Harnessing Floods to Enhance Livelihood and Ecosystem Services

Project Launch Workshop

April 28 to 30, Kassala, Sudan

Groundwater Modeling

By

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Introduction

- Groundwater basins are part of the Ecosystem.
- Understanding and addressing any ecosystem problems in Gash basin requires the understanding of the present and future performance of aquifers within the basin

- Catchments and groundwater basins are hydrogeologicly defined
- Need to understand local hydrology and hydrogeology
- Critical to understand where and how water is delivered, how hydrology changes along aquifers , waterways and with land use, and how ecosystems services require different water quantities and qualities
- Recognize that ecosystem itself is a stakeholder

Objective

- Develop a strengthened conceptual foundation for local catchment and groundwater basins problems using an ecosystem approach.
- Increase ability to develop and demonstrate alternate management approaches for groundwater in the Gash basin.
- Increase ability to identify, engage, and communicate with stakeholders, women and youth to participate in groundwater management and awareness.

Approach

- Incorporates knowledge about functioning of the catchment ecosystem into planning and management
- Focuses on managing groundwater and land resources within catchments
- Recognizes the need to maintain catchment and groundwater basin ecosystem health
- Incorporates ecosystem services to express value and influence behavior to address water security

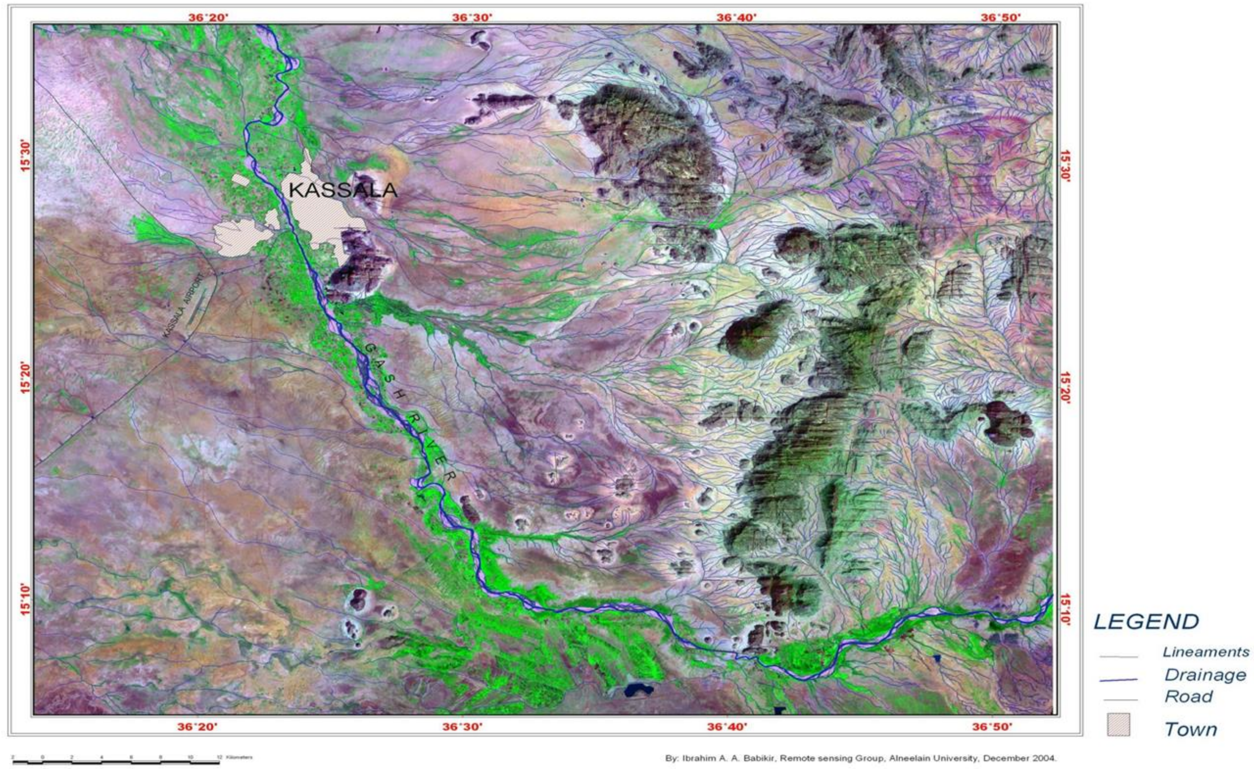
“focuses on the broader goal of balancing and sustaining ecosystem services, complementing IWRM as a strategy for the integrated management of water, land and living resources in a way that maintains ecosystem health and productivity in balance with sustainable groundwater use…it links ecosystem service delivery and human needs.”

Gash River Basin

- The Gash river basin is one of the most famous alluvial basins in Sudan.
- The Gash river is an intermittent stream originating in the highlands of Eritrea.
- It flows northwest across a flat plain and ends as an inland fan delta .
- It is the most important agricultural land in the area.

Gash River Basin

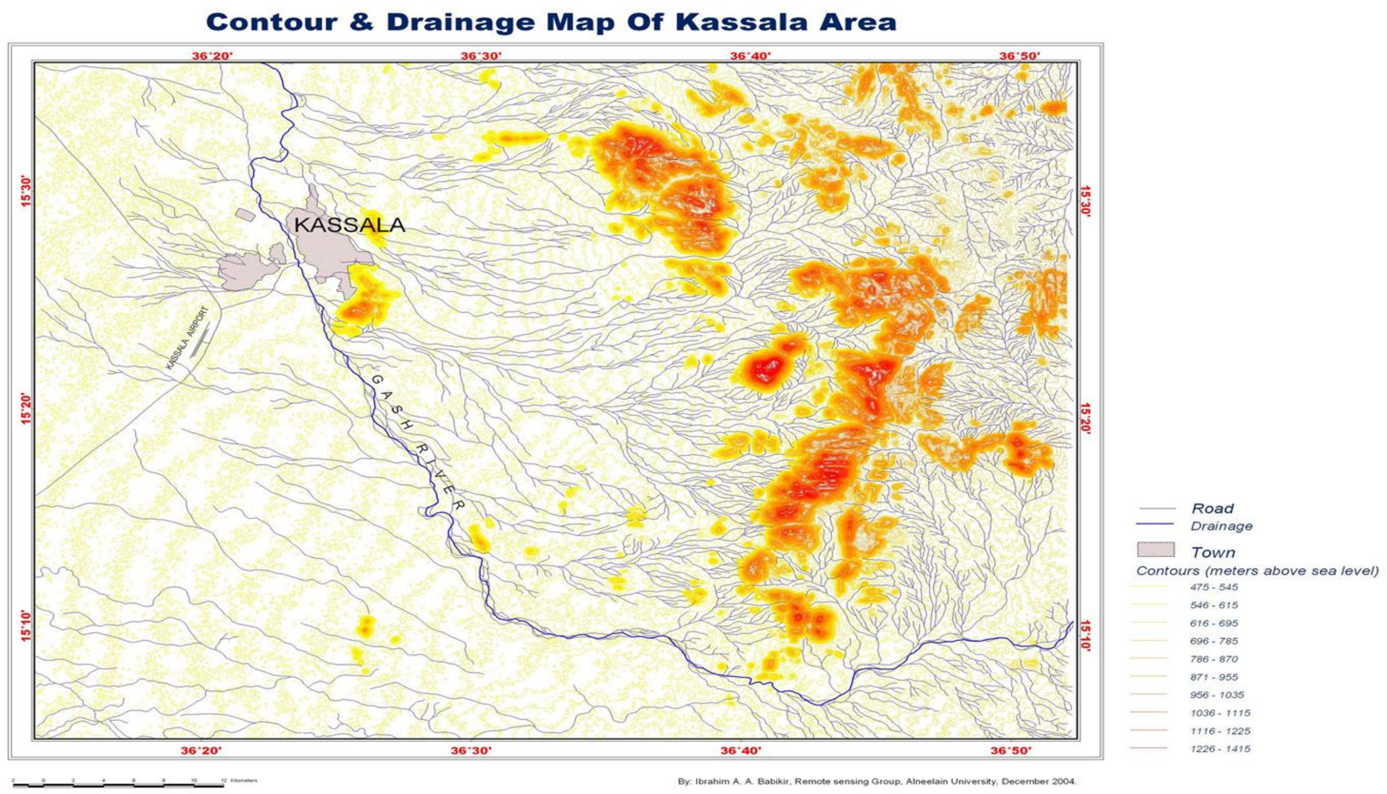
Landsat ETM+7 Color Composite Image of Band 7, 4, 1 represented in R, G, B respectively.
A subset for Kassala Area



Gash River Basin

- The region is characterized by semiarid climatic conditions. Two main seasons can be distinguished: summer and winter.
- The rainy period starts in July and continues to the end of September with an average annual rainfall of 150- 340 mm.
- The vegetation cover is governed by the intensity of the seasonal rains and it increases after the flood periods of the Gash River

Gash River Basin



Gash River Basin

- **The topography of the River Gash Basin is generally flat to slightly rolling with a gentle slope towards the northwestern part of the study area.**
- The elevation ranges from 500 m in the southeast to 450 m in the northwest

Gash River Basin

- The total length of the river from its source in Eritrea to the apex of the fan north of Kassala is about 280 km .
- When entering Sudan, the flow direction of the river changes from west to the north and the river attains its characteristic appearance of a wide shallow stream with a sandy bed bordered on either side by extensive flood plains.
- The drainage pattern is characterized by several minor khors flowing from the east to the northwest joining the River Gash

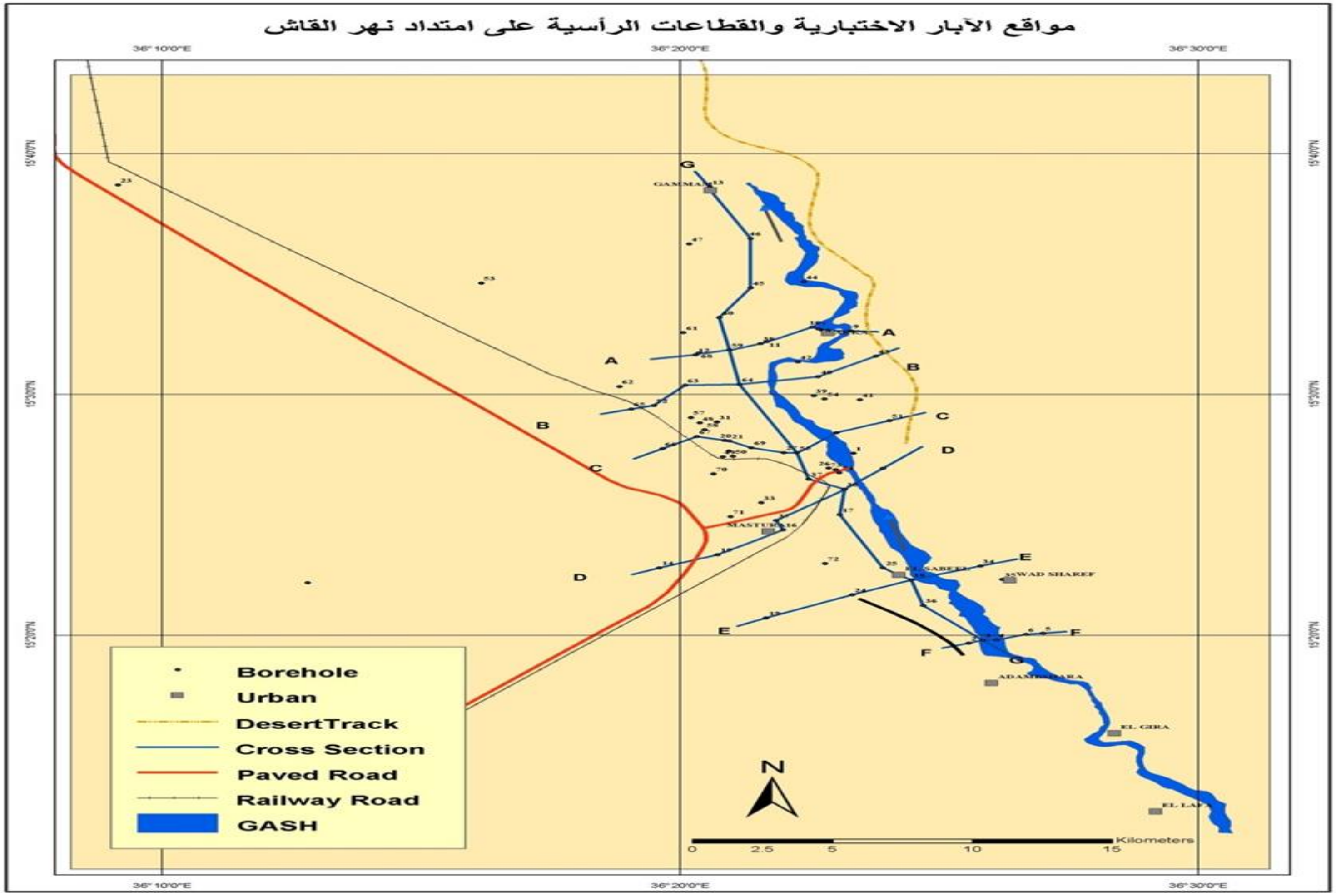
Groundwater

- **Alluvial deposits of Gash river form an important aquifer in the region of Kassala. The headwaters of the Gash lie in Ertria, where flow is perennial. At Kassala there is a flow for 88 days per year and an annual average discharge of 483 million m^3,**
- **Kassala is situated at the apex of the river delta which extends northwards for 60 km, in a ribbon up to 15 km wide.**

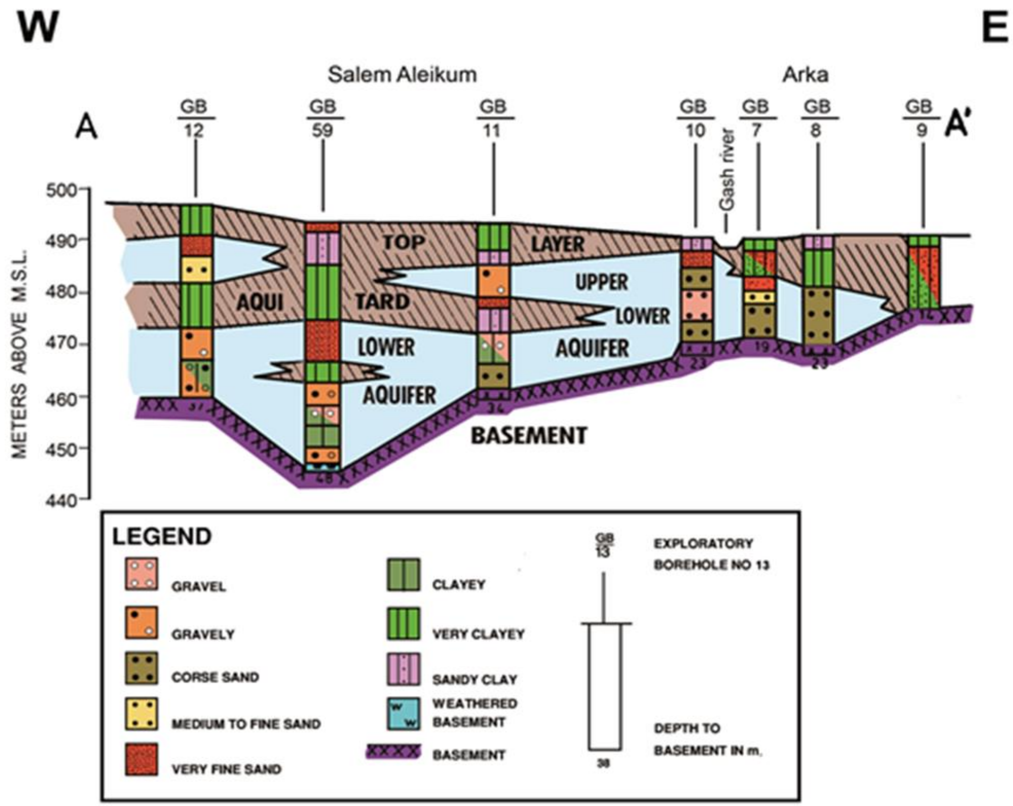
Groundwater

- The alluvium of the Gash River consists of intercalated unconsolidated beds of coarse to fine-grained sediments, gravel, sand, silt and clay. The alluvium of the Gash are the only aquifer of significance.
- The average saturated thickness of the alluvial sediments is 27 m and the depth to water increases away from the river, varying from 5 m to 30 m below surface.

Groundwater

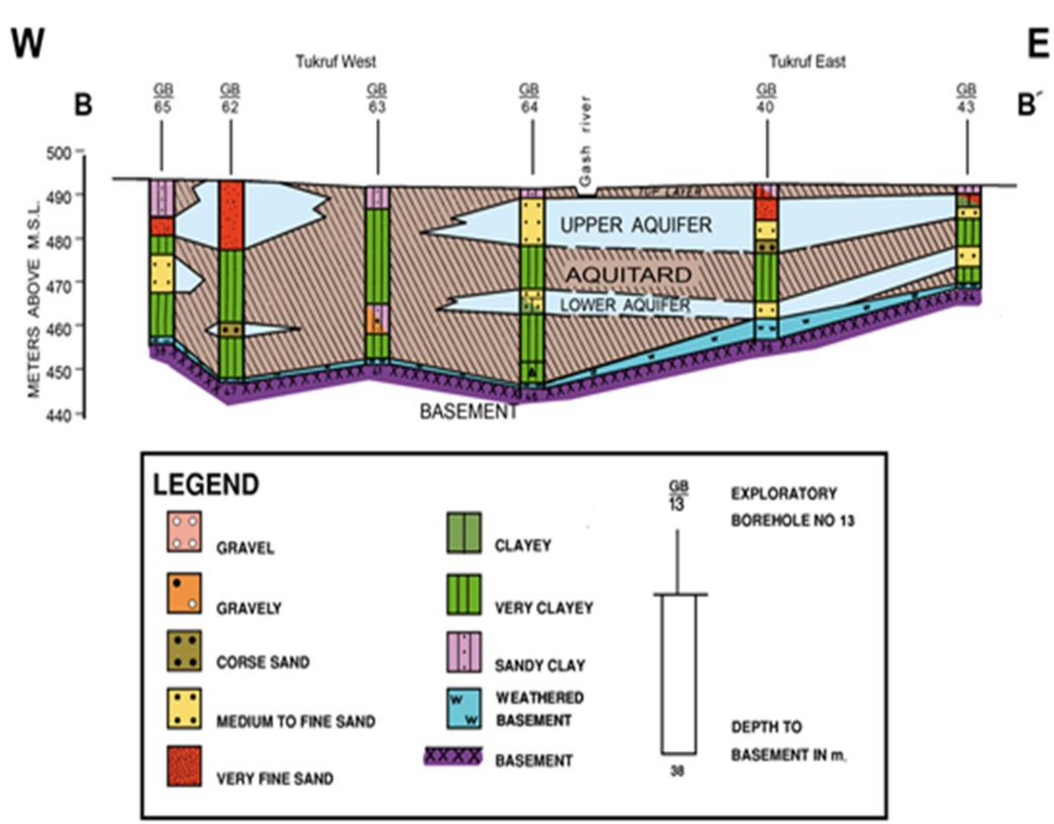


Groundwater



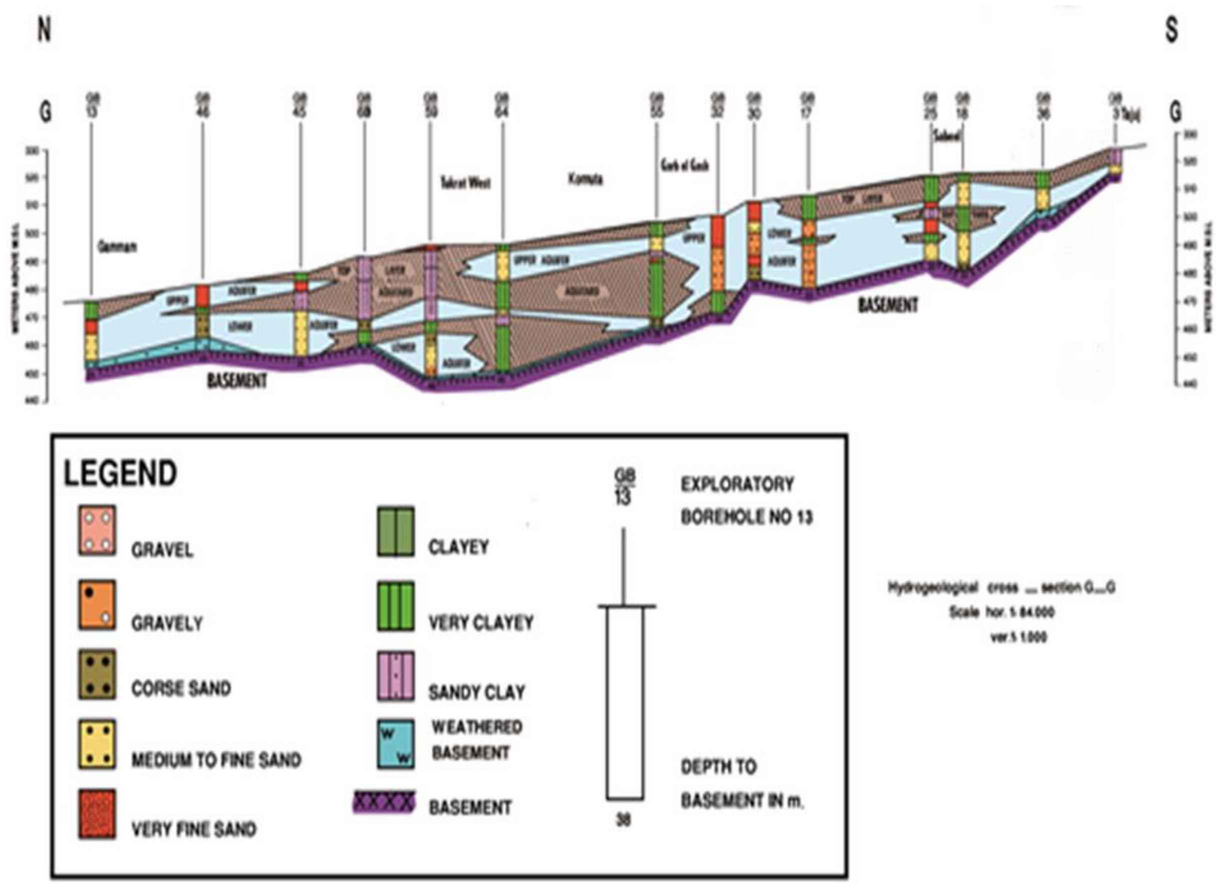
Hydrogeological Cross- Section A-A'
Scale: hor.:1:50 000
ver.:1:1000

Groundwater

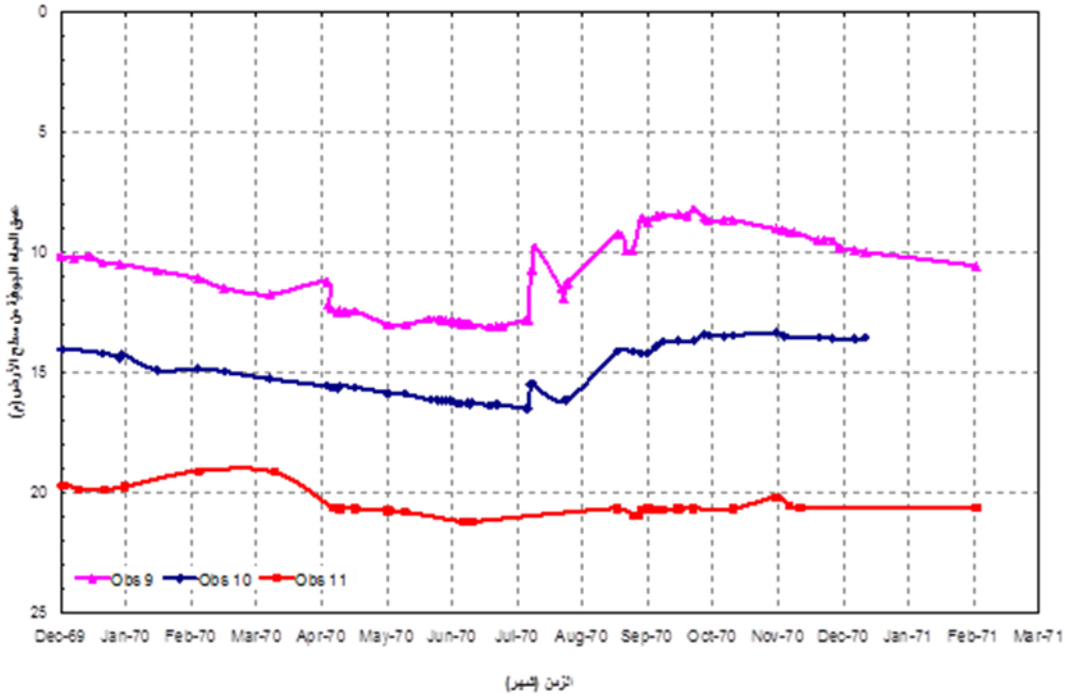


Hydrogeological Cross- Section B-B´
Scale: hor.1:50 000
ver.:1:1000

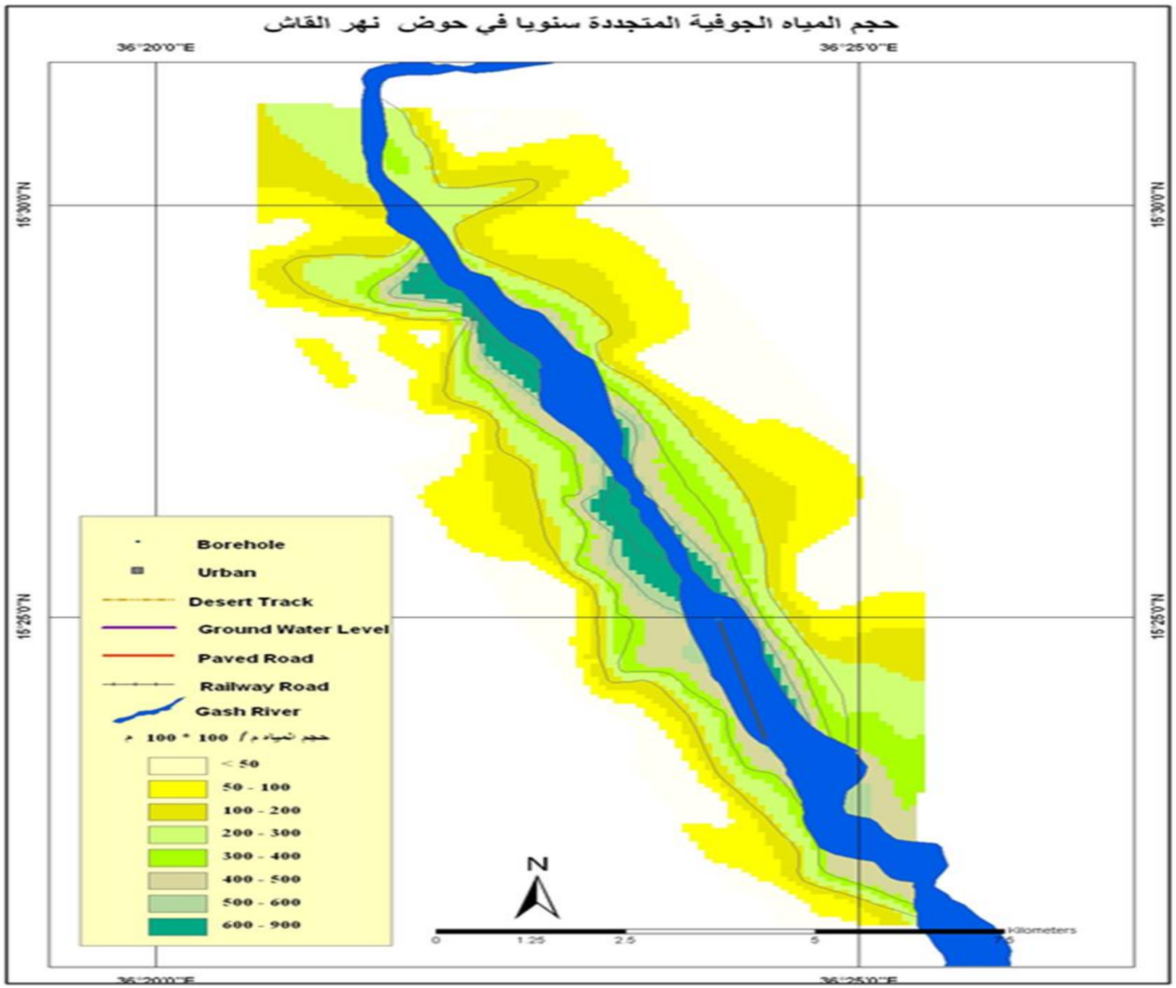
Groundwater



Groundwater



Groundwater



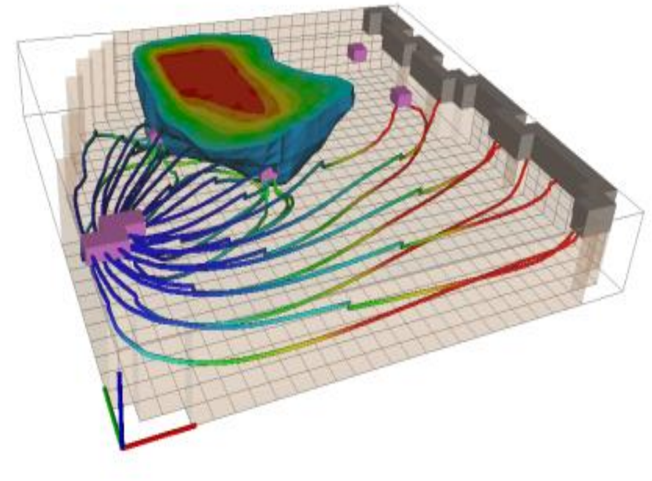
Groundwater

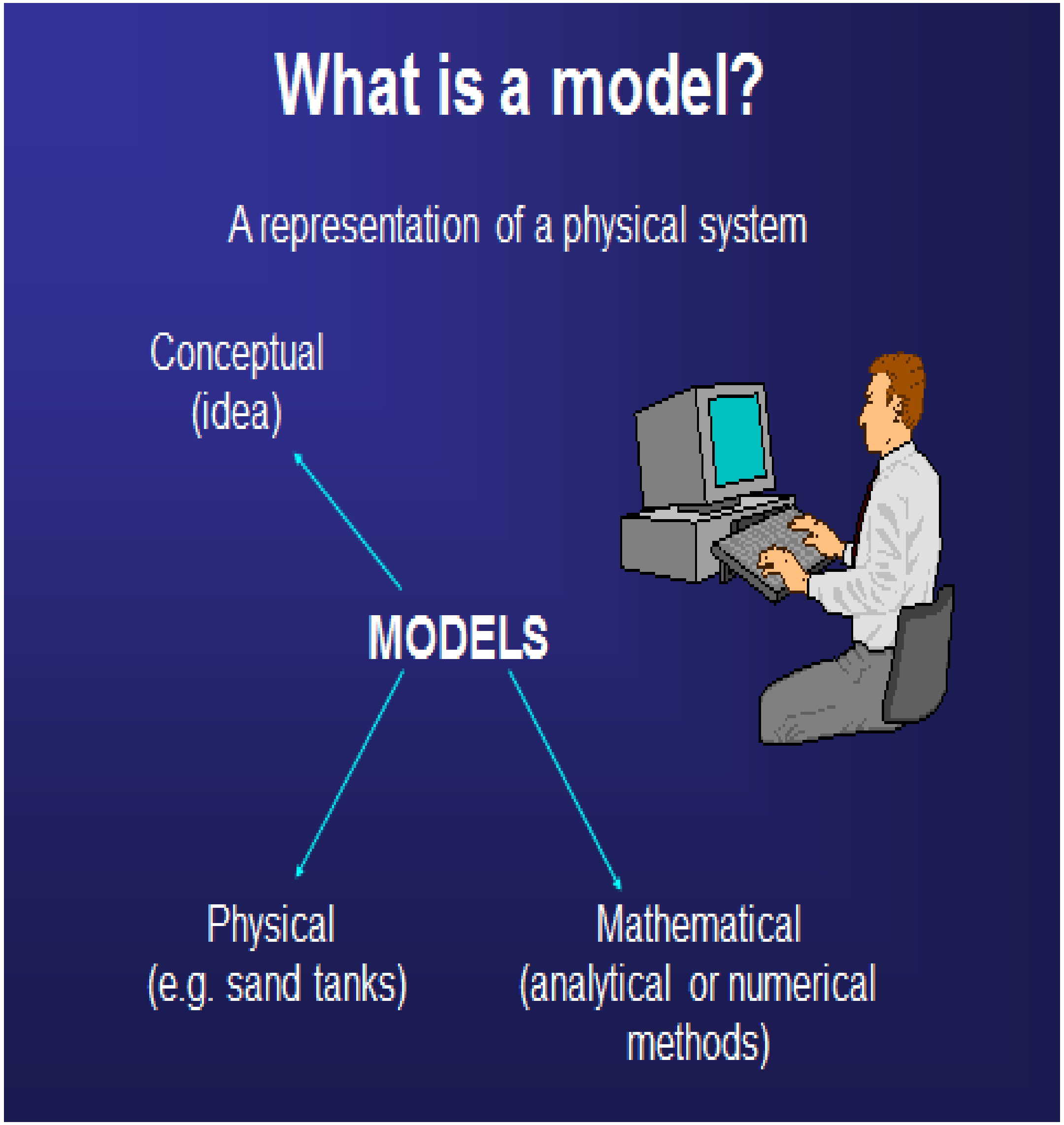
- **Recent Reports of the Groundwater performance in the Gash basin indicates a general trend of groundwater level decline due to high pumping and the aquifer mis-management.**
- ***Groundwater modeling is one of powerful tools to account for such problem***

Groundwater Modeling

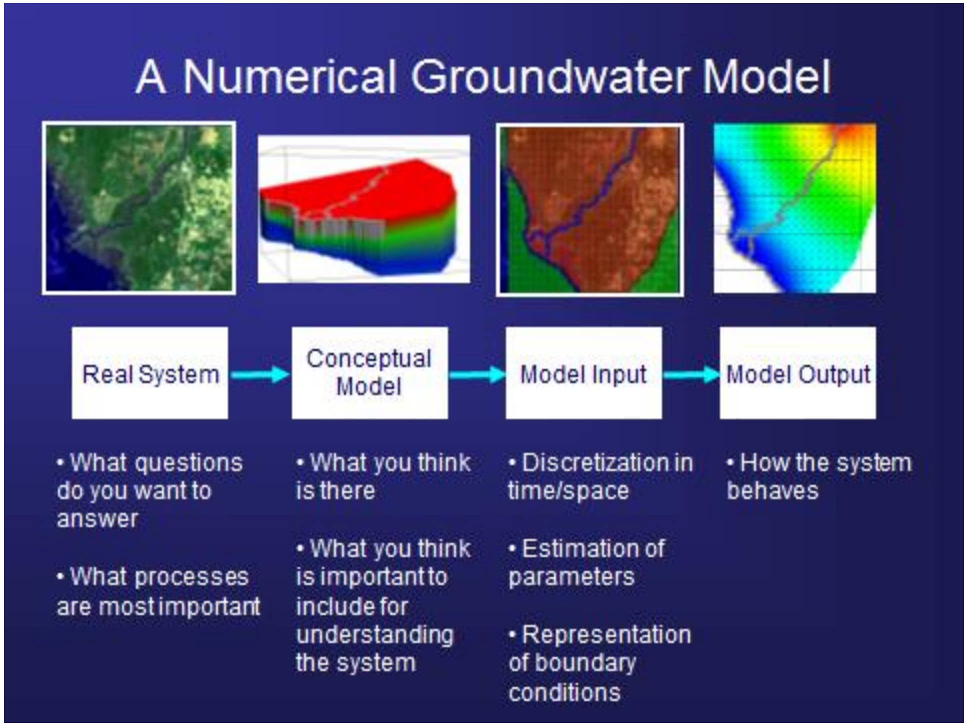
An introduction

- Modeling: an attempt to replicate the behavior of a natural system by defining the essential features of the system in some controlled physical or mathematical manner.
- A tool for scientists and engineers for solving groundwater problems.
- Modeling plays an extremely important role in the understanding and management of hydrologic and groundwater systems!




What is a model?
A representation of a physical system
Conceptual
(idea)
MODELS
Physical
(e.g. sand tanks)
Mathematical
(analytical or numerical
methods)

Groundwater Modeling



Purpose of modeling - *Why model?*

- To gain a better understanding of processes
  - how a system responds to a number of interactive simultaneous processes which defy intuitive analysis!
- Predictions & scenario modeling.
  - Development planning
  - Resource evaluation
  - Contamination sources
- Sensitivity analysis
  - How do groundwater processes respond to changes in critical parameters?
- Inverse modeling and Calibration
  - Estimation of system parameters based on observations

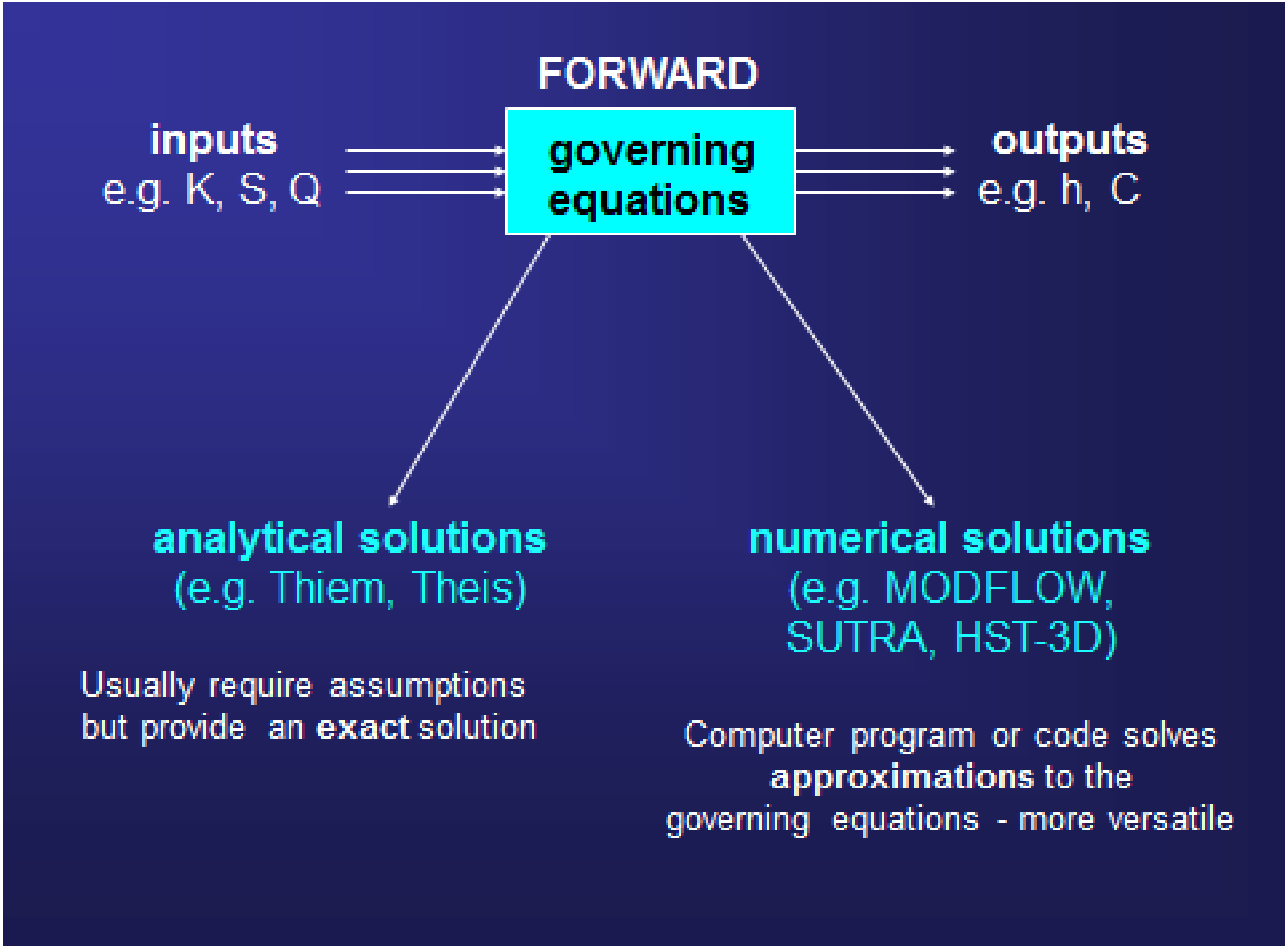
Questions:

1. How will a change in stream (flood)levels affect the water table in an adjacent aquifer in Gash basin?

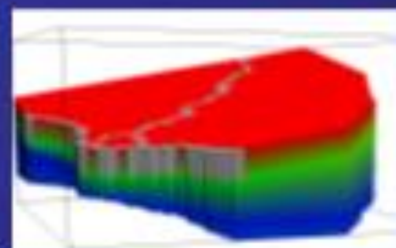
2. What is the most likely pathway of contaminants if there is in Gash basin aquifers

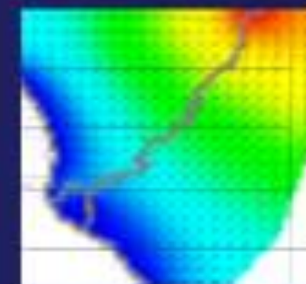
3. What changes can be expected in the groundwater levels in aquifers beneath Gash basin by the year 2030?

GROUNDWATER FLOW AND SOLUTE TRANSPORT MODELS ARE A TOOL TO HELP HYDROGEOLOGISTS ANSWER QUESTIONS LIKE THESE!


FORWARD
inputs
e.g. K, S, Q
governing equations
outputs
e.g. h, C
analytical solutions
(e.g. Thiem, Theis)
Usually require assumptions but provide an **exact** solution
numerical solutions
(e.g. MODFLOW, SUTRA, HST-3D)
Computer program or code solves **approximations** to the governing equations - more versatile

A Numerical Groundwater Model





Real System → Conceptual Model → Model Input → Model Output

Real System

- What questions do you want to answer
- What processes are most important

Conceptual Model

- What you think is there
- What you think is important to include for understanding the system

Model Input

- Discretization in time/space
- Estimation of parameters
- Representation of boundary conditions

Model Output

- How the system behaves

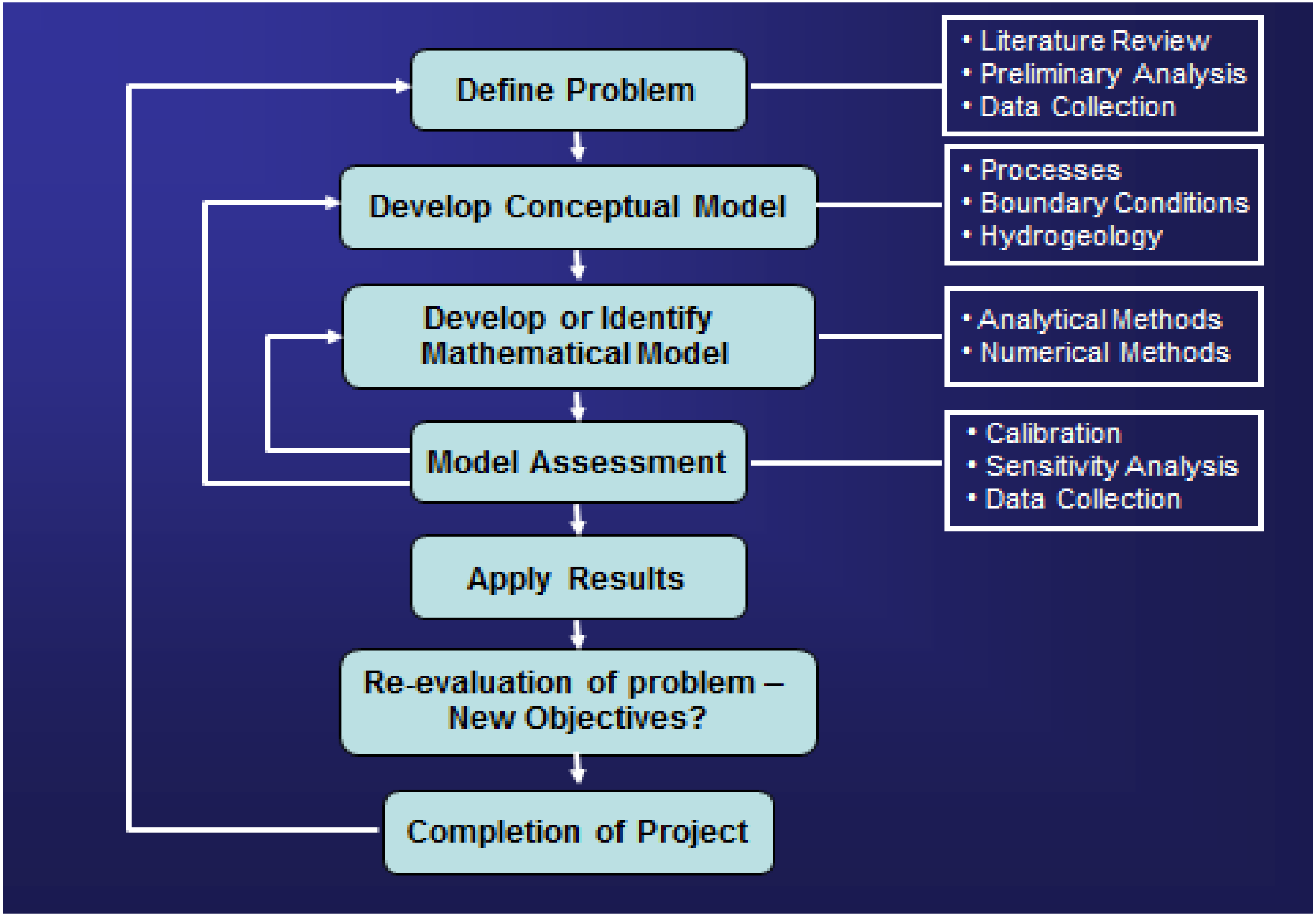
Model Results (output) depend on:

The Modeler's:

→ Simplifications

→ Representations

→ Estimations


Define Problem
• Literature Review
• Preliminary Analysis
• Data Collection
Develop Conceptual Model
• Processes
• Boundary Conditions
• Hydrogeology
Develop or Identify Mathematical Model
• Analytical Methods
• Numerical Methods
Model Assessment
• Calibration
• Sensitivity Analysis
• Data Collection
Apply Results
Re-evaluation of problem – New Objectives?
Completion of Project

Groundwater Model

Necessary Data for Groundwater Models

- **Hydrogeologic Structure**
- **Aquifer Properties**
- **Boundary Conditions**
- **Recharge and Discharge**
- **Initial Data**

Necessary Data for Groundwater Model

1- Hydrogeologic Structure

For Each Aquifer Unit....

- **Top Elevation**
- **Bottom Elevation**
- **Thickness**
- **Extent**

Those data should be assigned to Each Model Cell

Necessary Data for Groundwater Model

2- Aquifer Properties

For Each Aquifer Unit....

- Transmissivity or Hydraulic Conductivity
- Storage Coefficient or Specific Storage
- Effective Porosity
- Leakance or Vertical Hydraulic Conductivity
- Specific Yield (for Unconfined Aquifer)

Necessary Data for Groundwater Model

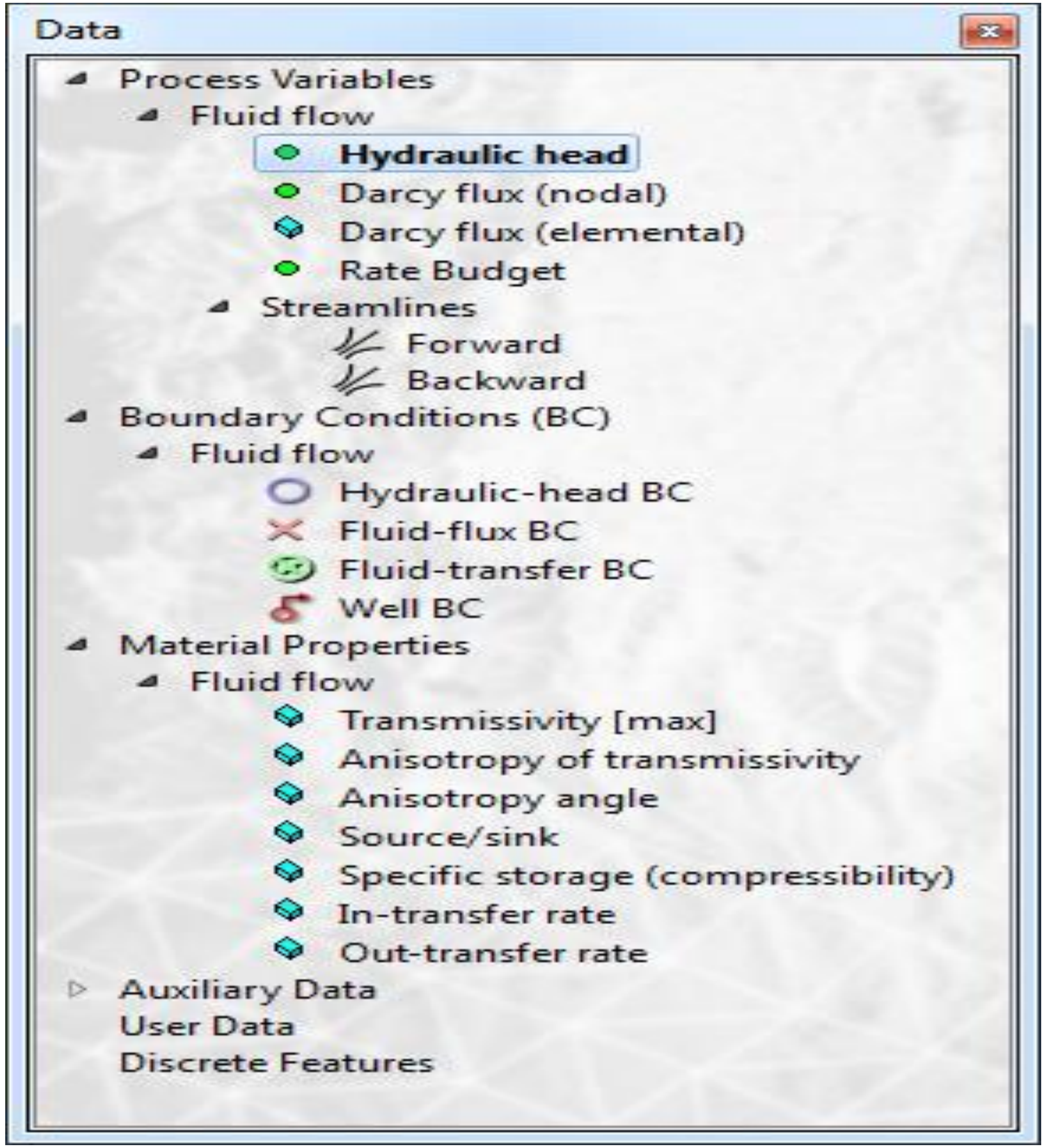
3- Boundary Conditions

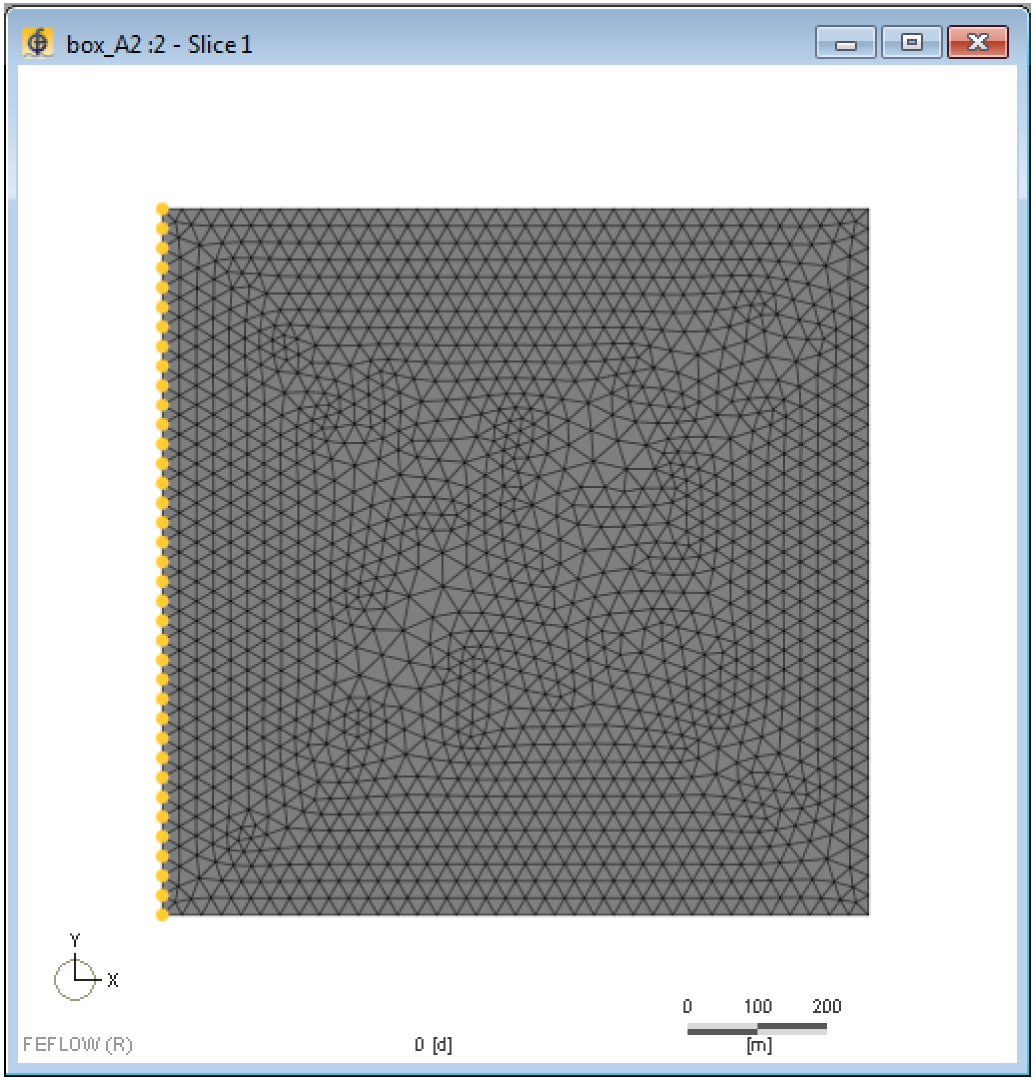
For Flow Model…

- **Constant-Head Boundary**
- **No-Flow Boundary**
- **General-Head Boundary**
- **Time-Variant Specified Boundary**

For Transport Model…

- **Constant-Concentration Boundary**


Data
Process Variables
Fluid flow
Hydraulic head
Darcy flux (nodal)
Darcy flux (elemental)
Rate Budget
Streamlines
Forward
Backward
Boundary Conditions (BC)
Fluid flow
Hydraulic-head BC
Fluid-flux BC
Fluid-transfer BC
Well BC
Material Properties
Fluid flow
Transmissivity [max]
Anisotropy of transmissivity
Anisotropy angle
Source/sink
Specific storage (compressibility)
In-transfer rate
Out-transfer rate
Auxiliary Data
User Data
Discrete Features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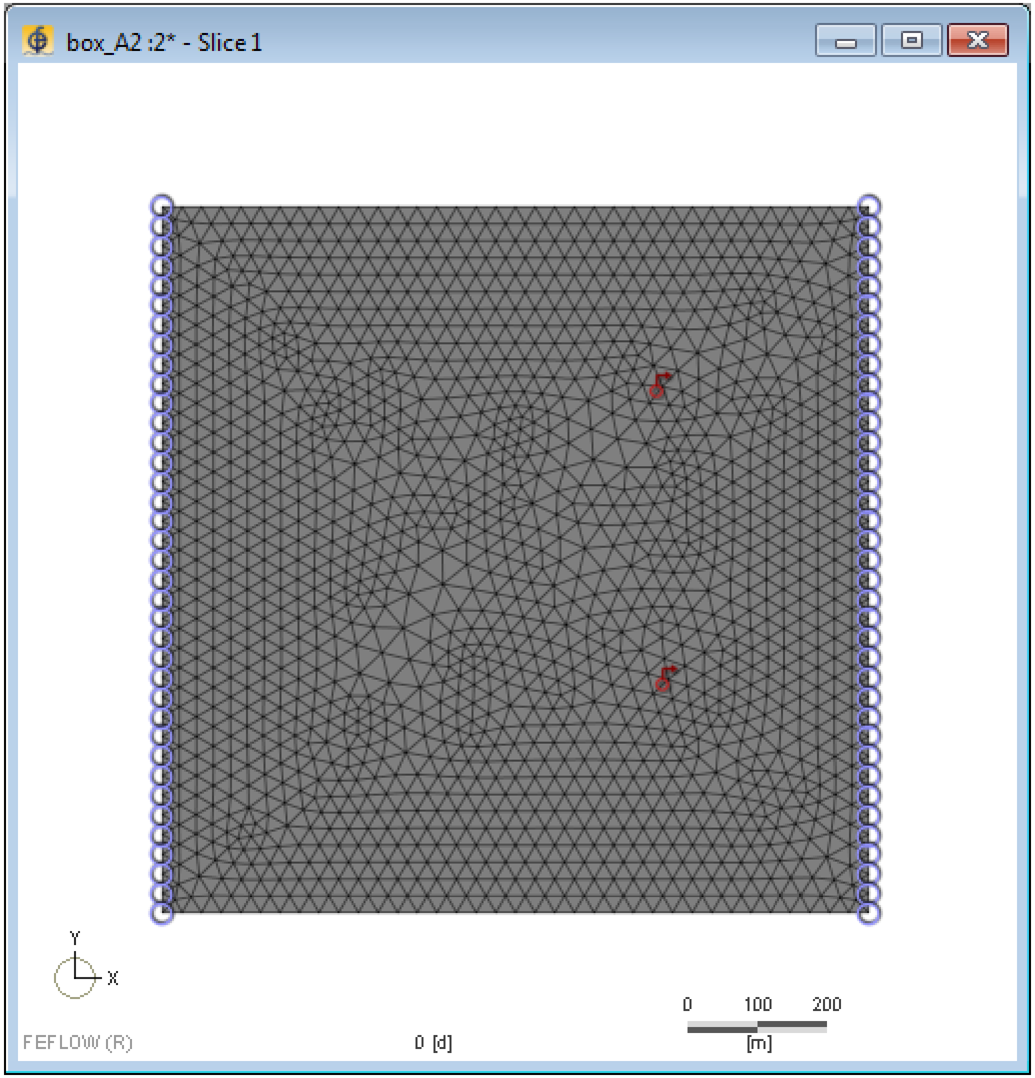


box_A2 :2* - Slice 1
Y
X
FEFLOW (R)
0 [d]
0
100
200
[m]

Necessary Data for Groundwater Model

Constant-Head Boundary

- **The Initial Hydraulic Head remains the same throughout the simulation**
- **When *S* (Storage Coefficient) is very large, the cell becomes Constant-Head Boundary.**

Very Strong Boundary Condition!!

Necessary Data for Groundwater Model

No-Flow Boundary

- **There is no Flux across the boundary.**

To express the continuity of aquifer system at the perimeter of the model domain….

- ***Use General-Head Boundary or***
- ***Time-Variant Specified-Head Boundary***

Necessary Data for Groundwater Model

4- **Recharge**

For Flow Model…

- **Recharge Rate by cell in each Stress Period**

The Layer to be Recharged should be specified.

For Transport Model…

- **Recharge Concentration**

Necessary Data for Groundwater Model

5- Discharge

For Flow Model…

- Discharge Rate per Stress Period

  Pumped Cell and Layer should be specified.

For Transport Model…

In case of Recharge Well, Recharge Concentration should be specified

Necessary Data for Groundwater Model

6- Initial Data

For Flow Model…

- **Initial Hydraulic Head**

For Transport Model…

- **Initial Concentration**

Basic Idea of Practical Parameter Estimation

- **Utilize Existing Well Data as much as possible**
- **Better to have data at many locations to evaluate regional aquifer characteristics**
- **Transmissivity is the most sensitive parameter to control Groundwater Flow**

Basic Idea of Practical Parameter Estimation

- **Review Geologic Control of Aquifer Parameters**
- **Use Sc to estimate T**
- **Investigate Relationship between T and Sc**

Methodology of Practical Parameter Estimation

- **1.Classify production wells by aquifer unit using screen depths**
- **2.Compute specific capacity value from production test.**
- **3.Estimate apparent transmissivity from specific capacity using well data.**
- **4.Estimate hydraulic conductivity from apparent transmissivity and screen length**

- **5.Compute clay content of each aquifer unit.**
- **6.Compute transmissivity of aquifer facies from estimated hydraulic conductivity, clay content, and thickness of the aquifer unit.**
- **7.Compute hydraulic conductivity for MODFLOW input by dividing transmissivity of aquifer facies by thickness of the aquifer unit**

Output Presentation

Essential Matters for Output Presentation

- Clearly Identify Actual Data and Estimated Data
- Describe Process of Data Estimation
- Describe Process of GW Modeling
- Show Evidence of Model Calibration

Report of GW Modeling (1)

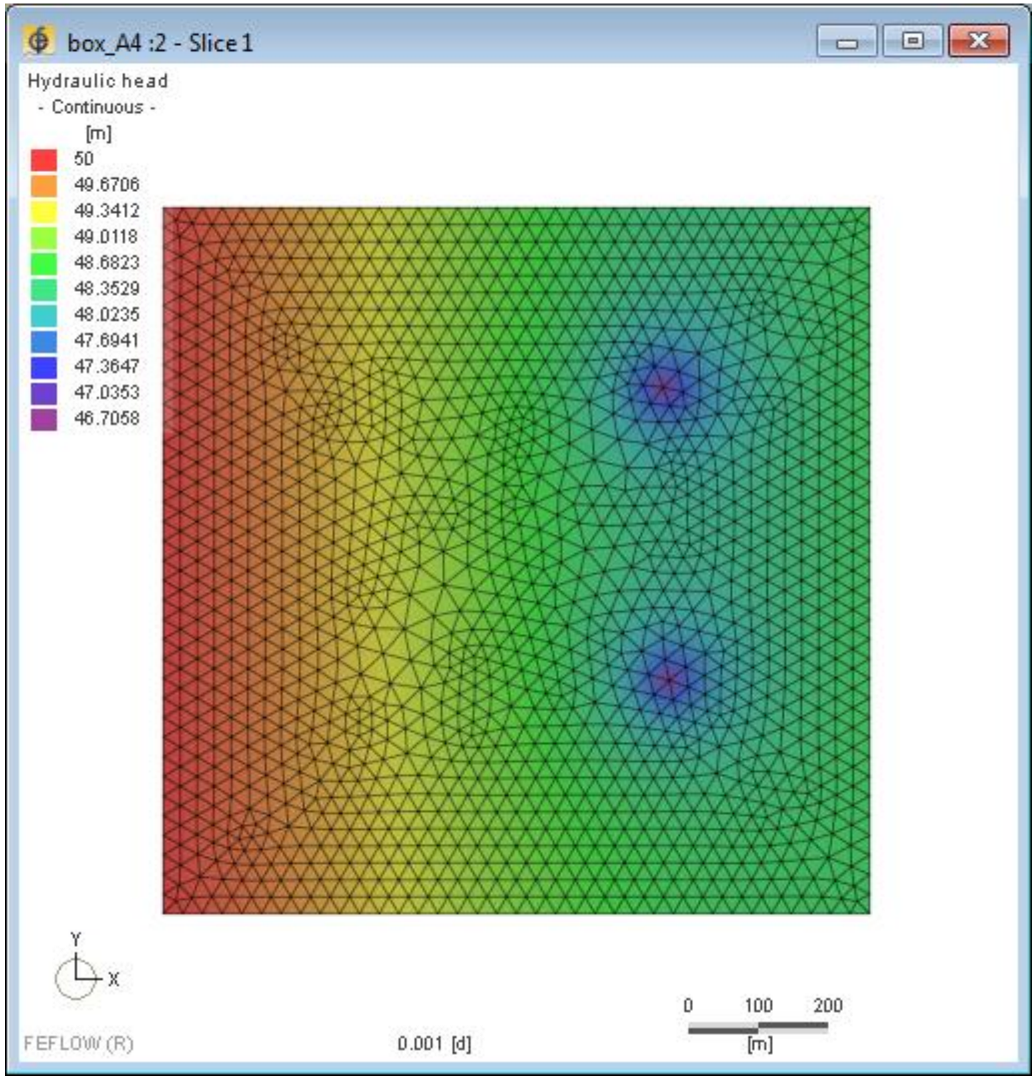
- **Groundwater modeling documentation must be described in detail the process by which the model was selected, developed, calibrated, verified and utilized**

Report of GW Modeling (2)

- **A description of the purpose and scope of the model application.**
- **Presentation of the hydrogeologic data used to characterize the site.**
- **Documentation of the source of all data used in the model, whether derived from published sources or measured or calculated from field or laboratory tests.**
- **Description of the model conceptualization**

Report of GW Modeling (3)

- **Identify the model selected to perform the task, its applicability and limitations(Modeling Software Selection).**
- **A discussion of the modeling approach.**
- **Documentation of all calculations.**
- **Summary of all model calibration, history matching and sensitivity analysis results.**
- **Present all model predictive simulation results as a range of probable results given the range of uncertainty in values of model parameters**
- **Recommendations and Conclusions**


box_A4 :2 - Slice 1
Hydraulic head
- Continuous -
[m]
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49.6706
49.3412
49.0118
48.6823
48.3529
48.0235
47.6941
47.3647
47.0353
46.7058
Y
X
0
100
200
[m]
FEFLOW (R)
0.001 [d]

THANKS

for

ATTENTION