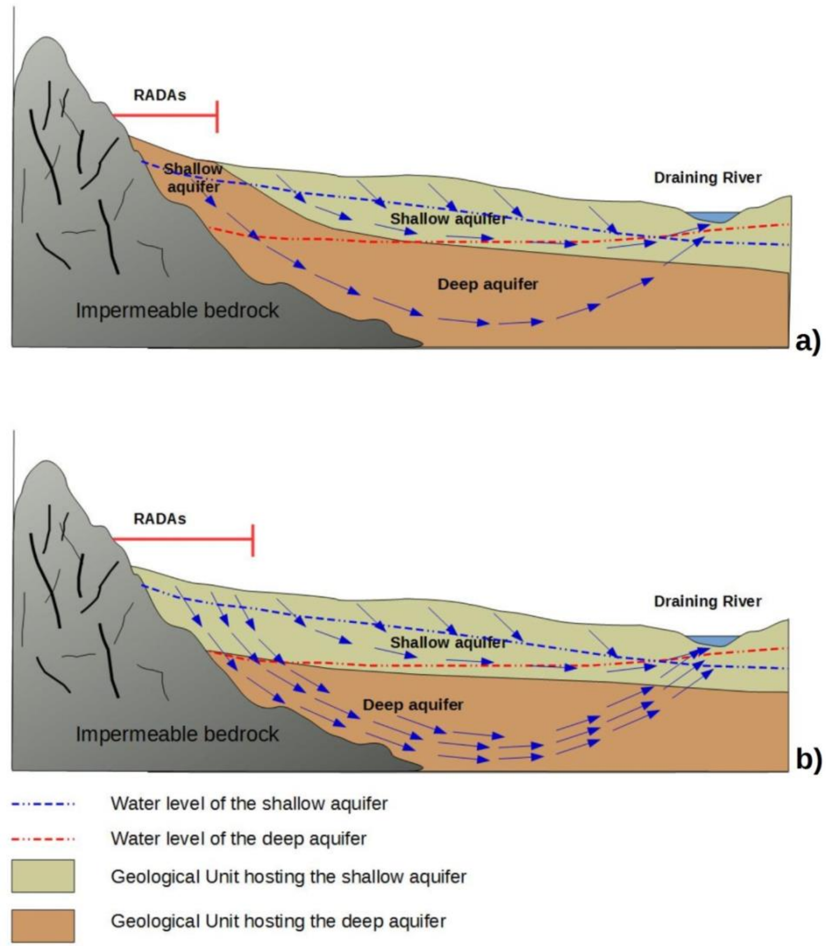
Step 3: INCLUSION AND EXCLUSION CRITERIA

INCLUSION CRITERIA

2) Criterion of geological units hosting deep aquifers outcrop:

where geological units hosting deep aquifers outcrop, there is a direct recharge of deep aquifers and RADA at a minimum correspond to outcropping areas.

All areas that satisfy the criterion are included into the RADA.

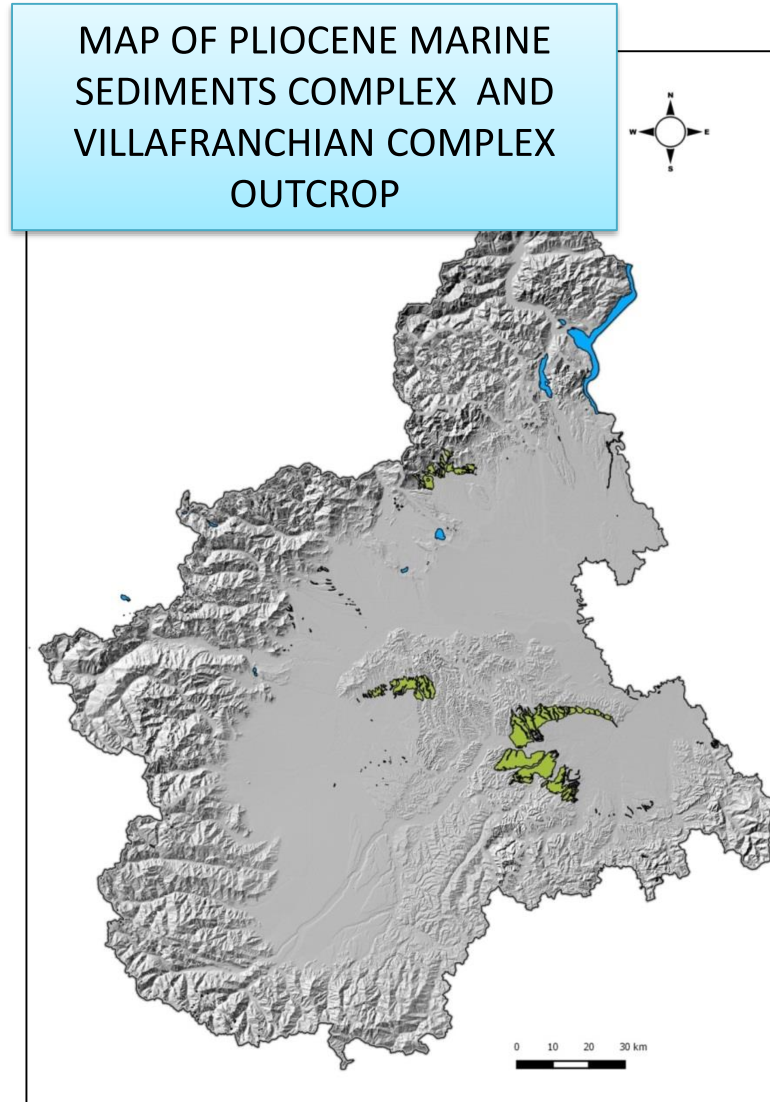


Locations of RADA in two different geological settings where geological units hosting deep aquifers outcrop (a) or do not outcrop (b).

Step 3: INCLUSION AND EXCLUSION CRITERIA

INCLUSION CRITERIA

2) Criterion of geological units hosting deep aquifers outcrop:



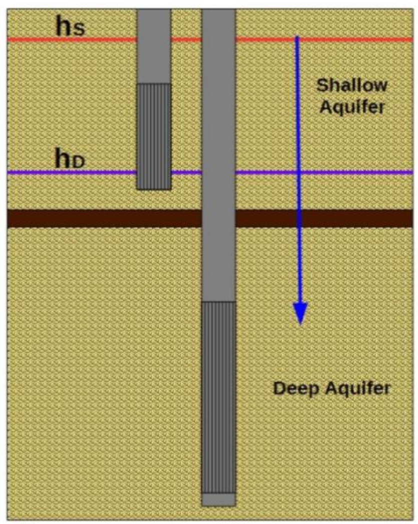
Step 3: INCLUSION AND EXCLUSION CRITERIA

EXCLUSION CRITERIA

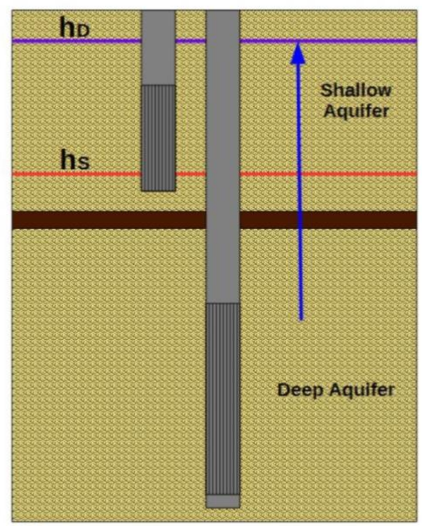
1) Negative or null water head differences between aquifers (Δh):

$$\Delta h = h_S - h_D$$

a) **Recharge areas** are positioned in areas where $h_S > h_D$ and thus where groundwater travels downward.



a)



b)

b) **Discharge areas** are positioned in areas where the $h_D > h_S$ and thus where groundwater travels upward.

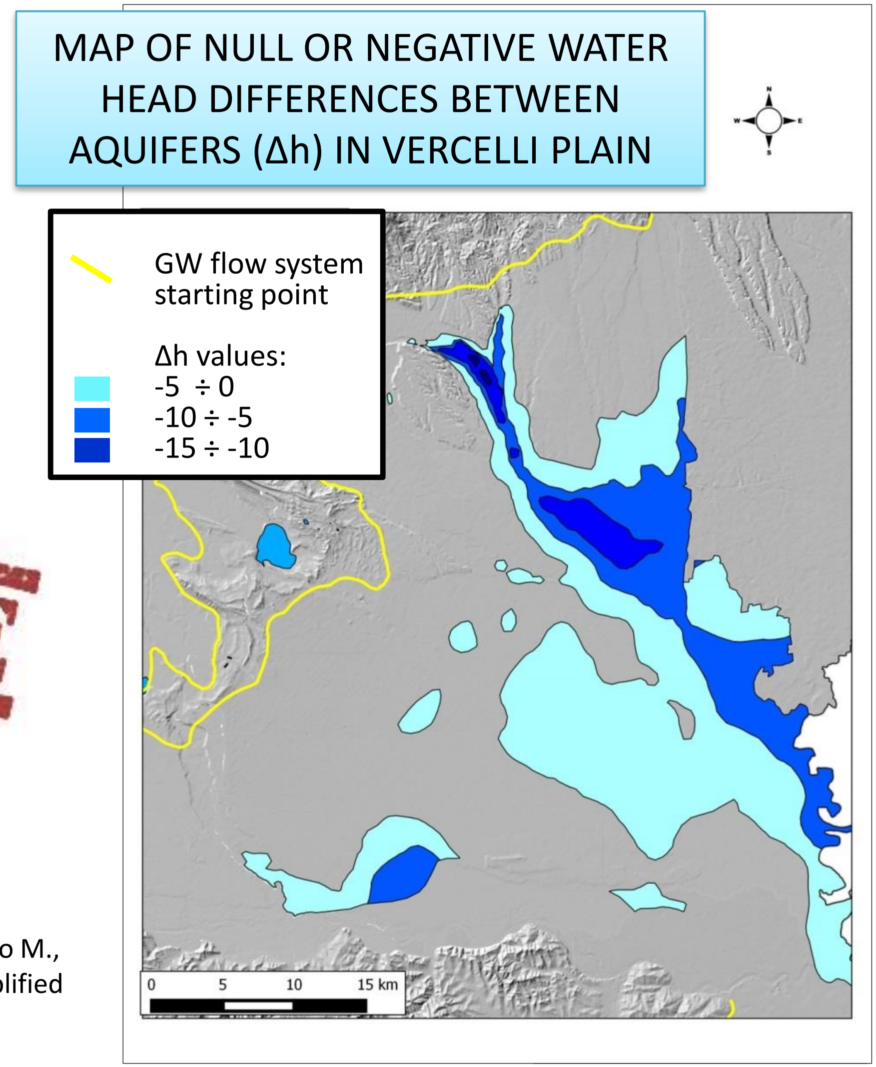
Blue arrow: groundwater flow direction; h_S: shallow aquifer water level; h_D: deep aquifer water level.

All areas characterized by null or negative Δh values are excluded by RADA.

Step 3: INCLUSION AND EXCLUSION CRITERIA

EXCLUSION CRITERIA

1) Negative or null water head differences between aquifers (Δh):



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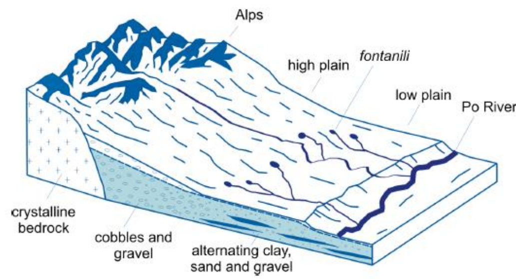
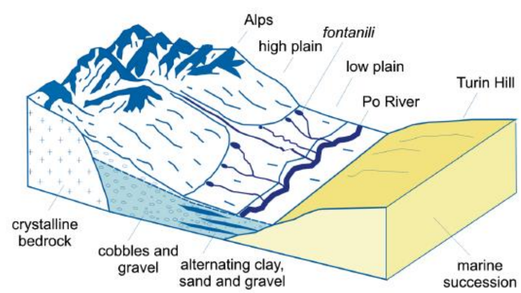
Step 3: INCLUSION AND EXCLUSION CRITERIA

EXCLUSION CRITERIA

2) Areas with *fontanili* (typical lowland springs in Northern Italy) or artesian wells

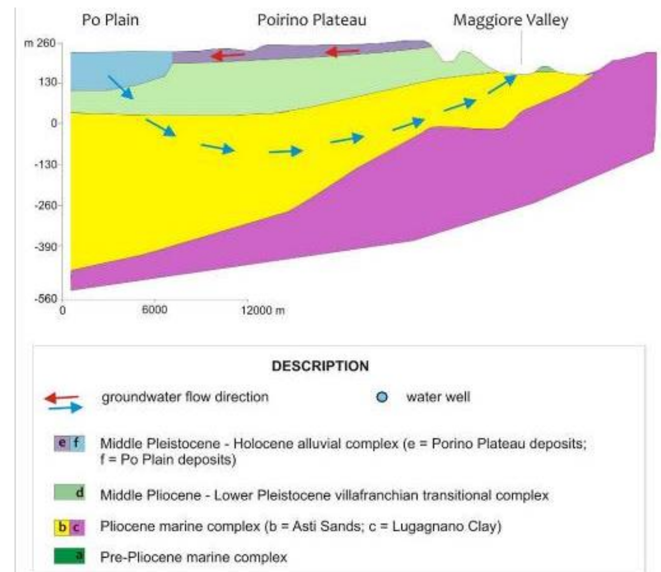
Fontanili: resurgences of phreatic water due to a change of the sediment permeability or to the abrupt change in slope of the topographical surface and to the presence of the impermeable marine succession in the subsoil.





De Luca D.A., Destefanis E., Forno M.G., Lasagna M., Masciocco L. (2014). *The genesis and the hydrogeological features of the Turin Po Plain fontanili, typical lowland springs in Northern Italy*. Bull Eng Geol Environ 73:409–427.

Artesian area in Piedmont Region.

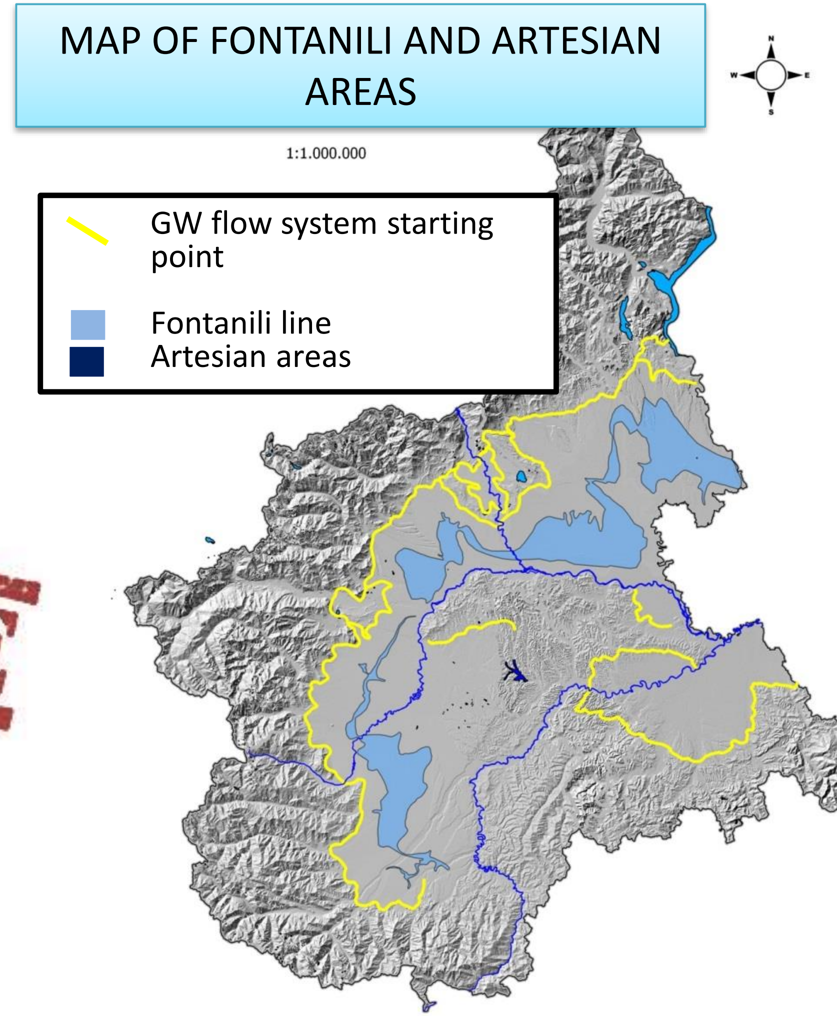


Lasagna M., Caviglia C., De Luca D. A. (2014). Simulation modeling for groundwater safety in an overexploitation situation: the Maggiore Valley context (Piedmont, Italy). Bull Eng Geol Environ (2014) 73:341–355.

Step 3: INCLUSION AND EXCLUSION CRITERIA

EXCLUSION CRITERIA

1) Areas with fontanili (typical lowland springs in Northern Italy) or artesian wells

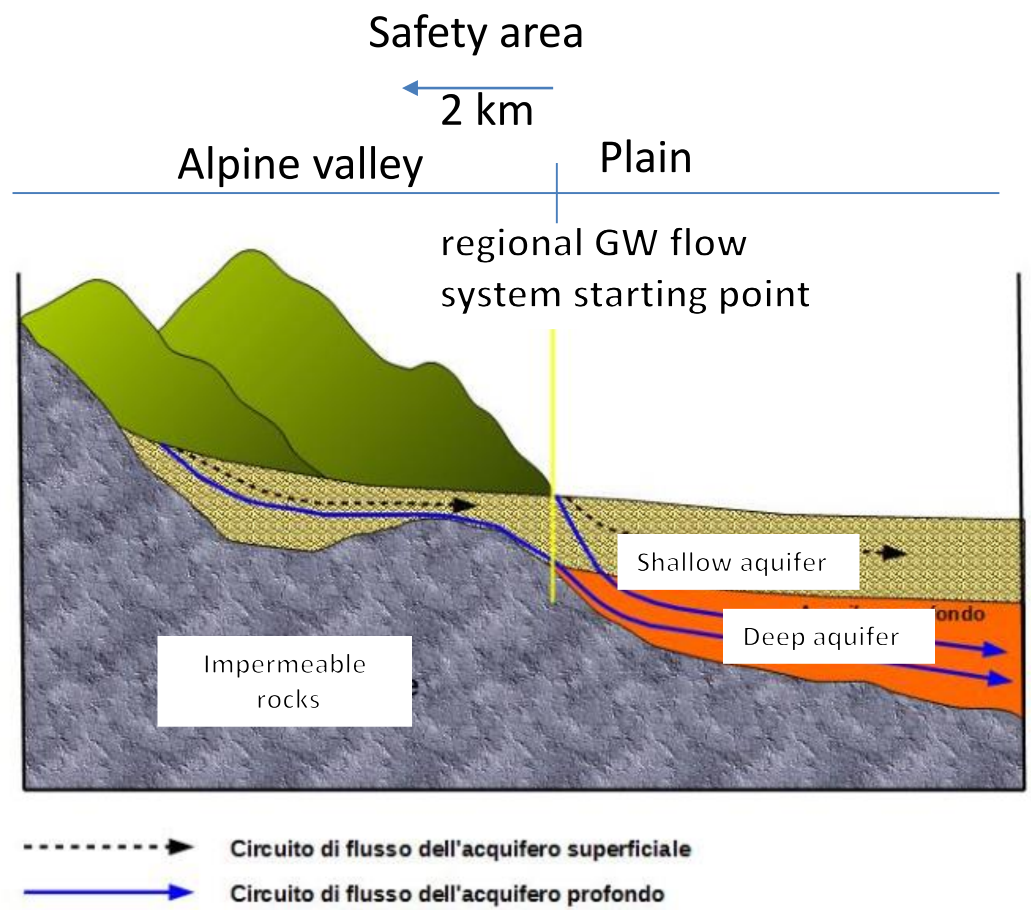


Step 3: INCLUSION AND EXCLUSION CRITERIA

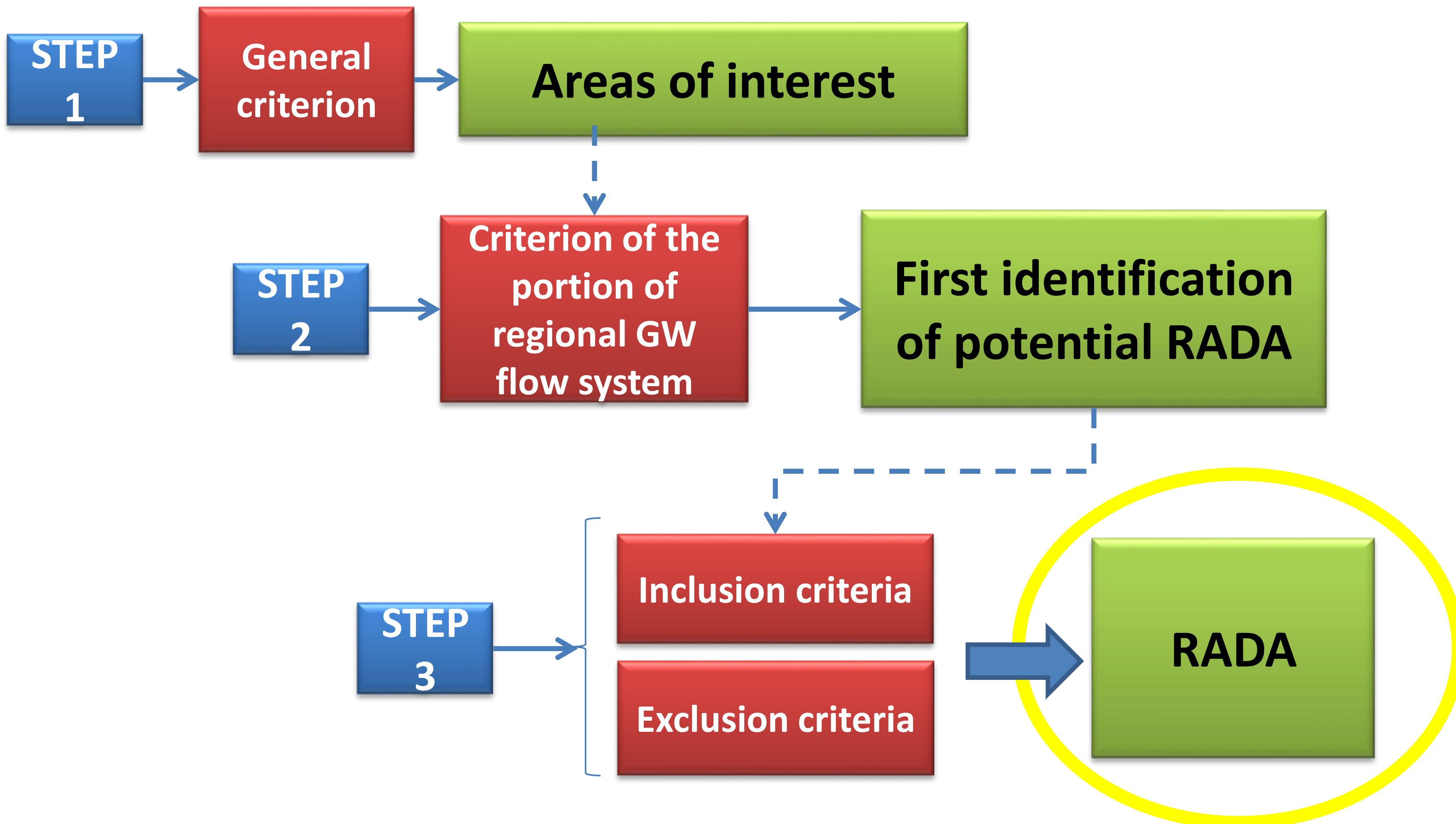
SAFETY AREAS

Buffer areas of 2 km, generally corresponding to a portion of alpine valley floors with alluvial deposits.

The safety areas are added to RADA.

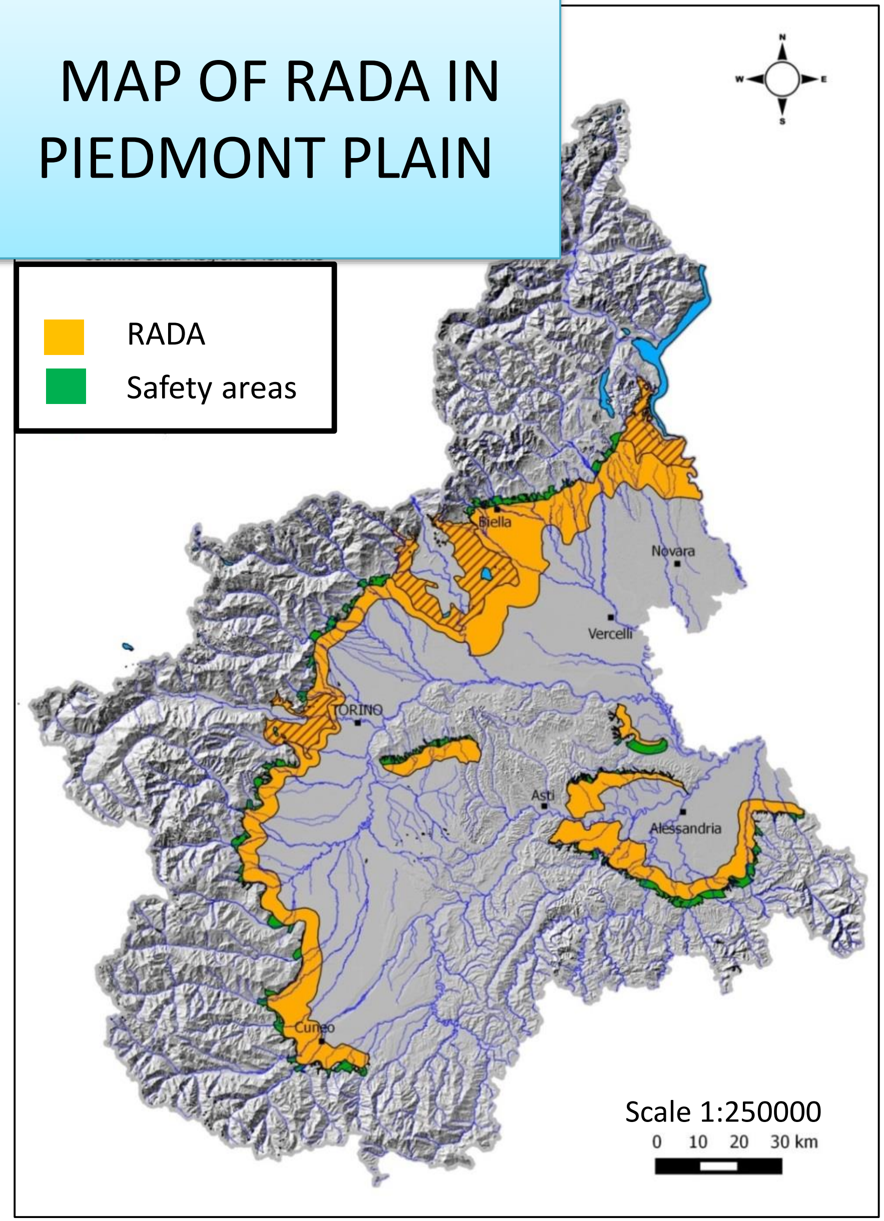


SIMPLIFIED APPROACH FOR RADA DELIMITATION



MAP OF RECHARGE AREAS OF DEEP AQUIFERS (RADA)

MAP OF RADA IN PIEDMONT PLAIN



CONCLUSION

- ✓ The identification and mapping of **recharge areas of deep aquifers (RADA)** is very important because the deep aquifers often represent one of the most important supply of drinking water in plain. Moreover it is also required by law in Italy.
- ✓ The proposed approach is an **expeditious method** for mapping RADA at a regional scale, based on easily available data. It is especially useful to have an estimate of RADA extension in areas where **hydrogeological and chemical data are locally absent.**
- ✓ The method is **implementable**, introducing additional criteria; as a consequence, the map of RADA is **updatable**.


THANK YOU