GROUNDWATER FLOW and SEEPAGE

Engineering Department of
Hydraulic Strutures & Environment

Master of Hydraulics

Academic Year 2012 – 2013

Course n°1: Introduction

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FOREWORD

Groundwater flow and Seepage problems are encountered

- in Civil and Environmental Engineering (i.e. flow through or under dams, toward wells or drains, around a sheetpile wall or a clay blanket,…);

- in Hydrology (i.e. infiltration of rain water in soils, water exchanges between embankment and rivers,…);

- and also in Hydrogeology (i.e. long term subsurface flows, ground water resource and quality, polluted soils rehabilitation, pumping,…).

FOREWORD

In all these problems, we have to deal with a fundamental principle which is the Darcy's Law.

The objective over an investigated area can be resumed as the following:

- If the soil hydrodynamic properties are known, we can calculate the groundwater discharge (Q), the head (H) and pore pressure (P), and then anticipate the occurrence of a breaking (Civil Engineering) or make the assessment of the water resource (Hydrogeology).
- If the spatial profile of groundwater is known for a given time (i.e. by means of field measurements) then the soil hydrodynamic properties can be estimated.

FOREWORD

So using Darcy's Law, we would like through this course, to develop the following skills:

- Calculate the groundwater discharge, head and pressure, under various configurations (i.e. spatial geometry, anisotropy, saturated conditions, transient flow,…) with different methods graphical, analytical and numerical.

- Make the critical thinking of a numerical model (i.e. Hydronap, Modflow, Seep-2D);

- Estimate the hydrodynamic properties of soils (i.e. hydraulic conductivity K, storage coefficient S, porosity n, transmissivity T), from field measurements (SERES Stat.).

FOREWORD

The level throughout this course will be placed between undergraduate (Darcy's Law, Flow Net calculations,…) and postgraduate (complex potentiel, transient flow,…).

Hard working students could at the end, acquire an interesting background and be ready to join companies involved in the following topics :

- Earth Dams design, construction and inspection (EDF,…)
- Management of Embankment and Rivers (CNR,…)
- Soils and Environmental Studies in relation with groundwater or pollution (Antea, Artelia, Burgeap, Safege,…)
- Research issues (CEA, Cemagref, Andra, Brgm,…)

FOREWORD

This course will be taught on the following basis :

- 9x2=18h of main courses (theoretical),
- 4x2=08h of tutored exercices,
- 1x4=04h of a field work (practical, on the SERES Station).

The final grade will consist of an exam (1.5 ects), and the practical work report (0.5 ects)

The course documents will be available on a printed form. Whatever, a French version will be placed on the intranet.

The students can feel free to ask their questions either in French or in English.

New: Some courses will end with a written quiz for 5 to 10 minutes. It will help, to capture what the students understand and where are difficulties.

SUMMARY

- INTRODUCTION
- HYDRODYNAMIC PROPERTIES (exercices)

- STEADY STATE FLOW (equations, analytical solutions)
- STEADY STATE FLOW (flow nets, exercices)
- STEADY STATE FLOW (complex potentiels, wells group)
- STEADY STATE FLOW (numerical modeling)

- TRANSIENT FLOW (drainage, groundwater pumping,…)
- TRANSIENT FLOW (numerical modeling)

- HYDRAULIC CONDUCTIVITY FIELD MEASUREMENTS

1: INTRODUCTION

As mentionned before, Drainage and Seepage will be a matter of concern in this course.

The 3 mains causes of dam’s breaking are:

- Structural failure (cracking resulting from excessive strain)
- Overtopping failure (due to heavy flooding conditions)
- Seepage failure (excessive pore pressure or high flow rate)

Seepage flows are unavoidable in earthen dams. It has to be controlled, if we want to anticipate increasing troubles with sometimes significant damages. This can be achieved with various equipments (i.e. toe drains, a clay core, a chimney drain, an upstream impervious blanket, a cutoff wall for pervious fondations, an upstream sloping core, etc…). These equipments help keeping dry the downstream slope of the dam or reducing the flow rate.

INTRODUCTION

Embankment dams (or earthen dams) are designed to prevent flooding along rivers, or collect water resource for hydropower, drinking water, irrigation and recreation.

Serre Ponçon Dam (photo on the right) is the biggest embankment (remblai) dam in Europe, with the following settings: Height=123,5m, Base width=650m, Crest width=10m, Length=600m, Zoned earth dam equipped with a clay core, Material Volume=14 millions m3, Storage=1,27 billion m3.

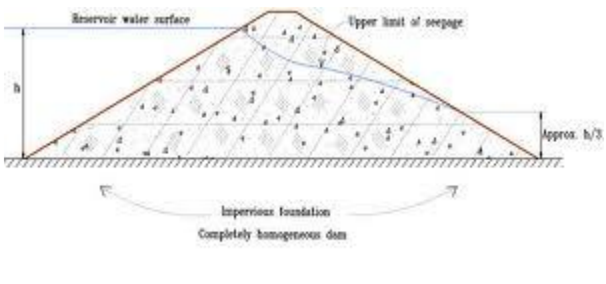
INTRODUCTION

The Pomme de Terre Dam: an earth and rockfill embankment; 7,240 ft long, 155 ft in height; covering 7,820 acres in the Missouri River Basin (Kansas State). Equipped with a compacted clay core. Construction 1957-1961 for $15 millions. Fonction: flood protection and recreation.

The Banasura Sagar Dam: the biggest earth dam in India, 2nd in Asia;
3300 ft long.

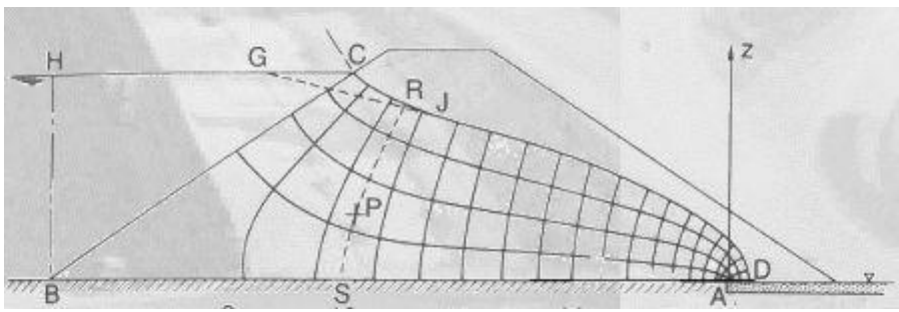
Benmore Dam (New Zealand): the largest earth dam in south hemisphere, built for hydroelectricity.

INTRODUCTION

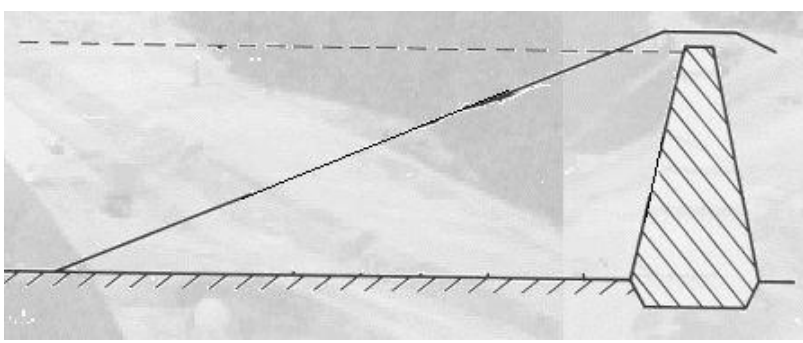


Seepage flow through earth dam with no filter at the dam toe

Seepage through a dam, without a drainage system. The phreatic line (or upper saturation line) is shown. The foundation is considered as impervious.



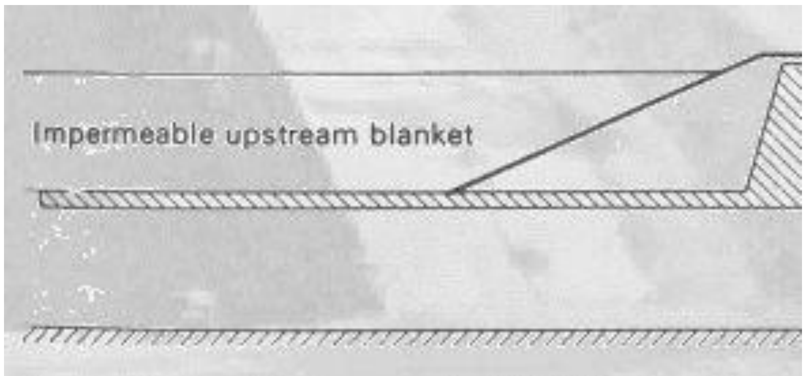
A dam equipped with a toe drain. The flow network (graphical solution) is shown. The foundation is considered as impervious.



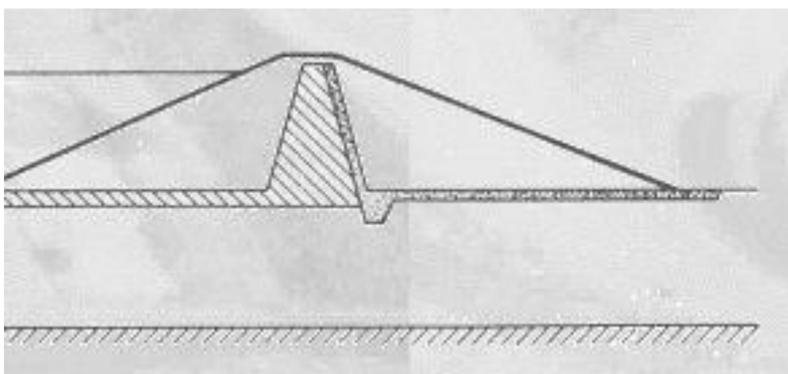
A zoned dam equipped with a central clay core. The foundation is considered as impervious.

Courtesy : Thomas Henry; The Engineering of Large Dams
Wahlstrom; Dam, Foundations and Reservoir Sites
Craig R.; Soil Mechanics.

INTRODUCTION



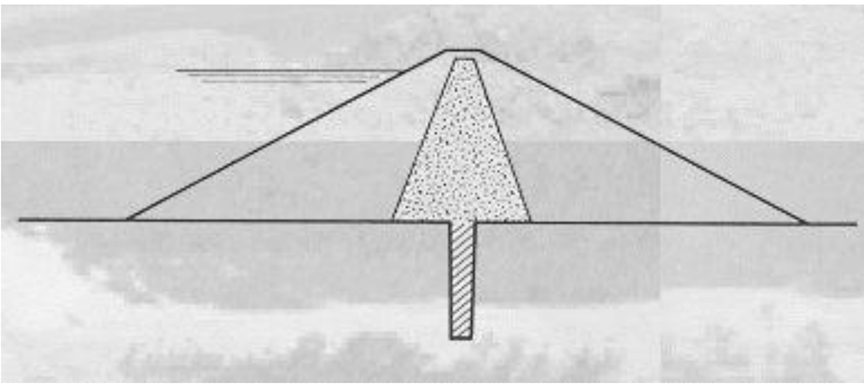
This dam is equipped with a clay core and an upstream impervious blanket.



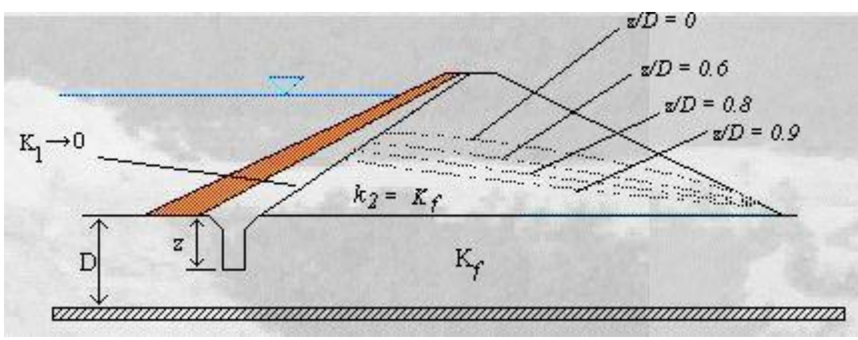
Here we have a clay core and a chimney drain completed with a downstream pervious blanket.

Courtesy : Thomas Henry; The Engineering of Large Dams
Wahlstrom; Dam, Foundations and Reservoir Sites
Craig R.; Soil Mechanics.

INTRODUCTION



A zoned dam equipped with a central clay core and a cutoff wall, in the case of pervious foundation.



A zoned dam equipped with a sloping clay core set upstream, and a partial cutoff wall, in the case of pervious foundation. The different phreatic lines with respect to wall size are shown.

Courtesy : Thomas Henry; The Engineering of Large Dams
Wahlstrom; Dam, Foundations and Reservoir Sites
Craig R.; Soil Mechanics.

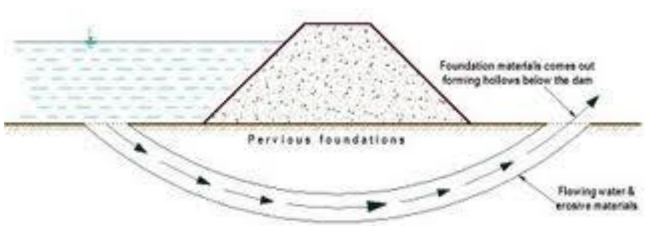
1: INTRODUCTION

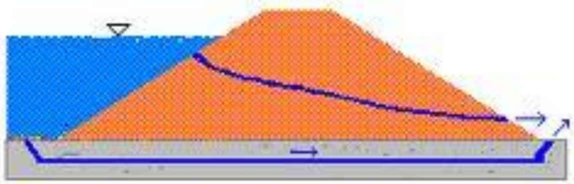
In seepage failures, we include Slide and Piping failures.

Seepage can cause slide or slope failure by creating high pressures in the soil pores or by saturating the slope. The shear resistance is reduced and the soil become weak. This can happen after long or heavy rainfall on the downstream slope, or rapid drawdown near upstream slope.

1: INTRODUCTION

If the seepage velocity is uncontrolled, it can progressively erode soil from the embankment or its foundation, resulting in rapid failure of the dam. Erosion of the soil begins at the downstream side of the embankment, either in the dam proper or the foundation, progressively works toward the reservoir, and eventually develops a direct connection to the reservoir. This phenomenon is known as “Piping (Renardage)."



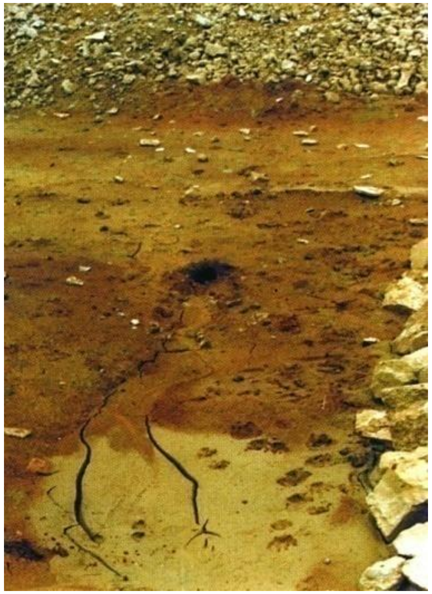


This dam is hazardous.

1: INTRODUCTION

Buget Dam (France). A piping from downstream.

Courtesy : D. LAUTRIN



Gourdon Dam (France). A piping from upstream.

Courtesy : D. LAUTRIN

St-Julien Dam (France). A piping along outlet works.

Courtesy : P. MERIAUX, P. ROYET

Piping action can be recognized by an increased seepage flow rate, the discharge of muddy water, sinkholes on the embankment, a sand boil (Boulance) downstream, or sometimes a whirlpool in the reservoir (when it's to late to intervene).

1: INTRODUCTION

Teton Dam (1976, Idaho, USA).

Saint-Aignan Dam (France).

Cowlitz Dam (USA).

Acidic seepage failure near Donana's National Park (1998,Southern Spain).

1: INTRODUCTION

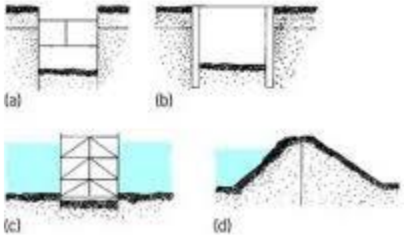
Some other examples of groundwater flows in Civil Engineering are given by Excavation dewatering (pumping works):




Many wellpoints are set around the working area and their individual drawdown are superimposed for the total dewatering.

Flow under a sheetpile (palplanche),   Flow under a cofferdam (batardeau).

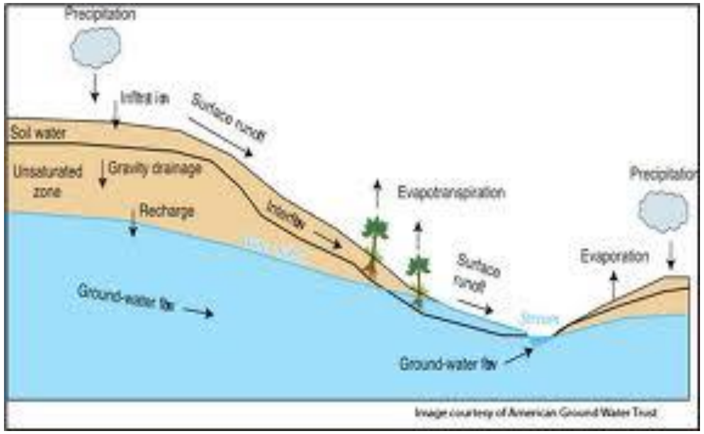




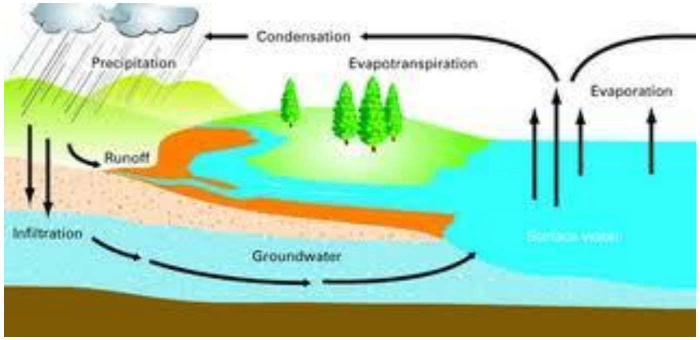
1: INTRODUCTION

After Seepage in Civil Engineering, we will next focus on Drainage in Groundwater Resource and Environmental Issues.

Groundwater flows through pervious aquifer, from recharge zones upstream where infiltration takes place, to discharge zones downstream which can be linked to a surface body water (i.e. river, lake or even ocean).



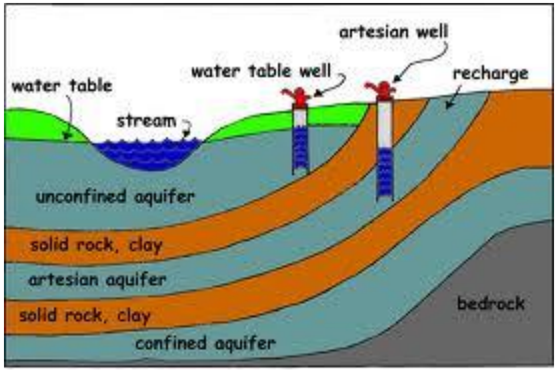
This is part of the global water cycle, which include, others hydrological flux terms such as evaporation, precipitation and run off.



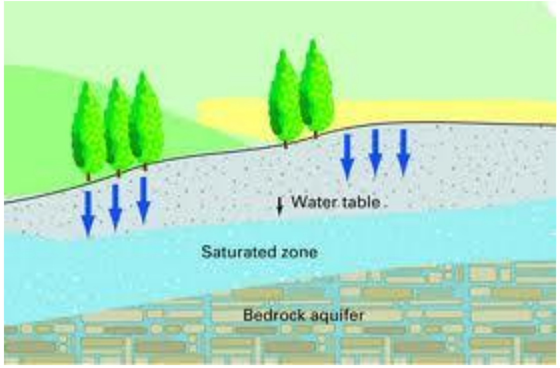
1: INTRODUCTION

The flow rate and water quality depend on the aquifer type : confined, unconfined or fractured.

In unconfined aquifers, the upper saturated line is at atmospheric pressure (then set to zero) and exchanges with stream water are frequent. Whereas for confined aquifer, groundwater is kept tight between 2 impervious layer (solid rocks or clay).



The phreatic line is also called water table. One may notice that very often, the upper part of a solid bedrock presents some cracks, then leading to another type of aquifer with higher flow rate.

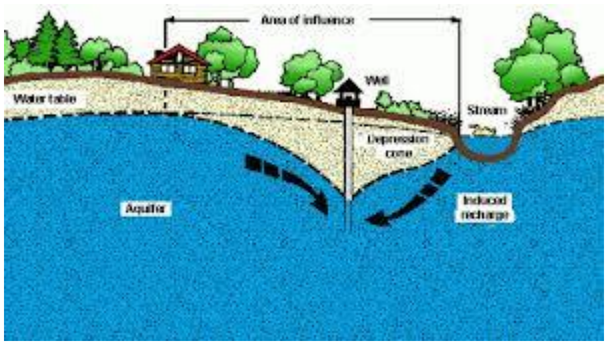


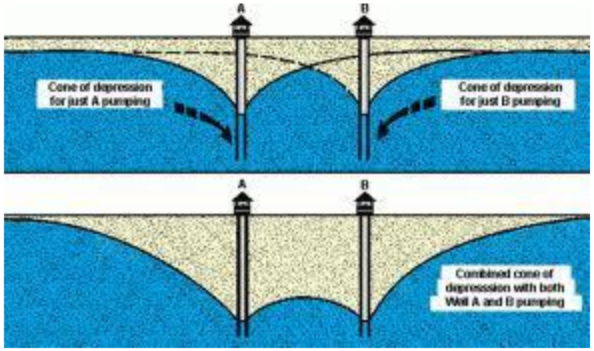
1: INTRODUCTION

A key engineering operation with groundwater management is undoubtly pumping.

With a given pumping flow rate, what drawdown in space and time, will we have ? Does it make a difference to pump near a river ? What is the influence of water table slope, type of aquifer,…? We will make efforts to address these questions.

How to calculate spatial drawdown in the case of a group of pumping ? We will also see the theory of imaging wells.





1: INTRODUCTION

It’s worthwhile to make a difference between a well and a borehole

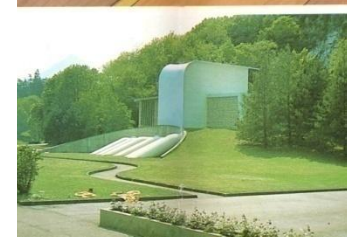
A well is often made in masonry, not too deep (a few ten meters), and with a diameter of about 1 meter or even more.

A borehole consists of steel material, can be drilled up to hundred or thousand of meters deep, with quite small diameter (i.e. 0.60 m)

1: INTRODUCTION

A wellfield, is a protected area where many wells are operated to supply a city with drinking water.

At Crepieux-Charmy (France) not less than 114 wells are pumped everyday to provide about 930000 people with 275000 m3 (61% of the supply capacity). Many recharge zones are present on the site to anticipe a chemical pollution in the nearby stream.This is one of the largest wellfield in Europe (375 ha).



4 wells with radiant drains at the Rochefort wellfield (Grenoble), can extract from 2000 to 3000 m3/h at 30m depth, in the alluviums of the Drac River.

1: INTRODUCTION

Our teaching tools will include: The *SERES Station and 2 numerical codes HYDRONAP* + *MODFLOW based on finite differences scheme of an iterative resolution.*

The SERES Station

1: INTRODUCTION

SERES Station History :

SERES Station has been designed and built up by Dr. Robert WOUMENI, as a platform for experimental field testings on seepage and drainage.

- 1994, **Pumping tests** in an unconfined aquifer for field hydraulic conductivity measurements were ready.
- 1995, Stepwise **Well Tests** for the assessment of well performance have been worked out.
- 2000, ***Tracer tests*** for groundwater pollution were achieved for dispersivity measurements in the field.
- 2002, Some ***hydraulic rehabilitation testings*** by groundwater removals were done.
- 2008, We created a **Pilot Scale Aquifer Model**, for toxic contaminant transport tests.
- 2010, A study for **geothermal application** on the site was launched.
- 2011, Preliminary results on our ***Vertical Electrical Sounding Tests*** (geophysical method) for pollutant studies were obtained;
- 2014, We will design and carry out some ***Infiltration Tests*** for the studies on wastewater filtration systems.

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1: INTRODUCTION

SERES Station Location :

The Seres Station is located on the Grenoble University Campus, at about 300m from the Isere River.

An unconfined sandy aquifer (not used for drinking water) is underneath at about 3m depth.

Latitude:	45°11’ 47.26’’ N
Longitude:	5° 46’ 11.86’’ E
Elevation:	210 m

A surface area near than 1 ha is available for testings on the groundwater resource.

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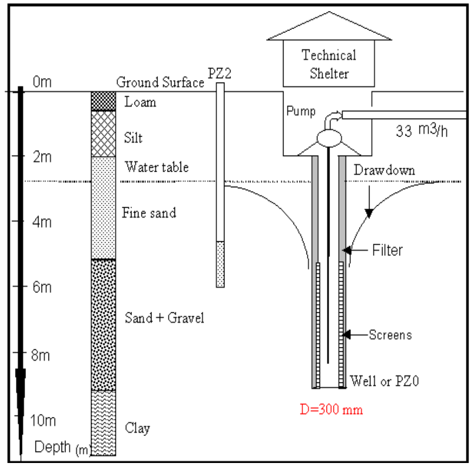
1: INTRODUCTION

SERES Station Equipments :

A view of the borehole.



Lithology

The discharge pipe.

A 33m3/h Pump.

An observation Well

Our Pilot Scale Aquifer Model

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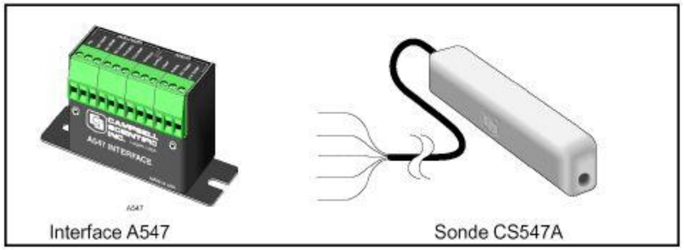
1: INTRODUCTION

SERES Station Devices :

A Data logger

Pressure transducer probe

Water level device



Conductivity probe

Spectrophotometer

Electrical Sounding device

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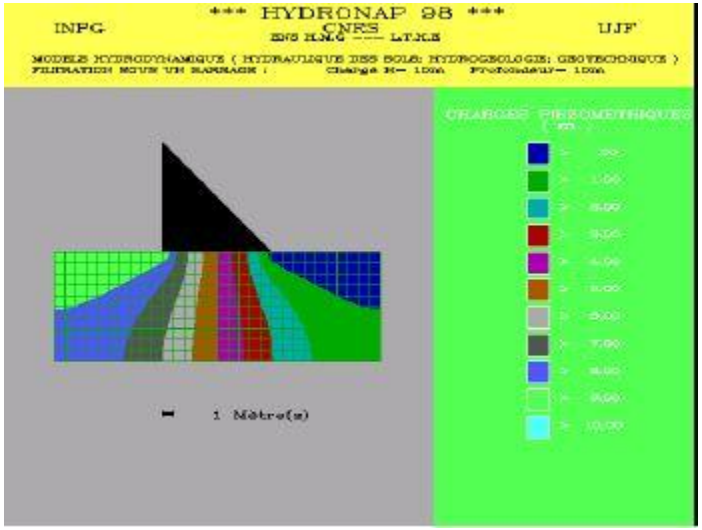
1: INTRODUCTION

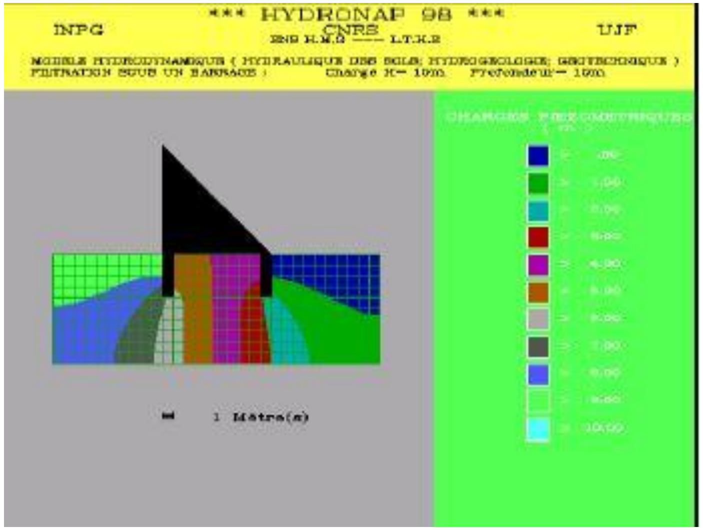
Numerical code HYDRONAP *has been designed and built up in 1998 by Dr. R WOUMENI.*

After taking 2h to learn how to use the code, the students can improve their understandings in seepage and drainage problems.

The following items can be addressed

- Seepage in dams foundations;
- Influence of cutoff walls;
- Transient Pumping;
- Pumping near a river or wall;
- Designing a hydraulic barrier;
- Flow under cofferdams, etc..



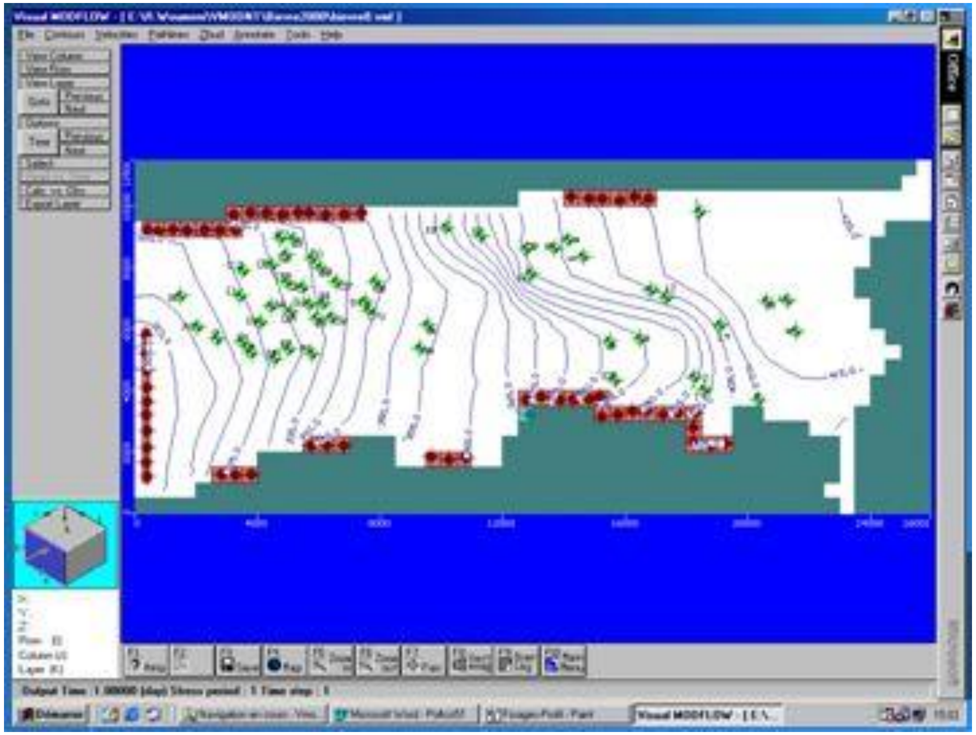


An example of transient pumping problem using HYDRONAP

1: INTRODUCTION

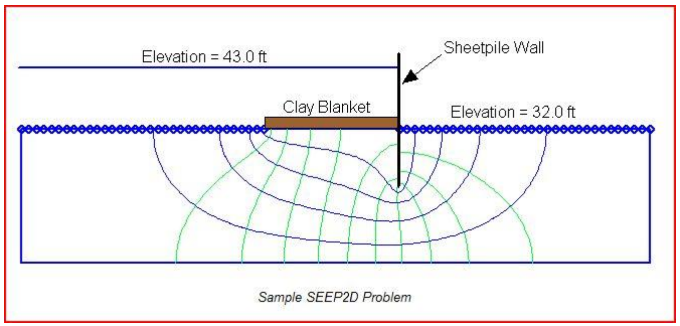
The numerical code MODFLOW is certainly the most popular numerical code used for groundwater management studies.

On the example hereby, groundwater levels for the Bievre plain, range from 400m (right) to 300m (left side). The wells around (in red colour) help to simulate inflow or outflow on the boundaries.

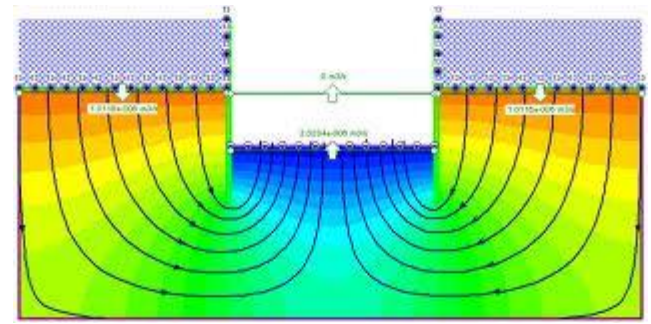


1: INTRODUCTION

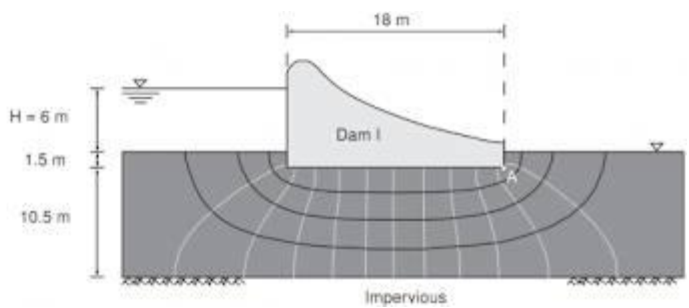
Let us mention other numerical codes which can be useful in this course : Seep2D, Plaxis, SVFlux, Phase2, Feflow,…..



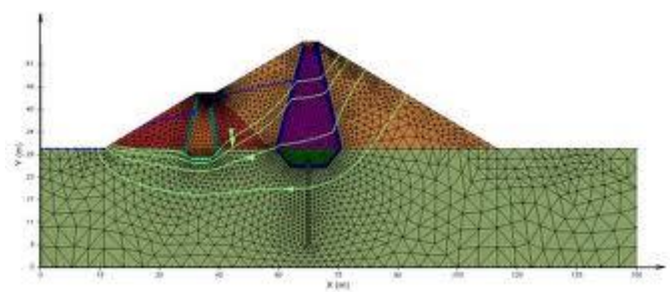
Flow around a sheetpile with Seep2D (by the Seepage Analysis Group, US).



Seepage flow toward a cofferdam with Phase2 (by RocScience, Canada)



Flow under a concrete dam with Plaxis 2D (by Plaxis BV, Netherland)



Flow through a clay core earth dam with SVFlux (by SoilVision, Canada)

An example of transient flow through a dam using SVFlux

1: INTRODUCTION

Then Seepage and Drainage cover a large range of applications, and many classical knowlegdes are involved : Geotechnics, Hydrogeology, Hydrodynamics in Porous Media, Soil Mechanics, Fluid Mechanics, Hydrology.

This is very wealthy but also a cause of difficulties, as for a given problem, we need to combined theoretical and practical aspects on a balanced way. The resulting solution may often depend on a variety of factors: Is the flow confined or unconfined ? Is the soil homogeneous ? Do we have a 1D-2D or 3D problem ? Is there some symmetry ? What are the types of boundary conditions ? Are we under steady state or transient conditions ? Is the soil fully saturated ? What type of spatial coordinates would be suitable ?