WS-6 Groundwater Simulation

THCHICAL SEMENAR ON GROUNDWATER SIMULATION

Dr. Lei Peifeng
JICA Study Team

2011.05.25

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Main Topics of Today’s Presentation

- Conception and theory about groundwater system
- History of groundwater simulation
- Methods and program of groundwater simulation
- Function and main packages in Modflow based programs
- Basic process for groundwater model creation
- Case study

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Profile of the lecturer

Name : Lei Peifeng

Age : 55

Occupation : Chief Hydrogeologist,
Kokusai Kogyo Co., Ltd.(KKC)

Academic background:
- Mar.1982: Graduated from Changchun Geology Institute, China
- Mar.1988: Agriculture Doctorate in Tsukuba University, .Japan

Employment record:
- 1988-1990: Beijing Vegetables Research Center ,China
- 1990-1993: Foreigner Expert Bureau of China
- 1994-Now: Kokusai Kogyo Co., Ltd

Overseas working track:
Philippine, China, Thailand, Tanzania, Cambodia, Bangladesh, Mexico, Sri Lanka, Colombia, Ethiopia, Kenya, Senegal, Cuba

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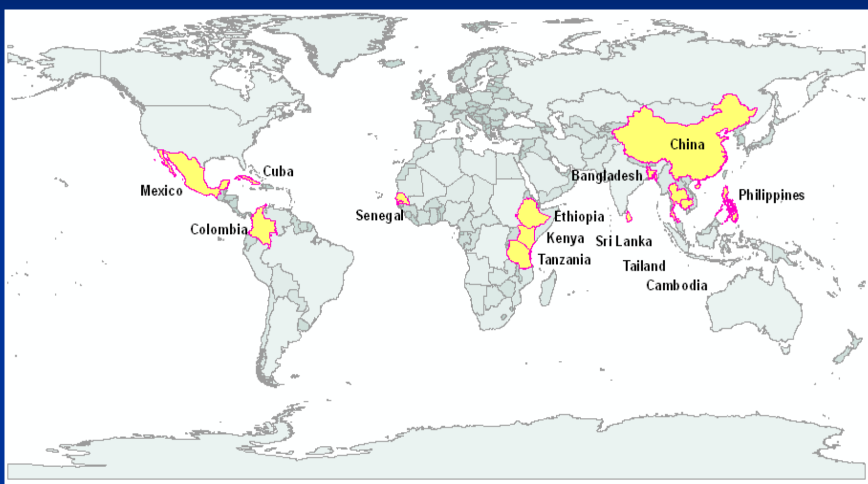
Overseas working track



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Part 1
Conception and Theory about Groundwater System

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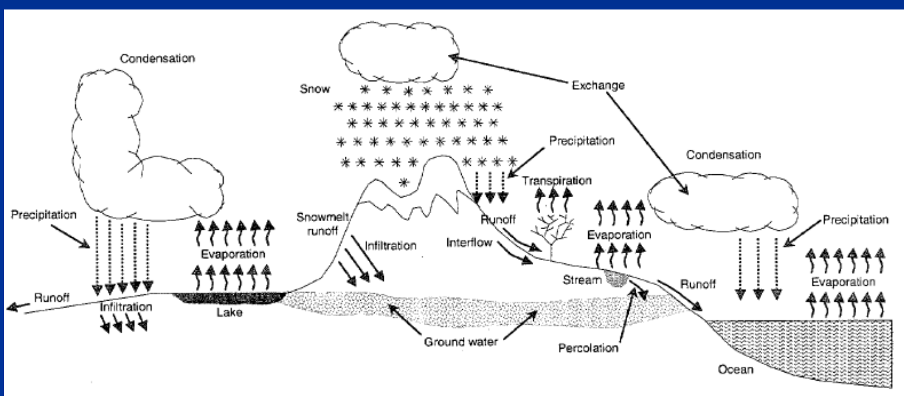
Concept of Hydrologic Circle



Graphic Source: US Department of Transportation

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Concept of Hydrologic Circle in Land Area

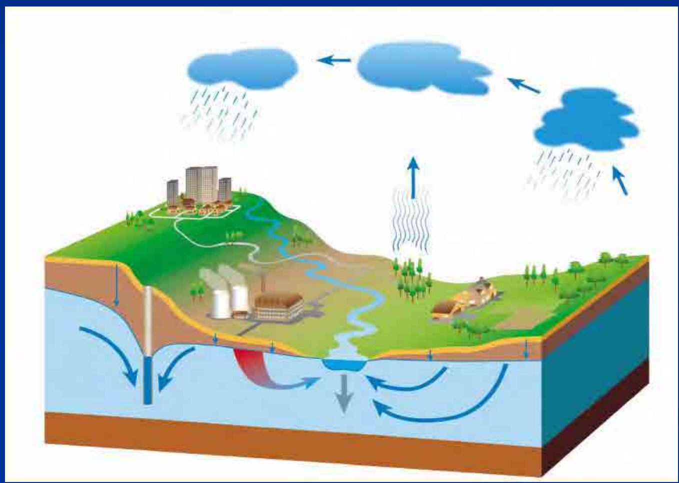

Image from: http://www.eurogeosurveys.org/

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Water in the World

	Water Amount (km³)	Residence time
Ocean	1,349,929,000 (97.5%)	3,200 years
Iceberg	24,230,000 (1.75%)	9,600 years
Groundwater	10,100,000 (0.73%)	830 years
Soil water	25,000 (0.00 %)	0.3 e years
Lakes	219,000 (0.02%)	Several or several hundreds years
Rivers	1200 (0.00%)	13 days
Water vapor	13,000 (0.00%)	10 days
Total	**1,384,517,200**	

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What is Groundwater?

Water stored in pores, fractures, and small cavities below the ground surface.

Groundwater flows through pores in soil and through fractures in rock.

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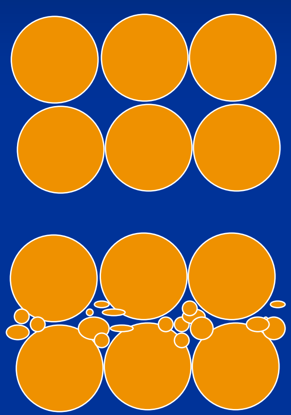
Grain Size Sorting Effects on Porosity



Well Sorted

Poorly Sorted

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Porosity

$$p = \frac{W}{V} \times 100 \quad (\%)$$

V : total volume of soil or rock,
W: volume of space in soil or rock,
p: porosity in %.

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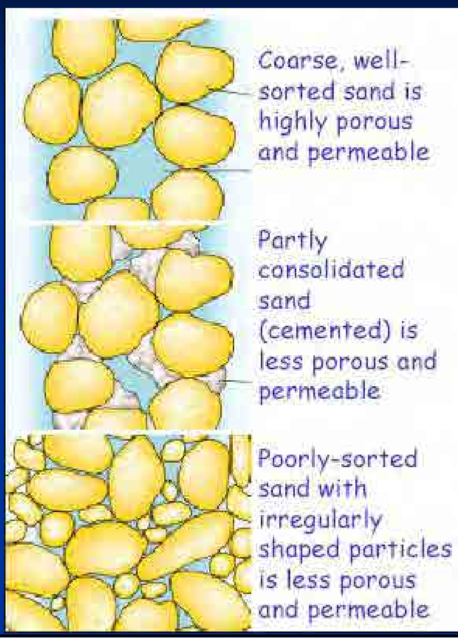
Porosity and Permeability (1)



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Porosity and Permeability (2)

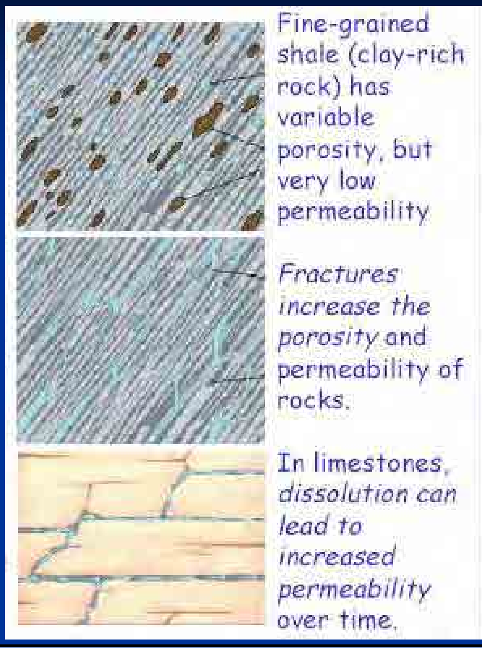

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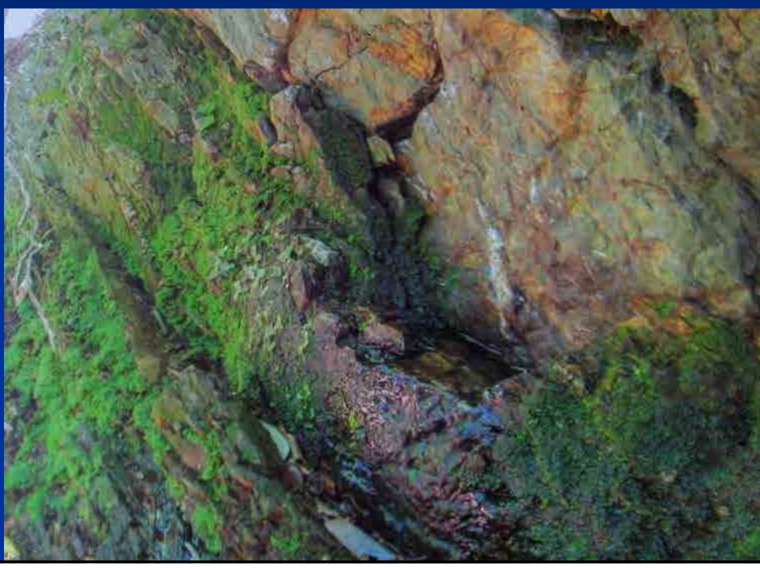
Photo of Fissure Water



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Typical Porosity Values

Well sorted sand	0.25-0.50	(25-50%)
Poorly sorted sand	0.20-0.35	(20-35%)
Silt	0.35-0.50	(35-50%)
Clay	0.35-0.60	(35-60%)
Till	0.10-0.30	(10-30%)
Rock	0-0.02	(0-2%)
Weathered Rock	0.0-0.60	(0-60%)

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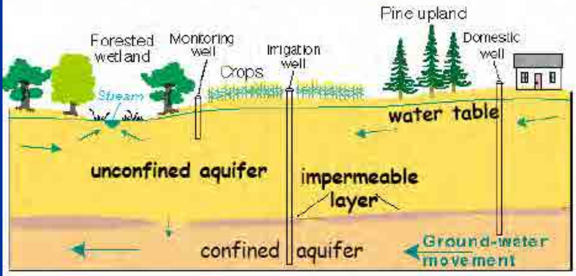
What is Aquifer?

An *aquifer* is a geological unit that is capable of producing a useful quantity of water.

Such a geological unit must have sufficient water storage capacity (*porosity*) and must allow for the movement of that water (*permeability* or transmissivity).



Types of aquifers

- *unconfined* (or water table) aquifer; lower bound is an impermeable layer, upper bound is top of the saturated zone; water in well rises to the water table.

- *confined* aquifer; lower and upper bounds are impermeable layers; water in well rises above top of aquifer layer (i.e., top impermeable layer keeps water under pressure).

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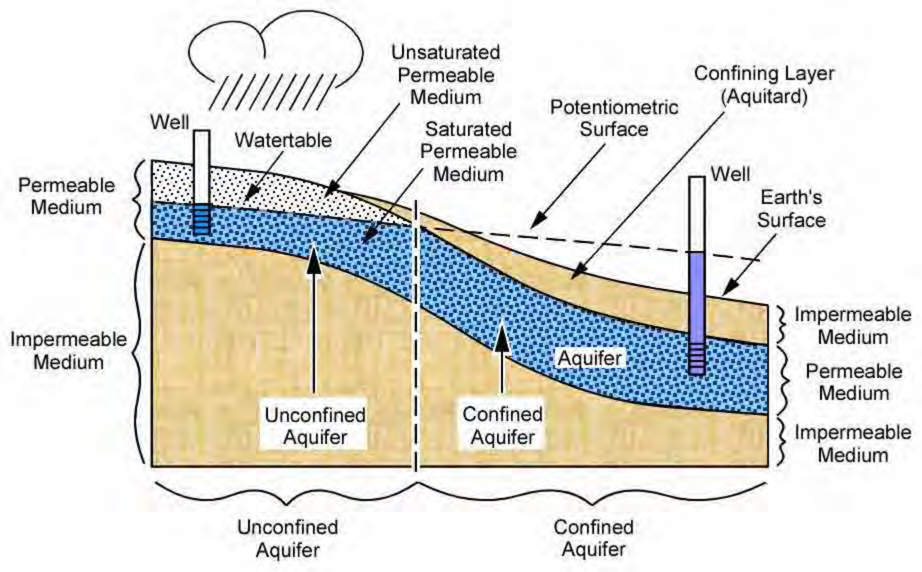
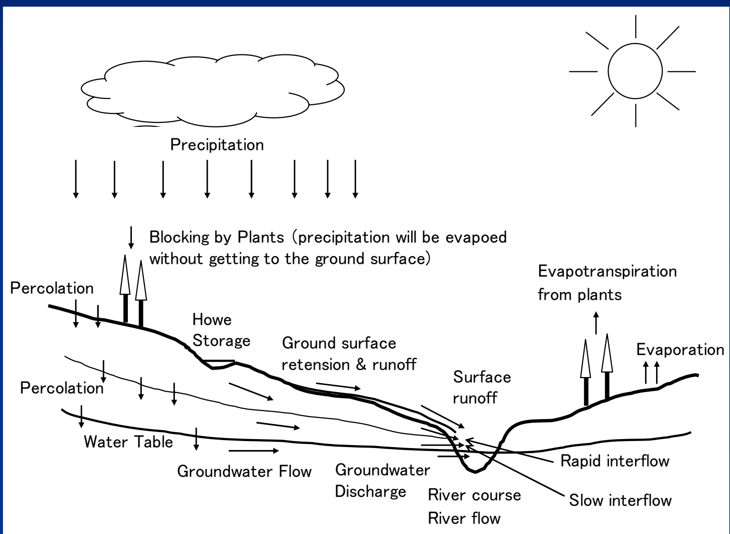
Confined and Unconfined Aquifers



Recharge, Flow and Discharge



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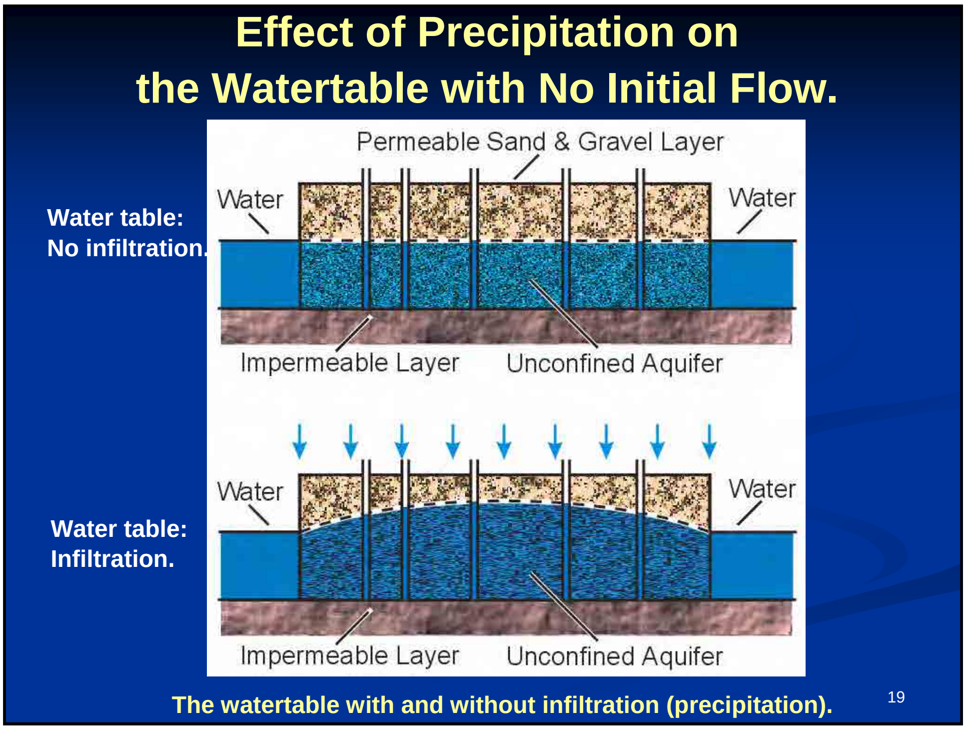

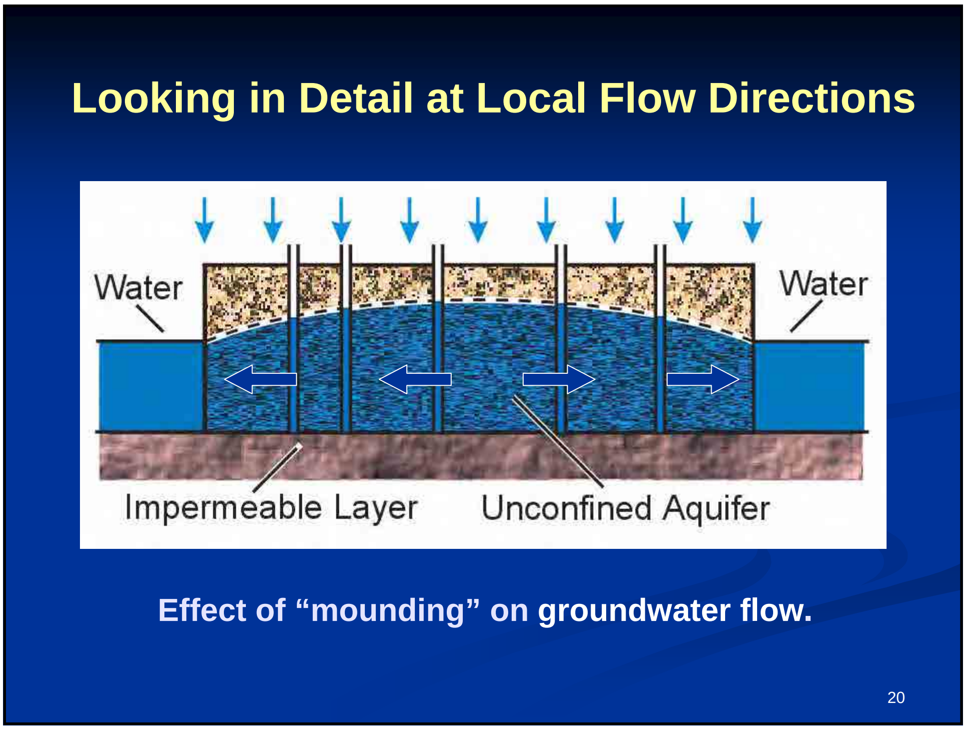

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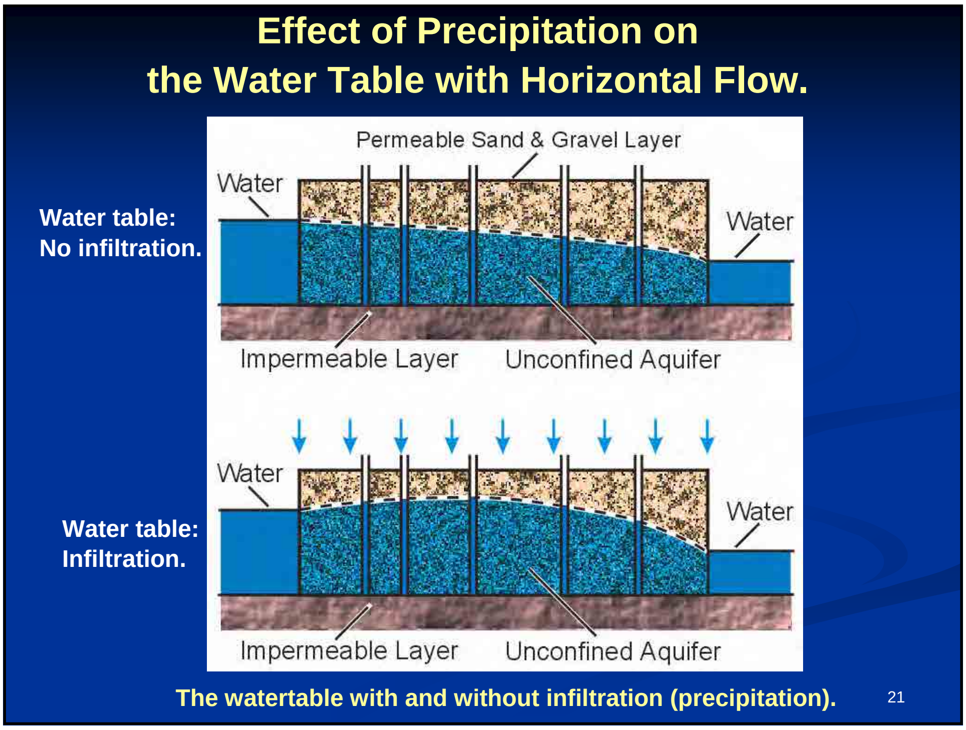
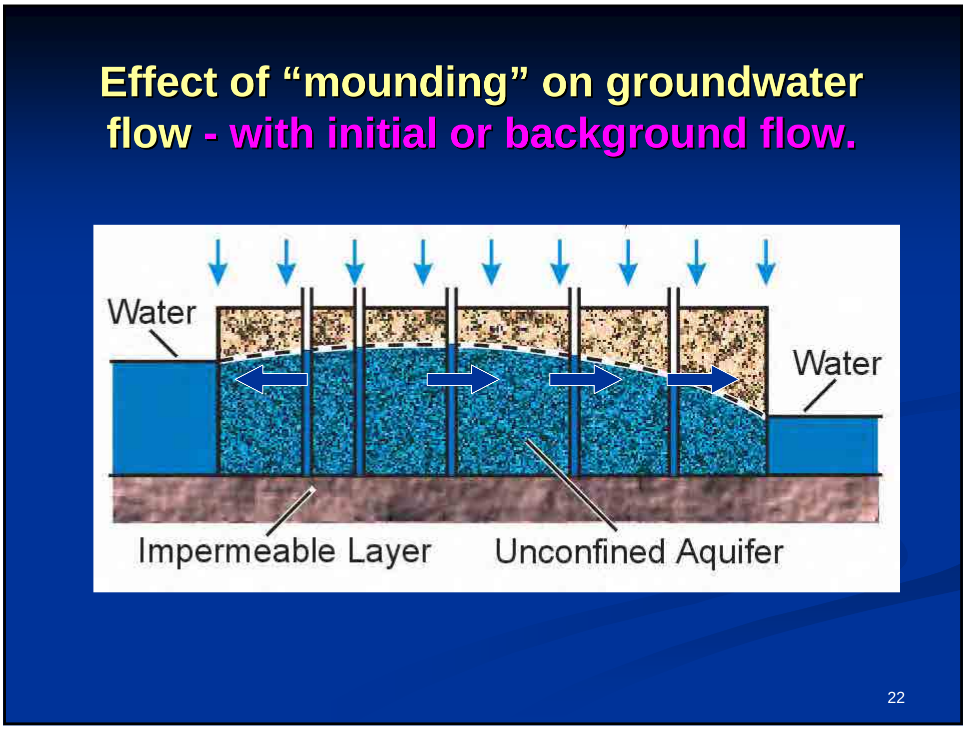
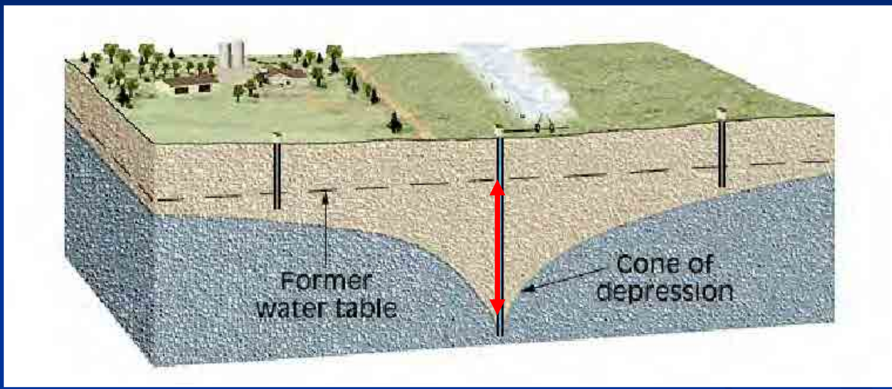




Drawdown



Drawdown = (Static Water Level before Pumping)
- (Dynamic Water Level during Pumping)

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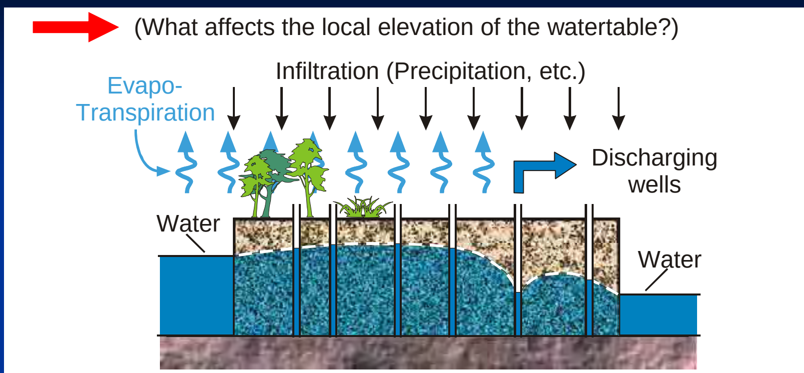
The Water Budget for an Unconfined Aquifer



Local groundwater elevations in wells are a function of the following:

- Whether confined or unconfined aquifer;
- Differences in the static head of various "sources;
- Partitioning of precipitation among infiltration, surface runoff and evapotranspiration (vegetation);
- Local production of water from wells;
- Hydraulic conductivity or transmissivity.

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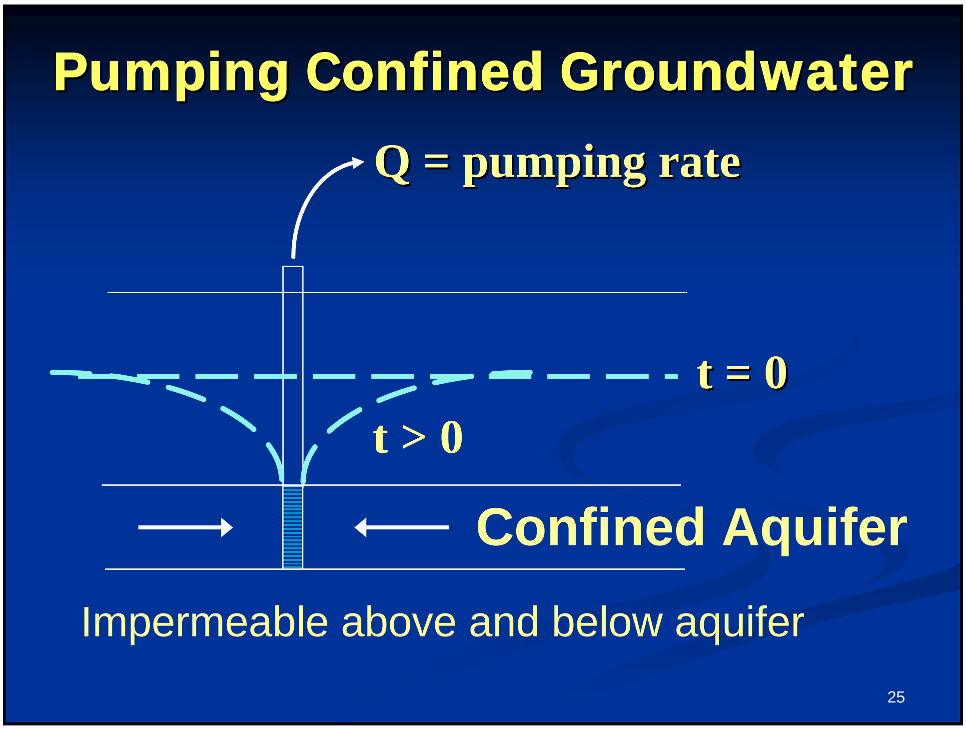
Pumping Confined Groundwater
Q = pumping rate
t = 0
t > 0
Confined Aquifer
Impermeable above and below aquifer
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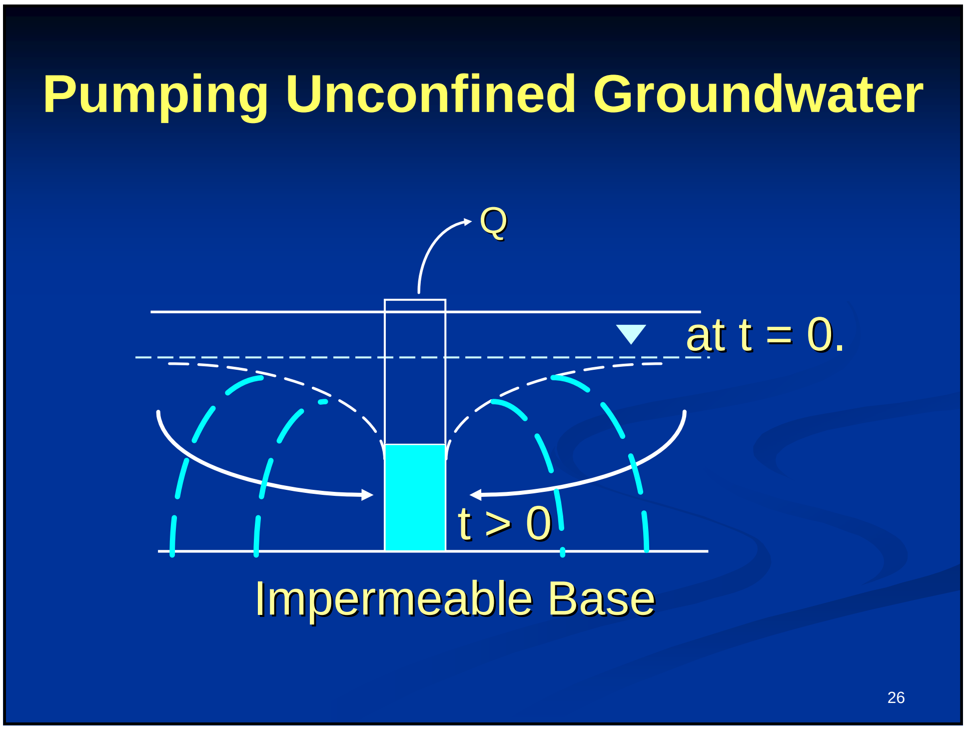
Pumping Unconfined Groundwater
Q
at t = 0.
t > 0
Impermeable Base
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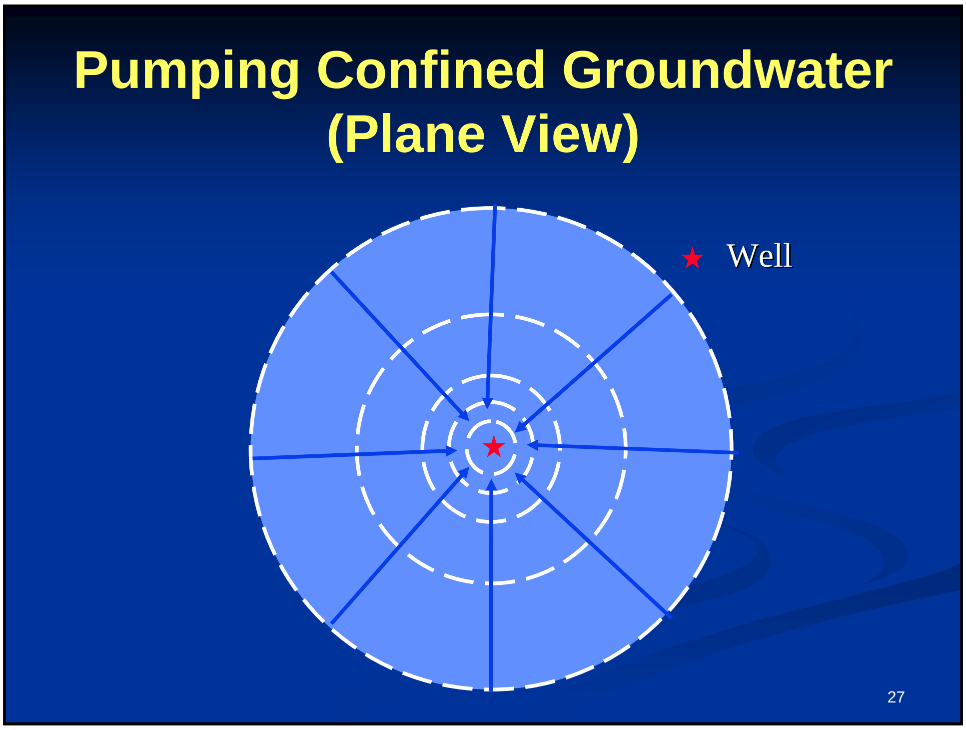
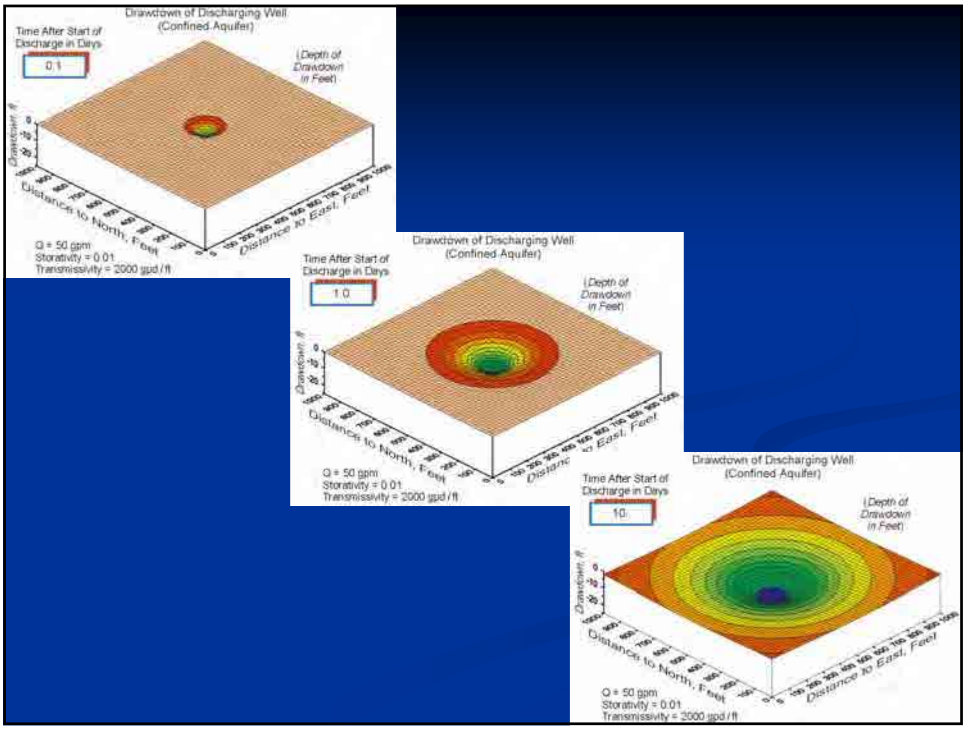
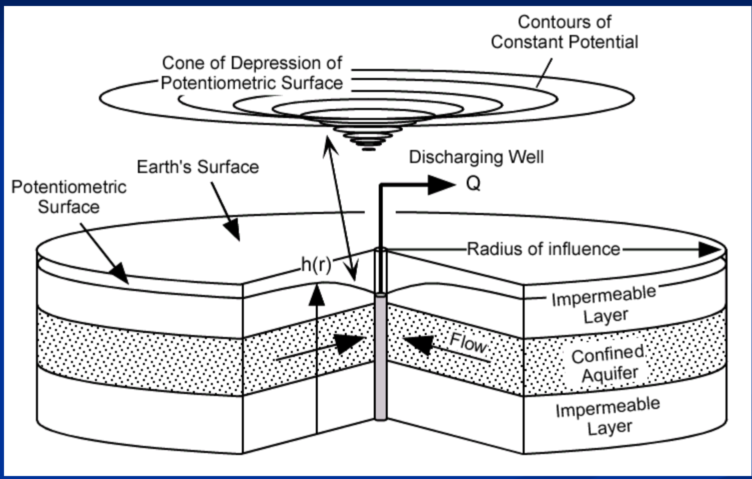




Details on the Geometry of Drawdown and the "Cone of Depression".



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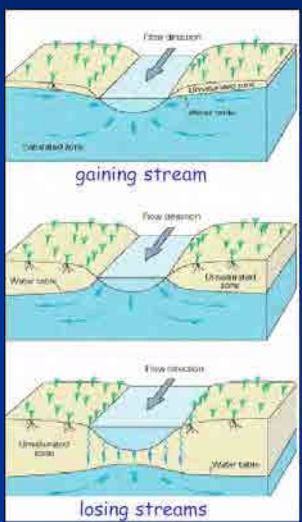
Discharge to and from Stream



Groundwater discharges to Stream.

Stream Water discharges to Groundwater.

Groundwater Recharge from Stream

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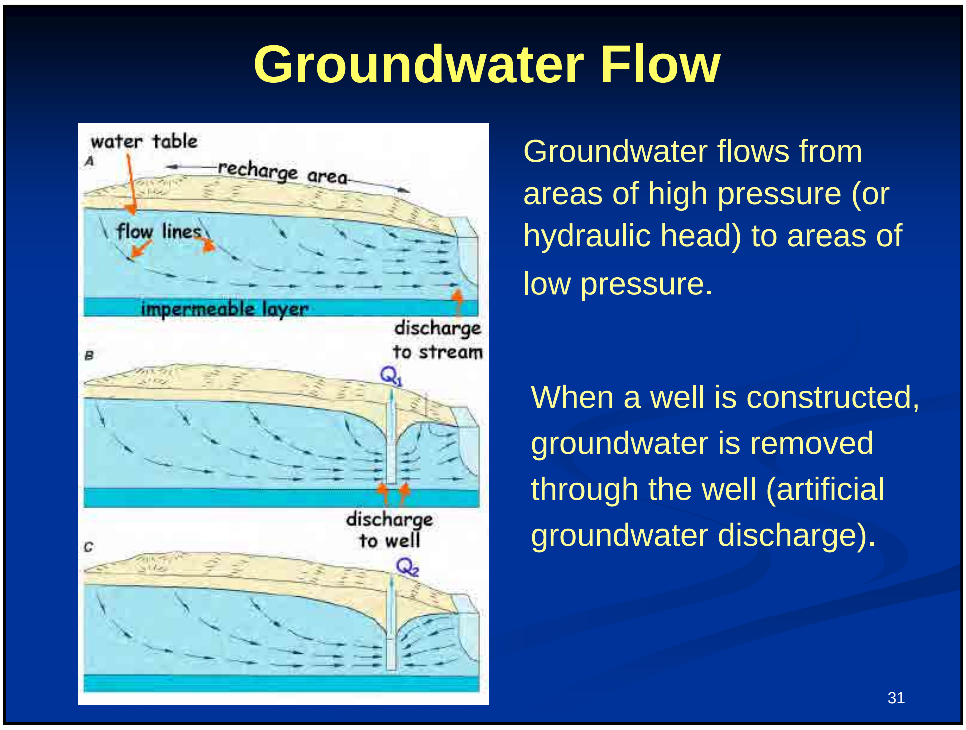

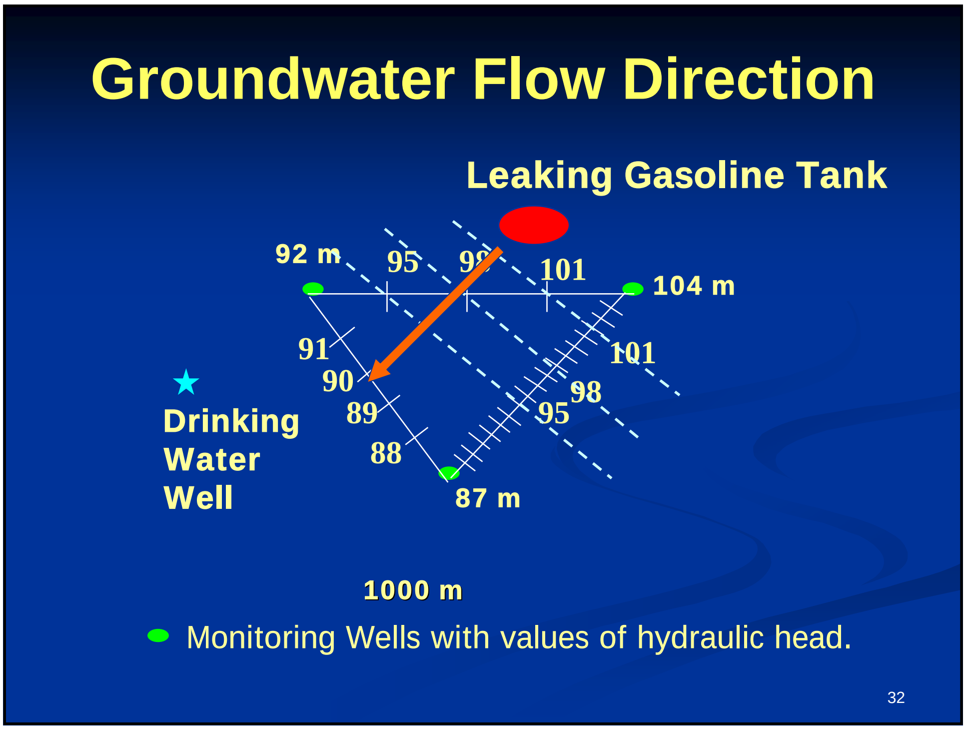

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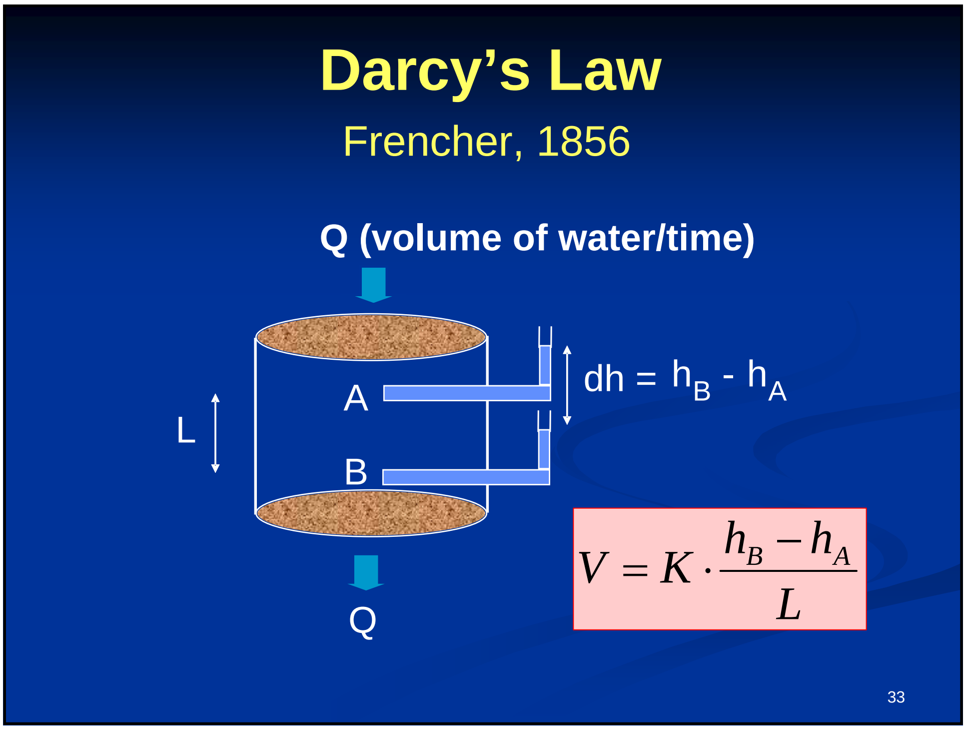

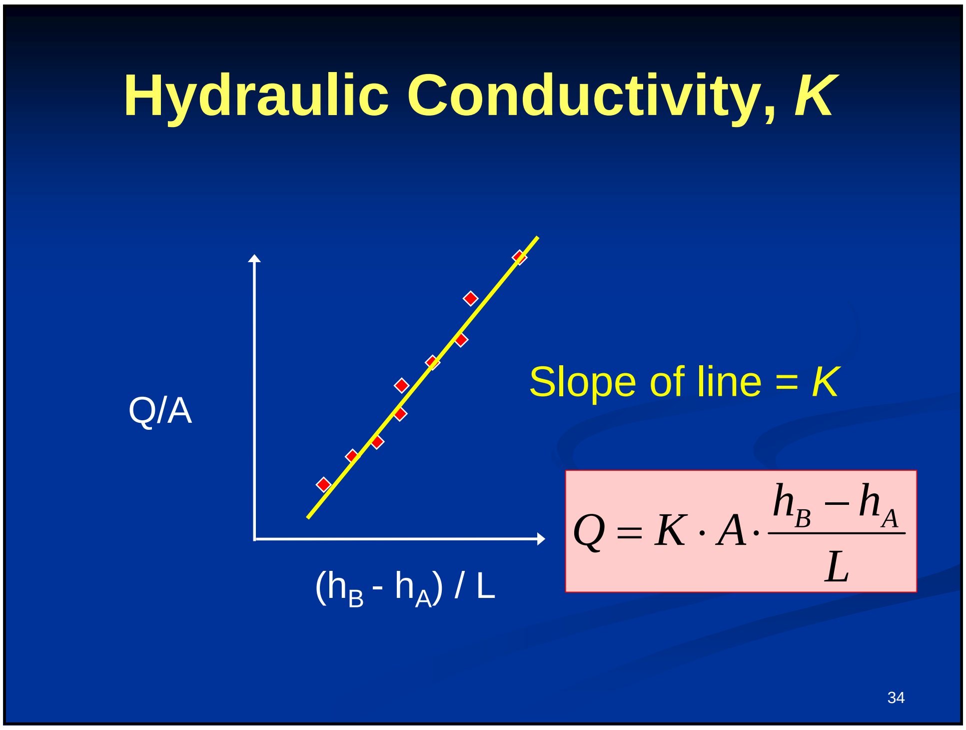

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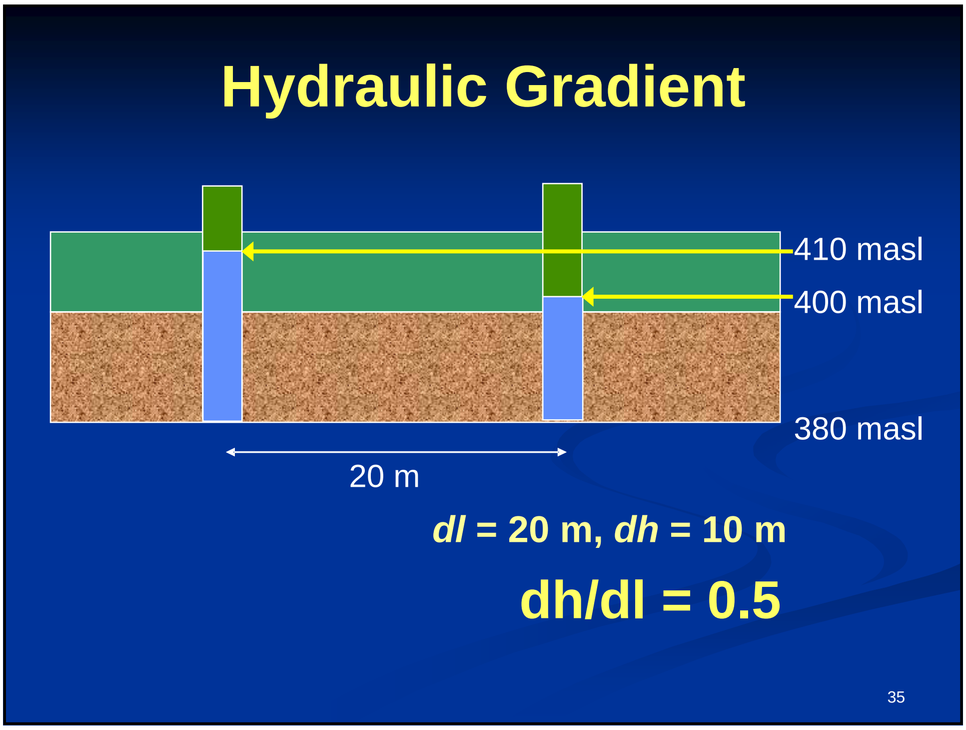
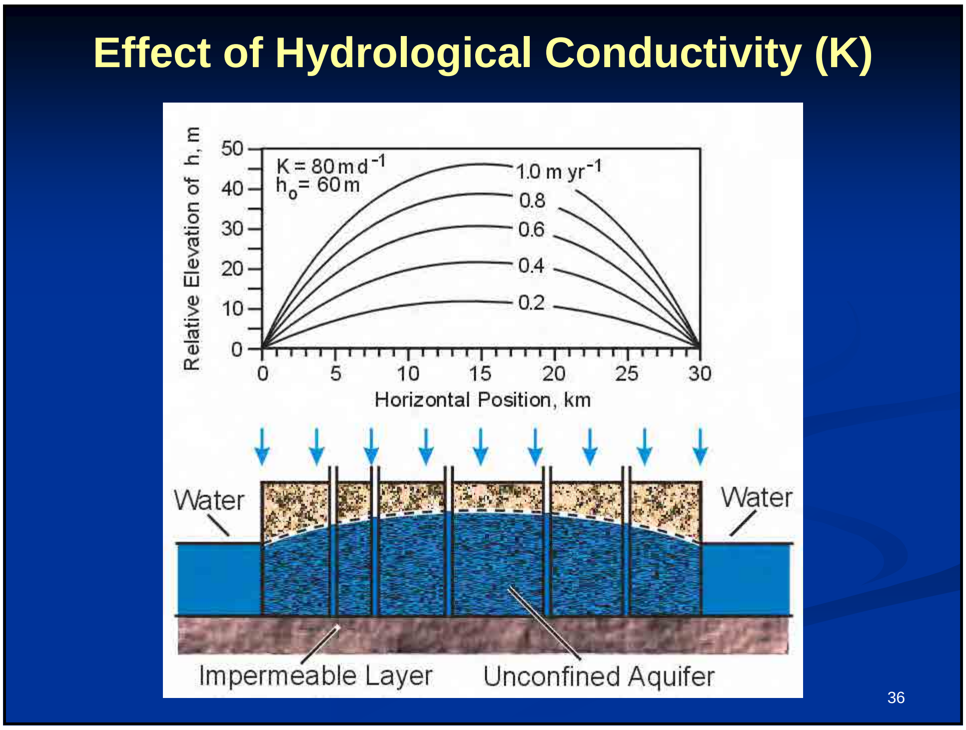
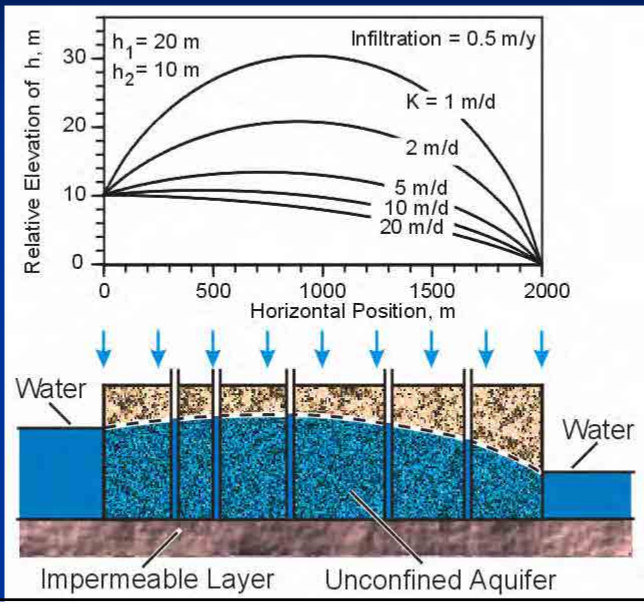




Effect of Hydrological Conductivity (K)



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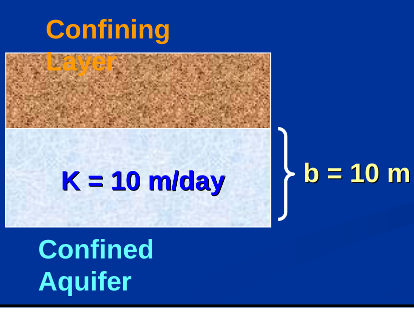
Transmissivity of Confined Aquifer

$$T = K \times b$$

T : Transmissivity [L^2/T]
K : Hydraulic Conductivity [L/T]
b : Thickness of Aquifer [L]



$$T = K \times b$$
$$= 10 \text{ m/d} \times 10 \text{ m}$$
$$= 100 \text{ m}^2\text{/day}$$

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Transmissivity of Unconfined Aquifer

$$T = K \times h$$

T : Transmissivity [L^2/T]
K : Hydraulic Conductivity [L/T]
h : Thickness of Saturated Zone [L]

Unconfined Aquifer

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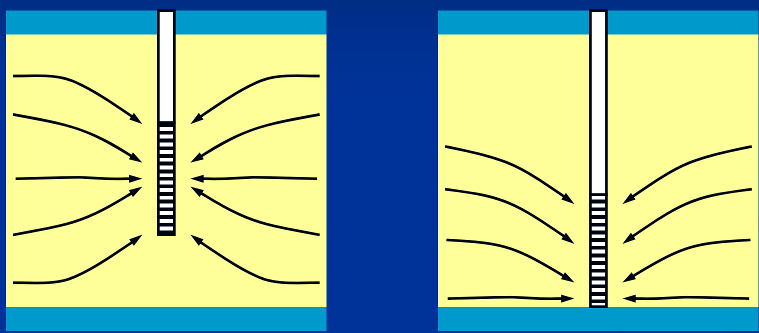
Groundwater Flow



Partial penetration effects occur when the intake of the well is less than the full thickness of the aquifer

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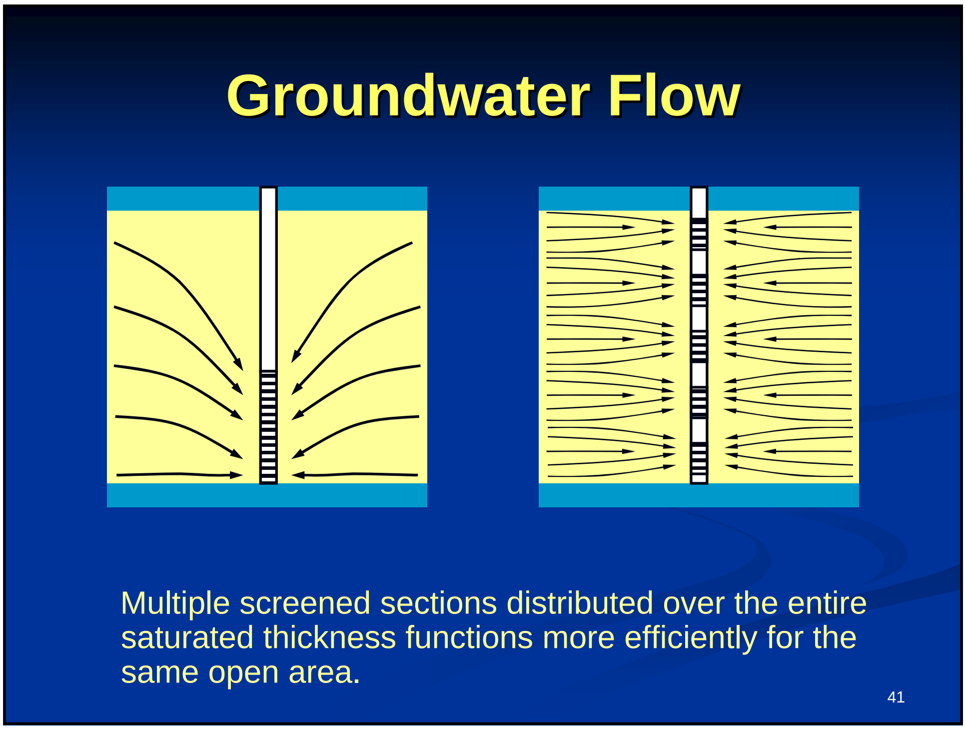

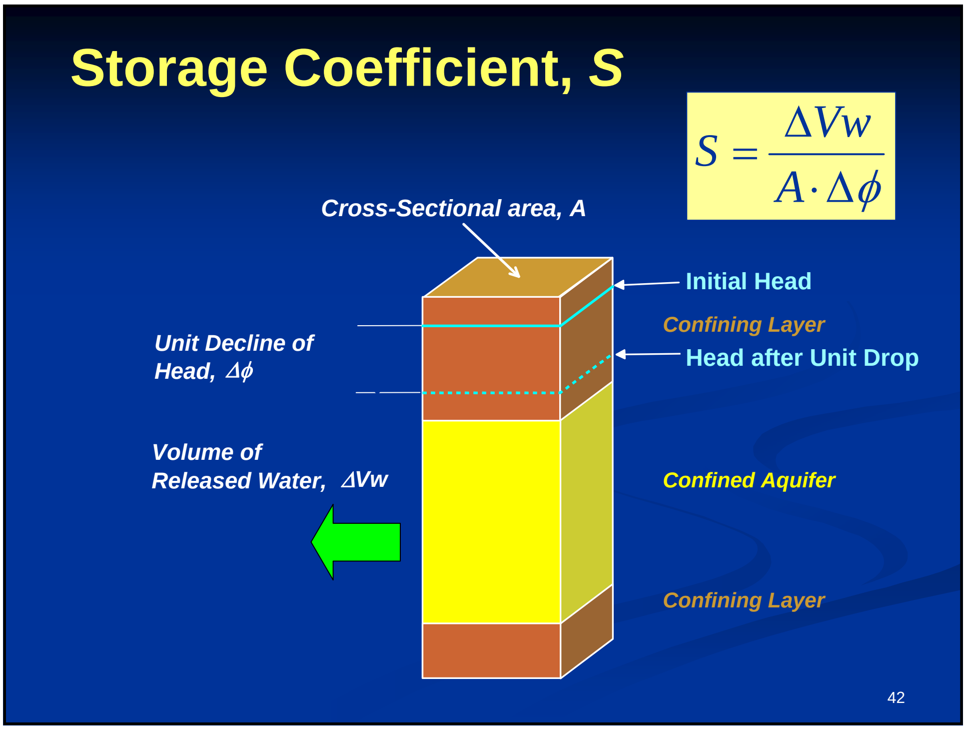

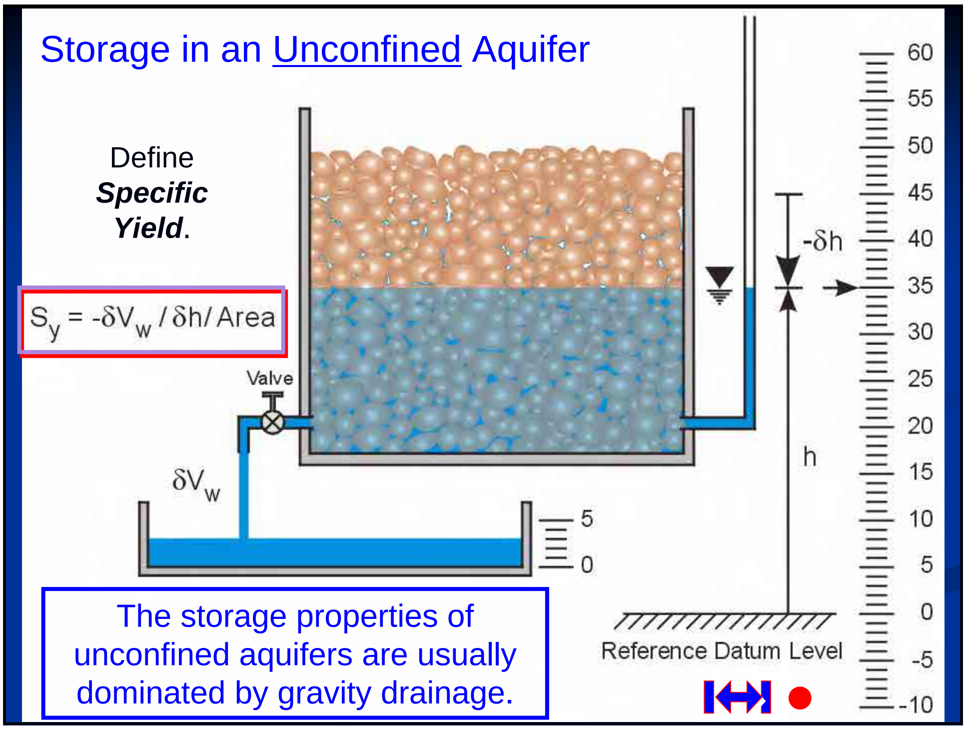

Groundwater Balance Equation

$$R(t) - D(t) = \frac{dS}{dt}$$

R(t): Recharge to a Groundwater Basin for a period

D(t): Discharge from the Groundwater Basin for the period

dS/dt: Storage change in the Groundwater Basin for the period

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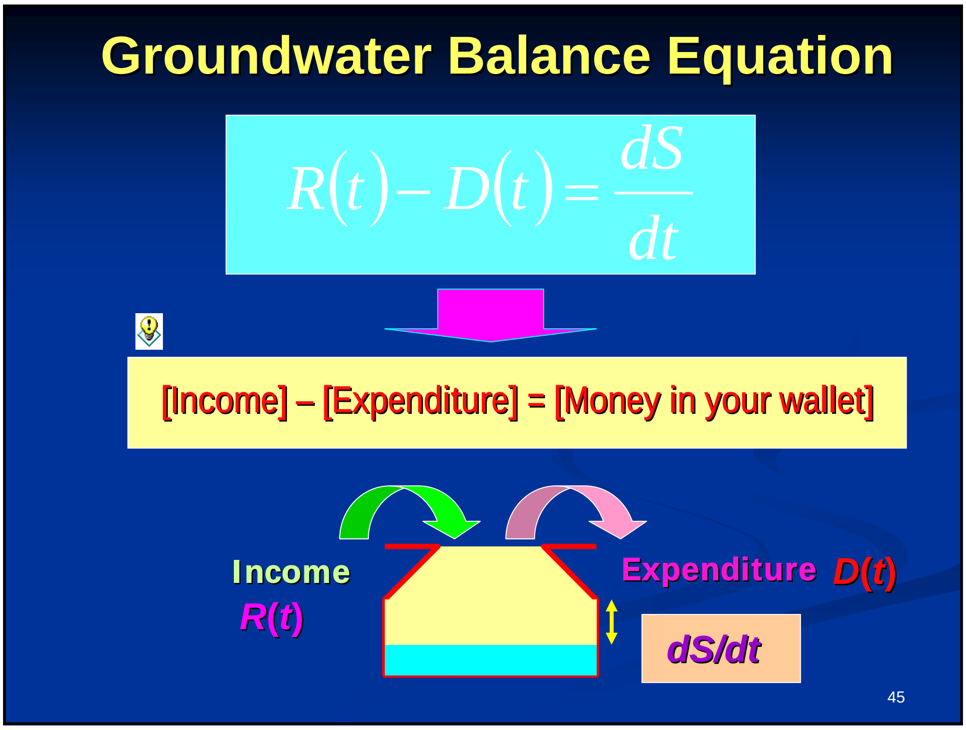

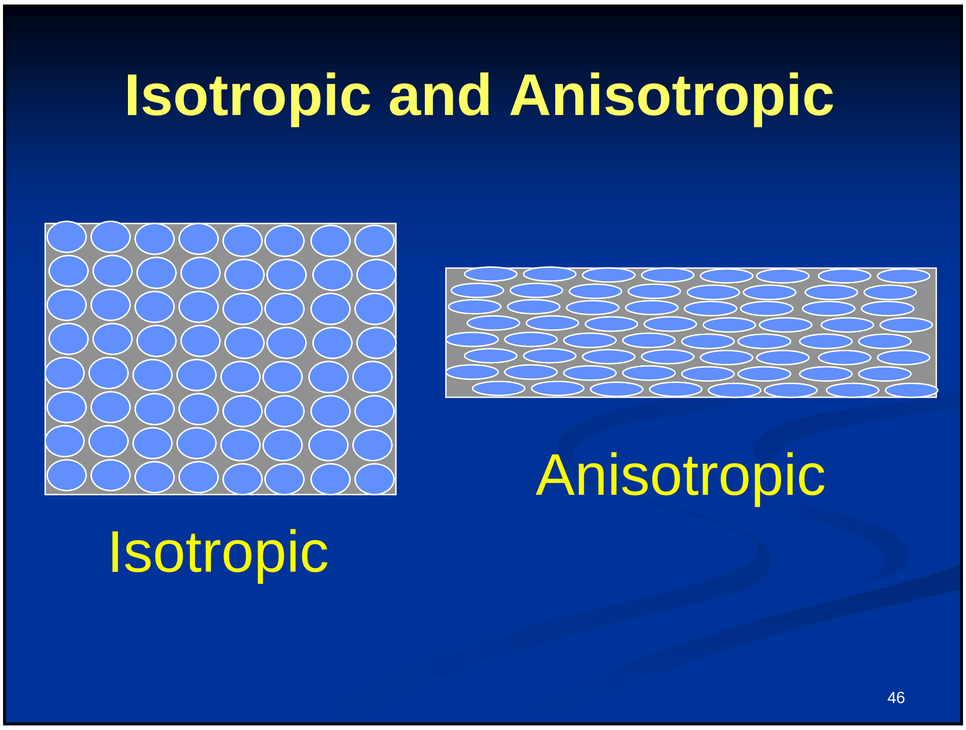

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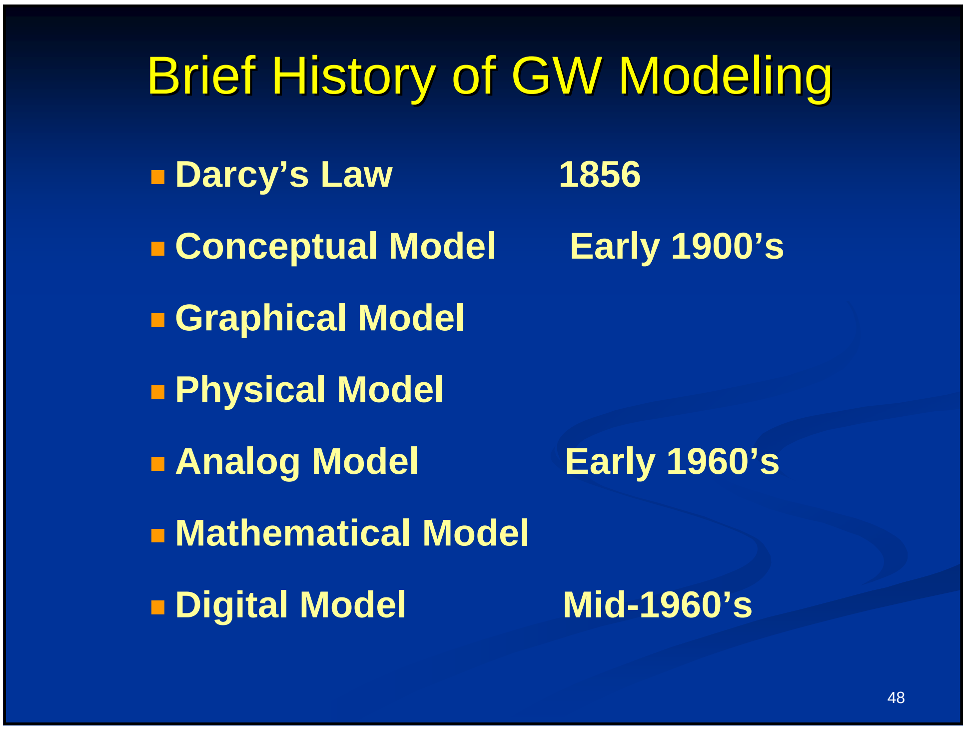
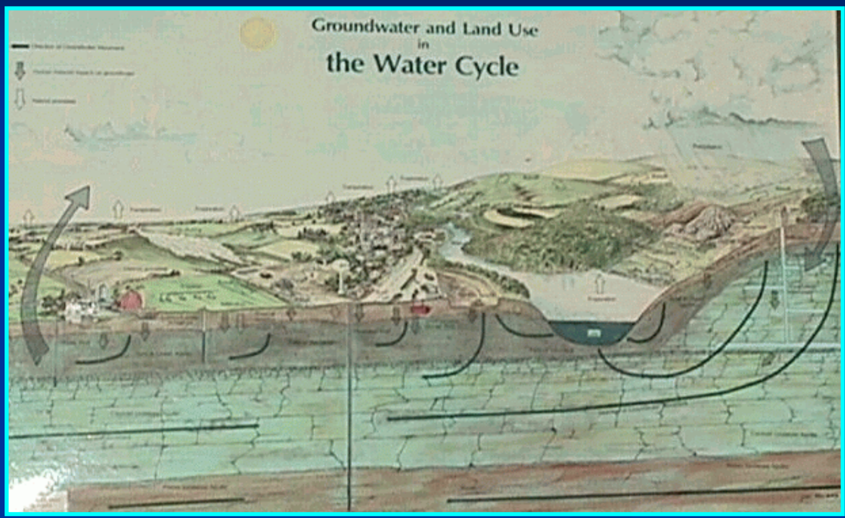


Conceptual Model



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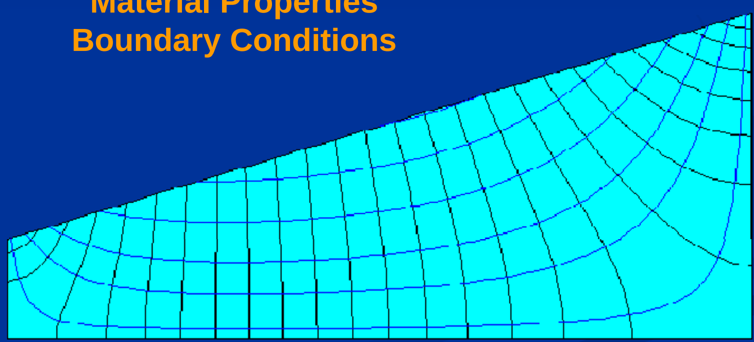
Graphical Model

Flow Net

Geometry
Material Properties
Boundary Conditions



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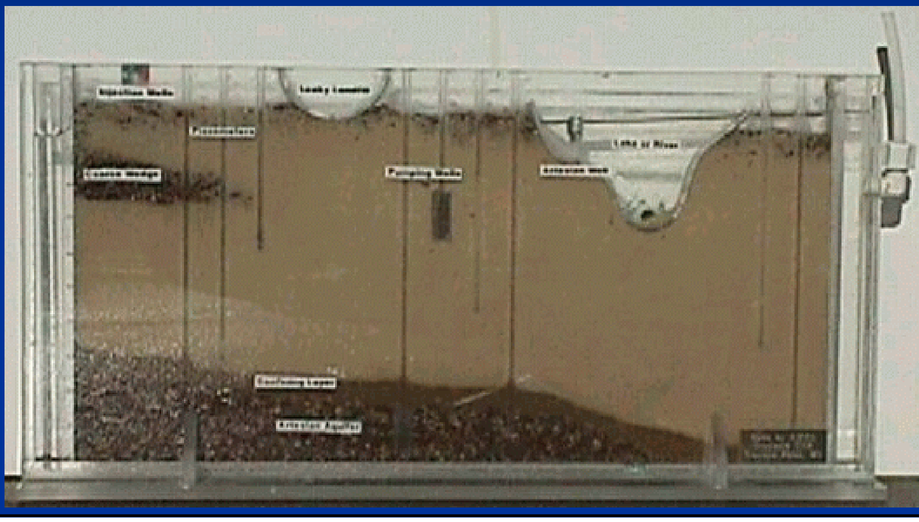
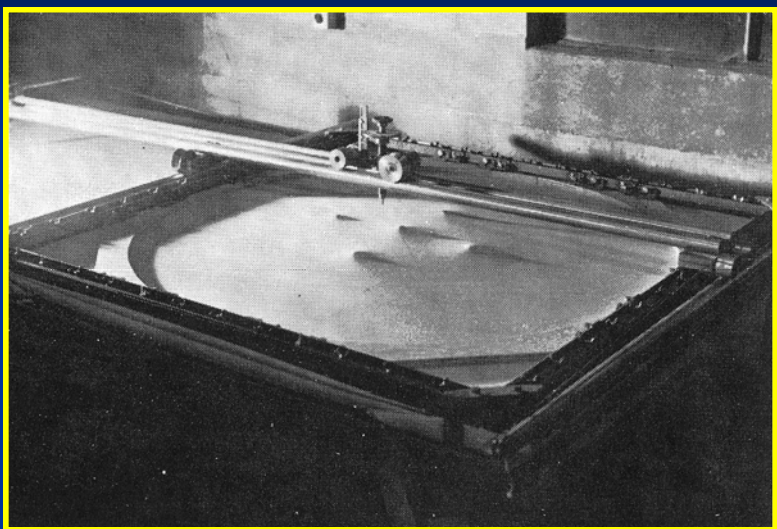
Physical Model

Sand Tank



Analog Model (Rub Sheet Model)



Source : D.K.Todd「Groundwater Hydrology, 2nd」 (Wiley,1980)

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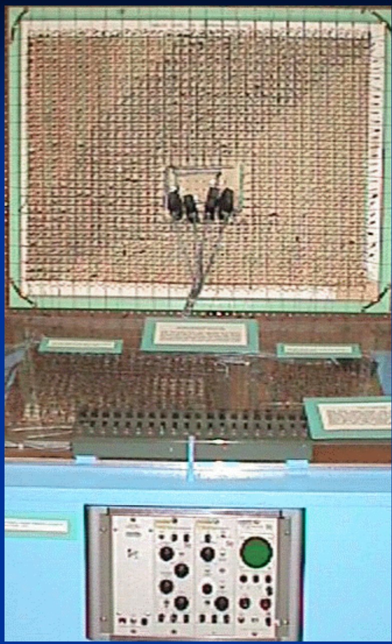
Analog Model



Electrical Analog Model

Ohm's Law

V = RI

Darcy's law

V = KI

The model was prepared for Champaign-Urbana Illinois Area (circa 1960).

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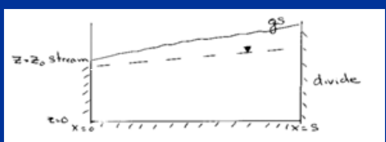
Mathematical Model

Analytical Solution

Toth (1962) developed a solution for Steady State flow in a 2-D section from a stream to a divide



he solved the Laplace Equation

$$\frac{\partial^2 h}{\partial x^2} - \frac{\partial^2 h}{\partial z^2} = 0$$

boundaries

left $\frac{\partial h}{\partial x}(0,z)=0$ right $\frac{\partial h}{\partial x}(s,z)=0$

lower $\frac{\partial h}{\partial z}(x,0)=0$

upper water table $h(x,z_o)=z_o+cx=z_o+\tan(\alpha)x$

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Result of Toth (1962) solution

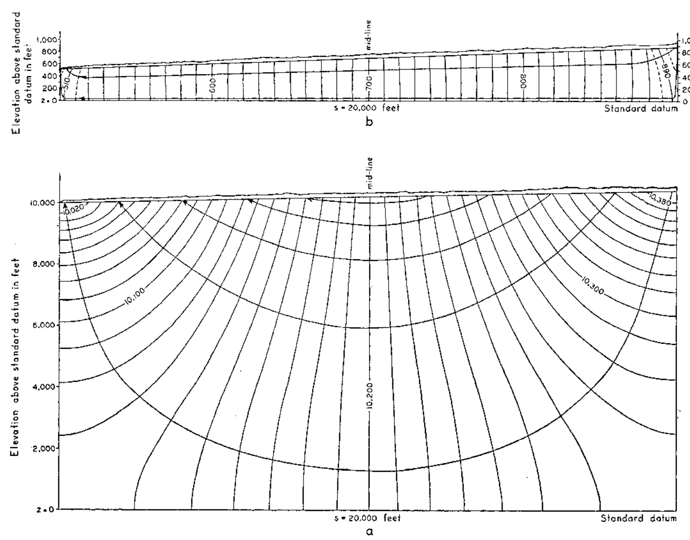

Fig. 3. Two-dimensional theoretical potential distributions and flow patterns for different depths to the horizontal impermeable boundary.

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History of Digital Computer Model

The First Numerical Simulation Model was prepared by

Tyson and Weber (1964)

The model was applied to the study of groundwater basin under the coastal plain near Los Angeles, California.

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Tyson and Weber (1964) Model

A horizontal two-dimensional groundwater flow model, which used the finite-difference method.

$$\frac{\partial}{\partial x}\left(T\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(T\frac{\partial h}{\partial y}\right)-Q=S\frac{\partial h}{\partial t}$$

T : Transmissivity,
S : Storage coefficient,
Q : Net external inflow,
h : Head,
t : Time.

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Themes for Groundwater Flow Theory

- **Limitation of Darcy Law's application**
  - Depends on the flow velocity
  - Critical point or range between laminar flow and turbulent flow
  - Effect of adsorptivity of soil grains
- **Mechanism of groundwater flow in fissure aquifer and Karst aquifer**
- **Parameters about substance transport**

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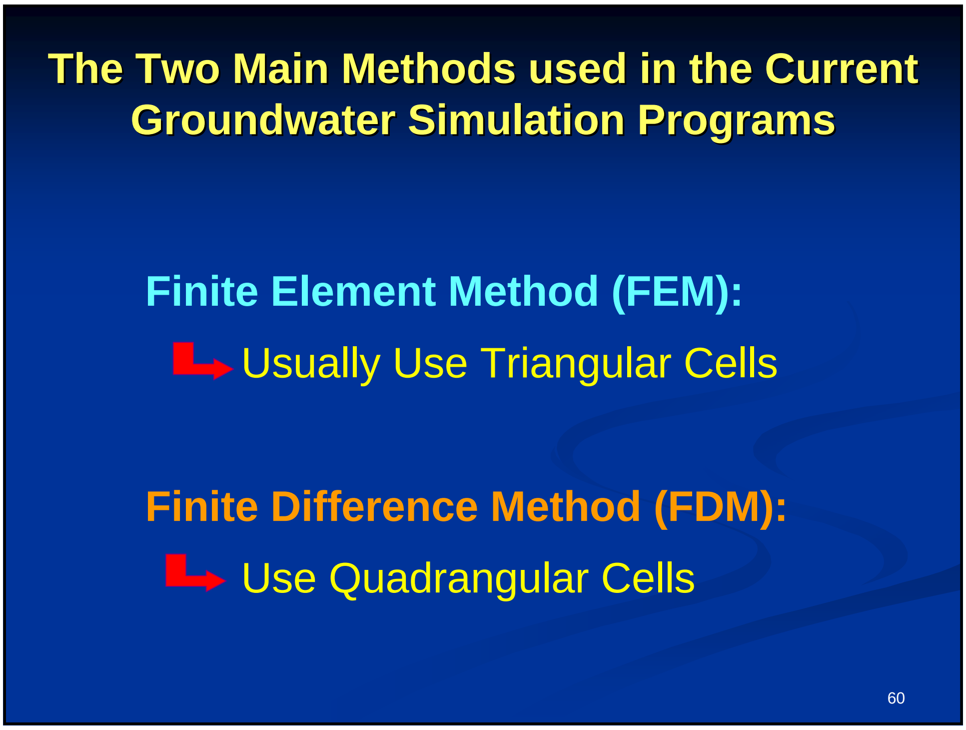
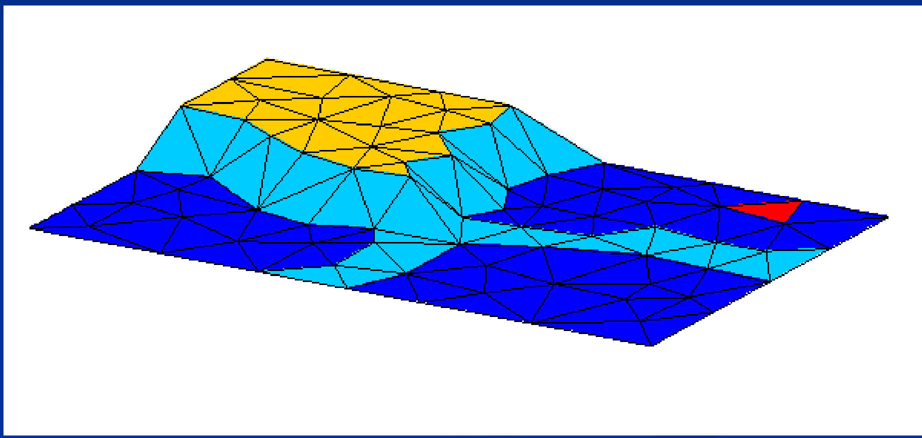


An Example of FEM Grid



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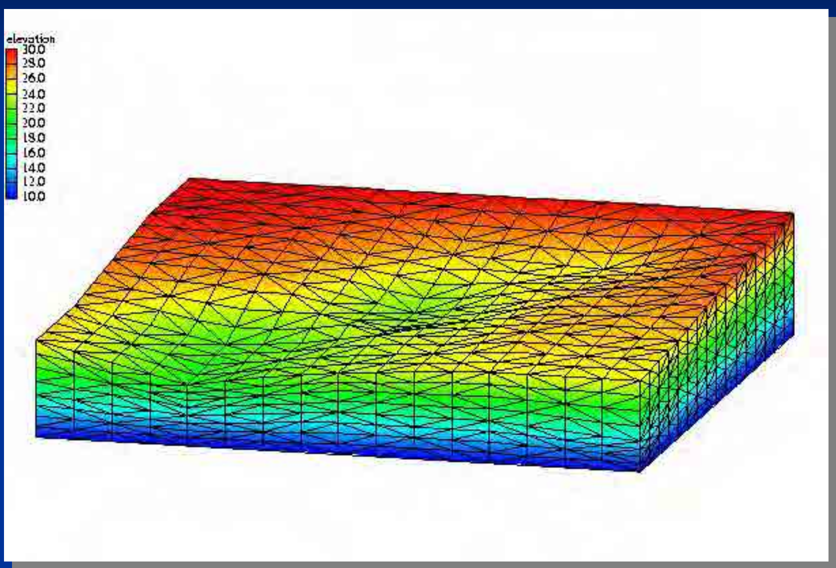
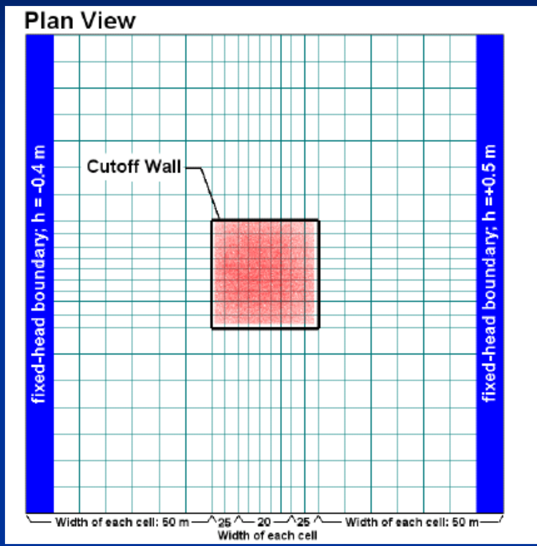
An Example of 3-D FEM Grid



An Example of 2-D FDM Grid



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An Example of 3-D FDM Grid

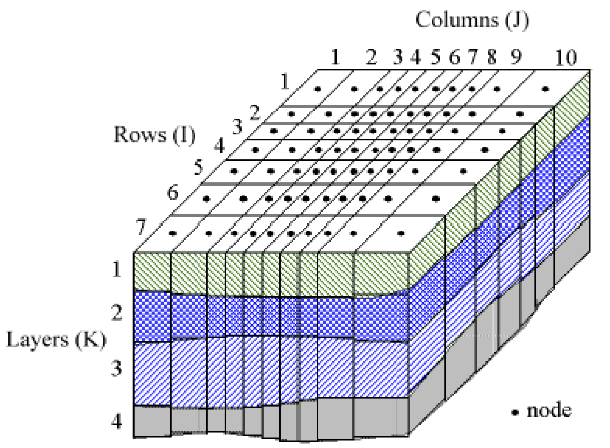

Figure 2.1. Spatial discretization of an aquifer system and the cell incides

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Model Classification by Scale of GW Flow

- Regional Groundwater Flow Model
- Intermediate Groundwater Flow Model
- Local Groundwater Flow Model

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Model Classification by Aquifer Structure

- Single Aquifer Model
  One-Dimensional Model
  or
  Two-Dimensional model
- Multi-Aquifers Mode
  Two-Dimensional model
  or
  Three-Dimensional model

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Model Classification by Model Structure

- One-Dimensional (1-D) Vertical Model
- Two-Dimensional (2-D) Plane Model
- Two-Dimensional (2-D) Vertical Model
- Quasi Three-Dimensional (Q3-D) Model
- Three-Dimensional (3-D) Model

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How Many Programs Can We Use

http://www.scisoftware.com/html/products.html

Page1

- 3DFATMIC - 3-D Subsurface Flow and Transport Model
- 3DFEMFAT - 3-D Flow and Transport Model through Saturated-Unsaturated Media
- AQUA3D - 3-D Groundwater Flow and Contaminant Transport Model
- AquiferTest for Windows - Pumping Test and Slug Test Analysis
- Aquifer Test Toolbox - Excel Workbooks for Aquifer Test Data
- AquiferWin32 - Pump Test and Slug Test Analysis Software
- AQUIPACK - Aquifer Properties and Contaminant Transport Analysis
- AT123D - Analytical Groundwater Transport Model for Long-Term Pollutant
- BIOF&T 2-D/3-D - Biodegradation, Flow and Transport in the Saturated/Unsaturated Zones
- BIO1d - 1-D model which simulates biodegradation and sorption in contaminant transport
- Chemflo - Simulates Water and Chemical Movement in Unsaturated Soils

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How Many Models Can We Use

http://www.scisoftware.com/html/products.html

Page2

- FEFLOW - Finite Element Subsurface Flow System
- ChemFlux - Finite Element Mass Transport Model
- FLONET/TRANS - FLONET/TRANS 2-D cross-sectional groundwater flow and transport
- FLOWPATH II - 2-D Groundwater Flow, Remediation, and Wellhead Protection Model
- GFLOW 2000 - Conjunctive Surface Water and Groundwater Flow
- GMS - Groundwater Modeling System - Sophisticated Groundwater Modeling
- Groundwater Vistas - Advanced Model Design and Analysis for MODFLOW, MODPATH, MT3D, and so on.
- Kinetic/Equilibrium Reactions in Saturated-Unsaturated Media Model

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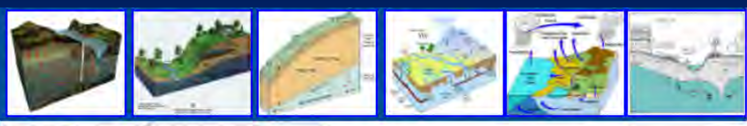
Example of HP of a Commercial Software Site



Software

3DFATMIC	3DFATMIC - 3D microbe and chemical flow and transport model for computing and predicting the distribution of pressure head, moisture content, flow velocity, and total head.
3DFEMFAT	3DFEMFAT is a 3-Dimensional Finite-Element Model of Flow And Transport through Saturated-Unsaturated Media, including coupled density-dependent flow and transport.
AQUA3D	AQUA3D - AQUA3D solves transient groundwater flow with anisotropic flow conditions. Solves transient transport of contaminants and heat with convection, decay, adsorption and velocity-dependent dispersion.
Argus ONE	Argus Open Numerical Environments (Argus ONE) - A finite-element and finite-difference numerical preprocessor providing a unified modeling solution for groundwater models
BIOF&T	BIOF&T - BIOF&T models biodegradation, flow and transport in the sat/unsat zones in 2 or 3 dimensions in heterogeneous, anisotropic porous media or fractured media
Bioslurp	BIOSLURP is an areal finite-element model to simulate three-phase (water, oil and gas) flow and multicomponent transport in ground water in the unsaturated zone gas phase.
ChemFlux	ChemFlux is a contaminant transport software modeling package for modeling of mass transport, contaminant concentrations and plume migration.
FEFLOW	FEFLOW Model - 2D/3D finite element subsurface flow system - model for density dependent groundwater flow, heat flow and contaminant transport
GMS - Groundwater Modeling System	GMS supports both finite-difference and finite-element groundwater models in 2D and 3D including MODFLOW 2000, MODPATH, MT3DMS/RT3D, SEAM3D, ART3D, UTCHEM, FEMWATER, PEST, UCODE, MODAEM and SEEP2D.

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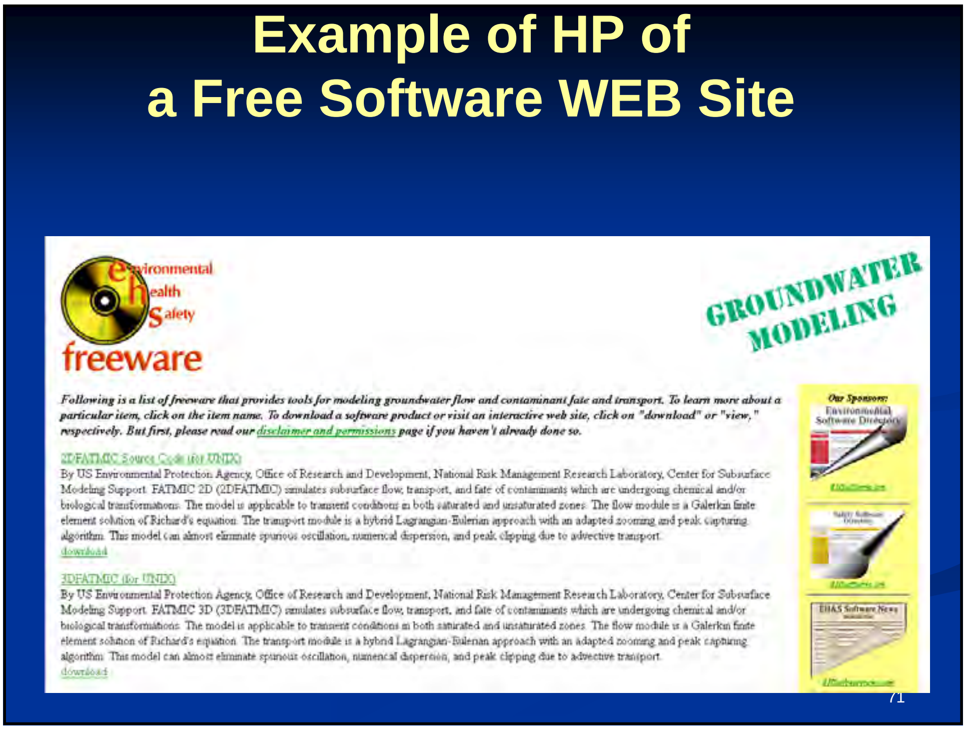
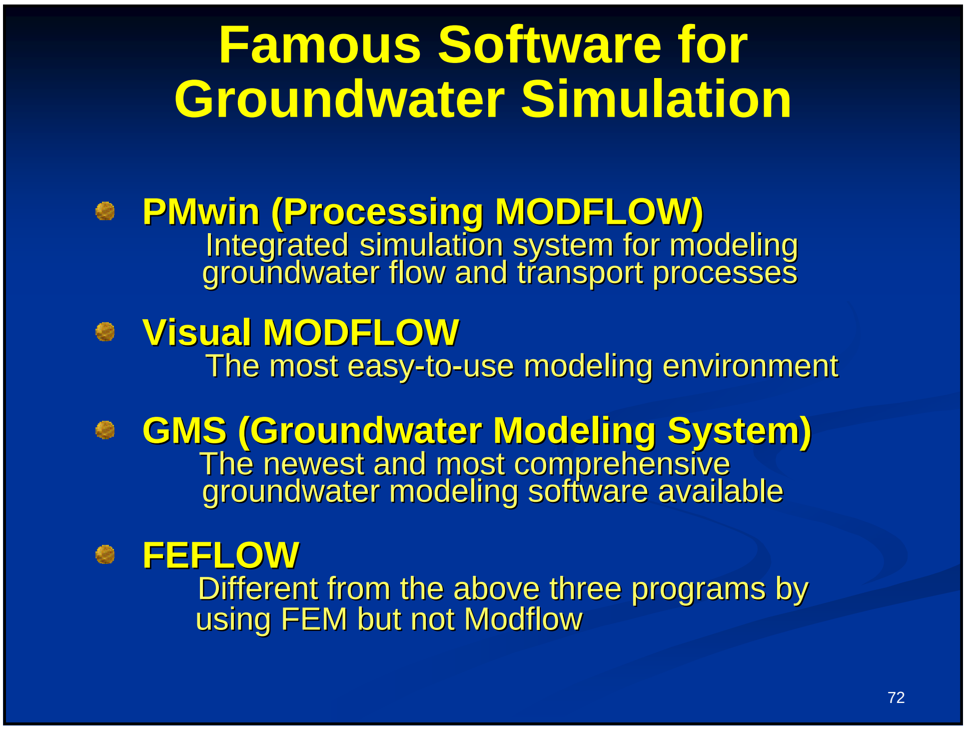
WS-6 Groundwater Simulation





About MODFLOW

- Most famous, but is not perfect.
- Very difficult to be modified
- Five times renewed. The newest version (Modflow 2005)
- Source code is free released by USGS
  ttp://water.usgs.gov/nrp/gwsoftware/modflow.html
- Difficult to be compiled, so be used for many commercial software.

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Free Released Groundwater and Hydrological Software from USGS

USGS science for a changing world

MODFLOW and Related Programs

MODFLOW: 3D Finite-Difference Groundwater Flow Model

Status of MODFLOW Versions and MODFLOW-Related Programs Available on USGS Web Pages *(January, 2011)*
MODFLOW-2005 Version: 1.8 *(Dec. 18, 2009)*
MODFLOW-LGR Version: 1.2 *(May 18, 2010)*
MODFLOW-NWT Version: 1.0 *(May 11, 2011)*
(**MODFLOW-2000** can be found under the banner "Legacy and Superseded Software")

Related Programs for Simulation of Hydrologic Processes, Model Calibration, and Groundwater Management

CFP Version 1.8 *Feb 23, 2011*
Conduit Flow Process for MODFLOW 2005

GSFLOW Version: 1.1.3 *(March 1, 2011)* new
Coupled Groundwater and Surface-water FLOW model based on the USGS Precipitation-Runoff Modeling System (PRMS) and Modular Groundwater Flow Model (MODFLOW-2005

GWM-2000 Version 1.1.3 *[Dec. 7, 2009]* and GWM-2005 Version 1.3.0 *[March 9, 2011]* new
Capability for groundwater management using optimization techniques with either MODFLOW-2000 or MODFLOW-2005

MF2K-FMP (Win) Version 1.00, *(May 19, 2006)* and MF2005-FMP2 (Win) Version 1.0.00, *(Oct 28, 2009)*
Estimate dynamically integrated supply-and-demand components of irrigated agriculture as part of the simulation of surface-water and groundwater flow

MF2K-GWT Version 1.9.8 and MOC3D Version 3.52, *(Oct 22, 2008)*

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MODFLOW Equation

$$\frac{\partial}{\partial x}\left(Kxx\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(Kyy\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(Kzz\frac{\partial h}{\partial z}\right)-W=Ss\frac{\partial h}{\partial t}$$

Kxx, *Kyy*, and *Kzz* : values of hydraulic conductivity along the *x*, *y*, and *z* coordinate axis, which are assumed to be parallel to the major axes of hydraulic conductivity (LT^{-1});

h : the potentiometric head (L);

W : a volumetric flux per unit volume;

Ss : the specific storage of the porous material (L^{-1}); and

t : time (T).

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Recommended Software

PMWIN53

- The first graphical user interfaces for MODFLOW (from 1991).

  The longest history of program development
- Easy to input and modify parameters and factors.
- Kindly error check function and model running record
- High speed of running and excellent stability of model running.

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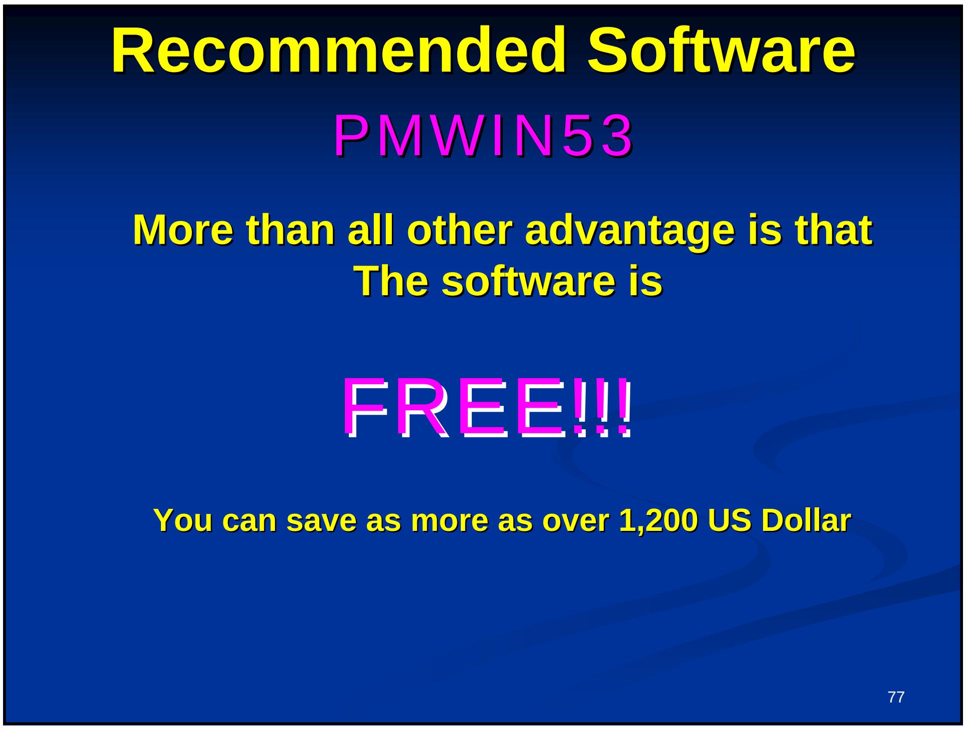
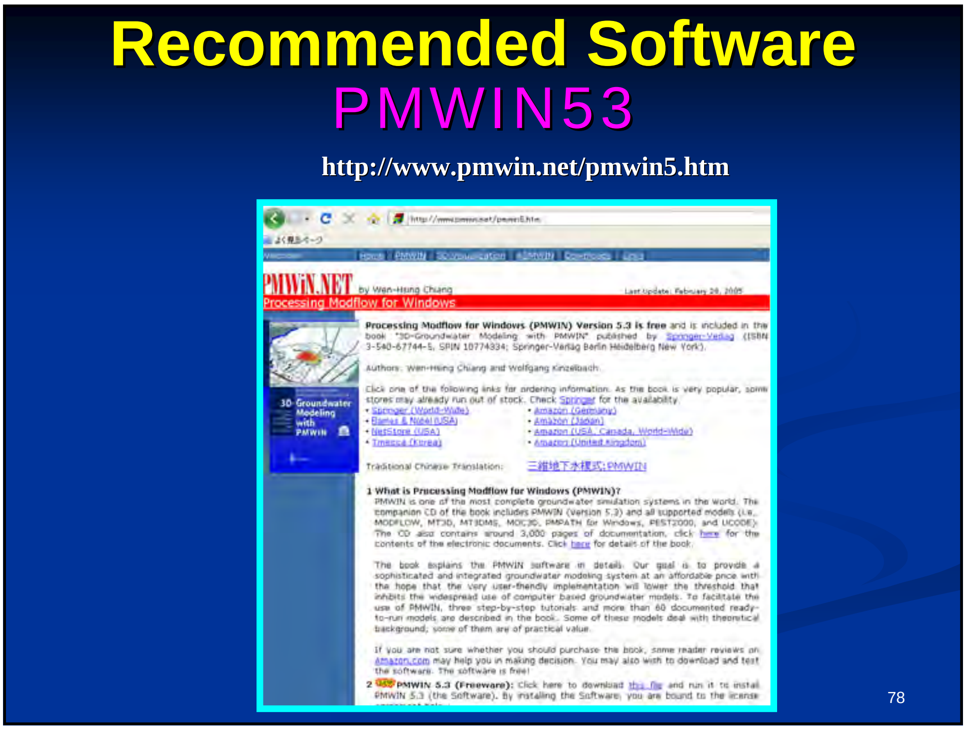

Recommended Software
PMWIN53
More than all other advantage is that
The software is
FREE!!!
You can save as more as over 1,200 US Dollar
77


Recommended Software
PMWIN53
http://www.pmwin.net/pmwin5.htm
PMWIN.NET
Processing Modflow for Windows
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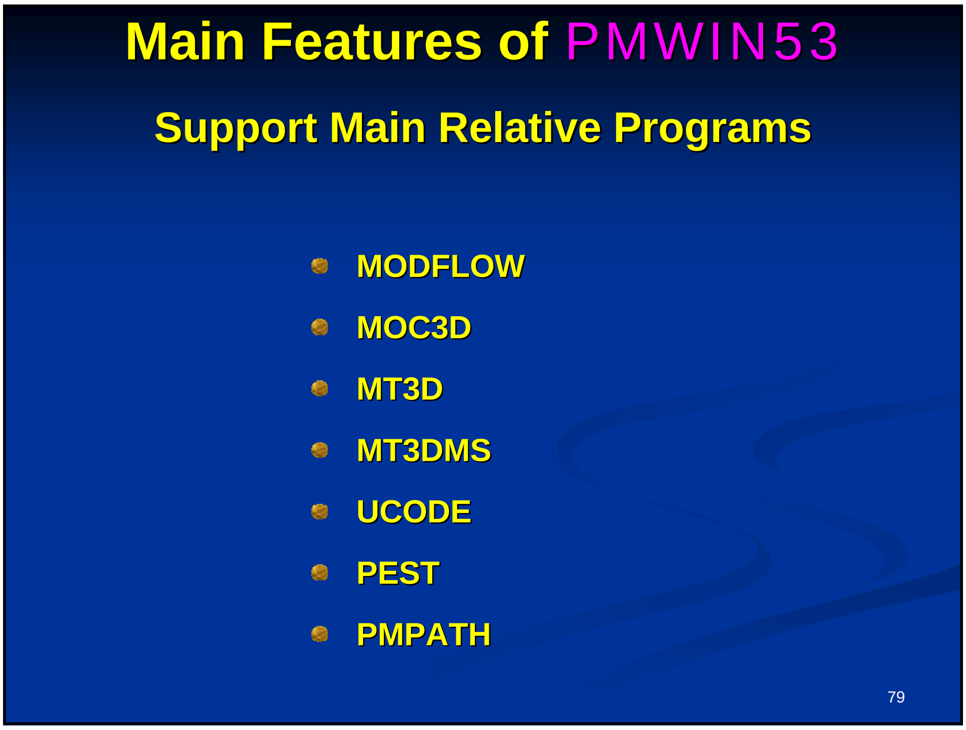
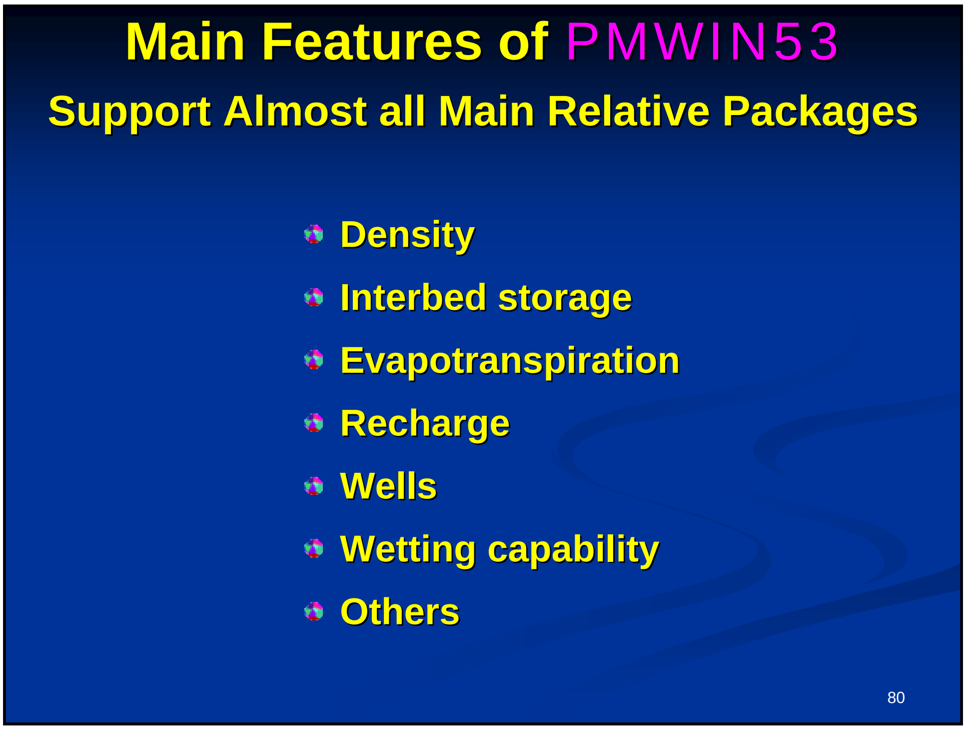
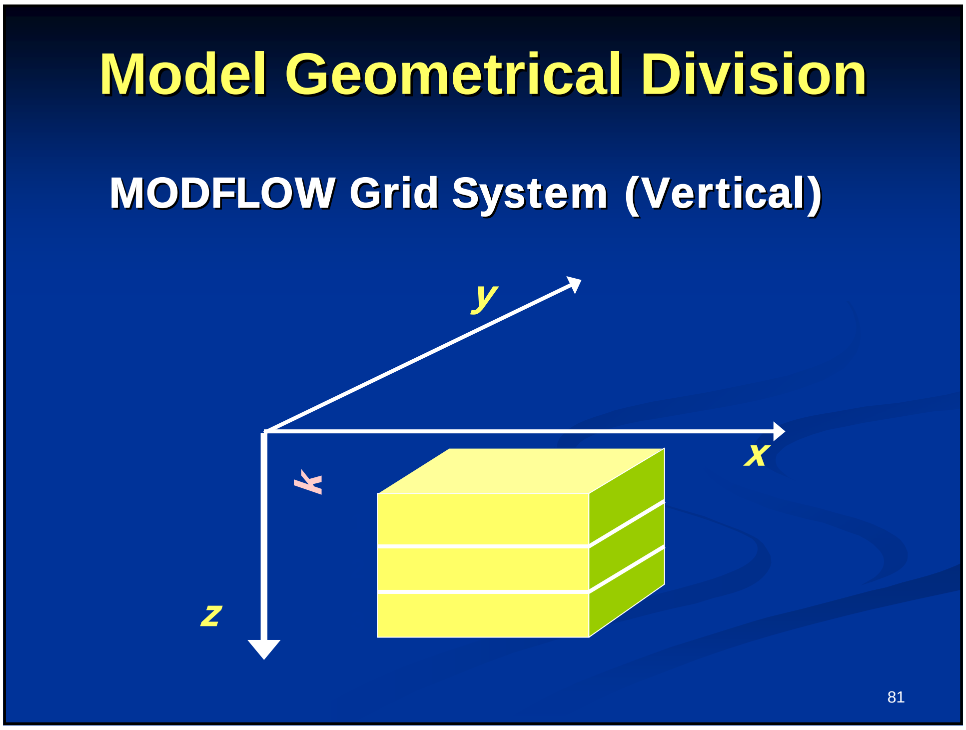
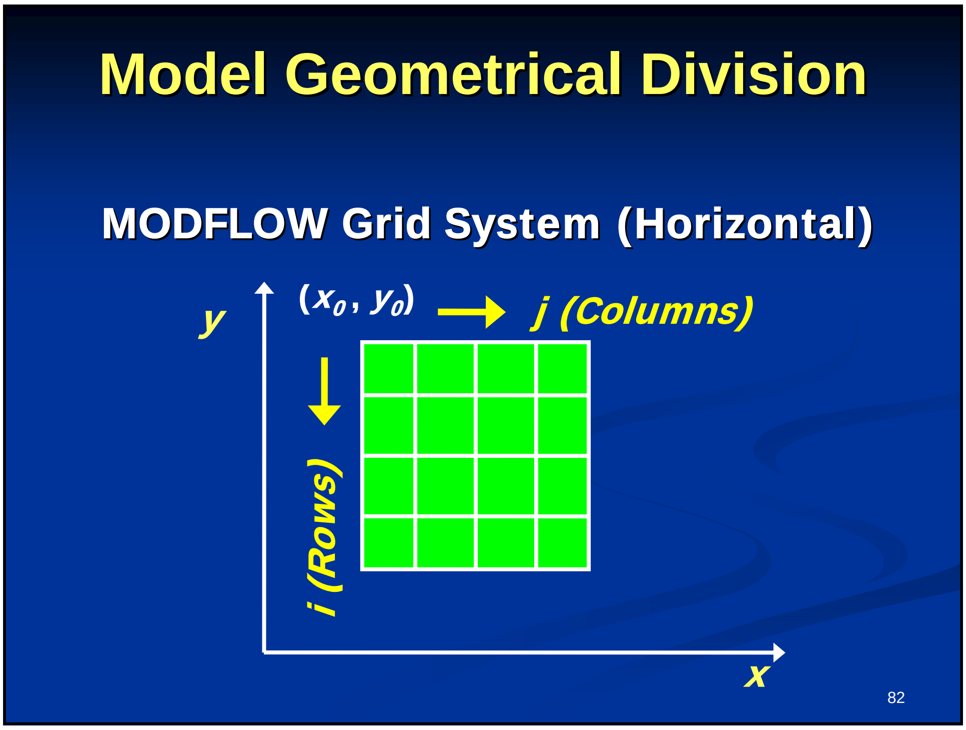
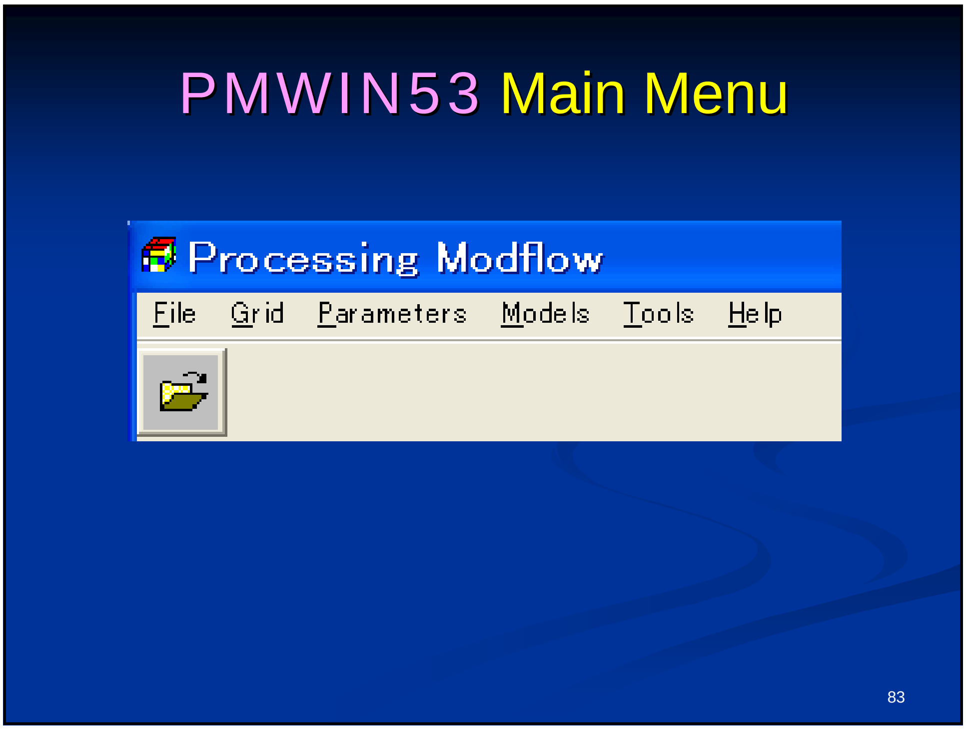
WS-6 Groundwater Simulation

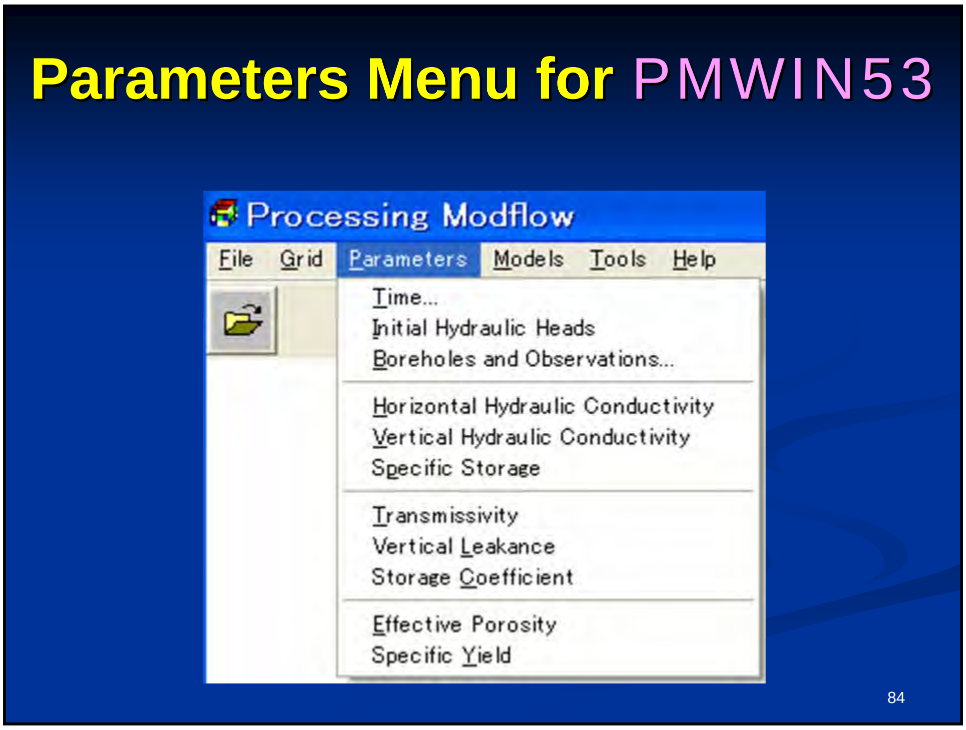


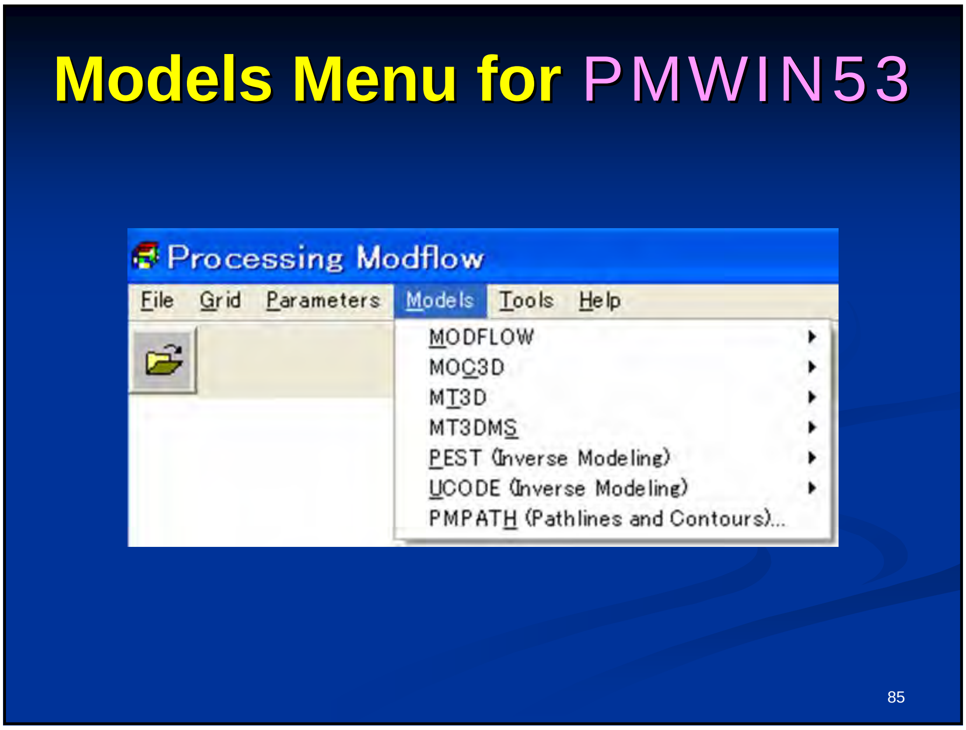


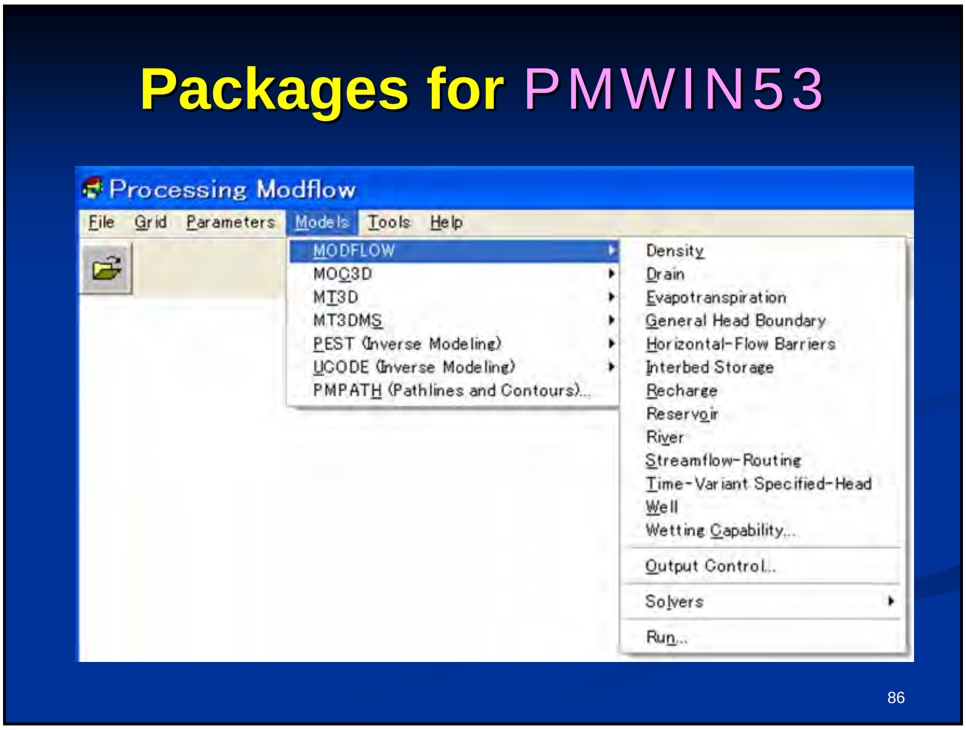

Model Geometrical Division
MODFLOW Grid System (Vertical)
y
x
k
z
81


Model Geometrical Division
MODFLOW Grid System (Horizontal)
y
(x0 , y0)
j (Columns)
i (Rows)
x
82


PMWIN53 Main Menu
Processing Modflow
File
Grid
Parameters
Models
Tools
Help
83


Parameters Menu for PMWIN53
Processing Modflow
File
Grid
Parameters
Models
Tools
Help
Time...
Initial Hydraulic Heads
Boreholes and Observations...
Horizontal Hydraulic Conductivity
Vertical Hydraulic Conductivity
Specific Storage
Transmissivity
Vertical Leakance
Storage Coefficient
Effective Porosity
Specific Yield
84


Models Menu for PMWIN53
Processing Modflow
File Grid Parameters Models Tools Help
MODFLOW
MOC3D
MT3D
MT3DMS
PEST (Inverse Modeling)
UCODE (Inverse Modeling)
PMPATH (Pathlines and Contours)...
85


Packages for PMWIN53
Processing Modflow
File Grid Parameters Models Tools Help
MODFLOW
MOC3D
MT3D
MT3DMS
PEST (Inverse Modeling)
UCODE (Inverse Modeling)
PMPATH (Pathlines and Contours)...
Density
Drain
Evapotranspiration
General Head Boundary
Horizontal-Flow Barriers
Interbed Storage
Recharge
Reservoir
River
Streamflow-Routing
Time-Variant Specified-Head
Well
Wetting Capability...
Output Control...
Solvers
Run...
86

Utility of Groundwater Simulation Model (1) Purpose

- Identification Model
- Prediction Model
- Management Model

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Utility of Groundwater Simulation Model (2) Simulation Target

- Flow Model
- Land Subsidence Model
- Solute Transport Model
- Density Fluid Model
- Heat Transport Model

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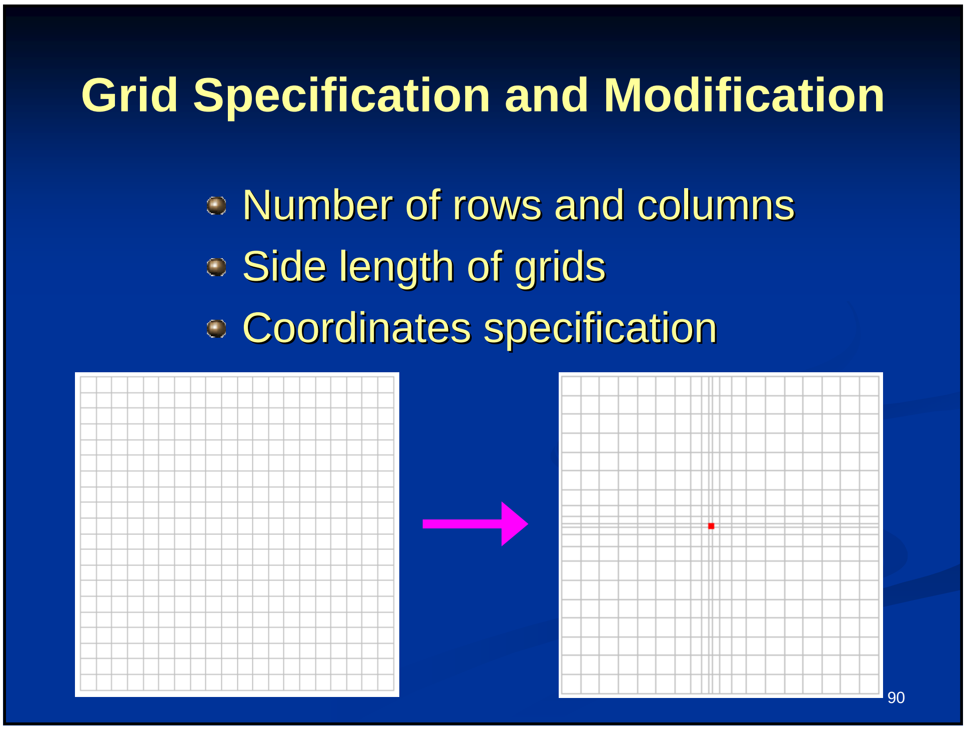
WS-6 Groundwater Simulation



Layer Properties Specification

- Confined Aquifer
- Unconfined Aquifer
- Confined / Unconfined Aquifer
- Horizontal Anisotropy
- Vertical Anisotropy

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Boundary Specification

For groundwater flow simulation

- Active variable-head boundary
- Fixed-head or time-varying specified-head boundary
- Inactive and inactive boundary

For substance transport simulation

- Active concentration boundary
- Constant concentration boundary
- Inactive concentration boundary

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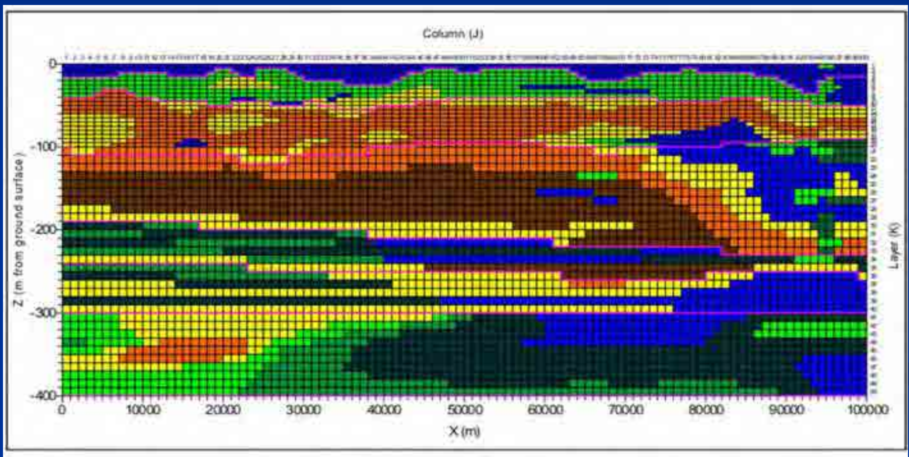
Layer Top and Bottom Elevation

Example 1: uniform layer elevation specification



93

Layer Top and Bottom Elevation

Example 2: nonuniformity layer elevation specification

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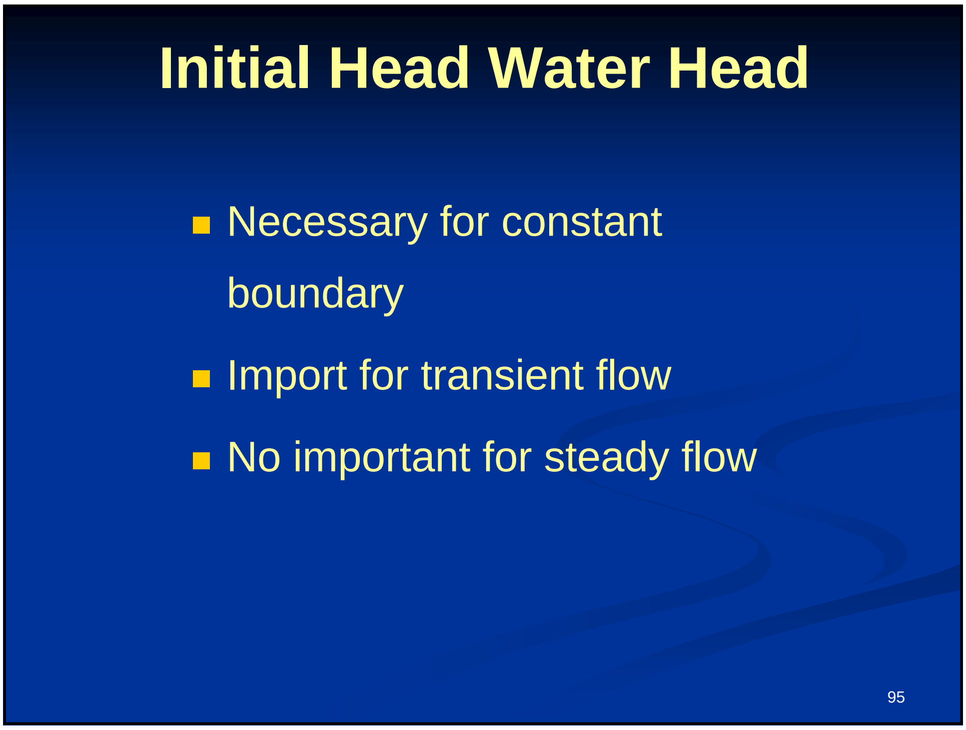
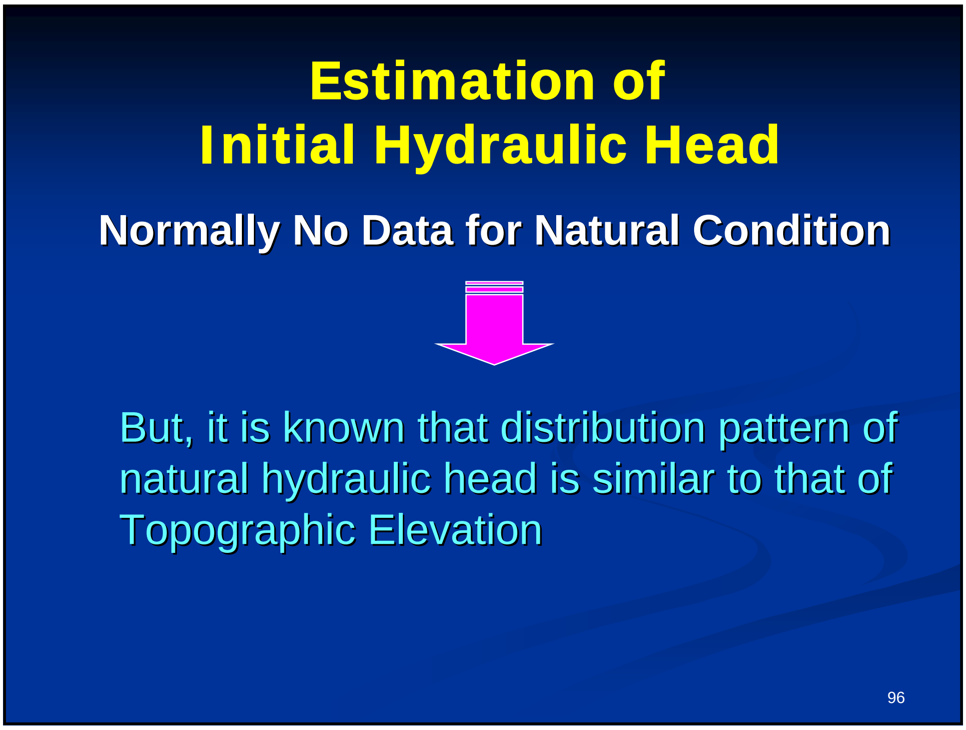
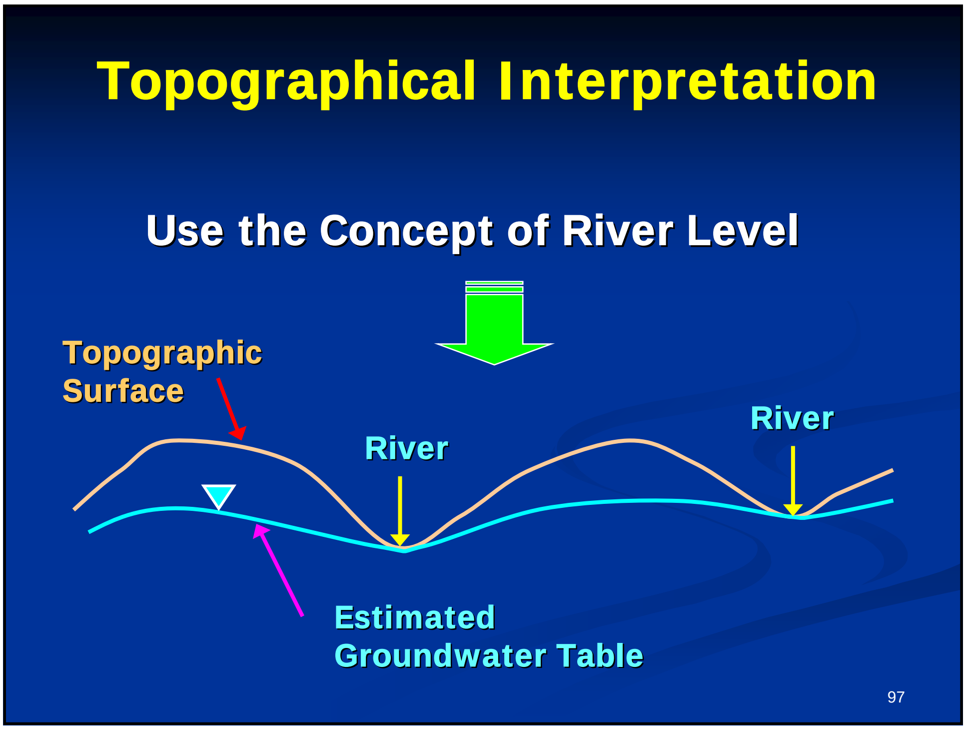
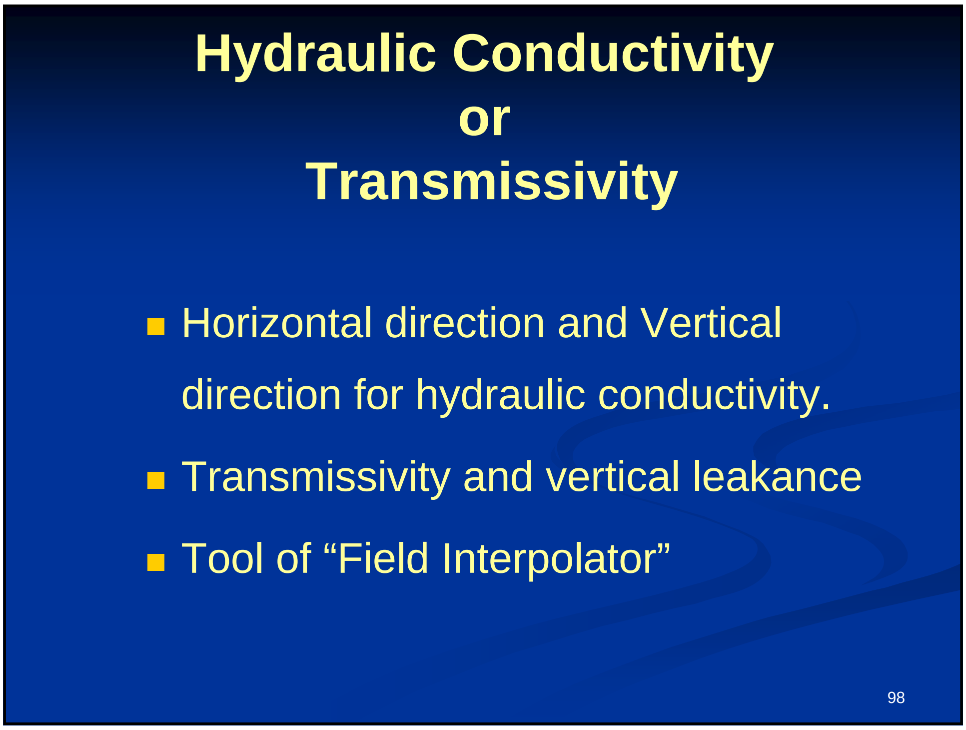
WS-6 Groundwater Simulation





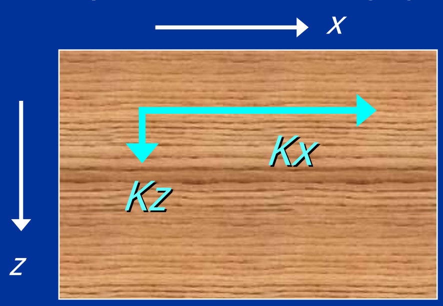
WS-6 Groundwater Simulation





Vertical Hydraulic Conductivity of Aquifer

- One of the Unreliable Parameters
- Consider Sedimentary Structure
  (Lamina, Thin clayey beds, etc.)



Generally
Kz / Kx =
1/2 to 1/50

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Other Parameters

- **Effective porosity**
- **Specific Storage**
- **Specific Yield**
- **Bulk Density**

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MODFLOW Drain Package

- **Purpose:**

  To simulate effects of features such as agricultural drains, which remove groundwater from aquifer at a rate proportional to the head difference between the aquifer and the drain.

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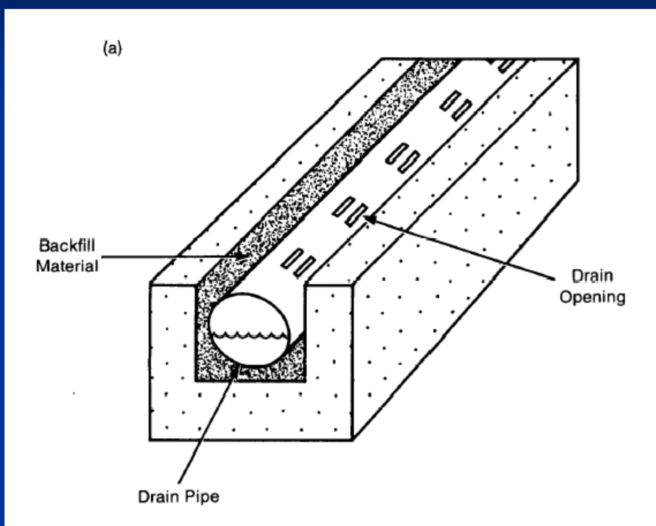
Concept Drain Package (1)



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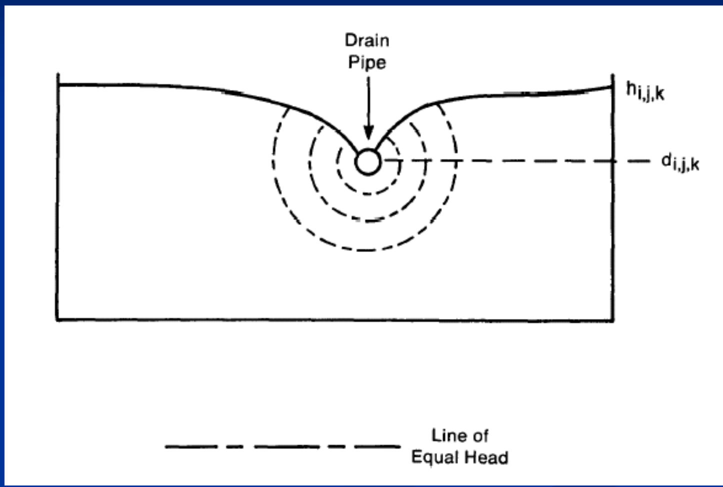
WS-6 Groundwater Simulation

Concept Drain Package (2)



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Evaporation Package

Three parameters

- Maximum Et rate (L/T)
- Elevation of the surface (L)
- ET extinction Depth (L)

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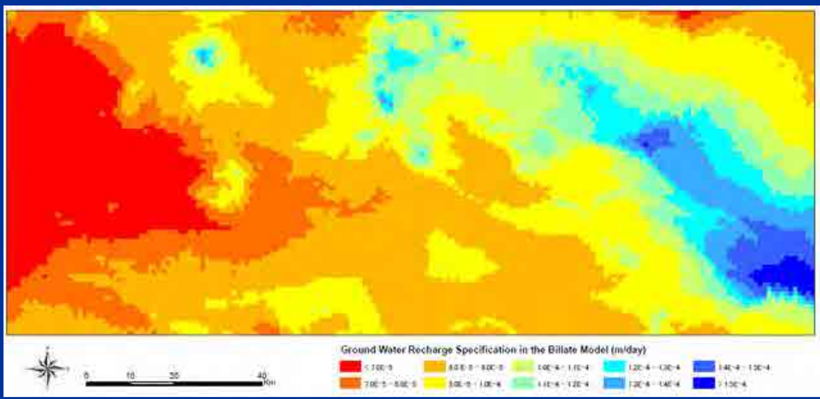
Recharge Package

One parameter: Recharge Flux (L/T)

Example of Recharge package specification for the Billate River basin groundwater simulation model:



105

General Head Boundary

Purpose: solve the problem of the implicit specification of inactive cell for the domain boundary. Two parameters:

- **Hydraulic conductance (L^2/T)**
- **Head on the external source (L)**

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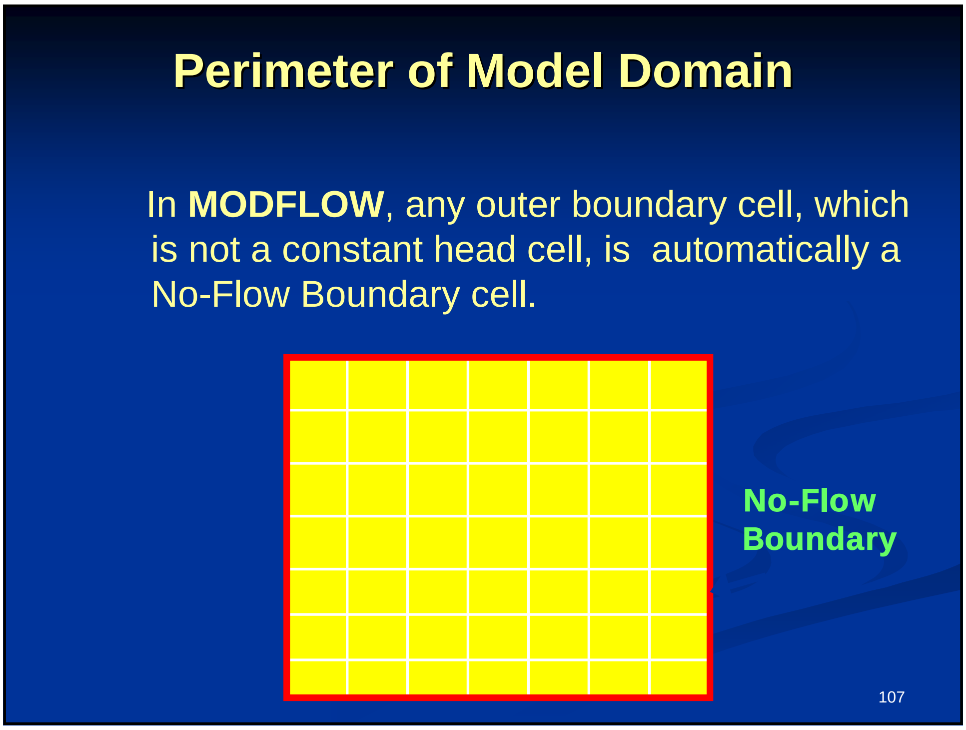
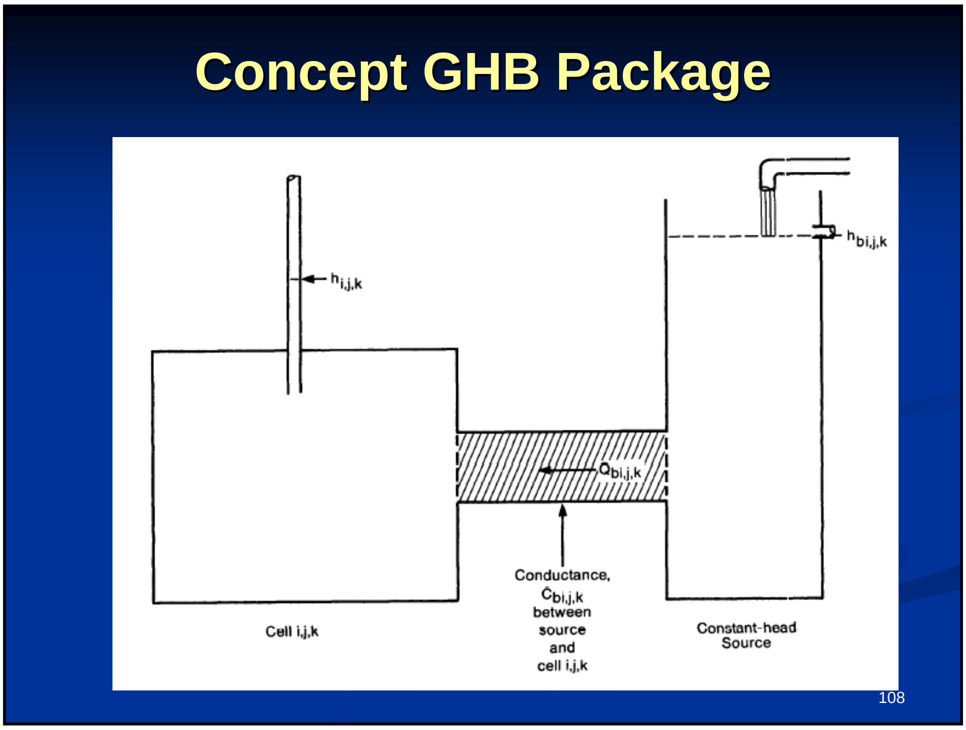

Perimeter of Model Domain
In MODFLOW, any outer boundary cell, which is not a constant head cell, is automatically a No-Flow Boundary cell.
No-Flow Boundary
107


Concept GHB Package
$h_{i,j,k}$
$h_{bi,j,k}$
$Q_{bi,j,k}$
Cell i,j,k
Conductance, $C_{bi,j,k}$ between source and cell i,j,k
Constant-head Source
108

How to Calculate Q_{GHB}

$$Q_{GHB} = C_{GHB}\,(h_b - h)$$

where,

Q_{GHB} : Flow through GHB Cell [L^2/T]

C_{GHB} : GHB Hydraulic Conductance

h_b : Head on the External Source

h : Hydraulic Head in the Aquifer

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GHB Hydraulic Conductance C_{GHB}

$$C_{GHB} = K * L$$

where,

K : Equivalent Hydraulic Conductivity

L : Length of the General-Head Boundary within the Cell

Similar to the River Package and Drain Package

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Horizontal – Flow Barrier package

Purpose: Simulate the effect of faults

Two parameters:

- **Barrier direction**
- **Hydraulic conductivity / thickness (1/T)**

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River Package

Purpose: Simulate the effect of rivers in the model domain.

Three parameters:

- **Conductance of the river bed (l^2/T)**
- **Head in the river (1/T)**
- **Elevation of the river bed bottom (L)**

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MODFLOW River Package

- **Purpose:**

  To simulate the effect of flow between groundwater systems and surface water features, such as rivers, lakes or reservoirs.

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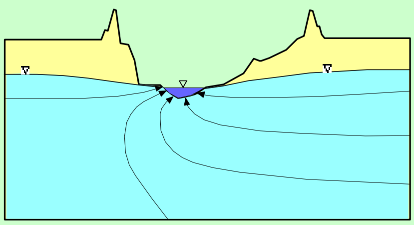
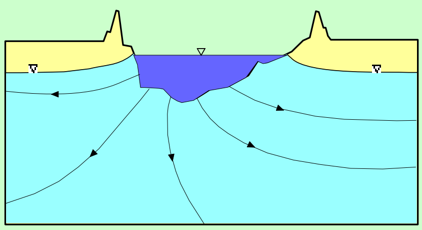
Relation between Groundwater and River Water

RW Level< GW Level



GW to RW

GW Level< RW Level



RW to GW

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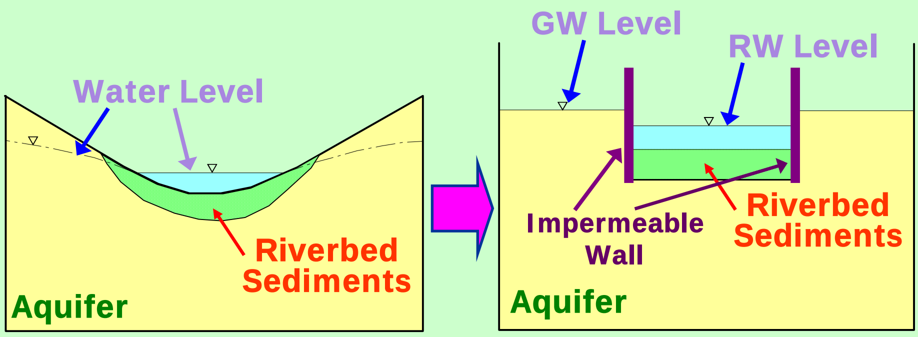
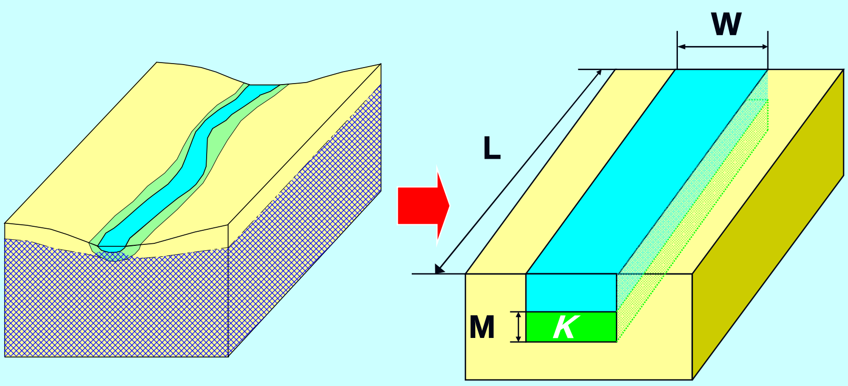
Concept of River Package



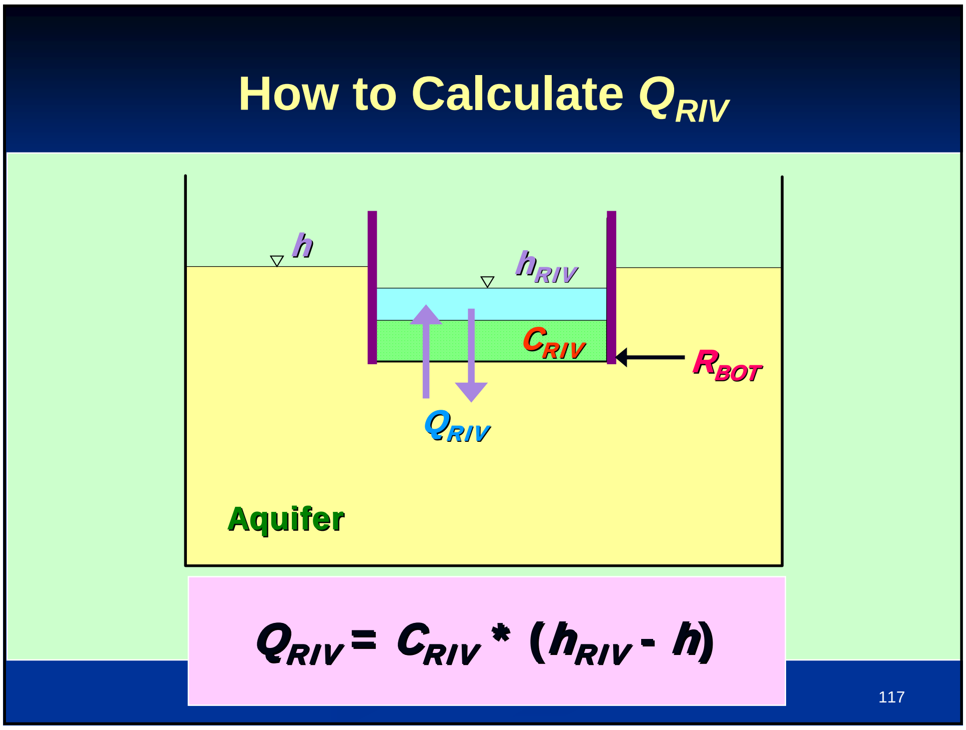
115

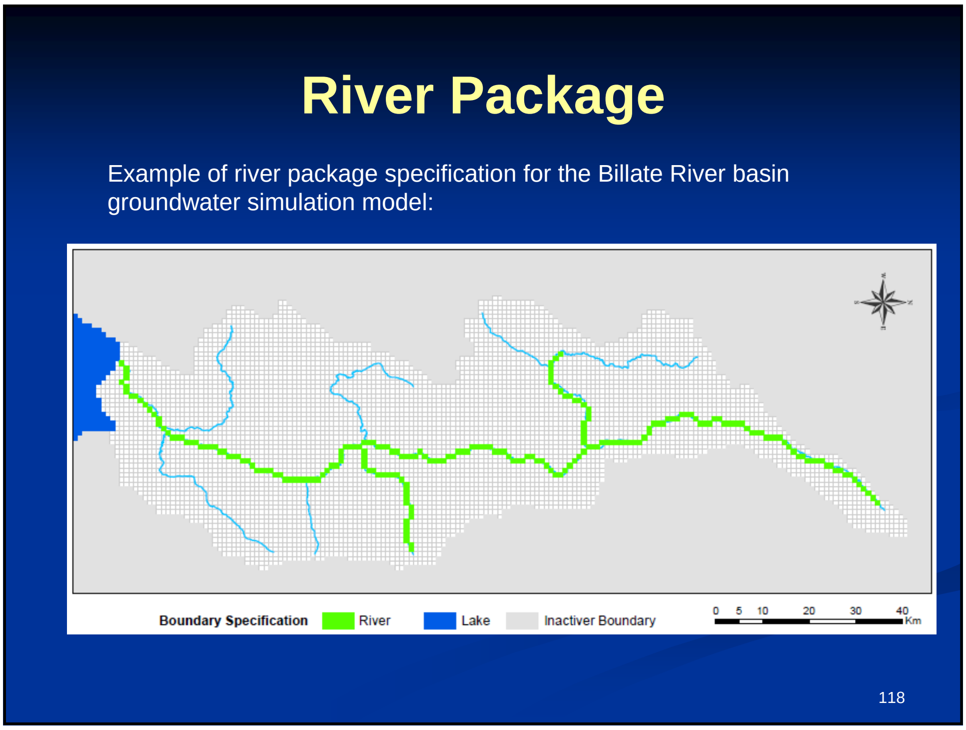
Modeling of River Cell



$$C_{RIV} = \frac{K \cdot L \cdot W}{M} \quad [L^2T^{-1}]$$

116


How to Calculate Q_{RIV}
h
h_{RIV}
C_{RIV}
R_{BOT}
Q_{RIV}
Aquifer
$Q_{RIV} = C_{RIV} * (h_{RIV} - h)$
117


River Package
Example of river package specification for the Billate River basin groundwater simulation model:
Boundary Specification
River
Lake
Inactiver Boundary
0 5 10 20 30 40
Km
118

Well Package

Purpose: Simulate the effect of groundwater use.

One parameters of recharge rate (L3/T):

- >0, recharge well
- <0, withdrawal well

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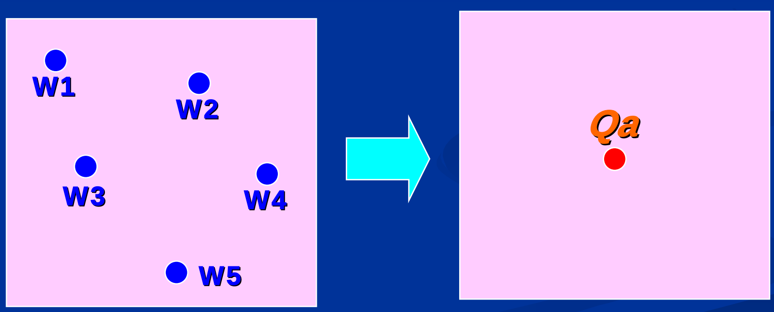
Concept of Assigning Well Pumpage into MODFLOW CELL

Horizontal View



Model Cell

Qa = Q1+Q2+Q3+Q4+Q5

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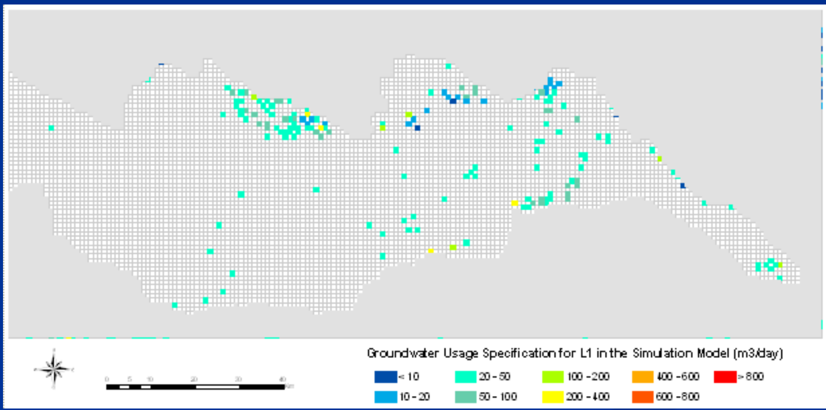
WS-6 Groundwater Simulation

Well Package

Example-1: well package specification for the Billate River basin groundwater simulation model layer_1



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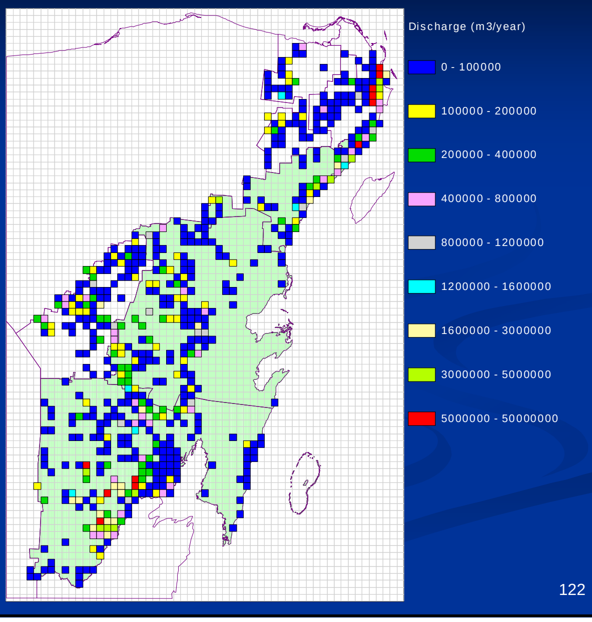
Well Package

Example-2:

well package specification for the area of Quintana Roo State, Mexico



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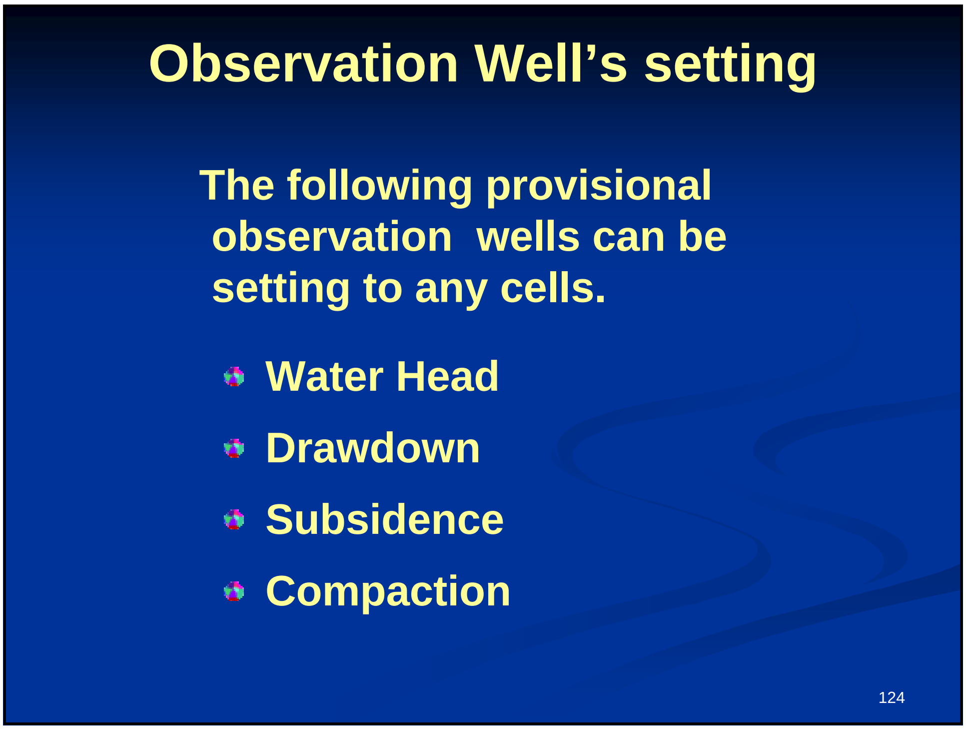
WS-6 Groundwater Simulation



Solver Selection and Parameter Setting

Different solutions can be selected:

- DE45…
- PCG2
- SIP
- SSOR

Different parameters can be set:

- Out Iteration
- Inner Iteration
- Head Change
- Residual and so on

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Model Error Check

The following data will be checked:

- 1. Geometrical setup of the model
- 2. Starting head at constant head cells
- 3. Time-independent data (if used)
- 4. Horizontal hydraulic conductivity or Vertical hydraulic conductivity
- 5. Storage coefficient, specific storage or specific yield
- 6. All used packages

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Model Error Check

Example of error identification:

>>>GEOMETRICAL SETUP

>>Thickness of layers:

Error: The thickness of the following active cell(s) is zero or negative. (COL, ROW, LAYER) (3,3,1)

Warning: The thickness of the following inactive cell(s) is zero or negative (COL, ROW, LAYER)

>>Starting head of constant head cells: --- OK ---

>>>TIME-INDEPENDENT DATA:

>>Effective porosity --- OK ---

>>>TIME-DEPENDENT DATA:

>WEL1 Package: --- OK ---

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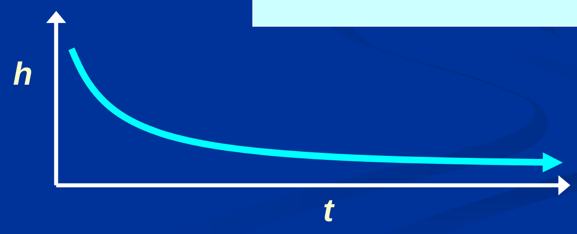
Simulation Flow Type Selection (1)

Steady-State

Not time dependent

time t: $t = 1 \rightarrow \infty$



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Simulation Flow Type Selection (2)

Transient

Time dependent (Unsteady-state)

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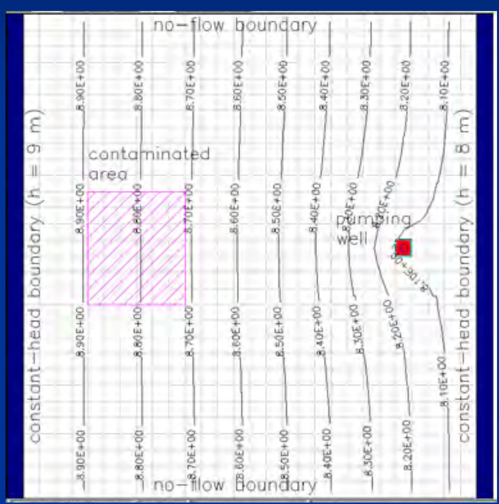
Groundwater Flow Simulation

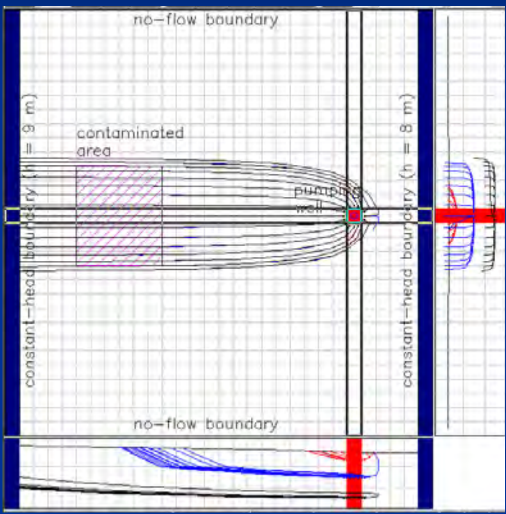
Example: Result of PMWin Pro tutorials.



130

Groundwater Flow Simulation

Example: Result of PMWin Pro tutorials.



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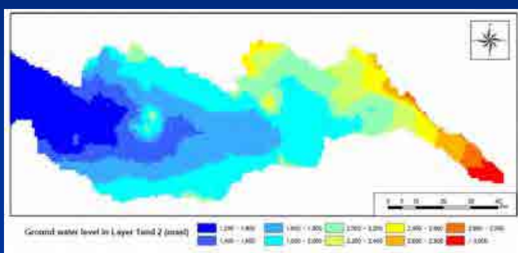
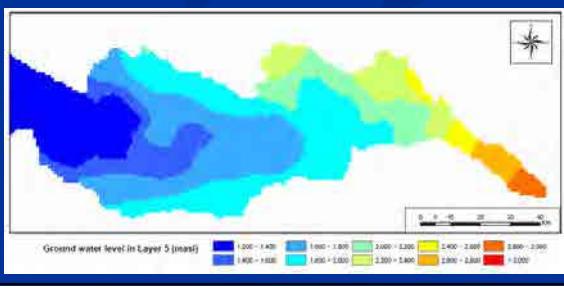
Groundwater Flow Simulation

Example: Water head distribution in Billate River basin.



Water level in layer_1



Water level in layer_5

Solute Transport Simulation

Using Advection-Dispersion equation (Konikow and Bredehoeft, 1978)

$$\frac{\partial C_n}{\partial t} = \frac{\partial}{\partial x_i}\left(D_{ij}\frac{\partial C_n}{\partial x_i}\right) - \frac{\partial}{\partial x_i}\left(C_n V_i\right) - \frac{C'_n W}{\varepsilon}$$

D_{ij} : Coefficient of hydrodynamic dispersion (a second order tensor) (L^2T^{-1})
V_i : Seepage velocity in the direction of x_i (LT^{-1})
C_n : Concentration of the *n*th constituent (ML^{-3})
C'_n : Concentration of the *n*th constituent in the source or sink fluid (ML^{-3})
ε : Effective porosity (dimensionless).

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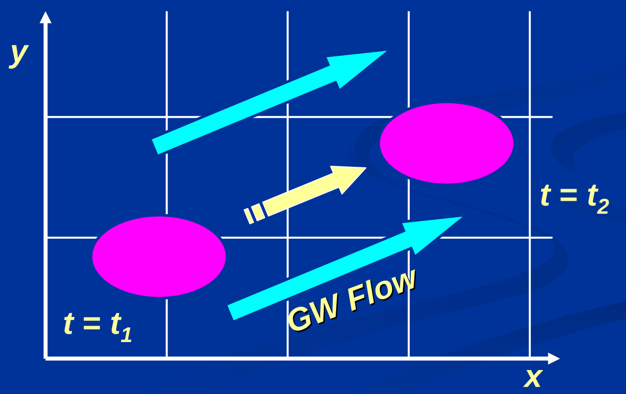
Advection

The process by which solutes are transported by moving groundwater. (= Convective Transport)



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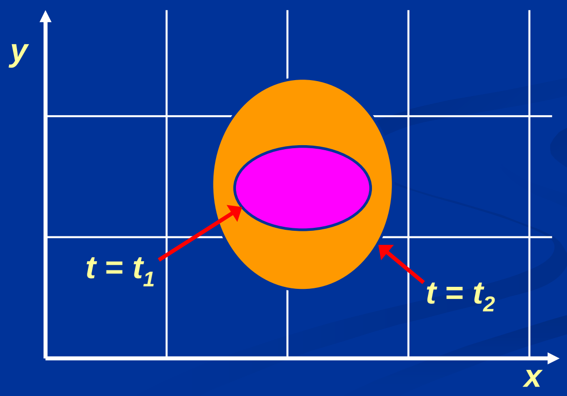
Dispersion

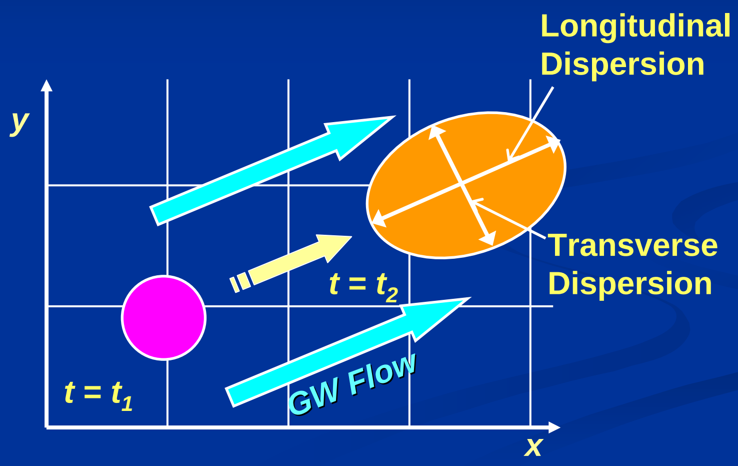
Spreading of solute concentration in groundwater caused by irregular shape of pore space and velocity variations.



135

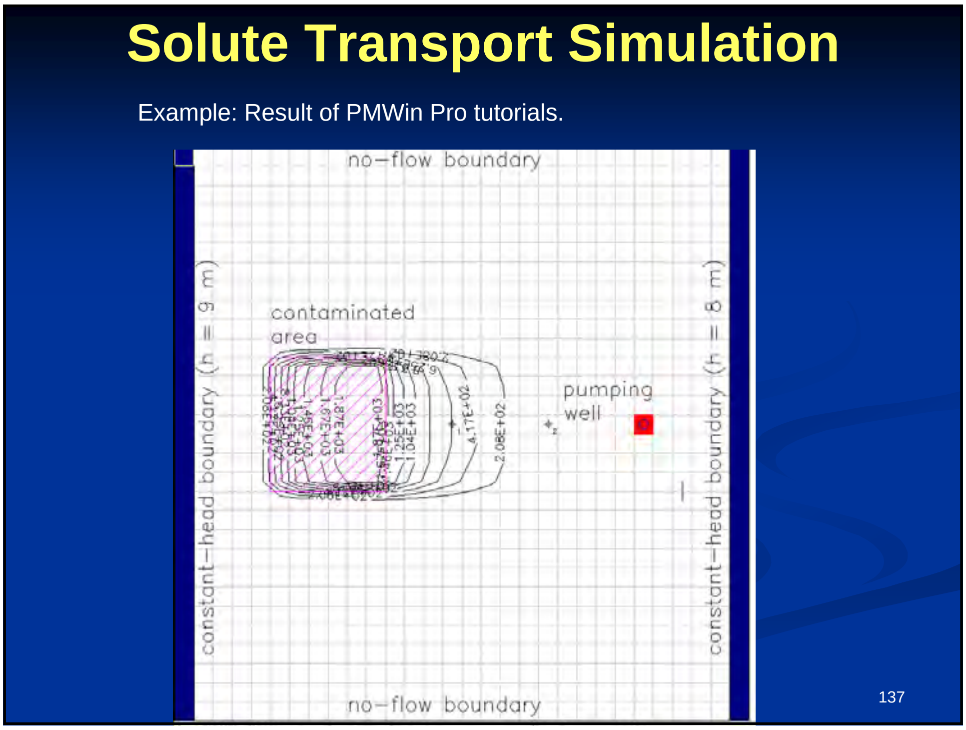
Advection-Dispersion

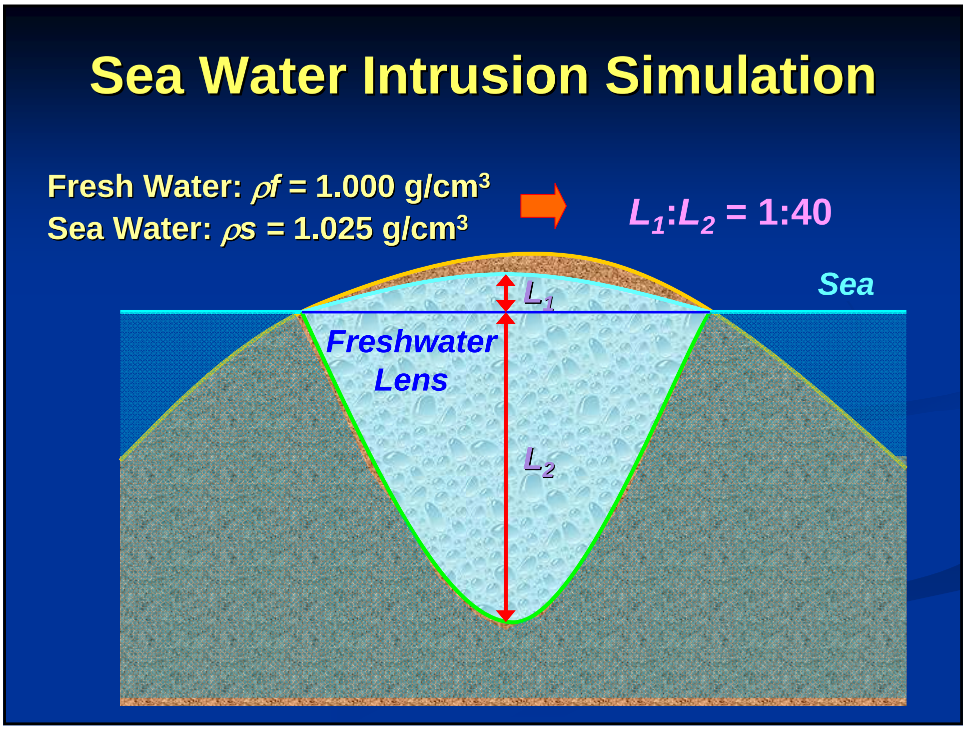
Combination of Advection and Dispersion.



136

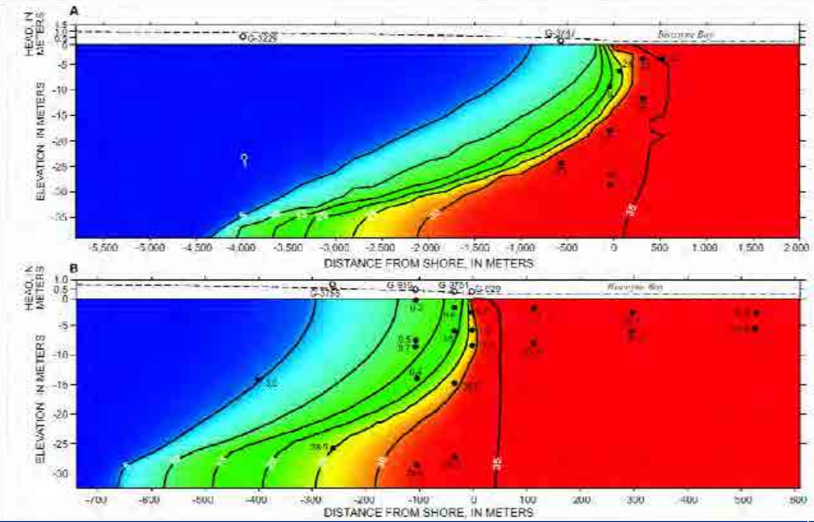
WS-6 Groundwater Simulation





Seawater Intrusion Simulation

Density Fluid Model can simulate Ghyben-Herzberg Principle



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The Type Classification of Groundwater Simulation Model

All models in the world can be simply classified into 3 ranks

- WHITE MODEL
- BLACK MODEL
- GRAY MODEL

Groundwater simulation model is never a WHITE MODEL, but also not a BLACK MODEL. The suitable classification should be considered as a GRAY MODEL.

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Annex

Minutes of Meeting

MINUTES OF MEETING

ON

THE INCEPTION REPORT

FOR

THE STUDY ON

GROUNDWATER RESOURCES ASSESSMENT

IN THE RIFT VALLEY LAKES BASIN

IN

THE FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA

Addis Ababa,

February 4, 2010

Mr. Toshiyuki Matsumoto	Ato. Abera Mekonnen
Team Leader	Chief Engineer
Study Team	Ministry of Water Resources
Japan International Cooperation Agency (JICA)	Federal Democratic Republic of Ethiopia

Witnessed by

Dr. Yuji Maruo

Senior Advisor

Japan International Cooperation Agency (JICA)

In response to the official request of the Government of the Federal Democratic Republic of Ethiopia (hereinafter referred to as "the Government of Ethiopia"), the Japan International Cooperation Agency (hereinafter referred to as "JICA") dispatched the Preparatory Study Team. The Japanese side and the Ethiopian side came to an agreement on the Scope of Work (hereinafter referred to as "S/W") which was signed on July 23rd, 2009.

JICA sent to Ethiopia the JICA Study Team (hereinafter referred to as "the Team") for THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN (hereinafter referred to as "the Study"). The Team held a meeting with the officials of the Ministry of Water Resources (hereinafter referred to as "MoWR") and other authorities concerned with the Study. The list of those who attended this meeting is shown in Appendix-1.

In the course of discussions, both sides confirmed the main items described on the Inception Report (hereinafter referred to as "IC/R"). The Team will submit the Final Report on December 2011, when the Study comes to an end.

1. Explanation of Inception Report (IC/R)

The Team submitted twenty (20) copies of the IC/R to the MoWR on 25th January, 2010.

The inception report was presented by the Team to the MoWR and concerned authorities, and discussed in Addis Ababa on 25th, 26th January, 2010. In this presentation, Ato Abera Mekonnen (Chief Engineer of the MoWR) chaired the meeting.

The Team presented the basic objectives, outline and scope of the study proposed in the IC/R, including the technical transfer proposed in the Study. Technical discussions were conducted between the Team and the MoWR, Geological Survey of Ethiopia (hereinafter referred to as "GSE") and concerned authorities on each of the study items, surveys and data required for the Study.

The Ethiopian side agreed on the contents of the IC/R in principle, understood the study objectives, schedule, activities and methodology, and promised close cooperation with the Team during the Study.

Major issues and the contents regarding the IC/R are as follows.

1) Designation of Counterpart (hereinafter referred to as "C/P") personnel

The C/P personnel were confirmed by the Ethiopian and JICA sides in the S/W that was signed on July 23rd, 2009. The candidates of the C/P personnel will be,

1. EWTEC: Ato Tamiru Fekadu, Ato Mulgeta Kenfu and Ato Shumet Kebede,

2. GSE: To be filled in the name of C/P personnel after confirmation,

3. Addis Ababa University (hereinafter referred to as "AAU") To be filled in the name of C/P personnel after confirmation,

4. Oromia Water Bureau: To be filled in the name of C/P personnel after confirmation,

5. Southern Nations, Nationalities and People (hereinafter referred to as "SNNP") Water Bureau: To be filled in the name of C/P personnel after confirmation, and

6. MoWR: To be filled in the name of C/P personnel after confirmation

All C/P personnel shall closely cooperate with the Team for the smooth implementation of the Study. The Team strongly requested that the MoWR and Ethiopia Groundwater Resources Assessment Program (hereinafter referred to as "EGRAP"), which is the Implementing Agency of the Study, should select the above permanent C/P personnel and keep the assignment and budget for their activities. The Ethiopian side agreed to select the above personnel.

2) Participation of the members of Oromia and SNNP Regions for the C/P of the Study

The Team emphasized that it was very important to involve the members of Water Bureau of Oromia and SNNP regions. Because, water supply plans for both of these regions were included as one of the aims of this Study. The Team requested that the Water Bureau members of the above two regions provide with pertinent data of the study area and they join the Team during the course of the survey. The Team explained that the technology transfer for the water supply plan was carried out targeting the C/P of the two regions. The Ethiopian side agreed that the Water Bureau members of Oromia and SNNP regions participated as the C/P of the Study.

3) Collection of existing data

The Team requested that the MoWR should cooperate on the collection of existing data for the Study with Team through the participation of the C/P personnel, including the Water Bureau members of Oromia and SNNP regions. The Ethiopian side agreed to facilitate data collection.

4) Selection of small towns for the water supply

The Team explained that the number of small towns in the study area will be narrowed down for priority projects from 80 towns proposed by the Oromia and SNNP regions to the appropriate numbers of small towns of which population is less than about 10,000, based on the criteria in the IC/R. Therefore, the Team requested that the Water Bureau of Oromia and SNNP regions submit accurate data of the target small towns. The Ethiopian side promised

Addis Ababa Ethiopia

Japan International Cooperation Agency

to submit reliable data of target small towns of Oromia and SNNP regions to the Team.

5) Utilization of equipment and drilling machinery of EWTEC

The Team request to borrow and use geophysical equipment and drilling machine with operator from EWTEC during the study in consideration of the term of training in EWTEC. The Ethiopian side agreed to render EWTEC's equipment and machinery.

2. Undertakings by the Government of Ethiopia

The Government of Ethiopia shall accord privileges, exemptions and other benefits to the Team in accordance with the Agreement on Technical Cooperation between the Government of Japan and the Government of Ethiopia, signed on July 23, 2009.

3. Other relevant issues

1) Joint Steering Committee (JSC)

- Members of JSC are as follows:

(1) The Chairperson: Chief Engineer of the MoWR.

(2) Permanent members

- EGRAP+, MoWR
- EWTEC, MoWR
- Water Resources Development Fund (WRDF), MoWR
- GSE
- AAU
- WRDB of Oromia Region
- WRDB of SNNP Region
- JICA Ethiopia Office
- The Team
- Others as necessary (EWTEC Japanese experts)

JSC meeting is to be held as follows:

- Schedule of meeting

The JSC will convene around the time of each report submission

2) Official language for the Study

Both sides agreed that English is the principal language for the Study documents, including the M/M.

3) Outline of study schedule:

The outline of study schedule is as follows:

Fisical Year	2009				2010												2011								
Cal. Month	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Report		▲ IC/R							▲ P/R(1)						▲ P/R(2)				▲ IT/R				▲ DF/R		▲ F/R
JSC		1							2						3				4				5		

Note: IC/R: Inception report IT/R: Interim Report P/R: Progress report
DF/R: Draft Final Report F/R: Final report

4) Dissemination of information and know-how transfer

Both sides agreed that the major aim of the Study also includes sharing of results and techniques or various surveys where technical transfer to the related Ethiopian authorities constitutes important means of mutual sharing.

END

ATTENDANCE LIST

ETHIOPIAN SIDE

Ministry of Water Resources (MoWR)

Ato Abera Mekonnen
Ato Tsegaye Telila
Ato Zebene Lakew

Ethiopia Groundwater Resources Assessment Program (EGRAP+)

Ato Tesfaye Tadese
Ato Zenaw Tessema

EWTEC

Mr. Masahiko Ikemoto
Mr. Hiroshi Takashima

GSE

Dr. Tesfaye Demissie
Ato Demis Alamirew

JAPANESE SIDE

JICA Study Team

Mr. Toshiyuki Matsumoto	Team Leader of Study Team
Mr. Hisayuki Ukishima	Hydrogeologist 1
Mr. Kensuke Ichikawa	Hydrogeologist 2
Mr. Ryohei Matsumoto	Coordinator

JICA Official Mission

Dr. Yuji Maruo	Leader of Official Mission

List of Counterparts (draft)

Study Team		C/P	
Expertise	Name	Name	Position
Team Leader/Groundwater development plan	Toshiyuki MATSUMOTO	1.Ato Tesfay Tadese 2.Ato Zenaw Tessema	EGRAP+ EGRAP+
Hydrogeology 1	Hisayuki UKISHIMA	1. Ato Shumet Kebede	EWTEC
Hydrogeology 2/Water quality	Kensuke ICHIKAWA	2. Ato Tamiru Fekadu 3. 2 persons 4. 1 person	EWTEC GSE AAU
Volcanic geology	Toshiaki HOSODA	1. 1 person 2. 1 person	GSE AAU
GIS database	Yoshimizu GONAI	1.Ato Shumet kebede 2. Ato Tamiru Fekadu	EWTEC EWTEC
Geophysical survey	Nobuo KIMURA	1.Ato Shumet kebede 2. Ato Tamiru Fekadu	EWTEC EWTEC
Well Drilling/Hydrology	Naoki YASUDA	1. Ato Mulgeta Kenfu	EWTEC
Water supply	Hiroshi TAKASHIMA	1. 1 person 2. 1 person 3. 1 person	WRDB of Oromia WRDB of SNNP EWTEC
Socio-economic survey	Masaru OBARA	1. 1 person 2. 1 person	WRDB of Oromia WRDB of SNNP

KOKUSAI KOGYO CO., LTD. Addis Ababa, Ethiopia

Japan International Cooperation Agency 2

The Federal Democratic Republic of Ethiopia Ministry of Water Resources

MINUTES OF MEETING

ON

THE 1ST STEERING COMMITTEE

FOR

THE STUDY ON

GROUNDWATER RESOURCES ASSESSMENT

IN THE RIFT VALLEY LAKES BASIN

IN

THE FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA

Addis Ababa,
August 27, 2

Mr. Toshiyuki Matsumoto
Team Leader
Study Team
Japan International Cooperation Agency (JICA)

Ato. Abera Mekonnen
Chief Engineer
Ministry of Water Resources
Federal Democratic Republic of Ethiopia

Witnessed by
Ato. Tesfaye Tadese
Groundwater Study Development & Management Directorate Director
Ministry of Water Resources & National Coordinator/EGRAP
Federal Democratic Republic of Ethiopia

In response to the official request of the Government of the Federal Democratic Republic of Ethiopia, the Japan International Cooperation Agency (hereinafter referred to as "JICA") dispatched the Study Team ("the Team") for THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN based on the agreement on the Scope of Work ("S/W") which was signed on July 23rd, 2009.

The Ministry of Water Resources ("MoWR") held the first Steering Committee ("SC") meeting with the Team and Counterpart Personnel ("C/P") for the discussion of contents of Progress Report (1) submitted from the Team. The list of the participants is shown in the Annex.

1. Explanation of Progress Report (1) (P/R(1))

The Team explained the contents of P/R (1) using the documents summarized the important points of P/R (1) in the steering committee meeting chaired by Ato Abera Mekonnen on 3rd August, 2010. And also the Team submitted the P/R (1) printed to the SC members on 9th August, 2010.

The Team presented the basic objectives, outline and scope of the Study, and the results of survey, in particular geology, hydrogeology, geophysical survey, observation well drilling and survey of small town water usage explained in the P/R (1), including the role of SC proposed in the presentation. Technical discussions were conducted on each of the study items, and the results of survey.

The Ethiopian side agreed on the contents of the P/R (1) in principle, in particular, methodology of the Study, the Study results and activities.

Major issues and the contents regarding the P/R (1) in SC meeting are as follows:

1) Size of the study area

The participants mentioned that the Study area is too wide to draw over all hydrogeological pictures within the limited time frame. It is recommended compromise in the scope shall be considered. The Team said that it was mentioned in the project scope in IC/R explanation. To achieve the project goal, it is necessary to narrow down the target strategically such as focusing particular items of the Study.

2) Groundwater contour

The committee pointed out that the groundwater contour map explained in the presentation shall not be presenting the true distribution and level as the water level varies from a borehole to the other. Therefore, if aquifer status (such as confined or unconfined, or the aquifer formation) is not fully understood, it may give misinformation. The Team replies that the contour map was presented just for the general information, and the said point is fair. The Team mentioned the groundwater level distribution and/or partial groundwater level map will be figured out instead of the water level contour of whole Study area.

3) Precondition of drilling site selection

There are thousands of boreholes drilled in the area, and the intention of JICA boreholes in terms of its main purpose and particular difference with other borehole was questioned by C/P. The Team replied that the drilling location is considered to understand stratigraphical distribution of geology and cross sectional settings of the basins. Not only of the geological consideration, but also detailed aquifer interpretation and chemical, isotopic analysis will be made. It is obvious that the geophysical logging, water level measurement and other detail chemical approaches are noted to differ from the wells drilled in the conventional wells.

4) Water quality testing

The advantage and outcome of the water quality testing in order to achieve the results to characterize the Study area was also questioned. The Team answered that 93 sampling will be made, each sampling points are defined independently by basins, type of aquifer and source type. The water quality test and isotopic analysis will be made to grasp some tendency between those aquifers (formations) and water chemical composition, and its origin.

5) Continuation of detailed geological survey

The participants mentioned that they are concerned for continuing geological survey at southern area of RVLB in same scale because the study period is only around 3 month in the Study of second year. The Team answered that they may not spend much time in southern region; detailed geological maps made by EGS are available in that area and the survey will be conducted for confirmation and correlation of those maps with stratigraphy established in northern area by the Study.

6) Reviewing of existing geological map and data

The participants commented that it is better to compile and review existing data before the conducting of geological investigation. The Team answered that all the existing map of RVLB was well reviewed by Halcrow (2008) report. However after the Team reviewed this report, the Team believes that detailed stratigraphical investigation is necessary with special attention to the lithology and distribution of welded tuffs which might be deeply related to the aquifers.

7) Reviewing of geothermal exploitation data

The participant advised that there are some detailed studies for geothermal exploitation, and it is better to take into consideration for geological investigation. (Remark: The Team collected the geothermal exploitation report of Mt. Aluto, Corbetti and Dugna and the Team reflected those reports to the Study).

8) Interpretation of satellite imagery

The participant mentioned that the interpretation of faults and structures from satellite imagery give helps to the investigation. The Team answered that satellite imagery interpretation well be conducted in the Study of second year.

9) Dating of stratigraphic units

The participant advised that it is better to conduct dating of classified stratigraphic units to verify the position, correlation and relationship. The Team answered that it will be considered.

10) Volcano-geological point of view

The participant commented that the volcano-geological point of view is indispensable; volcanic center and distribution must be discussed for each pyroclastic unit. The Team agreed this opinion and will be discussed in the Study of second year.

11) Geological sections

The participant commented that the geological section is necessary to understand stratigraphy. The Team answered that the geological sections will be made in the Study of second year Study with consideration of drilling data.

After distribution of copies of P/R (1), the Team received the SC member's comments regarding the P/R (1), such as the general comments for the selection of small town, technical comments for the geology, hydrogeology, geophysical survey and the results of observation well drilling. Those items which were able to modify would be amended in the P/R (1) by the Team and the other items will be reflected in the Study of second year by the Team.

Finally, the Team submitted eighteen (18) copies of the P/R (1) to the MoWR on 27th August, 2010.

2. Other relevant issues

1) Steering Committee and responsibility and involvement of C/P

Although the Team explained the role of SC in the IC/R meeting, one of SC members who was absent from IC/R meeting questioned as SC and C/P side clarified the TOR of the committee. The participants suggested that the Team should be clarified in terms of person's commitment and duties. And the participants side also required explaining more about the involvement and duties as counterpart. Although it was already stated in the scope of the Project, the Team and MoWR (or EGRAP) agreed to submit certain activity and their involvement which shall be made by C/P.

END

Annex

ATTENDANCE LIST

ETHIOPIAN SIDE

Ministry of Water Resources (MoWR)

Ato Abera Mekonnen (Chairman)

Ato Zebene Lakew

Ethiopia Groundwater Resources Assessment Program (EGRAP+)

Ato Tesfaye Tadese

EWTEC

Ato Tamiru Fekadu

Ato Mulugeta Kiufu (Absence of meeting, but sending the comments about P/R (1))

GSE

Ato Muhuddin Abdela

Ato Sileshi Mamo

AAU

Prof. Dr. Gezahegn Yirgu

Prof. Dr. Tenalem Ayenew

WRDF

Ms. Ghrmawit Haile

SNNPRS

Ato Taddele Mugero (Absence of meeting, but sending the comments about P/R (1))

Oromia Rigion

Ato Debebe Muleta (in stead of Ato Samuel Tolessa)

JAPANESE SIDE

JICA Study Team

Mr. Toshiyuki Matsumoto	Team Leader of Study Team
Mr. Kensuke Ichikawa	Hydrogeologist 2
Mr. Toshiaki Hosoda	Volcanic geology
Mr. Hiroshi Takashima	Water supply plan
Ato Getachew Geletu	Adviser of project

MINUTES OF MEETING
ON
THE 2nd STEERING COMMITTEE
FOR
THE STUDY ON
GROUNDWATER RESOURCES ASSESSMENT
IN THE RIFT VALLEY LAKES BASIN
IN
THE FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA

Addis Ababa,
February 28, 2011

Mr. Toshiyuki Matsumoto	Ato. Abera Mekonnen
Team Leader	Chief Engineer
Study Team	Ministry of Water and Energy
Japan International Cooperation Agency (JICA)	Federal Democratic Republic of Ethiopia

Tesfaye Tadesse
Director, Groundwater Study
Development & Management Directorate

Witnessed by
Ato. Tesfaye Tadese
Groundwater Study Development & Management Directorate Director
Ministry of Water and Energy & National Coordinator/EGRAP
Federal Democratic Republic of Ethiopia

In response to the official request of the Government of the Federal Democratic Republic of Ethiopia, the Japan International Cooperation Agency (hereinafter referred to as "JICA") dispatched the Study Team ("the Team") for THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN ("the Study") based on the agreement on the Scope of Work ("S/W") which was signed on July 23rd, 2009.

Stakeholders of the Project gathered at the Ministry of Water Resources (name was changed to the Ministry of Water and Energy in October 2010 "MoWE") and held the series of discussion on the contents of Progress Report (2) ("P/R (2)") and the direction of the Project in the second Steering Committee ("SC") meeting. The list of the participants is shown in the Annex together with the Counterpart ("C/P") Meeting held on the same day.

The Counterpart Meeting was held on the same day prior to SC, and the contents of P/R (2) was explained and discussed between the Team members and the C/P.

1. COUNTERPART MEETING

2.1 Explanation of P/R(2)

The Team handed over the Draft of P/R (2) about 10 days prior to the Meeting, and the Team presented the progress of the Study after the P/R (1) focusing on the results of geology, hydrogeology, geophysical survey, observation well drilling and survey of small town water usage technical discussions were made on each of the Study items, and the results of the survey.

The Ethiopian side agreed on the contents of the P/R (2) in principle, in particular, on the methodology of the Study, the Study results and schedule after the discussion.

Major issues and the contents of the discussion regarding the P/R (2) are as follows:

2.2 Discussion on the Contents of P/R(2)

1) The stagnant condition of groundwater indicated on trilinear diagram

The participants asked for more detailed explanation on the water quality test results indicated in the tri-linear diagram. The team mentioned that the environment of groundwater is generally plotted in the area of I and II on the diagram which concludes that most of the collected water is from circulation and stagnant groundwater conditions. The C/P questioned that more detailed correlation between stagnant water condition and the aquifer shall be required. The Team said that the groundwater condition indicated in this diagram is a preliminary result to grasp the overall trend of groundwater in the study area, and correlation between independent aquifer and the environment of groundwater is not yet clarified.

2) Karstic condition of the groundwater

The C/P pointed out that the description of "Karstic Aquifer" in groundwater classification does not apply because there are no major limestone terrains in the study area. The Team replied that it is indicating the state of aquifer that is not classified under either strata aquifer or fissure aquifer. Such aquifer has a river like flow in the large and continuous conduit in a formation that may be generally called "Karstic Type Aquifer" in the Hydrogeological Map of Ethiopia published by GSE.

3) Scale of study area and relation with geological map

The C/P raised questions about the efficiency of the study when considering the amount of investigative efforts the Team is making and the number of test wells to be drilled as compared to the largeness of the study area. The Team replied that it would make the most of the existing data that are already available to achieve reliable results.

4) Well numbers in the Study

There are only 10 boreholes to be drilled in the study area, and the C/P mentioned that considering wide extent of area and the scope of the Project, it is too small number to clarify the hydrogeological features in the area. The Team replied that the drilling locations are considered to understand stratigraphical distribution of geology and cross sectional settings of the basins. Not only from the geological consideration, but also from the aspect of detailed aquifer interpretation and chemical, isotopic analysis will be made. It is very small in number but there is data from hundreds of existing boreholes available to supplement the data on aquifer distribution and its characteristics. The C/P side strongly emphasized the need for additional wells as required especially for deeper levels.

5) Butajila – Shalla, correlation of Geology

The C/P suggested that it would be better if the Team started the geological survey from Butajira area to move on to adjacent Shalla area but to start from Awassa area. The study team replied that that it was easier to start from Awassa area because a lot of information was available in that area and thus, it was suitable to establish the standard geological stratigraphy. The survey will continue to cover Butajira area.

6) Groundwater level fluctuation

The C/P asked if the monitoring results of the groundwater levels were not responding to the precipitation, what it was related to and asked if it could be related to lake water levels. The Team answered that the Team meant to explain that there was no direct or immediate response in the groundwater level to precipitation but the water level should show a delayed response to precipitation in the long run.

7) Iron content of water quality test result

The C/P mentioned that laboratory test result seemed too low at the particular site where the well was abandoned due to high iron contents. The site water quality shall be referred to and cross-checked with the laboratory water quality test. The Team replied that the laboratory water quality test was cross-checked with site tests. However the accuracy of the detection of parameter is very different and the laboratory tests are conducted based on the quality test standard applied in this country. Therefore, unless the data of the site and laboratory have big differences, the laboratory figure shall be considered as the true value.

8) Time of continuous pumping test.

The C/P commented that the duration of pumping test, 24 hours, was not enough and therefore should be revised. The Team answered that the duration was reasonable because it was long enough to stabilize the water level in a borehole and, thus, could calculate hydrogeological parameters, which is the major purpose of the pumping test. The C/P further questioned the capacity of the installed pumps and questioned that the fact that the water level has stabilized did not mean that the pumping duration was enough when we are using an inappropriate pump capacity, the type of pump used for the pumping test suggested 72 hrs. pumping for example. The Team repeated that the major purpose of the pumping test was to evaluate hydrological parameters and that could be done by the 24-hour pumping test.

9) Age dating of volcanic rocks

The C/P questioned about dating (chronology) of rock samples. The Team answered that the samples from two horizons of the welded tuff (Green strongly welded tuff and highly welded tuff characterized by the flattened obsidian) in the stratigraphic classification were taken in ten areas and already sent to Japan for the laboratory analysis of K-Ar dating method.

10) The relation between drilling depth and Fluoride concentration

The C/P questioned about the relation of fluoride concentration and well depths. The Team replied that the water samples have been taken every 5 meter in current drilling operation when drilled by DTH. The relation shall be further investigated after the data is collected.

11) Survey at the southern end of the study area

The C/P raised concern about the method of study of the southern area that had not been discussed yet. The Team replied that it had be in principle agreed on at the beginning of the study and the Team would depend only on the existing data since the area was off limit for the members.

12) The hand-drawn geological maps

The C/P mentioned that since PR(1), the geological maps are still drawn by hand (not digitized). For the future, it should be made as a form of electric file for GIS and other purposes. The Team answered that it would digitize the borders of delineation of the formation and faults as soon as the further confirmation of geological map was made.

Finally the Team received the question and comment letters from C/P during/after the meeting. The contents of those letters will be considered in the next Interim Report.

2. STEERING COMMITTEE

After distribution of copies of P/R (2), the Team received the C/P's comments regarding the P/R (2), such as the general comments for the selection of small town, technical comments for the geology, hydrogeology, geophysical survey and the results of observation well drilling. Those items which can modify would be amended in the P/R (2) by the Team and the other items will be considered in the Study of the second half of the second year by the Team.

Finally, the Team promised to submit eighteen (18) copies of the P/R (2) to the MoWE by 4th March, 2011.

The Team first explained the purpose of the committee and afterwards responded to the participants that the team will make efforts to consider the suggestions raised to improve the study.

The committee members commented that in consideration of the vastness of the study area and also the importance of this study in clarifying the hydrogeological conditions of the study area, the number of test well drilling sites and other relevant specifications are not sufficient to achieve the purpose and proposed the following ideas for improvement.

- Increase the number of test wells to 30
- Deeper target depths of the test wells
- Locate some wells in the southern part of the study area.
- Change specifications of boreholes to accommodate larger capacity pumps for pumping test.

They added that budget should be increased to realize the above changes and if necessary the schedule of the study should be revised (extended) to accommodate the changes.
The Team responded that the objectives of this survey are to 1) clarify groundwater potential of the study area, 2) create hydrological maps and cross sections of the study area, and 3) draw up a water supply plans for small towns in the study area and that these objectives could be achieved by employing the existing but not effectively utilized data in addition to the test well drilling work of current specifications. The Team added that balancing the input and outcome is important and that changing study specifications and schedule is difficult since they were agreed upon at the beginning of the project, although the Team will make maximum effort to improve better results of the Study.
The committee members proposed to set aside the budged issues that may result from changes in specifications, and suggested that participants will discuss how they can improve the quality of the study from only the technical aspects.

The committee members requested that at the end of the Study, recommendations should be made with regard to water quality issues as part of the results of groundwater potential evaluation, for example Fluoride contents. The Team answered that the Team are working to obtain some new scientific findings of the generation of fluoride in groundwater but can not promise if the Team will get any and that on the other hand, as for the health related recommendations, the Team will make appropriate suggestions since the groundwater potential should be evaluated in both quantity and quality.

The committee members suggested that the produced hydrogeologial maps (geological maps) were fragmented and thus they should be combined to produce a single map. The Team replied that it would produce a single map for the study area.

The Team commented that there were always limitations in any projects and the projects had to be conducted within those limitations to achieve the objectives and that this had to be understood. The Team added that the Team had compiled a small hydrological database by integrating all the existing data and some newly discovered data that had never been utilized. The committee members replied that such work done by the Team was very good and appreciated.

The Team explained the schedule of the remaining part of the study.

END

ANNEX

ATTENDANCE LIST

ETHIOPIAN SIDE

Ministry of Water and Energy (MoWE)

Ato Abera Mekonnen (Chairman)

Ato Zebene Lakew

Ethiopia Groundwater Resources Assessment Program (EGRAP+)

Ato Tesfaye Tadese

EWTEC

Ato Tamiru Fekadu

Ato Mulugeta Kiufu

GSE

Ato Muhuddin Abdela

SNNPRS

Ato Meskelu Tumiso

Oromia Rigion

Ato Fekadu Levekba

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Mr. Hideki Watanabe

JICA Study Team

Mr. Toshiyuki Matsumoto	Team Leader of the Team
Mr. Kensuke Ichikawa	Hydrogeology 2
Mr. Naoki Yasuda	Drilling supervision/Hydrorology
Mr. Yousuke Yamamoto	Project coordinator
Ato Getachew Geletu	Research Adviser of project

KOKUSAI KOGYO CO., LTD. Addis Ababa, Ethiopia

MINUTES OF MEETING

ON

THE 3rd STEERING COMMITTEE

FOR

THE STUDY ON

GROUNDWATER RESOURCES ASSESSMENT

IN THE RIFT VALLEY LAKES BASIN

IN

THE FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA

Addis Ababa,
July 6, 2011

KOKUSAI KOGYO CO., LTD. Addis Ababa, Ethiopia

Mr. Toshiyuki Matsumoto	Ato. Abera Mekonnen
Team Leader	Chief Engineer
Study Team	Ministry of Water and Energy
Japan International Cooperation Agency (JICA)	Federal Democratic Republic of Ethiopia

Tesfaye Tadesse
Director, Groundwater Study
Development & Management Directorate

Witnessed by
Ato. Tesfaye Tadese
Groundwater Study Development & Management Directorate Director
Ministry of Water and Energy & National Coordinator/EGRAP
Federal Democratic Republic of Ethiopia

The Federal Democratic Republic of Ethiopia Ministry of Water & Energy

In response to the official request of the Government of the Federal Democratic Republic of Ethiopia, the Japan International Cooperation Agency (hereinafter referred to as "JICA") dispatched the Study Team ("the Team") for THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN ("the Study") based on the agreement on the Scope of Work ("S/W") which was signed on July 23rd, 2009.

Stakeholders of the Project gathered at the Ministry of Water Resources (name was changed to the Ministry of Water and Energy in October 2010 "MoWE") and held the series of discussion on the contents of Interim ("IT/R") and the direction of the Project in the second Steering Committee ("SC") meeting. The list of the participants is shown in the Annex together with the Counterpart ("C/P") Meeting held on the same day.

The Counterpart Meeting was held on the same day prior to SC, and the contents of IT/R was explained and discussed between the Team members and the C/P.

1. COUNTERPART MEETING

2.1 Explanation of IT/R

The Team handed over the Draft of IT/R about 5 days prior to the Meeting, and the Team presented the progress of the Study after the P/R (2) focusing on the results of geology, hydrogeology, groundwater modeling, observation well drilling and survey of small town and water supply plan usage technical discussions were made on each of the Study items, and the results of the survey.

The Ethiopian side agreed on the contents of the IT/R in principle, in particular, on the methodology of the Study, the Study results and schedule after the discussion.

Major issues and the contents of the discussion regarding the IT/R are as follows:

2.2 Discussion on the Contents of IT/R

(1) Groundwater modeling

The C/P pointed out that the lakes should have outflows as well as inflows and that the exchange of water in this manner does not seem to be considered in the modeling. The C/P also asked a question about the groundwater modeling why the groundwater amount was calculated by multiplying by BFI.

The study team answered as follows: In progress report 2, the modeling was conducted for the whole Abalya Lake basin that is hydrologically a closed system. Thus, there are no inflows or outflow into/from the basin as rivers or groundwater. Thus almost all water is exchanged through the lake surface. In such case, groundwater recharge is equal to the

Hay 1

flow component. For the other basins for the modeling (Ziway-Shalla sub basin), they were combined with other lakes to form closed basins so the same method can be applied.

The C/P pointed out that the rivers should not necessarily be defined as constant head boundaries and asked what the reason is for applying constant head boundary conditions for the rivers in the model.

The study team replied as follows: the constant head boundary conditions applied to the rivers function in principle the same way as river boundary package. The groundwater can flow into the river based on the head of surrounding cells. Therefore there is no need to employ river boundary package.

The C/P suggested that the modeling should include water budget.

The study team replied that it is simply a matter of running the water budget package and that can be done any time.

The C/P asked if the study team has any plan to do the groundwater modeling for the area (southern most part of the study area) that is not covered in this study.

The study team answered as follows: The study area is very large and difficult to study thoroughly and the southern most part of the study area that is not covered by the groundwater modeling has very little data and the terrain is generally covered by hard bedrocks. Thus it is not worth running a groundwater model for the area.

The C/P asked if the study team obtained enough data of hydrogeological parameters for the modeling.

The study team replied as follows: It is a very serious issue in establishing groundwater models for the study area. There is not much data of actual hydrogeological parameters available for the study area. Thus, in this study, representative values of these parameters were applied to specific lithological facies of hdrogeological layers. There are around 10 different hydrogeological layers that were recognized. Even these values are however, adjusted to some reasonable extent during the model calibration. The data needs to be updated in the models as new sets of data are made available.

The C/P asked if any changes to the groundwater model will be made when the data from the existing some 1000 wells are obtained.

The study team replied as follows: The model will be definitely updated when such data is available. Although all available data was used in the model, the current model is far from perfect. Therefore, we need to improve the accuracy of the model by adding new data as such data becomes available. Then, the model will be calibrated again with the data obtained.

The C/P pointed out that the following: The groundwater recharge is affected by the conditions on the ground surface such as vegetation cover, degree of soil erosion, land use and also water pollution is another issue that concerns. However, such issues are not mentioned in this report.

The study team replied as follows: the amount of groundwater is considered for the entire study area that is hydrologically a closed system. It is based on the assumption that the incoming amount and outgoing amount from the basin is balanced over a long period of time. Thus, such changes as the land surface conditions will be buffered in the calculation process even if integrated in the model. In addition, determining the details of such conditions that may affect recharge in detail will take tremendous time and effort and thus, is not realistic.

(2) Groundwater level observation

The C/P asked if it is appropriate to determine that the groundwater levels at the observation wells show annual fluctuation pattern when the monitoring was just started.

The study team answered as follows: it is true that the monitoring was just started last year in this project but at three sites, nearly one year period of data was already collected and all of them show clear signs of annual fluctuation patter (annual cycle). Since it is common for a confined aquifer to show such delayed response to precipitation, the observed fluctuation is considered to be the annual cycle. This has to be however, confirmed though further monitoring activity by the CP side.

(3) Groundwater resources in general

The C/P asked if there is any indication of the amount of groundwater resources in this study.

The study team replied that the total available groundwater resources amount for the entire study area was discussed and mentioned in the Interim Report

(4) Project implementation method

The C/P asked if the project of small town water supply would be financed by grant aid or loan scheme.

The study team replied that it would be financed by some grant aid.

The C/P asked how the study team intended to improve the capacity of the operators of town water supply targeted for the project and asked if any proposals or suggestions would be made for those towns that had not been selected for priority project.

The study team answered that a capacity building training as a soft component would be incorporated as a part of the project and that also some kind of project proposals would be made for the remaining 54 towns.

The study team asked if Ethiopian government had its own criteria for defining small towns.

The C/P replied as follows: there is a criteria and according to the criteria, communities with more than 2500 people are small towns. Also according to the government policy, the cost of water supply project for those categorized as small towns should be at least covered by soft loans that are paid by the town's water supply operator.

The study team mentioned the following: the classification of small towns followed the one used in Amhara region water supply project by the Japan's grant aid but it will be checked again and the CP persons of both SNNPRS And Oromiya regions will be notified if there is any change.

2. STEERING COMMITTEE

As a feedback from the study, the study team made the following three recommendations about future activities in groundwater resources study and management and explained the details as well as the reasons for making these recommendations.

1. Establishment of groundwater database system (ENGWIS)
2. Future use of hydrogeological maps that are to be created in this study
3. Improvement of drilling technology of drilling companies

The SC members made the following comments on each of the recommendations.

(1) Recommendation 1 : Establishment of groundwater database system

A uniform format for data collection and description should be employed for every well drilling project in the country. At the level of drillers and woreda water offices where a computer is not always available, paper-based format should be used.

Since formats of data entry for drilling, borehole logging, and pumping test are already available under ENGWIS and these formats and its system should be more actively employed. At the same time, training on the use of ENGWIS should be given to more people at Ministry, regional and zonal levels.

Such system should be established and made official at the level of central government so that the regional and zonal offices can follow the system, data collection and record formats. Some persons in the MoWE should be leading this activity.

(2) Recommendation 2 : Use of hydrogeological maps

At least a few copies of the produced maps should be distributed to regional water offices to use.

(3) Recommendation 3 : Improvement of drilling technology of drilling companies

The government should mandate that the drillers have a qualification that is obtained through a certain period of education at designated institutions, to do the drilling work and that the companies should have such qualified drillers to start well drilling business.

There are not many institutions that can give training on drilling technology in the country but it is said that Mekele University will soon start a course on drilling technology.

Finally, the Team promised to submit eighteen (18) copies of the IT/R to the MoWE by 7th July, 2011.

The Team explained the schedule of the remaining part of the study.

END

KOKUSAI KOGYO CO., LTD. Addis Ababa, Ethiopia

The Federal Democratic Republic of Ethiopia Ministry of Water & Energy

ANNEX

ATTENDANCE LIST

ETHIOPIAN SIDE

Ministry of Water and Energy (MoWE)

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Mrs. Girmawit Haile (Director General/Water Resources Development Fund)

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Ato Tesfaye Tadese

EWTEC

Ato Mulugeta Kiufu

GSE

Ato Muhuddin Abdela

Ato Sileshi Mamo

SNNPRS

Ato Tadele Kibru

Ato Meskelu Tumiso

Oromia Rigion

Ato Fekadu Lebecha

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Ato Ephrem Fufa

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Dr. Lei Peifeng	Groundwater Modeling
Mr. Naoki Yasuda	Drilling supervision/Hydrorology
Mr. Hiroshi Takashima	Water supply plan
Mr. Yosuke Yamamoto	Project coordinator
Ato Getachew Geletu	Research Adviser of project

KOKUSAI KOGYO CO., LTD. Addis Ababa, Ethiopia

Federal Democratic Republic of Ethiopia Ministry of Water & Energy

MINUTES OF MEETING

ON

THE DRAFT FINAL REPORT

FOR

THE STUDY ON

GROUNDWATER RESOURCES ASSESSMENT

IN THE RIFT VALLEY LAKES BASIN

IN

THE FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA

Addis Ababa,
January 17, 2012

Mr. Toshiyuki Matsumoto
Team Leader
Study Team
Japan International Cooperation Agency (JICA)

Ato. Tesfaye Tadese
Groundwater Study Development & Management Directorate Director
Ministry of Water & Energy
Federal Democratic Republic of Ethiopia

Witnessed by
Dr. Yuji Maruo
Senior Advisor
Japan International Cooperation Agency (JICA)

Based on the Scope of Works agreed between the Japan International Cooperation Agency (hereinafter referred to as "JICA") and MoWE (then MoWR) on July 23rd, 2009, the JICA sent to Ethiopia the JICA Study Team (hereinafter referred to as "the Team") for THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN (hereinafter referred to as "the Study"). The Team started study in January 2010. And finally the Team prepared the Draft Final Report (hereinafter referred to as "DF/R") in January 2012.

The Team will submit the Final Report on March 2012 by airmail.

1. Explanation of DF/R

The Team submitted twenty (20) copies of the DF/R to the MoWE on 6th January, 2012.

The DF/R was presented by the Team to the MoWE and to concerned authorities, and was discussed at the time of the seminar for DF/R on 12th January 2012 in Addis Ababa and at the time of the steering committee (hereinafter referred to as "SC") on 16th January 2012 in Addis Ababa. The attendant list of the seminar and the SC are attached in Appendix-1.

Technical matters, such as geology, hydrogeology, groundwater modeling and water supply planning of the DF/R were discussed among the participants from the MoWE, Geological Survey of Ethiopia (hereinafter referred to as "GSE"), Addis Ababa University (hereinafter referred to as "AAU") and concerned authorities and the Team. The contents of discussion on DF/R in the seminar and the SC were shown in Appendix-2

The Ethiopian side accepted the contents of the DF/R in principle, understood the study results of DF/R, and confirmed the maximum utilization of the Final Report (hereinafter referred to as "F/R").

Major issue and the content regarding the DF/R are as follows:

1) The Team explained that the Ethiopian side should submit if any comments, questions and corrections on the DF/R to the Team by the 16th January 2012. The Team also explained that as the results of discussion made during the seminar and the SC, the correction and modification wherever necessary would be reflected in the F/R.

2. Recommendations from the Team

The Team made the following four recommendations on the groundwater resources study and management in Ethiopia at the time of seminar and 4th SC.

1. Establishment of groundwater database system (ENGWIS)
2. Maximum utilization of geological and hydrogeological maps produced in this study
3. Improvement of drilling capability of the drilling private sector

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4. Utilization of water supply planning of the study

Ethiopian side replied to the recommendations as follows;

Recommendation1: Due to the high cost for the server installation and maintenance, it is very difficult to upload the result of ENGWIS to share the information with the public. However the MoWE is trying harder to realize this action. The data and information is still not enough to demonstrate the result. The MoWE will try its best to provide the database to the public and update the accurate information.

Recommendation2: The MoWE will deliver all the reports and maps to the related organization as the form of hard and soft copies. The utilization of the map by their hydrogeologist and water supply engineer will definitely contribute to the development of both groundwater management and water scheme. The MoWE with the JICA mission indicated the idea of selling the geological and hydrogeological maps at the GSE and/or EMA (Ethiopian Map Agency) for the purpose of the maximum utilization of the results of the Study. The GSE replied that it is possible if the soft and hard copies of the maps and reports are made available.

Recommendation3: The poor drilling works in private sector is very serious problem and challenging matter. The MoWE plans to initiate two years diploma courses of the drilling technology in EWTEC. The Oromia TVETC has provided drilling technology training to about 20 persons graduated as information.

Recommendation4: The water supply plan of the Study is very important, so we will distribute the report to the local WASH project.

KOKUSAI KOGYO CO., LTD. Addis Ababa, Ethiopia

END

The Federal Democratic Republic of Ethiopia Ministry of Water & Energy

ATTENDANCE LIST

1. The seminar for DF/R

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Mr. Zebene Lakew	Staff of GSD&MD
Mr. Girum Admasu	Staff of GSD&MD
Mr. Dawit Tafesse	Staff of GSD&MD
Mr. Tesfaye Emiru Eshetie	National Fluorosis Mitigation Project
Mr. Tegenu Tsegaye	Permanent Groundwater Monitoring Section

EWTEC

Mr. Tamiru Fekadu	Hydrogeologist

GSE

Mr. Yohannes Belete	Head of groundwater resources assessment Department
Mr. Muhuddin Abadela	Hydrogeologist
Mr. Sileshi Mamo	Hydrogeologist
Mr. Degefe Shiferaw	Hydrogeologist

AAU

Prof. Dr. Tenalem Ayenew	Department of Earth Sciences
Dr. Seifu Kebede	Department of Earth Sciences
Mr. Adane Abebe	Department of Earth Sciences

Oromia Region

Mr. Fekadu Lebecha	Oromia Water Resource Bureau

SNNPRS

Mr. Tadele Kibru	SNNPRS Water Resource Bureau
Mr. Meskel Tumiso	SNNPRS Water Resource Bureau

Others

Mr. Abera Mekonnen	Senior consultant
Mr. Shiferaw Lilu	AG CONSULT
Mr. Asamenew Gebeyehu	World Vision
Mr. Shimels Fehadu	UNDP MDGs &Poverty reduction Deparment
Mr. Esayas Tilahun	Hydrogeologist
Mr. Moges Tigabe Asres	Hydrogeologist
Mr. Getachew Geletu	Hydrogeologist

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Mr. Hideshi Yamashita	Representative
Mr. Ephrem Fufa Leta	In-house consultant for water sector

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Mr. Kensuke Ichikawa	Hydrogeologist 2
Dr. Peifeng Lei	Groundwater Modeling
Mr. Hiroshi Takashima	Water Supply Planning

JICA Official Mission

Dr. Yuji Maruo	Leader of Official Mission
Mr. Shutaro Shiraki	Project Planning

2. The SC for DF/R

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Mr. Zebene Lakew	Staff of GSD&MD

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Mr. Kensuke Ichikawa	Hydrogeologist 2
Dr. Peifeng Lei	Groundwater Modeling
Mr. Hiroshi Takashima	Water Supply Planning

JICA Official Mission

Dr. Yuji Maruo	Leader of Official Mission
Mr. Shutaro Shiraki	Project Planning

Appendix-2

The discussion on the DF/R

1. The Seminar for DF/R

The questions, suggestions and comments from the participants and answer from JICA Study Team were as follows;

QUESTIONS AND ANSWERS ON GEOLOGY AND HYDROGEOLOGY

Q. In regard to the table 2.11 in page 2-23 of DFR, the classification in this table seems to be not correct to refer as aquifer.
A. As indicated in page 2-22, description in 2.3.3 Hydrogeology b. Aquifer of existing well, the table was aimed to point our the current problem on compilation of drilling log. We do think it is important description to note this fact to realize the current problem. However the Team decided to remove the description and Table 2.11 as requested by the chairman of the Seminar.

Q. The regulation line indicated in the figure of "Distribution of Hydrogen & Oxygen Isotope Ratio (by sub-basin)" (Figure 3.5 on page 3-19) shall be deleted if the anomaly values are included to formulate the line. And also the character of δ should be used instead of σ .
A. The team has agreed to this comment and will delete the regulation line as well as amendment of improper character used in the Figure 3.5.

Q. In regard to the relation between fluoride content and the depth (the trend of decrease of fluoride concentration by depth), it may lead to misunderstanding of proper understanding of distribution of fluoride in the rift valley lakes basin, as the drilling data in this area is almost shallow well of some 15-30m depth, and which occupies more or less 60% of the total number of the well.
A. The relation between fluoride content and the depth shall be studied more carefully for the future. However, utilizing the data available at this stage, there is tendency of decline of fluoride concentration in deeper groundwater. This shall be examined not in this report but to be further clarified by the new project highlight on fluoride concentration in the area.

In regard to the hydrogeological section, there were some other questions on the water quality (definition of stagnant condition on groundwater). These questions are individually explained by the Team and Questioner finally agreed with it.

Q. The ignimbrite is generally considered as aquiclude or impermeable basement in RVLB of

Ethiopia. However according to the geological cross sections of the Study Team, it seem like the hydrogeological impermeable basement is the Plio-Pleistocene Ryolite.

A. Basically, the startigraphy in RVLB is established based on the correlation with the strata of seven areas. Stratigraphy of seven areas in the study was correlated with respective existing articles, papers and chronology. The strata in the RVLB are divided by the lithological aspects in our study, and we correlate lithofacies of strata in outcrops with the results of drilling. During our survey, we have not recognized the ignimbrite, but welded tuff, acidic volcano-sedimentary rocks, welded pumicious pyroclastics, rhyolotic compacted tuff with pumice, rhyolite lava and tuff, white pumice and hard tuff including obsidian. Therefore we created the cross-section based on the above lithofacies.

QUESTIONS AND ANSWERS ON GROUNDWATER MODELING

Q. The precipitation has been summarized and shown in the Figure. How did you get this result?

A. Summarizing of precipitation is based on all available data (70 from local precipitation stations and 10 from WMO database), the detailed procedure of data check, modification station selection and station coverage area division were given in Interim Report, Chapter2 , Section2.

Q. What is the procedure for groundwater model recharge amount specification?

A. The model recharge amount calculation is conducted by using all available data for water resources balance analyzing in each model basin. The base data and detailed analyzing procedure are given in Progress Report (2), Chaper7, Section4 (Billate model) and Interim Report, Chapter5, Section3 (Ziway model), Section4 (Eastern Abaya Lake Model) and Section5 (Western Abaya Lake model).

Q. What is the aquifer type specification for different layer?

A. For all the 4 Models the top layer is specified as unconfined aquifer and all below layers are specified as confined aquifer. The description of models layer specification is given in Progress Report (2), Chaper7, Section5 (Billate model) and Inter Report, Chapter5, Section3 (Ziway model), Section4 (Eastern Abaya Lake Model) and Section5 (Western Abaya Lake model).

Q. How mach is the groundwater development potential for each basin?

A. Groundwater development potential is affected by many factors such as recharge amount, aquifer type, hydrological conductivities, topography, location of groundwater use, and so on. It's not easy to collect high precision data for all those parameters. On the other hand, when considering the water balance in a lake basin, the groundwater recharge amount can be calculated by water resources balance analysis. And the groundwater recharge amount is generally considered as the limitation of groundwater development potential. The groundwater recharge amount for each sub-basin in the Study area have been calculated and given in Interim Report, Chapter2, Section2 and Draft Final Report, Chapter3, Section3.

Q. What is the amount of storage in the Study Area?

A. The meaning of word "storage" can be taken by different ways.

a. Existing amount in aquifer. It is not a constant value, but mainly depends on parameters of porosity and depth.
b. The parameter in groundwater simulation model. That is a parameter of water volume compressibility with very small value.
c. What is the amount of the available groundwater for usage?

The answer for this concept is the same as the answer for groundwater development potential.

QUESTIONS AND ANSWERS ON WATER SUPPLY PLANNING

Q. The selected numbers and the small towns for priority are different between the Interim Report and the DF/R. The SNNPRs had already submitted the application of the priority small towns in accordance with the Interim Report for the Japanese Grant Project to Japanese Government.

A. The priority small towns on the Interim Report such as "Priority project towns" were selected during the hydrogeological study stage. On the Draft Final Report, these towns were revised by the result of hydrogeological study and which were prioritized.

The previous application document will remain to be valid.

2. The SC for DF/R

The questions and answers (Q&A) at the seminar for DF/R were compiled after the meeting as attached The Seminar for DF/R of Appendix 2. The records of this Q&A were further discussed with the C/P for the clarification of contents. This Q&A was also explained by the Team for further clarification. The contents of comments are compiled as follows;

1. In regard to the figure of isotope distribution, the regulation line will be deleted and the regulation line of Ethiopia will be added to the figure. The minor correction of characters will also be made.
2. It was requested to revise the legends and tables in the report, as its character is too small for reading. The Team replied to do so at some of the legends and tables in the report.
3. C/P asked the level of confidence about the hydrogeological survey results. The Team replied that they have confidence about what we done until today, but the survey results should be

updated by the C/P for the future.

4. C/P requested the list of reference and data should be attached to the Report. While the data is already indicated into Supporting Report and Data Book. The references shall be attached to the end of the main report.
5. The title of the Report. It was commented that the word of "Assessment" and "The Federal Democratic of Ethiopia" shall be deleted as it is indicated and known by the C/P. The Team replied that it is not possible as it is fixed officially as the title of the Project.
6. C/P asked the groundwater development potential for each basin has been calculated by water balance, and also how should it be considered about the 4m increasing of water level of Awasa Lake? The Team answered that as the standard method for hydrological analysis, the data used for the analysis should cover duration more than the hydrological circle. And then the average value for all kinds of data can be used for the analysis without large error. For Awassa Lake the main evaporation data used for water balance analysis covers 25 years from 1986 to 2010 about 2.5 times longer than the hydrological circle. Therefore, when conducting the hydrological analysis, lake's water level is set with average value. On the other hand, corresponding to the duration of evaporation data, the yearly water level change in Awassa lake is maximum 3.24m (1998), minimum 1.42 (1992) with difference of 1.83m. Even though the water level change is much smaller than 4 m but a lake water level increasing tendency can be found. And then the yearly water level increasing tendency can be calculated as 42mm/year by a linear regression equation. Comparing to the lakes evaporation amount of 1963mm/year, the lake's water level increasing value is less than 2%. Using the value of BFI 0.45 for Awasa Lake, the effect of water level change for groundwater recharge summarized in DFR report can be considered as less than 1%.
7. C/P questioned on the water potential in general in the study area; Abundant or scarce? The team mentioned that the potential differs by area in accordance with the hydrogeological map.
8. C/P mentioned that it is better to say the name of the reports instead of persons name such as "Dr Tenalem". The Team agreed on this issue.
9. C/P requested to mention on the particular area for the high potential aquifer. The Team replied to make additional descriptions in the Report of Cha 3.4 of the report about the high potential aquifer where identified during the Study.

KOKUSAI KOGYO Addis Ababa, Ethiopia CO., LTD.

The Federal Democratic Republic of Ethiopia Ministry of Water & Energy

END