Groundwater Flow and Solute Transport Modeling

Groundwater

Groundwater Flow and Solute Transport Modeling

Aims & Objectives

In this chapter, the methods of modeling the groundwater flow and solute transport will be studied.

Although there are various types of models, the concept and fundamental principles of numerical models and modeling will be discussed.

An overview of representative groundwater flow and solute transport models is to be introduced.

Contents

4

1. Type of Models

Why Modeling Ground Water Flow And Contaminant?

- To make predictions about a ground-water system’s response to a stress
- To make predictions about contaminant concentration
- To figure out the impacts of contamination activity or contaminant source
- To understand the System of flow and transport
- To design field studies
- To design remediation plan
- Use as a thinking tool

Those Of Groundwater Hydrology Work Are All Modeling

Model is a representation of a system.

Conceptualization of a hydrologic system, Application of equations (for example, Darcy's equation, Theis solution, analytical solutions for groundwater flow and solute transport)
to a simple problem, Laboratory test simulating flow and transport, Numerical simulation to a complex problem.

Types Of Models

conceptual model qualitative description of system
"a cartoon of the system in your mind"

mathematical model mathematical description of system
simple – analytical (provides a continuous solution over the model domain)
complex – numerical (provides a discrete solution – i.e. values are calculated at only a few points)

graphical model
e.g. flow nets, limited to steady state, homogeneous systems, with simple boundary conditions

analog model
e.g. electrical current flow through a circuit board with resistors to represent hydraulic conductivity and capacitors to represent storage coefficient

physical model
e.g. sand tank which poses scaling problems, for example the grains of a scaled down sand tank model are on the order of the size of a house in the system being simulated

Types of Models

- Predictive
  - Used to make predictions based on hypothetical future scenarios
- Interpretive
  - Used to gain a better understanding of an aquifer
- Generic
  - Based on a simple classical case, rather than on a real system. Used for academic purposes.

2. Numerical Models

Model Dimensions

- 2D areal models
- 2D profile models
- Quasi – 3D models
- Full 3D models

Selection of Numerical Model

- Does the code model all of the processes in the conceptual model?
- Use the simplest code possible in light of conceptual model and the purpose of the modeling study

Groundwater Flow and Solute Transport Numerical Models (1)

Model	Description
FEHM	Three-dimensional, time-dependent, multiphase, multicomponent,nonisothermal, reactive flow through porous and fractured media.
FEFLOW	Three-dimensional flow and transport code for saturated and unsaturated zones with capabilities for heat transport as well. Variable fluid density due to temperature or (salt) concentration effects also can be considered.
FEMWATER, FEMWASTE	Finite element flow (FEMWATER) and transport (FEMWASTE) models. FEMWATER can simulate variably saturated conditions in two and three dimensions. FEMWASTE can simulate transport in one, two, and three dimensions.
FRAC3DVS	Three-dimensional model for simulating steady-state or transient, variably saturated groundwater flow and advective–dispersive solute transport in porous or discretely fractured porous media.
Groundwater Modeling System (GMS)	Graphical user interface (GUI)-based software that combines applications in three-dimensional groundwater flow and contaminant transport modeling.

Groundwater Flow and Solute Transport Numerical Models (2)

Model	Description
HGS	Three-dimensional finite element simulator for modeling flow and transport of the portion of the hydrologic cycle.
HST3D	Program for simulating groundwater flow and associated heat and solute transport in three dimensions.
MODFLOW	Block centered finite difference code for steady-state and transient simulation of groundwater flow in two and three dimensions.
MODFLOW-SURFAC	Code based on the USGS MODFLOW code with flow and transport modeling capabilities for both the saturated and unsaturated zones.
MT3DMS	A new version of MT3D that has a comprehensive set of options and capabilities for simulating advection, dispersion/diffusion, and chemical reactions of contaminants in groundwater flow systems under general hydrogeological conditions.
RT3D	Simulates multispecies transport and reactions, including attenuation of chlorinated compounds, reaction packages for aerobic, instantaneous BTEX reactions, and multiple-electron-acceptor, kinetically limited BTEX reactions.

Groundwater Flow and Solute Transport Numerical Models (1)

Model	Description
SEAM3D	Reactive transport model used to simulate complex biodegradation problems involving multiple substrates and multiple electron acceptors. The code is based on MT3DMS.
SUTRA	Code for simulating two-dimensional fluid movement and transport of energy or dissolved substances.
SWMS_2D	Two-dimensional model for simulating water and solute movement in variably saturated media.
TMVOC	Numerical simulator for three-phase nonisothermal flow of water, soil gas, and a multicomponent mixture of volatile organic chemicals (VOCs) in multidimensional
UTCHEM	A program for modeling transient and steady-state three-dimensional flow and mass transport in the groundwater (saturated) and vadose (unsaturated) zones of aquifers.

15

3. Modeling of Groundwater Flow Systems

Governing Equation for Groundwater Flow

$$k_x \frac{\partial^2 h}{\partial x^2} + k_y \frac{\partial^2 h}{\partial y^2} + k_z \frac{\partial^2 h}{\partial z^2} = S_s \frac{\partial h}{\partial t}$$

This is sometimes called the "diffusion equation".

Note that now we have an expression relating head (h) to position (x, y, z) and time (t)

Governing Equation with Recharge/Discharge Source Term

$$k_x \frac{\partial^2 h}{\partial x^2} + k_y \frac{\partial^2 h}{\partial y^2} + k_z \frac{\partial^2 h}{\partial z^2} + R = S_s \frac{\partial h}{\partial t}$$

or

$$k_x \frac{\partial^2 h}{\partial x^2} + k_y \frac{\partial^2 h}{\partial y^2} + k_z \frac{\partial^2 h}{\partial z^2} = S_s \frac{\partial h}{\partial t} - R$$

For outflow, $R = -W$ where W is the withdrawal rate.

R can represent:

1. Injection well
2. Extraction well
3. Rainfall
4. evaporation

Data Collection

- Well/Borehole logs
- River/lake stages
- Pumping data
- Maps, Aerial photos
- Elevations
- Observation well data

Model Design / Model Discretization Options

Design

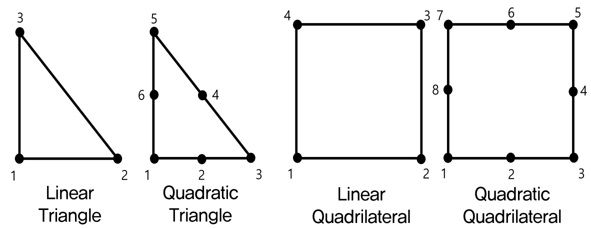
- Construct numerical model
- Find reasonable set of parameters and initial conditions

Discretization Options

- Finite element
- Finite difference
  - Mesh centered
  - Cell centered
  - Curvilinear
- Finite volume

Finite Element Method

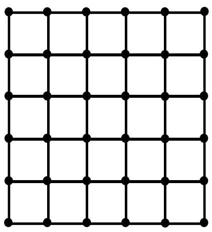
- 2D Element Types



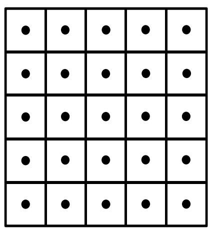
Model Design / Model Discretization Options

Finite Difference

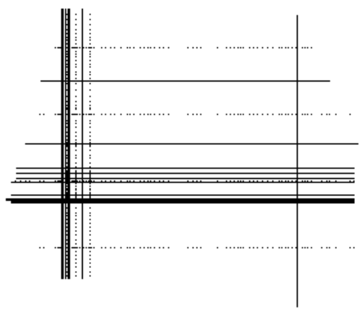
1. Mesh-Centered



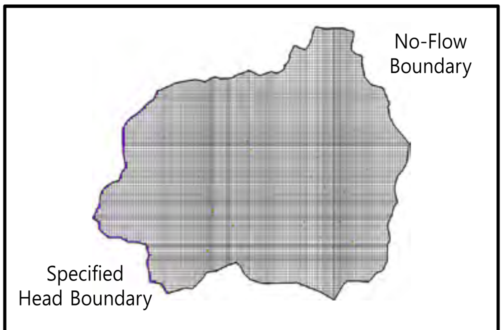
2. Cell-Centered



Grid Refinement



Boundary Placement



Calibration

- Modify input parameters until model output matches field-observed values
- Observations
  - Heads at wells
  - Flows at sources / sinks (rivers, lakes)
- Can be automated in some cases with MF2K PES, PEST, UCODE
- Should include sensitivity analysis

Verification

- Calibrate to multiple sets of observation data if possible
- In each case, adjust boundary conditions and model stresses to be consistent with conditions present when observations were made

Prediction / Post audit

Prediction

- Alter model, run simulation, and make predictions
- Can include stochastic analyses

Post audit

- When possible, review the model in later years to determine accuracy of predictions
- Can be used to improve model

24

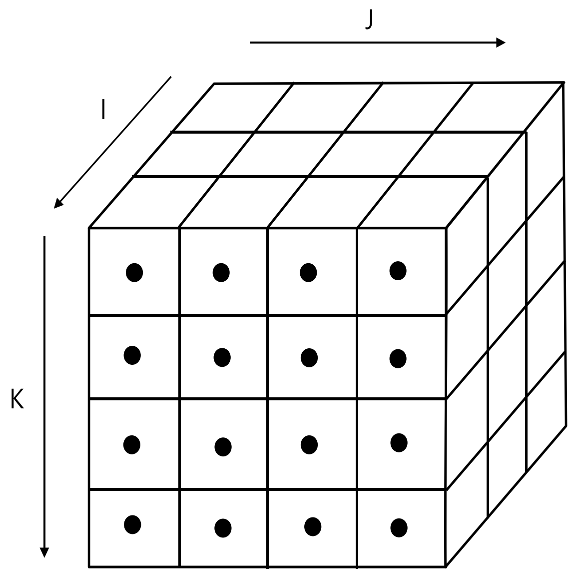
4. Introduction to MODFLOW

MODFLOW

- Cell-Centered, 3D, finite difference groundwater flow model
- Developed by McDonald & Harbaugh of the USGS, 1983
- Public Domain
- Most widely used groundwater model
- Steady state or transient saturated flow
- Currently using MODFLOW 2000 (MF23K)

Finite Difference Model

- 3D Cartesian Grid
- Cell-Centered



Governing Equation

$$\frac{\partial}{\partial x}\left(k_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(k_{zz}\frac{\partial h}{\partial z}\right)-W=S_s\frac{\partial h}{\partial t}$$

Where:

k_{xx}, k_{yy}, k_{zz} = $values\ of\ hyd.cond.along\ xyz\ axes$

h = $total\ head$

W = $Sources\ and\ sinks$

S_s = $specific\ storage$

t = $time$

Processes & Packages

- MODFLOW is divided into a series of processes & packages.
- Major tasks are organized as processes
- More specific tasks are performed by packages
- Each process may use one or more packages

MODFLOW Processes

- Global process
- Groundwater flow process
- Observation process
- Sensitivity process
- Parameter estimation process

Global Process

- Spatial discretization
  - #rows, cols, layers
  - Top / bottom elevation
- Temporal discretization
  - Stress periods
  - Time steps
- Units
- Package Selection

Stress Periods

- Time domain is divided into stress periods
- The values of transient stresses (Q, stage, etc.) can only change at the beginning of stress periods.
- Each stress period is further subdivided into time steps.

Groundwater Flow Process

- Formulation and solution of the groundwater flow equation by the FD method
- Main part of MODFLOW code
- Includes
  - Flow package (BCF, LPF, or HUF)
  - Source / sink packages
  - Solvers

Observation Process (OBS)

- Observed heads at observation wells
  - Single point
  - Averaged over screened interval
- Observed flows at :
  - rivers, streams
  - Drains
  - General head
  - Specified head (CHD)

Sensitivity Process (SEN)

- Defines parameter properties
- Used for
  - Sensitivity analysis
  - Parameter estimation

Parameter Estimation Process (PES)

- Built-in automated parameter estimation
- Uses OBS, SEN processes
- Fast, efficient
- Numerous output / statistics options

Packages

- Basic
- Global
- Output Control
- Flow Package
  - BCF
  - LPF
  - HUF
- River
- Drain
- General Head
- Well
- Changing Head Boundary
- Horizontal Flow Barrier
- Stream-Aquifer Interaction
- Recharge
- Evapotranspiration
- Solvers
  - SIP
  - SSOR
  - PCG
  - LMG

Flow Packages

- Block-Centered Flow (BCF)
- Layer Property Flow (LPF)
- Hydrogeologic Unit Flow (HUF)

BCF Package

- Original flow package
- Each layer is assigned a layer type
- Layer data are entered (depending on type)
  - Horizontal K
  - Bottom elevation
  - Transmissivity
  - Leakance
  - Etc.

Layer Property Flow (LPF) Package

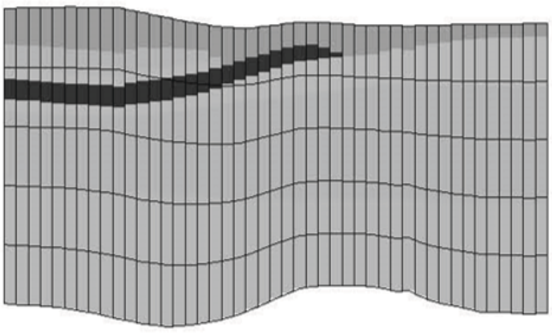
- User enters k_h, k_v and storage terms for all layers, regardless of type
- k_v can be entered as directly or in terms of vertical anisotropy
- Horizontal anisotropy entered on a cell-by-cell basis
- Two layer types
  - Confined
  - Convertible

LPF Property Input

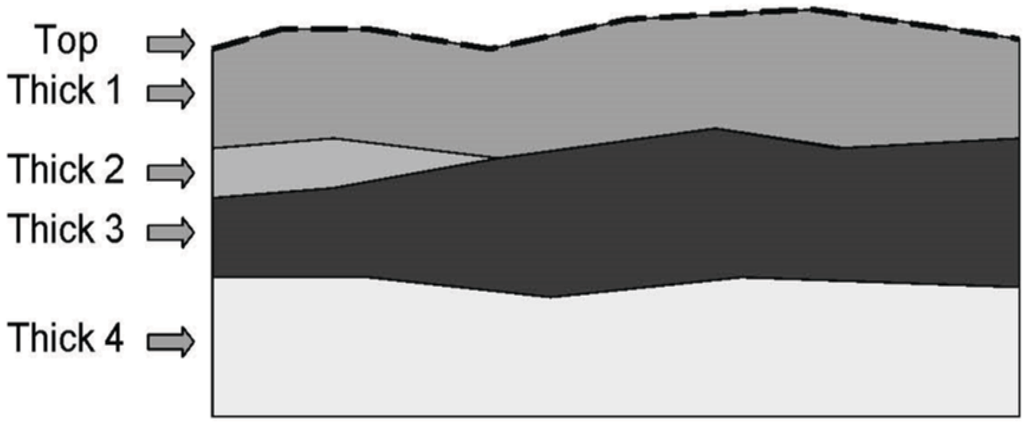
- Two options for inputting hydraulic properties :
  - Array input
    - One value per cell
  - Material id approach
    - Each cell is assigned a material id
    - Properties are inherited from material

Hydrogeologic Unit Flow (HUF) Package

- Aquifer stratigraphy represented in a grid-independent fashion
- Equivalent k_h, k_v computed at runtime



HUF Arrays



Recharge Package

- One value assigned to each vertical column
- Represent recharge due to precipitation
- Can be steady state or transient
- Infiltration rate must be assigned in correct unit

Factors Affecting Recharge Rate

- Rainfall
- Runoff
  - Slope
  - Soil type
  - Land use
- Evapotranspiration
  - Soil type
  - Vegetation

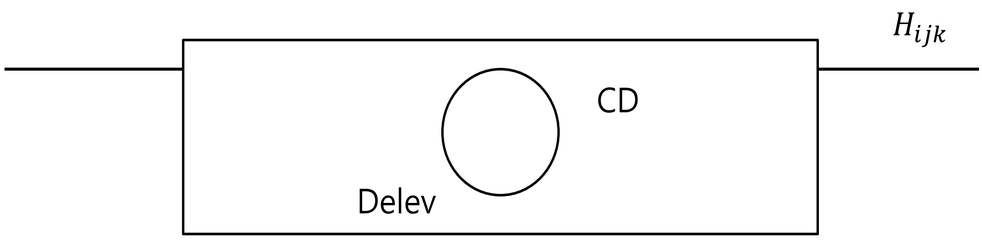
Well Package

- Assigned to individual cells
- Q can be steady state or transient
- Extraction well (negative Q)
- Injection well (positive Q)

Drain Package

- Assigned to individual cells
- Used to simulate
  - Agricultural drains
  - Springs
  - Creek beds
- Required parameters
  - Elevation
  - Conductance

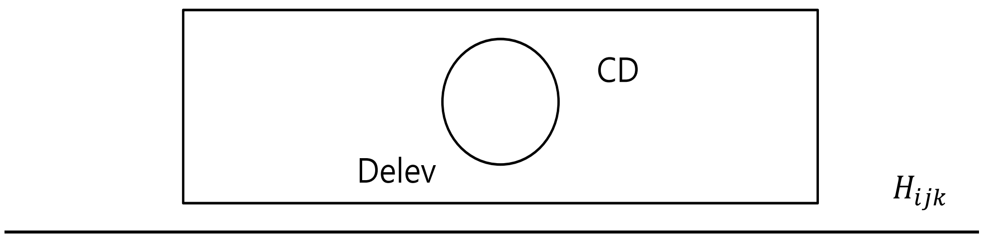
Drains



When head is above drain elevation :

$$Q = CD(H_{ijk} - Delev)$$
or
$$Q = CD(Delev - H_{ijk})$$
For proper sign on Q

Drains



When head is below drain elevation :

Q = 0

Conductance

Darcy's Law :

$$q = k\frac{\Delta h}{L}A$$

Where

$$q = flow\ rate$$
$$k = hydraulic\ conductivity$$
$$\Delta h = head\ difference$$
$$L = flow\ length$$
$$A = gross\ cross\text{-}sectional\ area$$

Conductance, Cont.

Darcy's Law can be rewritten as :

$$q = C \cdot \Delta h$$

Where

$$C = \frac{kA}{L}$$

The appropriate values for k, A, and L must be determined on a case-by-case basis

Solver Packages

- Iterative solvers
- Four choices
  - Strongly implicit procedure (SIP)
  - Slice-successive overrelaxation (SSOR)
  - Preconditioned conjugate gradient (PCG)
  - Linked multi-gird (LMG)
- Critical parameters
  - Max number of iterations
  - Convergence tolerance
  - Acceleration parameter

LMG Solver

- New with MODFLOW 2000
- Default solver
- link-AMG solver
- Uses algebraic multi-grid solver
- 2-25 times faster than PCG
- Uses 3-8 times more memory (RAM)

Advanced Packages

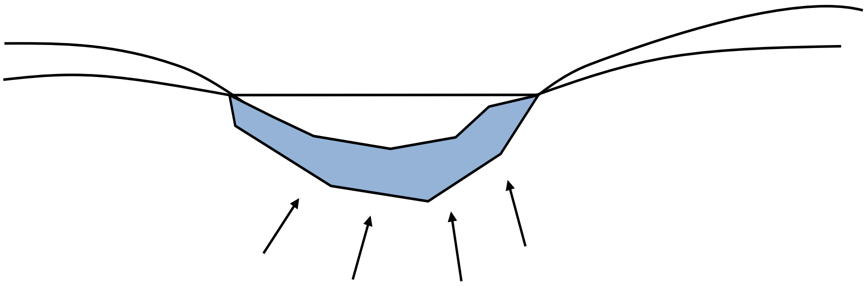
- River
- Stream-Aquifer interaction
- General Head
- Changing Head Boundary
- Horizontal Flow Barrier

River Package

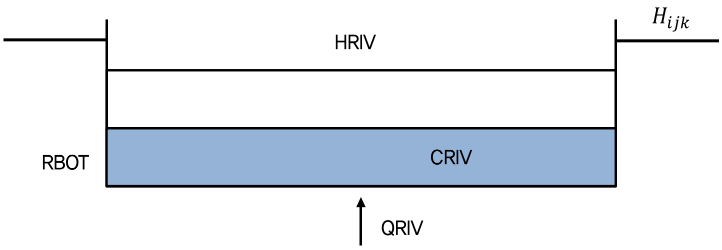
- Assigned to individual cells
- If head is above river stage, flow is from aquifer to river
- If head is below river stage, flow is from river to aquifer
- Required parameters
  - Conductance
  - Bottom elevation
  - Stage

River Package

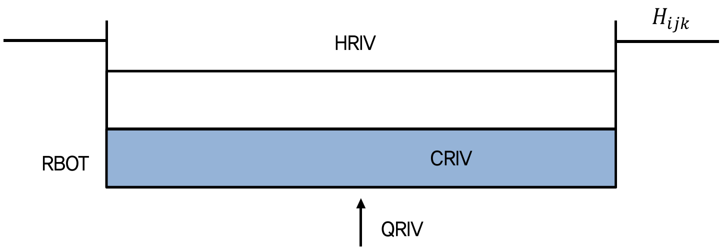
- Stream-aquifer system



- Idealized representation



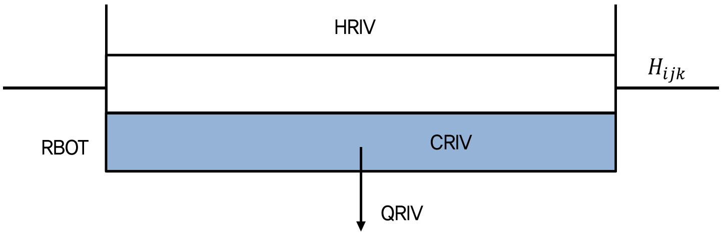
Case #1 – Head Above River Stage



$$QRIV = CRIV * (HRIV - H_{ijk})$$

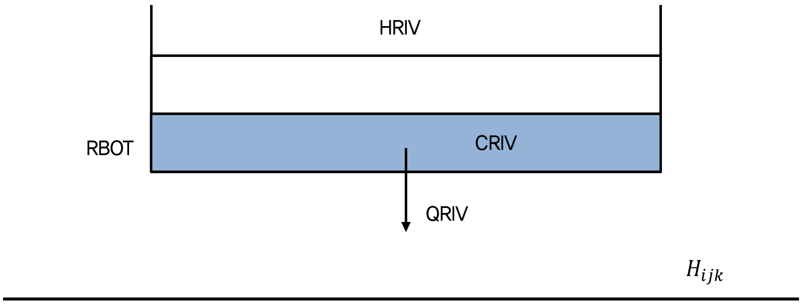
(–Q signifies flow out of cell)

Case #2 – Head Below River Stage but Above River Bottom



$$QRIV = CRIV * (HRIV - H_{ijk})$$

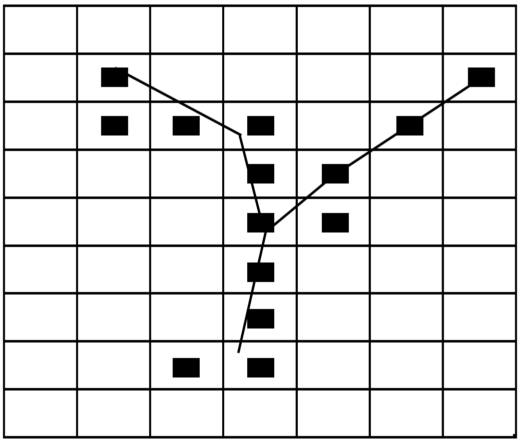
Case #3 – Head Below River Bottom



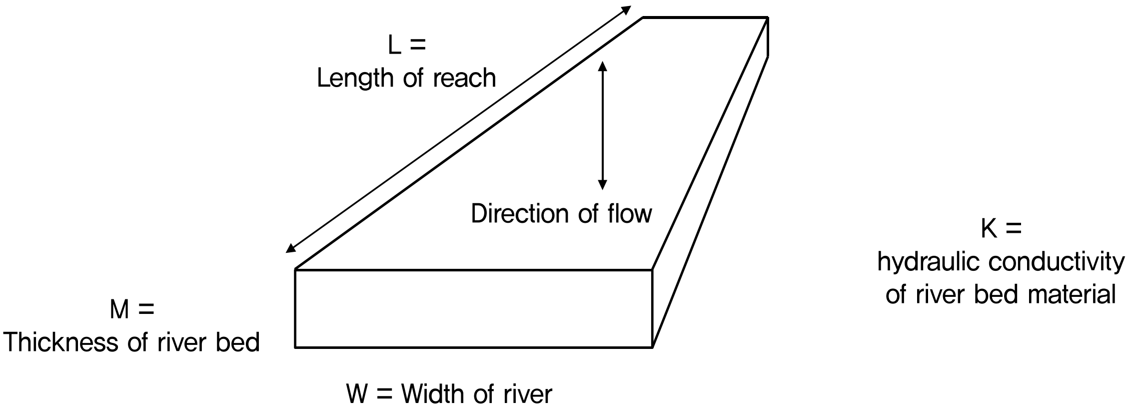
$$QRIV = CRIV * (HRIV - RBOT)$$

River Conductance

Length of reach in each river cell is computed



River Conductance

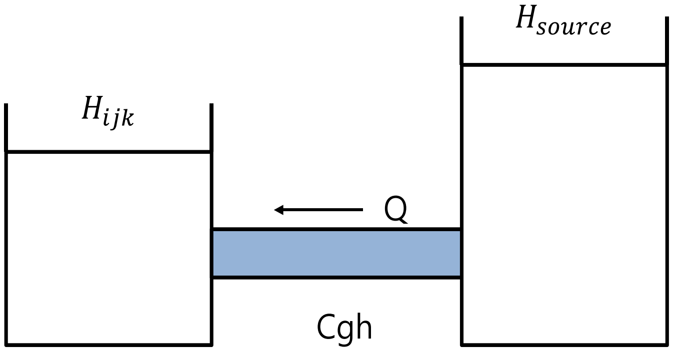


$$Cond = \frac{KLW}{M}$$

General Head Package

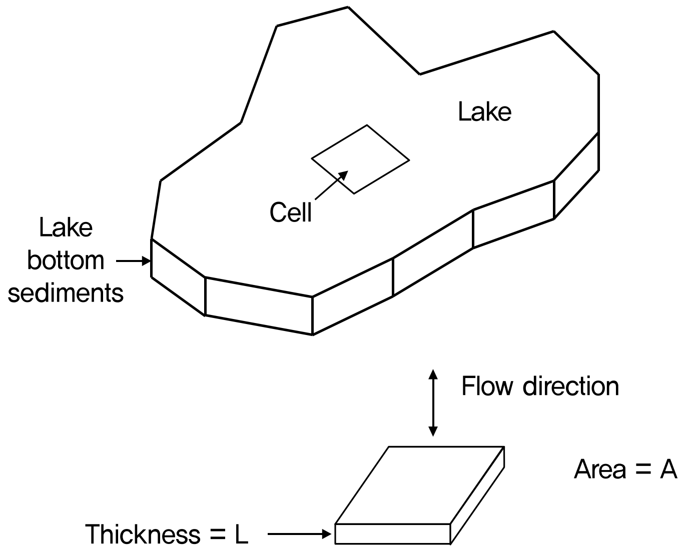
- Assigned to individual cells
- Often used to simulate lakes
- Required parameters
  - Head
  - Conductance

General Head



$$Q = Cgh * (H_{source} - H_{ijk})$$

Lakes and Reservoirs



$$C_{cell} = \frac{KA}{L}$$

64

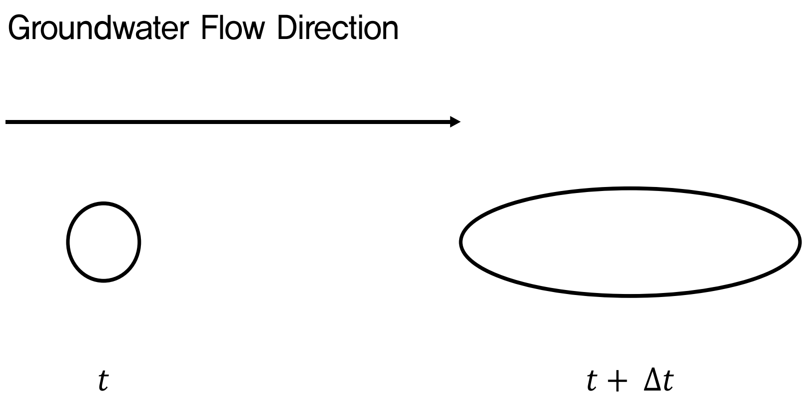
5. Solute Transport Modeling

Basic Transport Processes

- Advection
- Mechanical Dispersion
- Molecular Diffusion
- Internal Sinks and Sources
- Sorption
- Dual Domain Transport
- Chemical Reactions

Mechanical Dispersion

- Dispersion causes spreading of plume



Dispersivity Coefficient

- $\alpha_L = longitudinal\ dispersivity$
- $\alpha_T = transverse\ dispersivity$
- $\alpha_V = vertical\ dispersivity$

Sources and Sinks

- Injection or removal of contaminants from the aquifer
- Represents
  - Rivers
  - Wells
  - Recharge
  - Constant head boundaries
  - etc.

Sorption

- Equilibrium
  - Function of concentration only
- First order kinetic
  - Function of concentration, but rate-limited

Equilibrium Sorption

- Slowing of the plume due to sorption is called “Attenuation”
- Attenuation is represented by a retardation factor

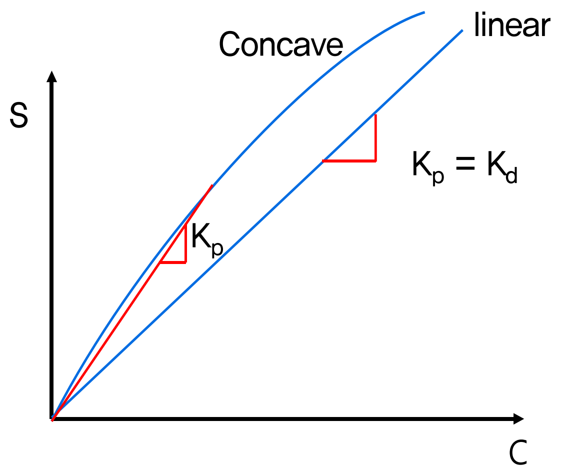
$$R_d = \frac{V_s}{V_r}$$

where

R_d = Retardation factor (typ. 1–3)
V_s = seepage velocity
V_r = transport rate

Retardation

- Retardation factor is a function of the sorption isotherm



K_p = Partitioning Coeff.

K_d = Distribution Coeff.

Standard Isotherm Options

- Linear

$$R = 1 + \frac{\rho_b}{\theta} K_d$$

- Freundlich (nonlinear)

$$R = 1 + \frac{\rho_b}{\theta} a K_f C^{a-1}$$

- Langmuir (nonlinear)

$$R = 1 + \frac{\rho_b}{\theta} \frac{\partial \bar{C}}{\partial C} \bar{C} = \frac{K_l \bar{S} C}{1 + K_l C}$$

First Order Kinetic Sorption

- Mass transfer is rate-limited

$$\rho_b \frac{\partial \bar{C}}{\partial t} = \beta \left(C - \frac{\bar{C}}{K_d} \right)$$

Where β = first order mass transfer rate between the dissolved and sorbed phases

Dual Domain Model

- Aquifer is assumed to consist of two domains
  - A mobile domain where the majority of advective flow occurs (fractures, preferential pathways, etc.)
  - An immobile domain with very little flow but where diffusive transport may occur
- Transport between the two domains is controlled by kinetic mass transfer

Chemical Reactions

- Simple approach
  - Monod or first order decay
  - Single species or no reactions between species
- Other approaches
  - Complex reactions between species can be simulated
  - Inhibition equations can be used to simulate sequential decay model

First Order Decay

- Used to simulate
  - Simple biodegradation
  - Radioactive decay
  - Kinetic (rate – limited) reaction

First Order Decay

- Reaction rate

$$\frac{d[C]}{dt} = -\lambda[C]$$

where

C = concentration

$\lambda = \ln 2 / t_{1/2}$

$t_{1/2}$ = half life of radioactive or biodegradable materials

Governing Equation

$$\frac{\partial(\theta C^k)}{\partial t} = \frac{\partial}{\partial t}\left(\theta D_{ij}\frac{\partial C^k}{\partial x_j}\right) - \frac{\partial}{\partial x_i}\left(\theta v_i C^k\right) + q_s C_s^k + \sum R_n$$

C^k	the dissolved concentration of species k, ML^{-3}
q	the porosity of the subsurface medium, dimensionless
t	time, T
x_i	the distance along the respective Cartesian coordinate axis, L
D_{ij}	the hydrodynamic dispersion coefficient tensor, L^2T^{-1}
v_i	the seepage or linear pore water velocity; LT^{-1}
q_s	the volumetric flow rate per unit volume of aquifer representing fluid sources (positive) and sinks (negative), T^{-1}
C_s^k	the concentration of the source or sink flux for species k, ML^{-3}
$\sum R_n$	the chemical reaction term, $ML^{-3}T^{-1}$

Hydrodynamic Dispersion

$$D_{xx} = \alpha_L \frac{v_x^2}{|v|} + \alpha_{TH} \frac{v_y^2}{|v|} + \alpha_{TV} \frac{v_z^2}{|v|} + D^*$$

$$D_{xy} = D_{xy} = (\alpha_L - \alpha_{TH}) \frac{v_x v_y}{|v|}$$

$$D_{yy} = \alpha_L \frac{v_y^2}{|v|} + \alpha_{TH} \frac{v_x^2}{|v|} + \alpha_{TV} \frac{v_z^2}{|v|} + D^*$$

$$D_{xz} = D_{zx} = (\alpha_L - \alpha_{TH}) \frac{v_x v_z}{|v|}$$

$$D_{zz} = \alpha_L \frac{v_z^2}{|v|} + \alpha_{TV} \frac{v_x^2}{|v|} + \alpha_{TV} \frac{v_y^2}{|v|} + D^*$$

$$D_{yz} = D_{zy} = (\alpha_L - \alpha_{TH}) \frac{v_y v_z}{|v|}$$

a_L	longitudinal dispersivity
a_{TH}, a_{TV}	transverse dispersivity
D*	effective molecular diffusion coefficient
v_x, v_y, v_z	components of the velocity vector
$\|v\| = (v_x^2+v_y^2+v_z^2)^{1/2}$	magnitude of the velocity vector

Thank you very much

Additional Groundwater Development for Climate Crisis

Groundwater

Additional Groundwater Development for Climate Crisis

United Nations Educational, Scientific and Cultural Organization

i-WSSM International Centre for Water Security and Sustainable Management

Aims & Objectives

- **The aims of the course are to:**

  (1) Study the types of artificial groundwater recharge
  (2) Study benefit of the surface dam installation and the reason for the need for artificial recharge

- **The objectives are that trainees will understand:**

  (1) Types of artificial recharge
  (2) Benefit of the surface dam installation
  (3) The needs for artificial recharge

Contents

1. Groundwater artificial recharge

1.1 Groundwater recharge
1.2. Type of groundwater recharge

1.1 Groundwater recharge

◆ Definition :

– A method that enables large–scale intake by increasing groundwater in the aquifer by withdrawing surface water from a river or lake, transporting it to an appropriate place, and forcibly infiltrating and cultivating the aquifer through various method

◆ Advantage : Reduction of environmental problems, evaporation loss, flooding, cost and improvement of water quality

◆ Disadvantage : Water quality problem and limit of soil texture

5

1.1 Groundwater recharge

◆ Artificial recharge

– Use of aquifers as water storage sites

– Increase the amount of water source cultivated and stored as an aquifer through artificial methods

– Purpose

Groundwater level recovery, water quality improvement, control of underground pollutants, prevention of salinization of groundwater

Surface water–groundwater integrated water resource management

1.1 Groundwater recharge

◆ Type of artificial recharge

– Direct method:

- Aquifer Storage and Recovery: ASR
- Artificial recharge through wells or surface recharge fields

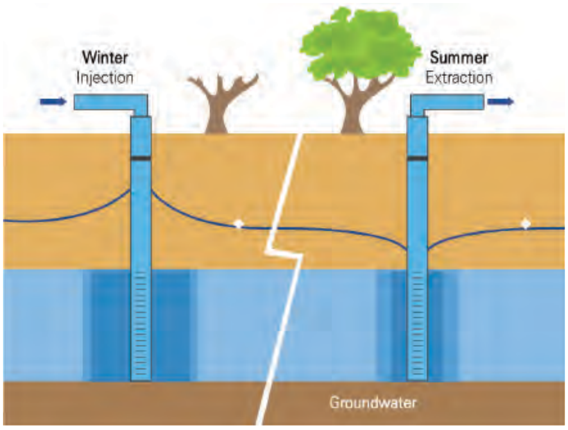
– Indirect method

- Riverbank filtration: RBF
- Groundwater dam

1.2 Type of groundwater recharge

(1) Aquifer storage and recovery(ASR)

- Treated water is directly injected into the aquifer through a well or recharge site to increase the groundwater storage,
- if necessary, the stored water is recovered and used
- Purified water can be stored for a long time in an aquifer
- Good water quality for injection water is required



1.2 Type of groundwater recharge

(1) Aquifer storage and recovery(ASR)

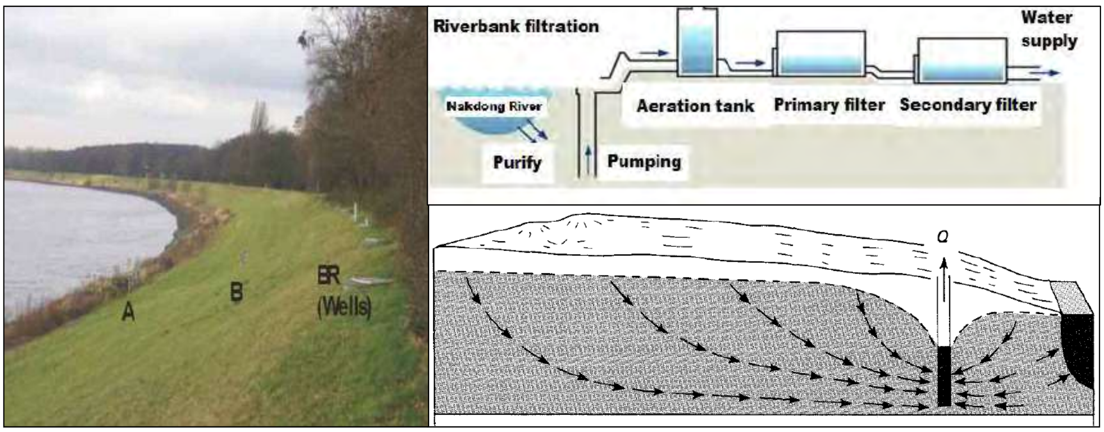
- ASR in Korea (Jeju)
  - short period of discharge time
  - water flows during rainy season
  - only 5–20 days per year
  - Artificial recharge using flood reduction reservoirs

Source) K-Water

1.2 Type of groundwater recharge

(2) Riverbank filtration (RBF)

- Collecting water filtered by pollutants while river water passes through the river bed sedimentary layer for a long period of time
- Started in the Rhine River in Germany from the 19th century

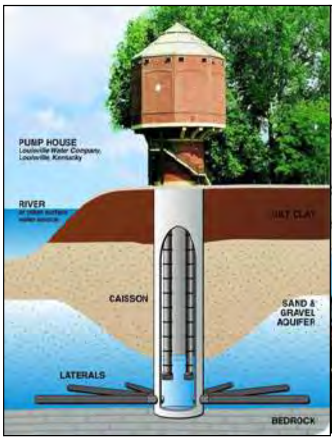


Source) K-Water

1.2 Type of groundwater recharge

(2) Riverbank filtration (RBF)

- Feasibility study was started in 1995 by K–water
- 60,000 ton Riverbank site was constructed during 2000 to 2005

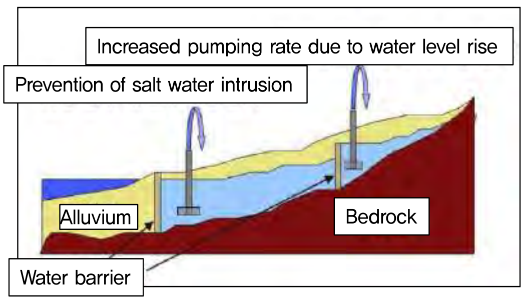


Source) K-Water

1.2 Type of groundwater recharge

(3) Groundwater dam

- By constructing a water barrier in the basement, groundwater is stored, and pumped
- Advantage
  - No loss due to evaporation, no submerged area on the surface
  - Low risk of water pollution and relatively low construction cost
- Disadvantage
  - Pumping facility required for pumping, maintenance cost
  - Difficult to evaluate the amount of groundwater storage



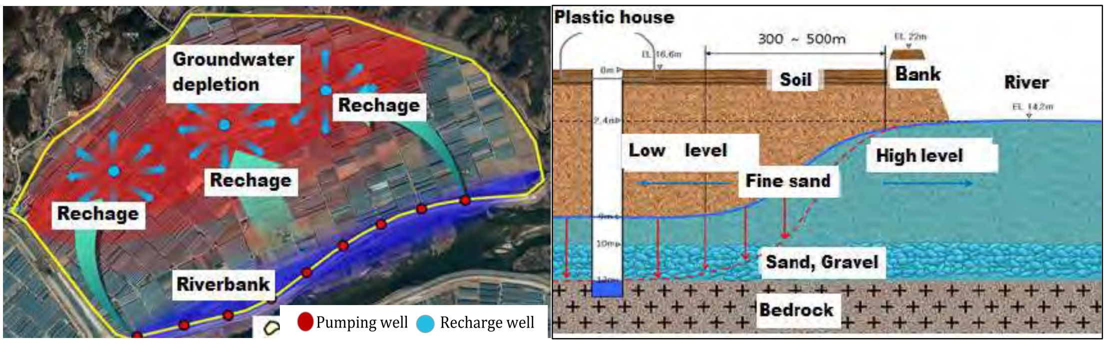
Source) Korea Rural Community Corporation

2. Case study of artificial recharge in Korea

2.1 Overview of the artificial recharge
2.2 Artificial recharge site investigation
2.3 Recharge plan at test site

2.1 Overview of the artificial recharge

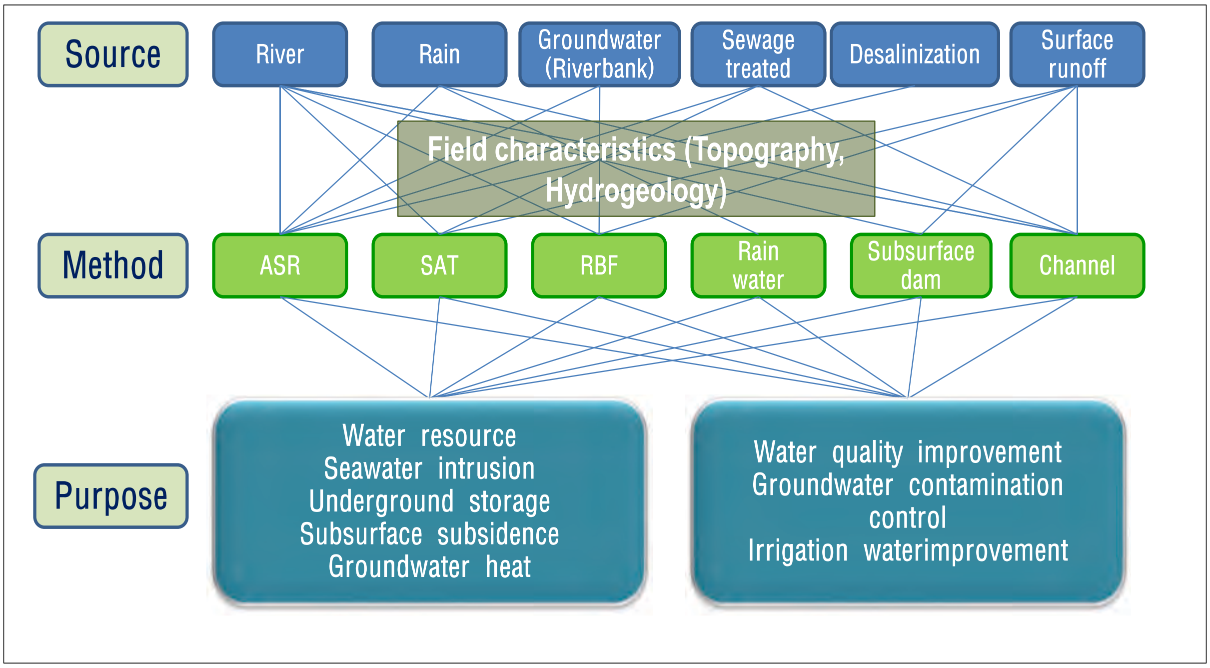
- Location of test site : Southern part of Korea
- Cause of water shortage : Excessive water use in collective facility cultivation complex
- Purpose of recharge : Supply of water through groundwater recharge to areas suffering from water agricultural water shortage



Source) Korea Rural Community Corporation

2.1 Overview of the artificial recharge

◆ Classification of artificial recharge

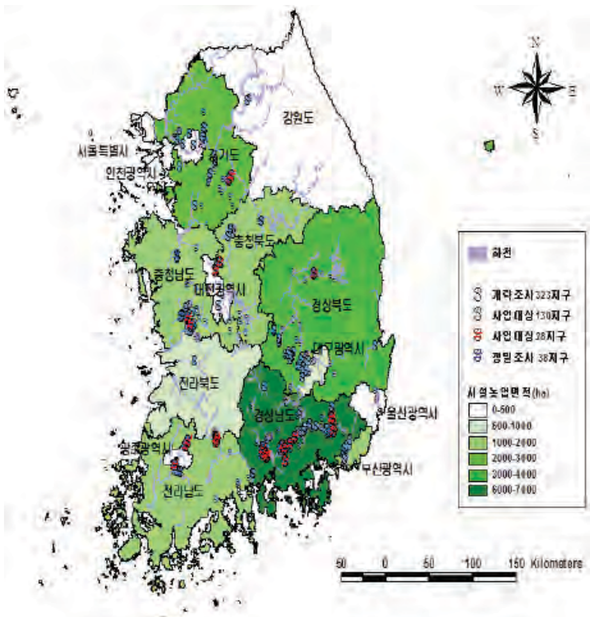


2.2 Artificial recharge site investigation

◆ Feasibility study for groundwater recharge project

- Facility agriculturel complex
- 323 site(more than 10 ha)
- Area : 18,936ha

- Water shortage occurred at 219 site out of 323 site (68%)
- 98 site is more than 50ha



Source) Feasibility report for artificially recharge groundwater in a facility agricultural complex, KRC 2015

2.2 Artificial recharge site investigation

◆ Investigation results

◆ Basic status of site	◆ Greenhouse crop (2,058 ea)
•Facility area : 250ha •Greenhouse : 2,058ea •Groundwater well : 972ea	•Main crop : Pumpkin(45.7%), paprijka(18.7%), pepper(13.8%), strawberry(10.2%), pimento(7.1%), etc(4.5%)

◆ **Groudwater well (972ea)**

•Water for growing : 439ea, 45.2%

•Water for energy : 189ea, 19.4%

•Water usage at each grounhouse : 64.18(㎥/day)

•Combined use : 334 ea, 35.4%

17

Source) Korea Rural Community Corporation

2.2 Artificial recharge site investigation

◆ Investigation results

〈 Test well location for soil texture 32ea 〉

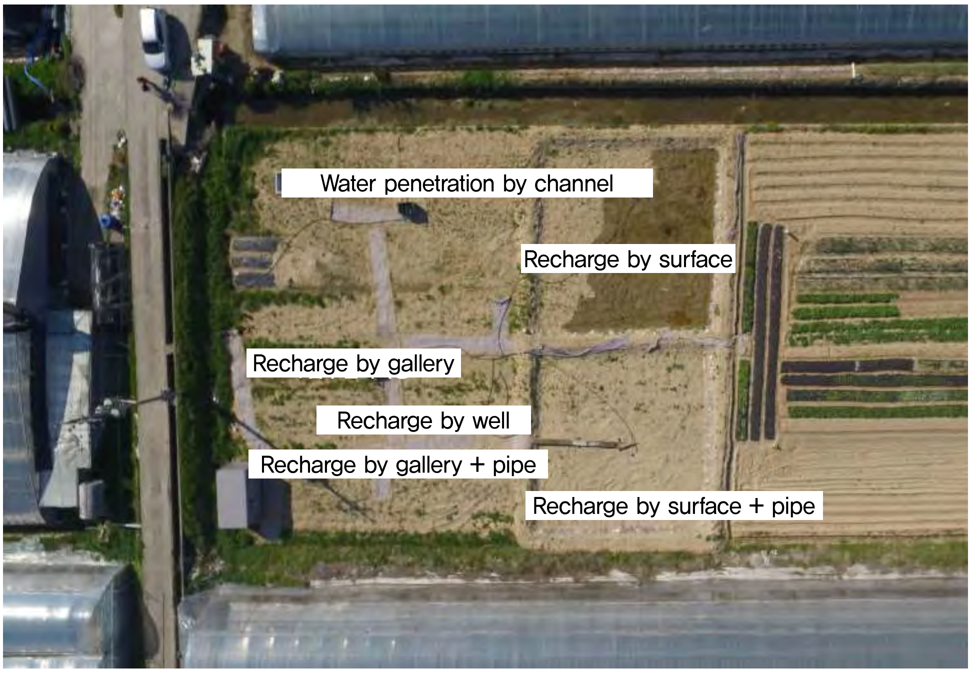
〈 Location of groundwater well 972ea 〉

18

Source) Korea Rural Community Corporation

2.2 Artificial recharge site investigation

◆ **Investigation results for recharge rate**



Source) Korea Rural Community Corporation

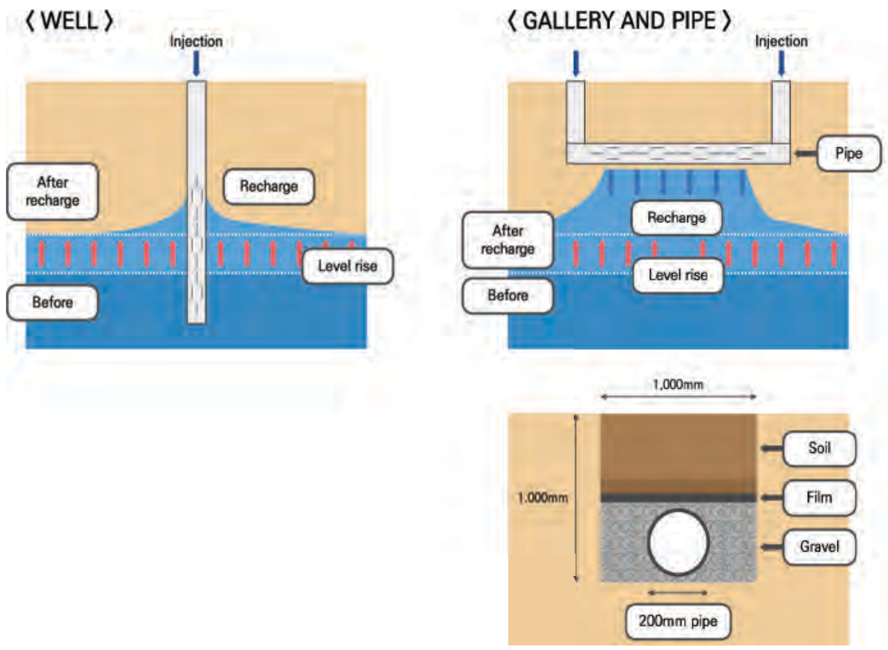
2.2 Artificial recharge site investigation

◆ **Investigation results for recharge rate**

Source) Korea Rural Community Corporation

2.3 Recharge plan at the site

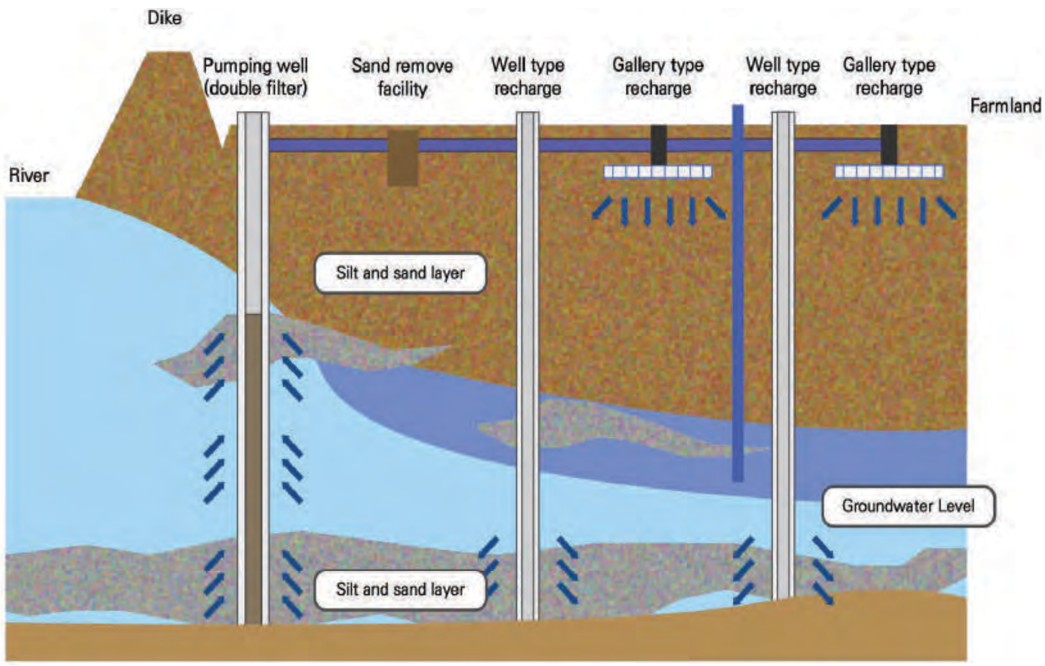
◆ Recharge plan



Source) Korea Rural Community Corporation

2.3 Recharge plan at test site

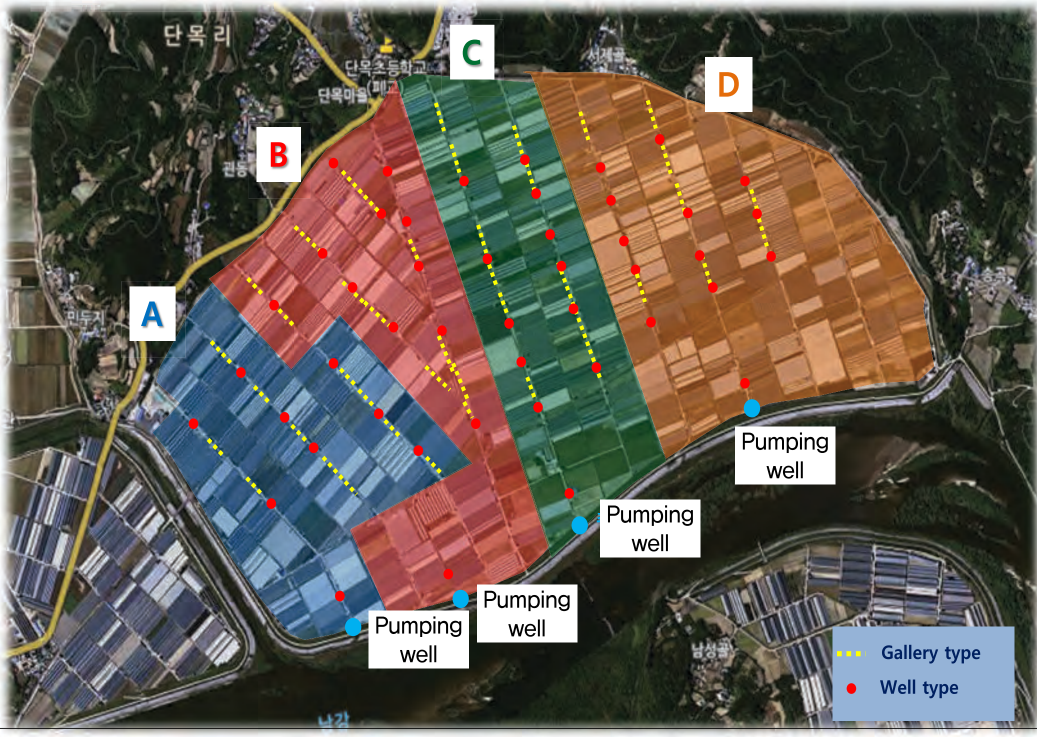
◆ Recharge plan



Source) Korea Rural Community Corporation

2.3 Recharge plan at test site

◆ **Recharge plan**



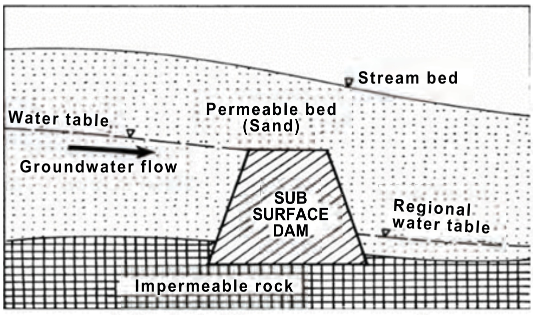
Source) Korea Rural Community Corporation

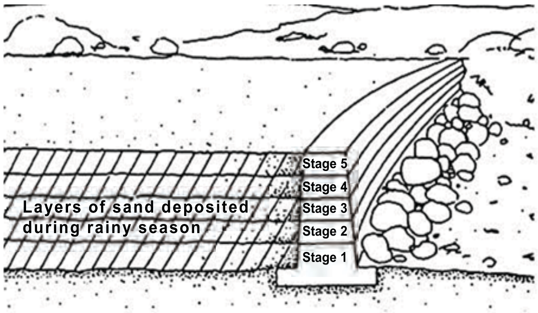
3. Case study of subsurface dam in Korea

3.1 Description of groundwater dam
3.2 Subsurface dam in Korea
3.3 Characteristics of irrigation by subsurface dam

3.1 Description of Groundwater dam

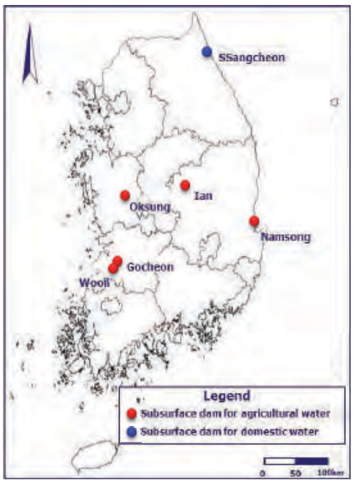
- Groundwater dam is classified into ***subsurface dam*** and sand storage dam.
- Subsurface dam is constructed ***to secure additional groundwater resources and to prevent seawater intrusion*** in coastal aquifer. (i.e. S. Korea, China, Japan)
- Sand storage dam is constructed to secure additional sand deposits (or aquifer). (i.e. Kenya, Ethiopia)





3.2 Subsurface dam in Korea

◆ Location and specification

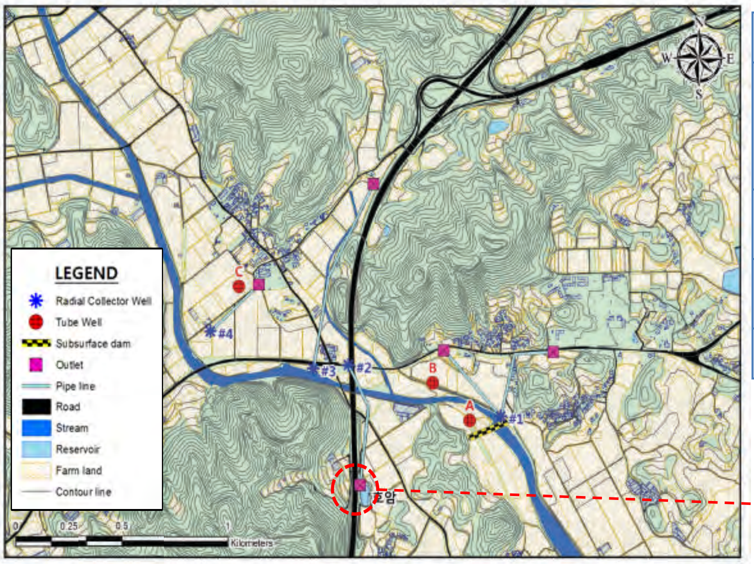


Name	Constructed year	Length (m)	Height (m)	Storage (×10³㎥)	Pumping rate (㎥/day)	Type
Ian	1984	230	4.0	4,143	24,000	Surface water–groundwater interaction type
Gocheon	1986	192	7.5	1,543	25,110	
Wooil	1986	778	6.7	2,457	16,200	
Oksung	1986	482	9.2	2,850	27,900	Linkage type to irrigation canal
Namsong	1986	89	18.8	4,017	27,000	Seawater intrusion prevention type
Ssangcheon	1998	840	27.0	7,300	41,000	

Source) Rural Research Institute

3.2 Subsurface dam in Korea

◆ Ian dam : surface water–groundwater interaction type

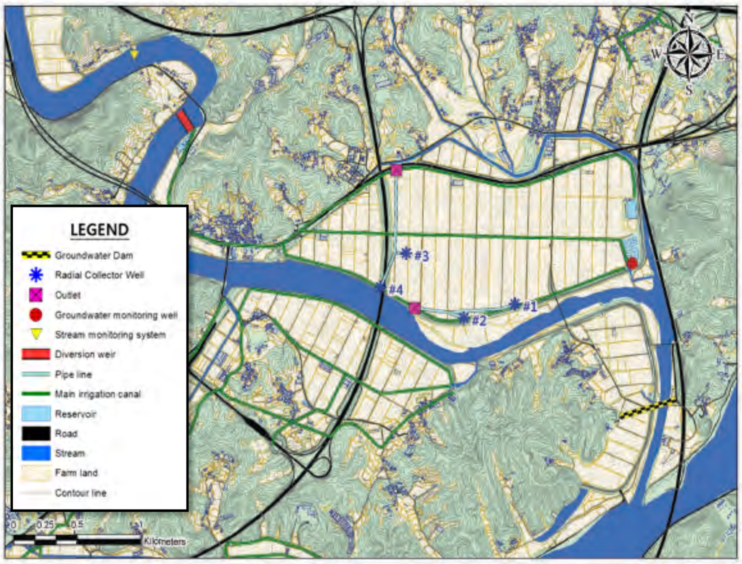


Role	Main source
Construction type	Stage grouting + Concrete Displacement
Benefited area	134ha
Catchment area	2,700ha
Pumping rate	24,000㎥/day

Source) Rural Research Institute

3.2 Subsurface dam in Korea

◆ Oksung dam : linkage type to irrigation canal



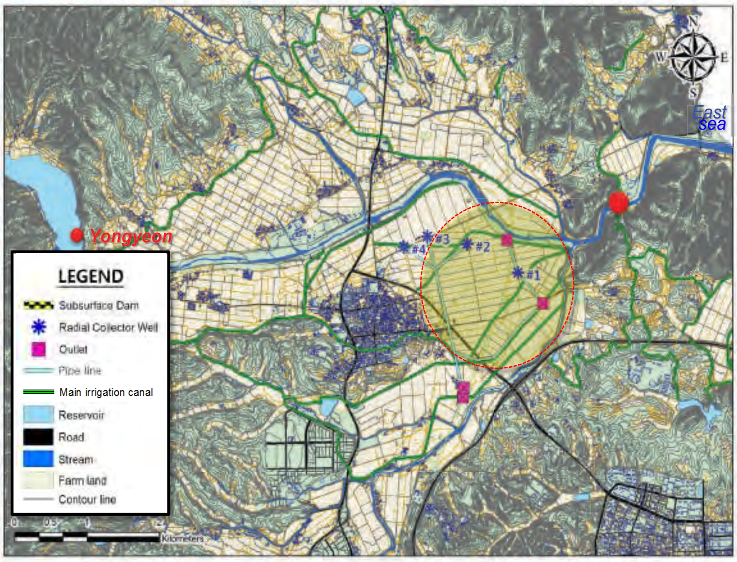
Role	Secondary source
Construction type	Stage grouting
Benefited area	146ha
Catchment area	27,500ha
Pumping rate	27,900㎥/day

- Subsidiary of Dongcheon diversion weir
- Water supply increases during drought periods

Source) Rural Research Institute

3.2 Subsurface dam in Korea

◆ Namsong : Seawater intrusion prevention type



Role	Secondary source
Construction type	Grouting
Benefited area	155ha
Catchment area	15,300ha
Pumping rate	27,000㎥/day

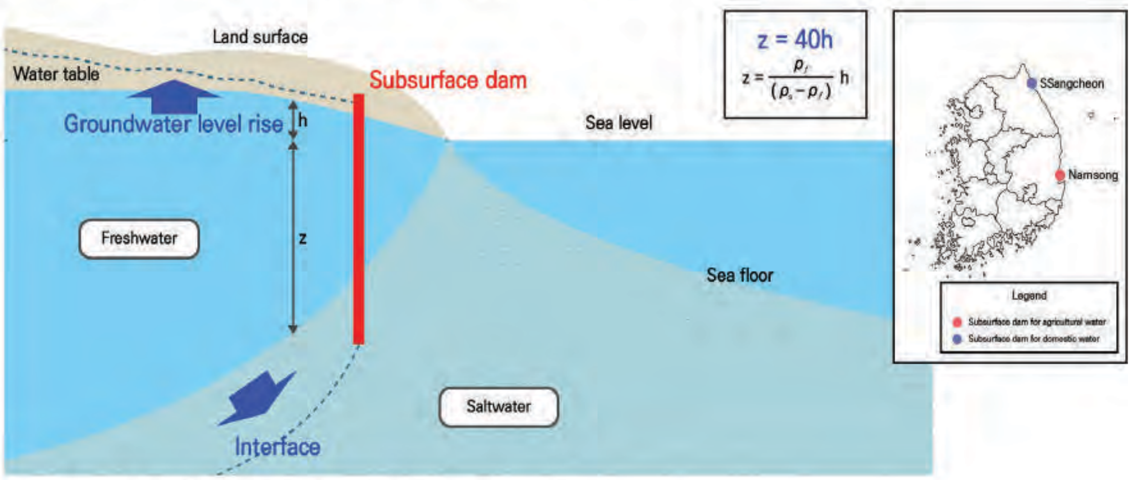
- To prevent seawater intrusion

Source) Rural Research Institute

3.2 Subsurface dam in Korea

◆ Prevention of seawater intrusion

Seawater intrusion can be prevented by subsurface dam.

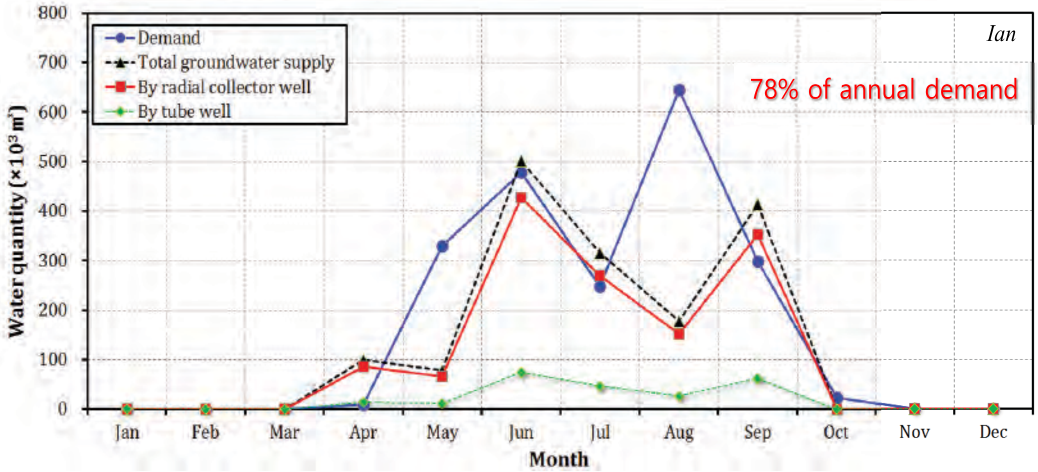


The interface is regressed into saltwater zone

Source) Rural Research Institute

3.3 Characteristics of irrigation by subsurface dam

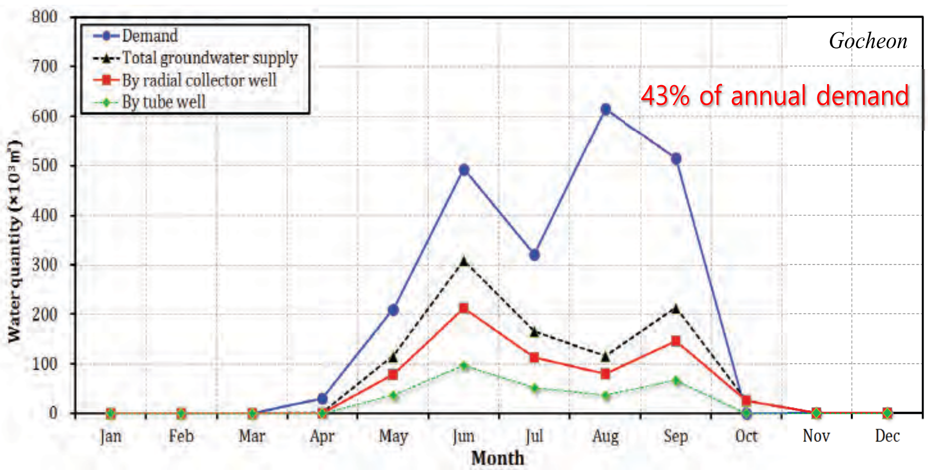
- *Monthly supply of each subsurface dam in 2015 at Ian dam*



Source) Rural Research Institute

3.3 Characteristics of irrigation by subsurface dam

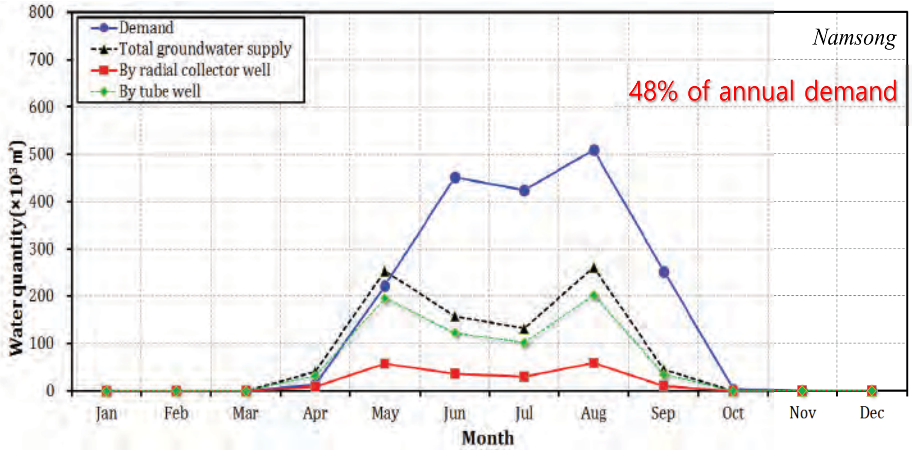
- *Monthly supply of each subsurface dam in 2015 at Gocheon dam*



Source) Rural Research Institute

3.3 Characteristics of irrigation by subsurface dam

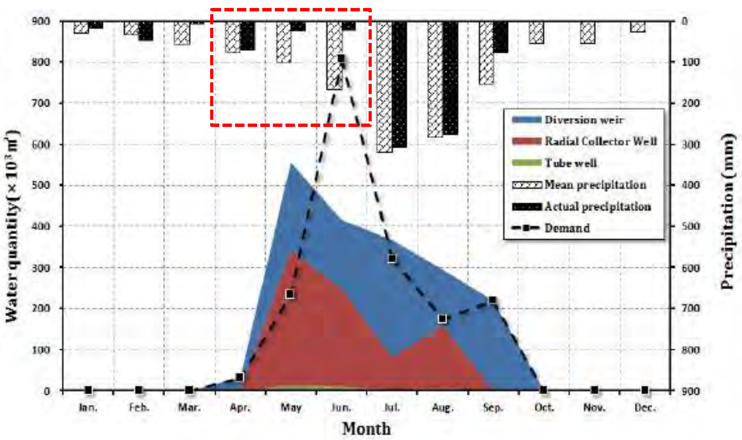
- *Monthly supply of each subsurface dam in 2015 at Namsong dam*



Source) Rural Research Institute

3.3 Characteristics of irrigation by subsurface dam

- *Monthly demand and water supply in Oksung area (2017)*



Time	Demand	Total Supply	Diversion weir (Surface water)	Subsurface dam (Groundwater)
Annual	1,787.7	1,883.4(105.4%)	1,051.8(58.8%)	831.6(46.5%)
April to June (drought)	1,072.5	1,002.8(93.5%)	412.6(38.5%)	***590.2(55.0%)***
				Unit : ×10³m³

Source) Rural Research Institute


Thank you very much

Climate Crisis Environment and Groundwater System: Drought and Irrigtation Water Requirement

Groundwater

Climate Crisis Environment and Groundwater System: Drought and Irrigation Water Requirement

Aims and objectives

- The aims of the course are to:

  (1) understand the impact the climate crisis on the groundwater system in the view point of hydrologic cycle, subsurface distribution of water, aquifer for mation, and sustainable groundwater development.

  (2) understand to trainees the effect of drought on groundwater system with standardized precipitation index (SPI) and standardized groundwater level index (SGI), and the determination of limit value of groundwater level with the evaluation method of drought for groundwater system.

- The objectives are that trainees will understand:

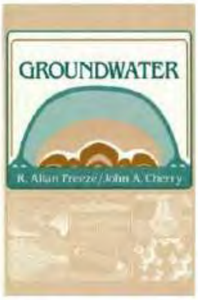
  (1) the sustainable groundwater development with the concept of aquifer type

  (2) the climate change impact on agriculture

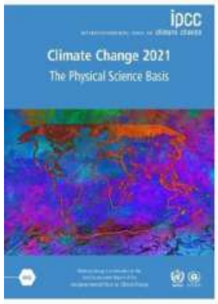
  (3) the concept of SPI and SGI

  (4) the calculation method of irrigation water requirement

References

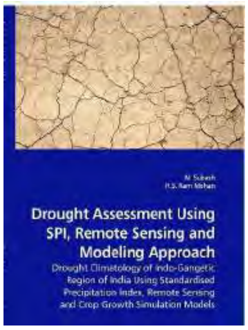


Groundwater (Freeze and Cherry, 1979)



Climate Change 2021: The physical science basis by IPCC

Crop evapotranspiration- Guideline for computing crop water requirement by FAO



Drought assessment using SPI, remote sensing and modeling approach

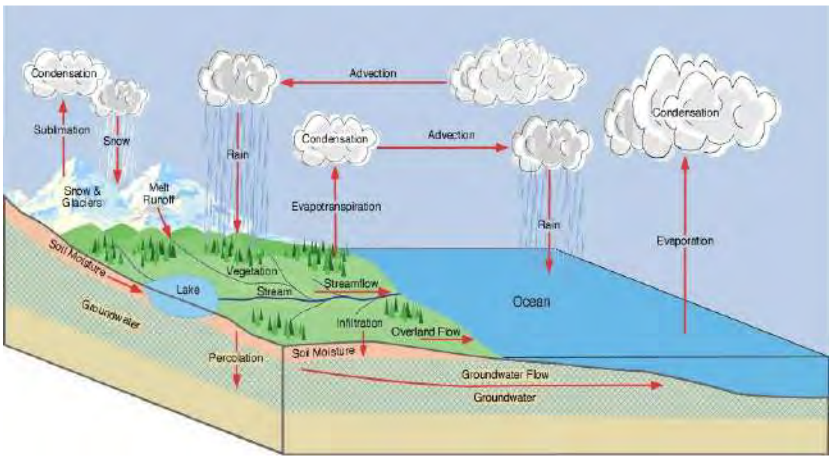
Contents

1. Understanding groundwater system

1.1 Hydrologic cycle

(Definition) is a conceptual model describing the storage and movement of water between the biosphere, atmosphere, lithosphere, and hydrosphere.

- Water can be stored in any one of the following major reservoirs: atmosphere, oceans, lakes, soils, rivers, glaciers, snowfields, and groundwater.
- Water moves from one reservoir to another by way of processes like evapotranspiration(EVT), precipitation(P), deposition, direct runoff(D), percolation(recharge, R) and groundwater flow.
- The oceans supply most of the evaporated water found in the atmosphere.

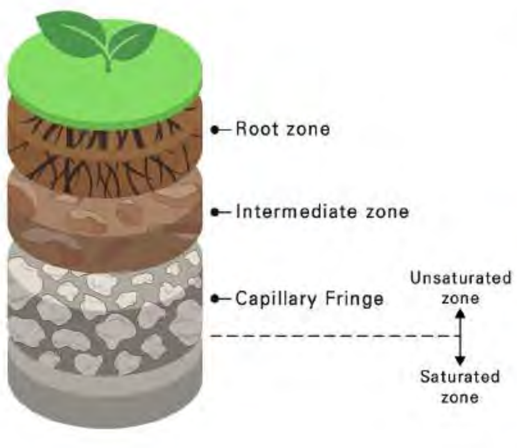


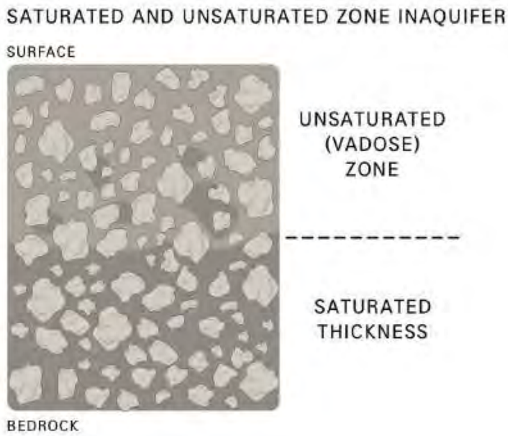
(http://sciencevsaving.org/fr/node/425)

1.2 Subsurface distribution of water

(Definition) Groundwater occurs in the subsurface in two broad zones.

- The unsaturated zone, also known as the vadose zone, consists of soil pores that are filled to a varying degree with air and water.
- The zone of saturation consists of water-filled pores that are assumed to be at hydrostatic pressure.
- For an unconfined aquifer, the zone of saturation is overlain by an unsaturated zone that extends from the water table to the ground surface.

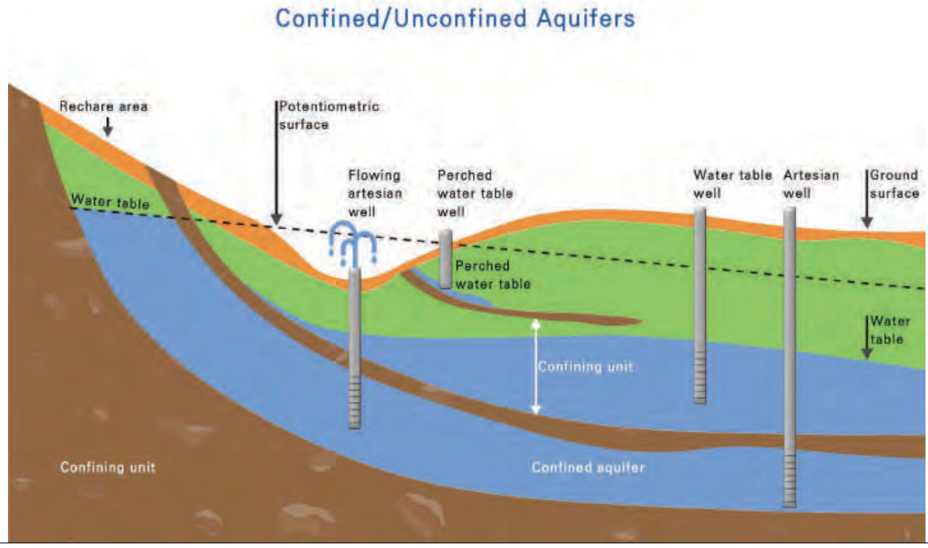




1.3 Aquifer formations

(Definition) An aquifer is a geologic unit that can store and transmit water.

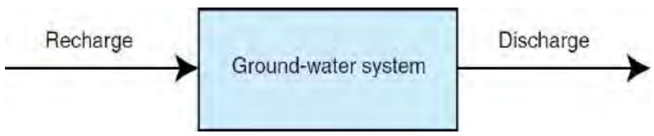
- Unconfined aquifer is not confined by impermeable material and its water table has a pressure that is everywhere the same as atmospheric.
- In unconfined aquifers, water seeps from the ground surface directly above the aquifer.
- In confined aquifers, an impermeable layer prevents water from seeping into the aquifer from the ground surface located directly above.



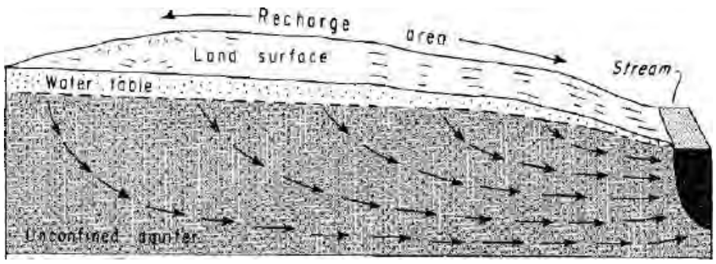
1.4 Sustainable groundwater development

(Definition) Total amount of recharge is equal to that of discharge in unconfined aquifer under predevelopment environment.

Predevelopment



Recharge (R) = Discharge (D)

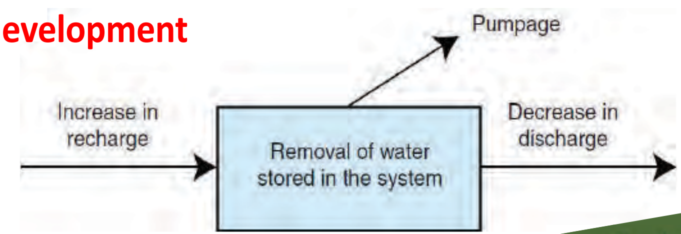


USGS(1999)

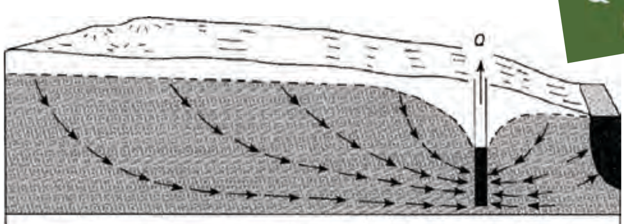
1.4 Sustainable groundwater development

Unconfined aquifer reaches to new equilibrium through transient state when groundwater is discharged from aquifer during pumping.

Groundwater development



$Q = C_S + C_D + C_R$ (GW capture)



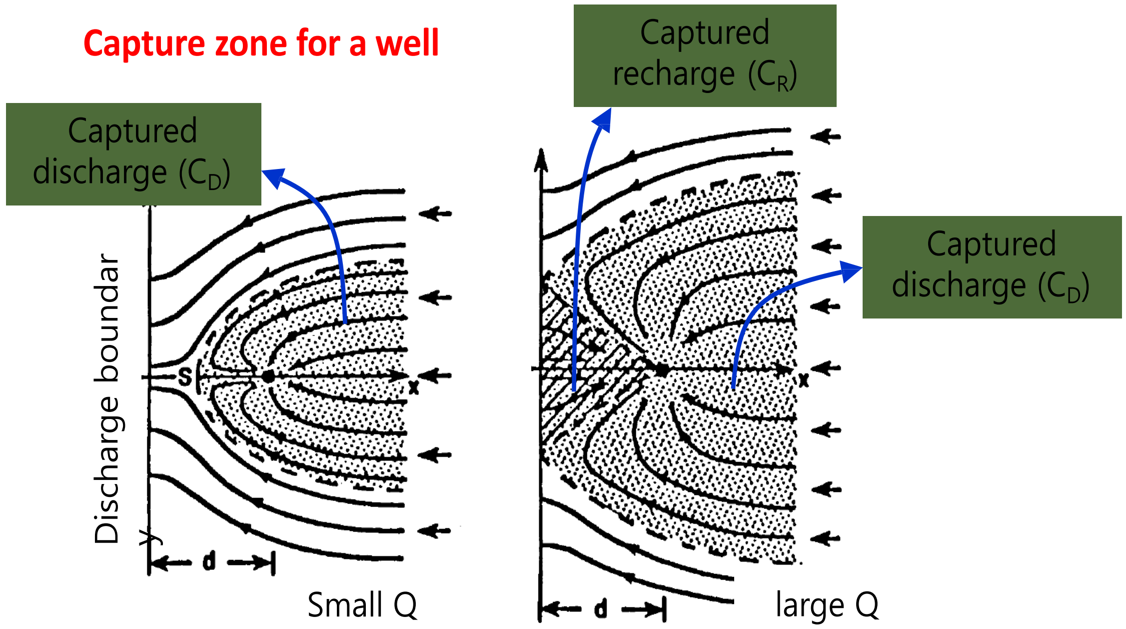
USGS(1999)

$R < D + Q$ (transient state) → $R' = D' + Q$ (new equilibrium)

10

1.4 Sustainable groundwater development

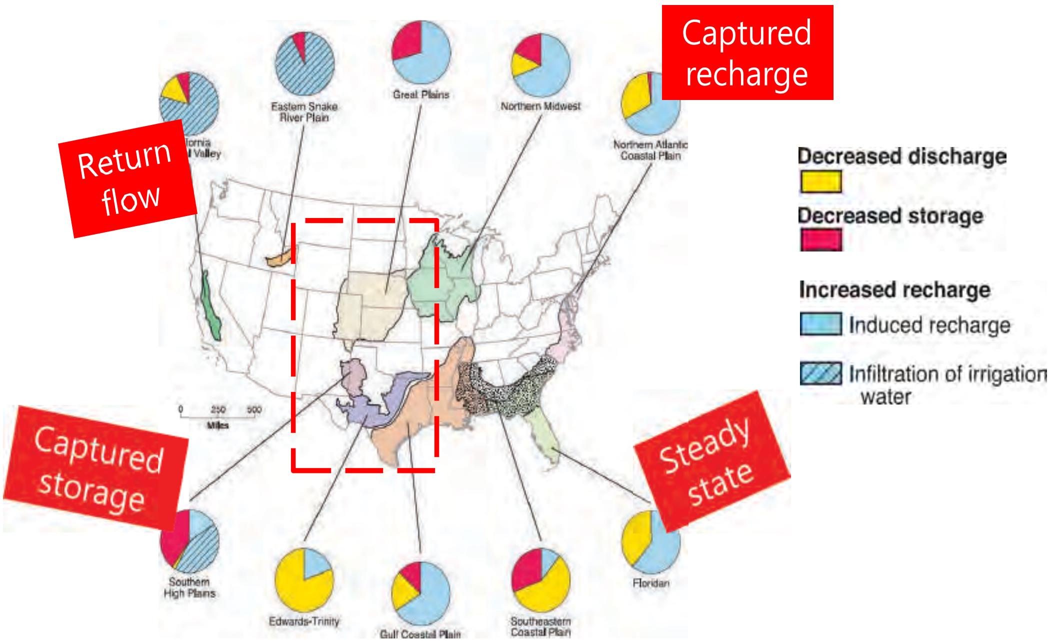
Capture zone is the three-dimensional region that contributes the groundwater extracted by one or more wells or drains.



11

1.4 Sustainable groundwater development

Sources of water that supply withdrawal from model simulations (Alley et al., 2002)



12

1.4 Sustainable groundwater development

Example of large-scale groundwater development

- Ogallala (High Plains) aquifer, USA
- Largest groundwater system in USA
- Unconsolidated deposits
- 190 feet in thickness (average)

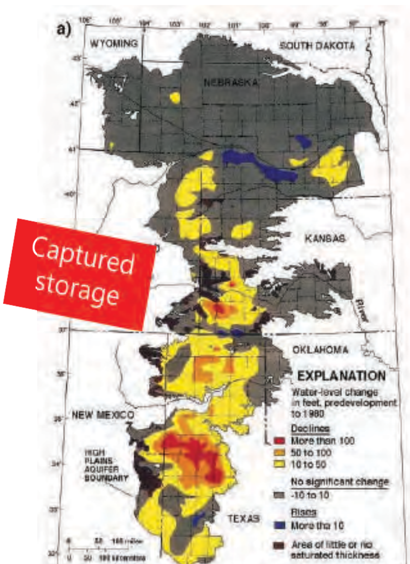
Central-pivot irrigation system

13

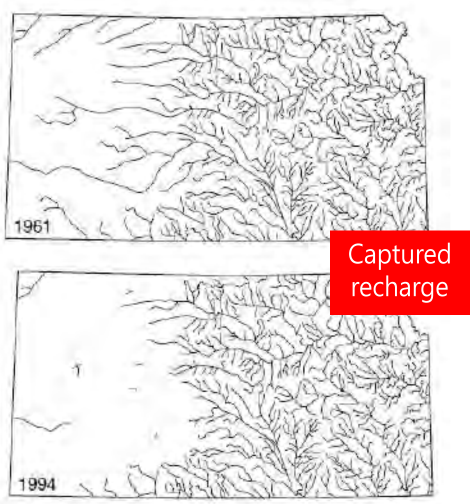
1.4 Sustainable groundwater development

Example of large-scale groundwater development

- Groundwater depletion in Ogallala (High Plains) aquifer, USA
- Disappeared major stream in Kansas after the depletion of groundwater



Predevelopment - 1980



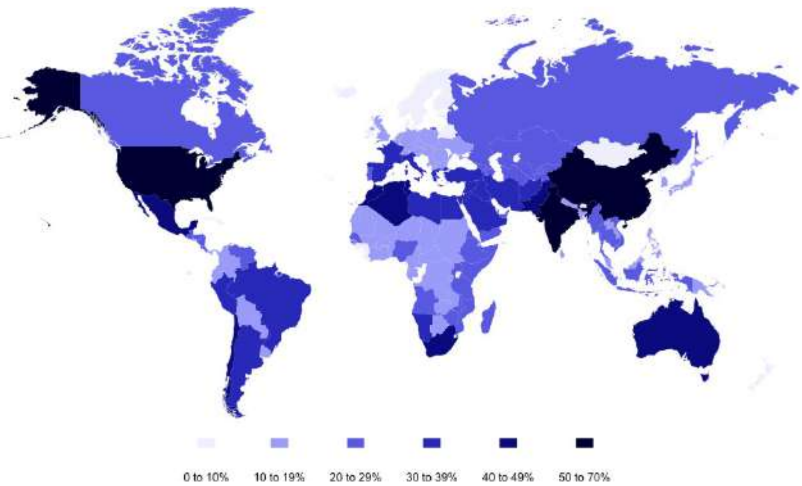
Major streams in Kansas (Sophocleous, 2000, JoH)

14

1.4 Sustainable groundwater development

Water risk hot spots for agriculture in the world (OECD, 2015)

Global assessment: China, India and the United States are expected to face the most water risks in the future



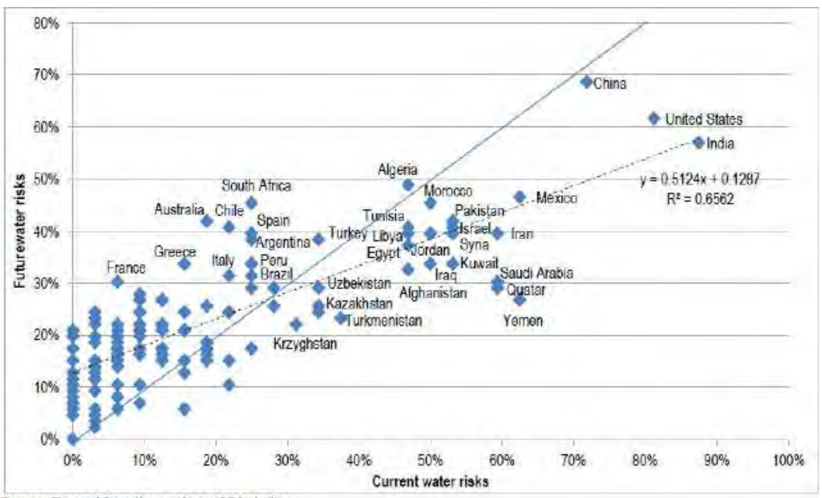
Frequency of observations listing countries as subject to high or very high future water risks

15

1.4 Sustainable groundwater development

Water risk hot spots for agriculture in the world (OECD, 2015)

Countries with lower current water risks may face relatively higher risk In the future



Source: Derived from the analysis of 64 studies.

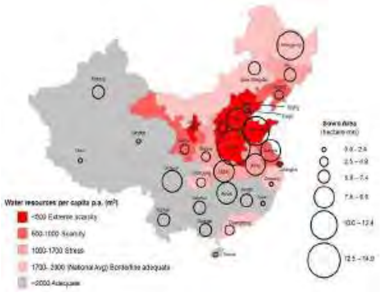
Shares of severe water risk future and past observations, across reviewed studies.
The continuous line represents the median (y=x), the dashed line is a linear regression.

16

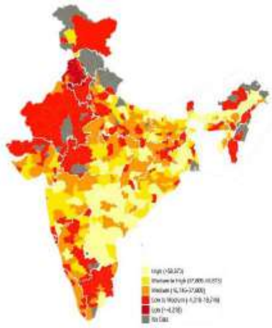
1.4 Sustainable groundwater development

Water risk hot spots for agriculture in the world (OECD, 2015)

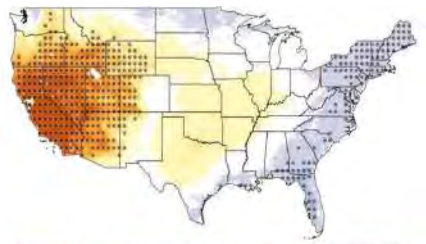
Water resources and agriculture areas in China: the Northeast hotspot region



Net groundwater availability for irrigation in 2025



Drying in the US Southwest: Weather systems that bring rains are becoming rarer



17

2. Climate crisis environment

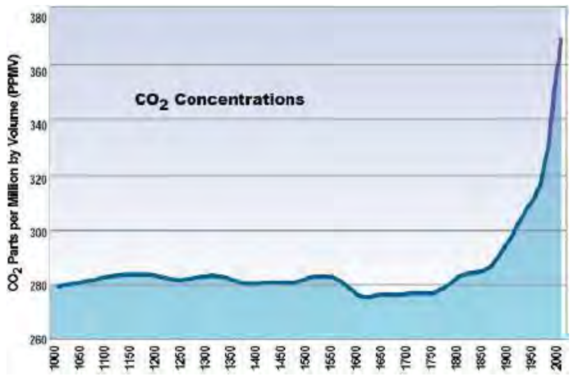
2.1 Climate crisis

2.2 Climate change impact on agriculture

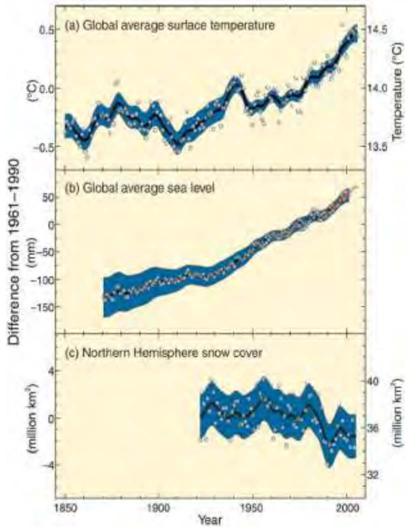
2.1 Climate crisis

(Definition) is a term describing global warming and climate change, and their consequences.

- The term has been used to describe the threat of global warming to the planet, and to urge aggressive climate change mitigation.



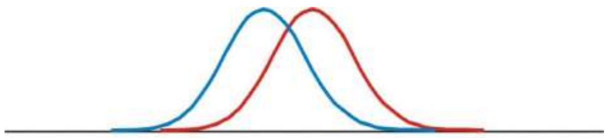
(National Assessment Synthesis Team, 2000)



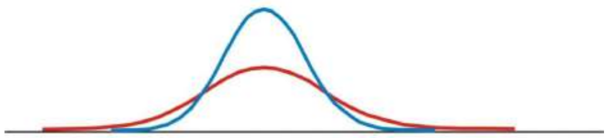
Observed changes from warming climate (IPCC, 2007)

2.1 Climate crisis

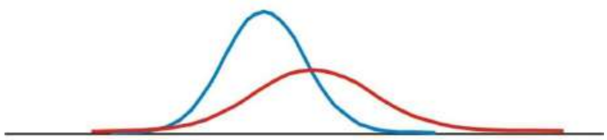
Possibilities of quantile shift of seasonal rainfall density



(a)



(b)

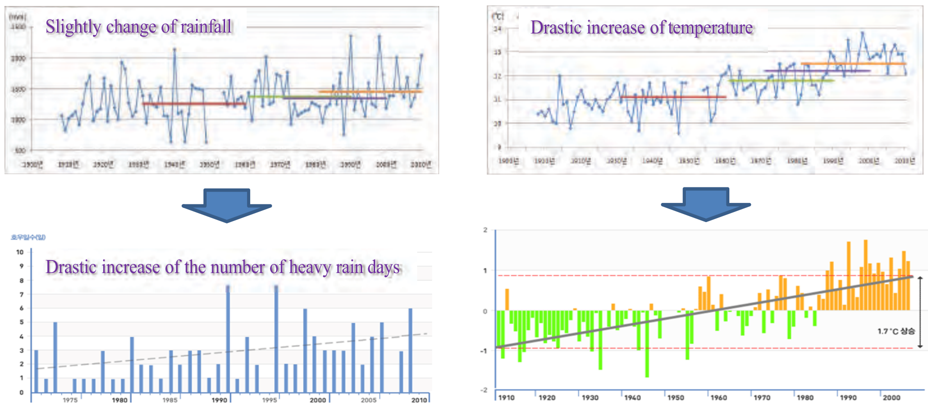


(c)

(a) change in season, (b) change in density, and (c) change in both

2.2 Climate change impact on agriculture

Variation of monthly mean hydrologic values for rainfall and temperature during each 30 year period



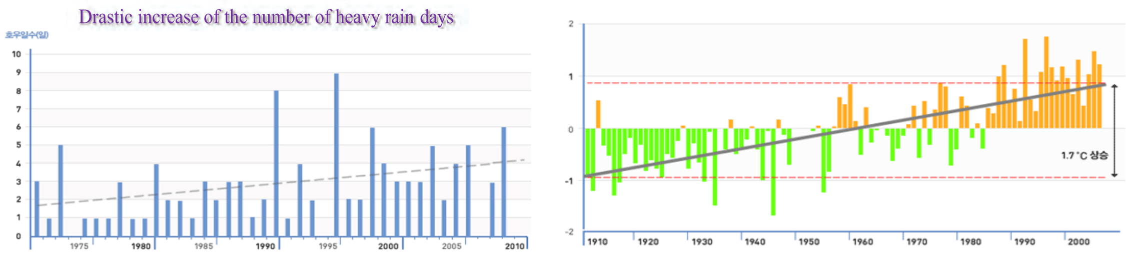
2 times of the 70'(< 80 mm/day)

(http://www.climate.go.kr/)

2.2 Climate change impact on agriculture

Variation of monthly mean hydrologic values for rainfall and temperature during each 30 year period

- Increase of no-rain days and EVT due to the rising of temperature
- Affect to the change of agricultural environment
- Increase of agricultural water demand and decrease of surface water due to the rising of runoff



2 times of the 70'(< 80 mm/day)

(http://www.climate.go.kr/)

3. Effect of drought on groundwater system

3.1 Standardized precipitation index (SPI)

3.2 Standardized groundwater level index (SGI)

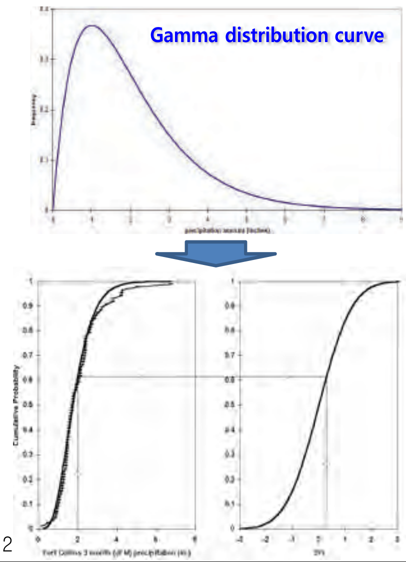
3. Evaluation of drought for groundwater system

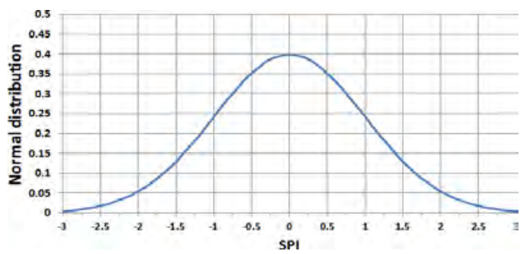
4. Determination of limit value of groundwater level

3.1 Standardized precipitation index (SPI)

(Definition) SPI is a drought index based on precipitation and a used index to characterize meteorological drought on a range of time scales.

- It is an index based on the probability of precipitation for any time scale such as day and month.
- To calculate SPI, a long-term precipitation record at the desired station is first fitted to a probability distribution (e.g., gamma distribution), which is then transformed into a normal distribution so that the mean SPI is zero.





SPI value	Classification	Percentile value
-0.99 ~ 0.99	Near normal	
-1.00 ~ -1.49	Moderate drought	0.2420
-1.50 ~ -1.99	Severe drought	0.1295
-2.00 >	Extreme drought	0.0540

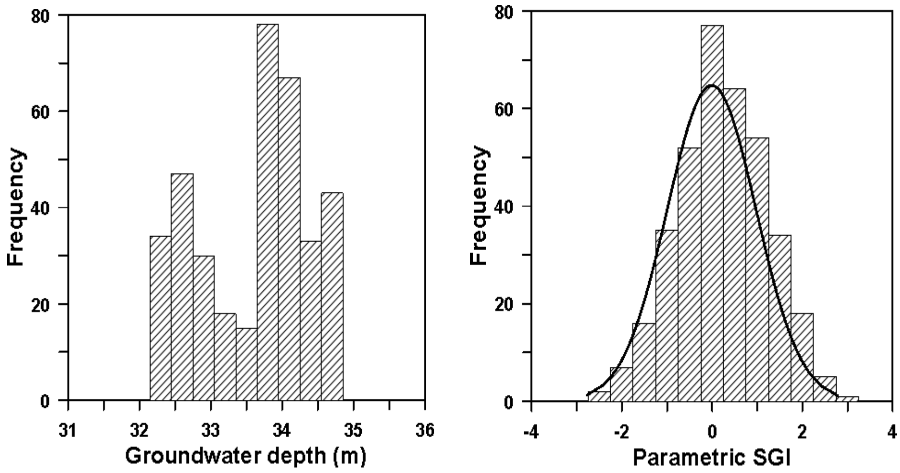
[References] McKee et al.(1993)

2

3.2 Standardized groundwater level index (SGI)

(Definition) SGI Builds on SPI to account for differences in the form and characteristics of groundwater level and precipitation time series.

- Like many other hydrological time series, the distributions of monthly observed groundwater levels may not conform to a gamma distribution.
- Histogram of daily groundwater depth and corresponding histogram of normalized value (SGI) with normal distribution curves during 1 tear in 2015.



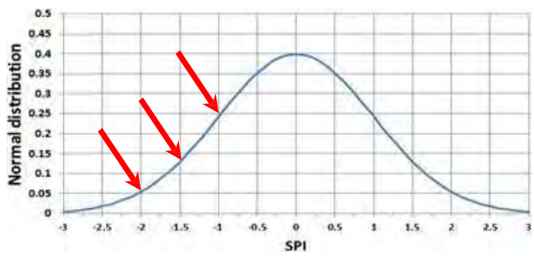
[References] Song (2018)

Gapyoung 1 monitoring well

3.3 Evaluation of drought for groundwater system

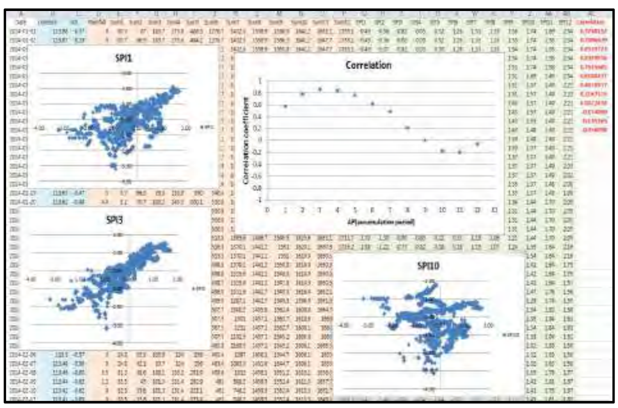
The drought effect on groundwater system is evaluated using SGI results which is calculated by SPI criteria.

- Therefore, the effects of drought on groundwater system may be quantitatively evaluated by correlation analysis with two indices using the same classification.
- Correlation coefficient is a number that quantifies a type of correlation and dependence, meaning statistical relationships between two values in fundamental statistics.



SPI value	Classification	Percentile value
-0.99 ~ 0.99	Near normal	
-1.00 ~ -1.49	Moderate drought	0.2420
-1.50 ~ -1.99	Severe drought	0.1295
-2.00 >	Extreme drought	0.0540

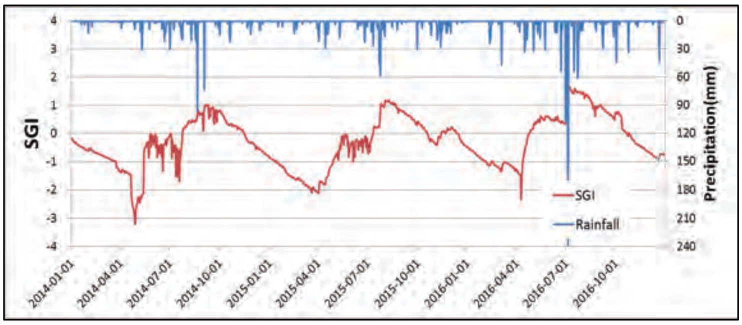
$$Correlation(X,Y) = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2\sum(y-\bar{y})^2}}$$

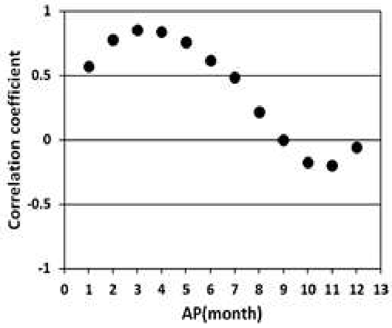


3.3 Evaluation of drought for groundwater system

Evaluation of drought effect on groundwater system using correlation analysis with SPI and SGI proceeds according to the following steps.

- Calculation of SPI for each month from one to twelve using daily precipitation data
- Calculation of SGI for each month from one to twelve using daily groundwater level data
- Determination of optimal accumulation period (AP) after correlation analysis with SPI and SGI
- AP values indicate whether drought situation will last or not





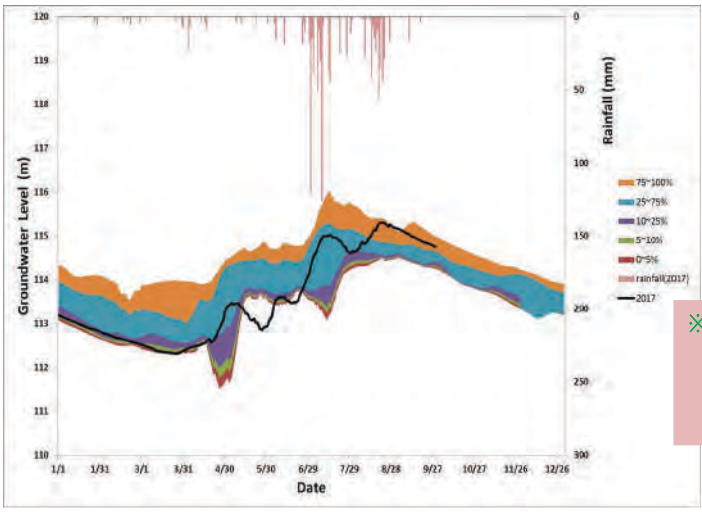
Gapyoung 1 monitoring well

[References] Song (2018)

3.4 Determination of limit value of groundwater level

According to different hydrologic conditions and hydrogeological situation, the lower limits of the controlled limit value of groundwater level are essential against drought under climate crisis environment.

- Calculation of daily statistical values of annual groundwater level applying the percentile standard of SPI at representative monitoring well
- A specific limit value should be established in consideration of the characteristics of each watershed



※ < 25 % : normal
10 ~ 25 % : moderate drought
0 ~ 10 % : severe drought 0
% < : extreme drought

[References] Song (2018)

4. Irrigation water requirement

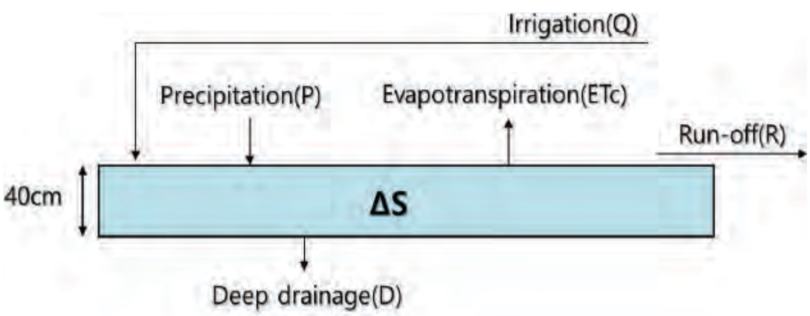
4.1 Irrigation water requirement (IWR)

4.2 Calculation of irrigation water requirement

4.1 Irrigation water requirement (IWR)

(Definition) IWR, quantity required for crop growth, is calculated by subtracting effective rainfall from crop evapotranspiration.

- Effective rainfall means useful or utilizable rainfall for crop production. The rainfall which is utilized by crops especially for evapotranspiration can be called as effective rainfall.
- Crop evapotranspiration is a physical process in which water passes from the liquid to the gaseous state while moving from the soil to the atmosphere.



$$Q = ET_c\,(=ET_o * K_c) - P_e \;@\; \Delta S = 0$$

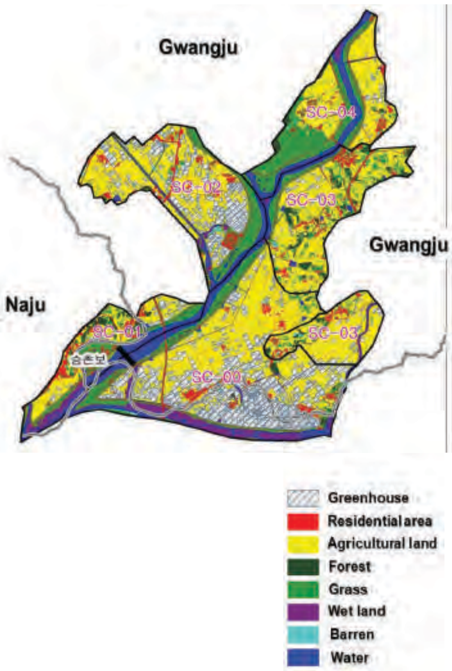
$P_e(= P - R - D)$: effective rainfall

[References] Song (2019)

30

4.2 Calculation of irrigation water requirement

(Example) Area of crop cultivation in the watershed



(unit : ha)

Greenhouse	Total	SC-00	SC-01	SC-02	SC-03	SC-04
Area	695	446	20	183	35	11
Ratio(%)	100	64.2	2.8	26.3	5.1	1.6

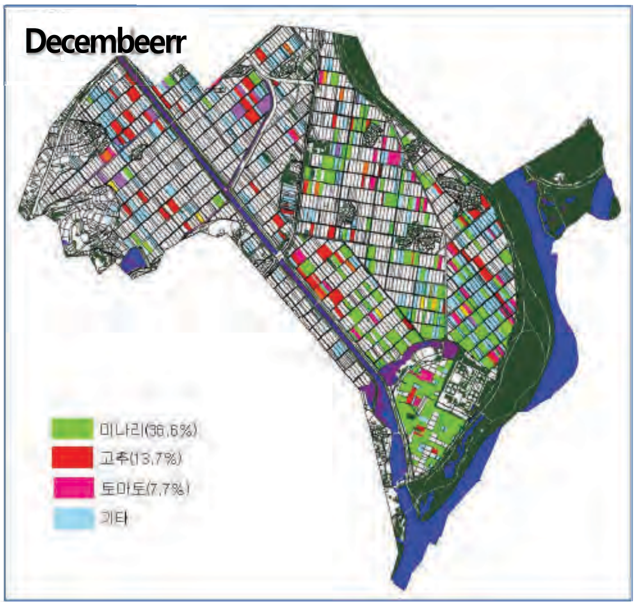
Area of SC-02~SC04	Single cropping	Double cropping	Total(㎡)	Ratio
Total	1,297,453	991,523	2,288,975	100.0%
Dropwort	200,944	470,373	661,749	28.9%
Tomato	354,340	119,774	477,726	20.9%
Young radish	349,118	44,680	395,509	17.3%
Chili(pepper)	91,765	120,832	215,650	9.4%
Water melon	103,071	-	104,886	4.6%
Eggplant	35,552	62,707	98,450	4.3%
Cucumber	55,158	16,649	72,302	3.2%
Leek	30,014	8,242	38,820	1.7%
Sesame	19,006	-	19,326	0.8%
Potato	10,416	2,938	13,458	0.6%
Strawberry	6,085	3,045	9,206	0.4%
Buckwheat	7,059	-	7,099	0.3%
The rest	34,927	142,283	174,793	7.6%

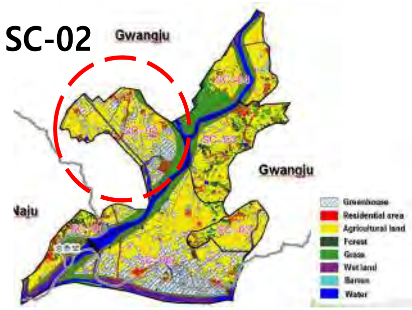
31

[References] Song (2019)

4.2 Calculation of irrigation water requirement

(Example) Crop cultivation status by month and land (lot)



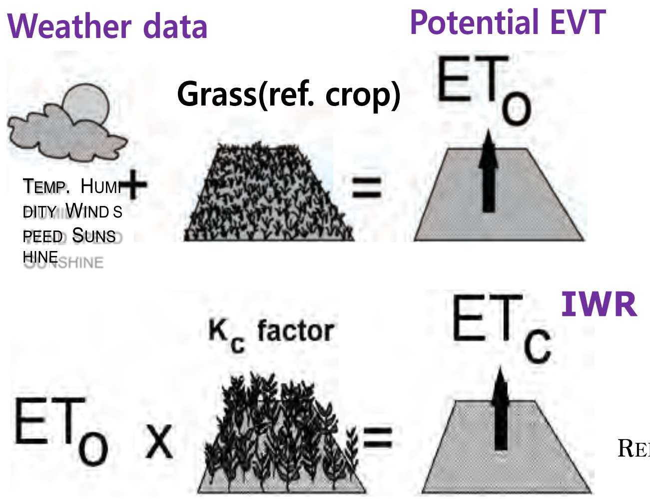


[References] Song (2019)

4.2 Calculation of irrigation water requirement

(Example) Calculation of irrigation water requirement

Irrigation water requirements (mm/day) = Potential EVT × Crop coefficient (Kc)



REF: FAO 56

4.2 Calculation of irrigation water requirement

(Example) Calculation of potential evapotranspiration (PET)

$$ET_0 = \frac{0.408\Delta(R_n - G) + r\frac{900}{T+273}U_2(es - ea)}{\Delta + r(1 + 0.34u_2)}$$

(unit : mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	PET
2010	25.9	34.7	58.1	83.1	113.7	116.3	106.5	108.5	92.0	65.6	40.3	28.8	**873.57**
2011	24.7	34.6	0.0	89.9	113.3	114.7	113.7	97.3	97.2	65.8	38.4	27.8	**817.49**
2012	28.8	34.2	0.0	94.4	127.4	125.3	122.2	130.1	92.3	71.5	41.8	23.8	**891.81**
2013	26.1	37.3	0.0	90.2	123.9	120.9	133.3	148.4	99.4	73.0	37.3	26.7	**916.50**
2014	31.1	41.4	0.0	93.8	139.2	125.6	124.7	100.3	96.8	71.6	37.4	23.8	**885.80**
2015	27.1	36.2	0.0	86.1	132.0	115.0	113.0	112.6	94.7	67.5	29.0	23.8	**837.08**
2016	25.0	37.6	0.0	90.6	124.6	103.8	125.7	132.4	80.0	53.4	37.9	25.3	**836.25**
2017	27.2	36.4	0.0	100.6	126.6	125.9	106.4	117.4	89.4	62.3	37.5	24.5	**854.07**
2018	24.2	35.6	0.0	91.5	105.4	121.2	143.7	136.0	82.2	59.6	34.3	27.9	**861.64**

[References] Song (2019)

4.2 Calculation of irrigation water requirement

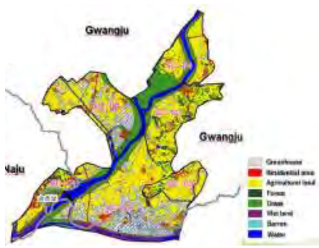
(Example) Calculation of crop coefficient

Month	Tomato	Young radish	Chili (pepper)	Water melon	Eggplant	Cucumber	Leek	Sesame	Potato	Strawberry	The rest
Jan	0.90	1.20	0.82	-	0.90	0.75	1.28	0.35	0.82	0.40	0.70
Feb	0.90	1.11	-	-	0.90	-	1.28	1.10	-	0.85	1.05
Mar	0.90	0.58	-	-	0.90	-	0.64	0.25	-	0.75	0.95
Apr	0.90	1.20	-	0.50	0.60	0.60	1.08	0.35	0.50	0.40	0.70
May	0.50	1.11	0.53	0.80	0.60	0.60	1.28	1.10	0.77	0.85	1.05
Jun	0.80	0.58	0.96	0.98	1.05	1.00	1.28	0.25	1.11	0.75	0.95
Jul	1.20	1.20	1.06	0.88	1.05	1.00	1.28	0.35	0.82	-	0.70
Aug	0.90	1.11	1.06	-	1.05	0.75	1.28	1.10	-	-	1.05
Sep	0.90	0.58	0.82	-	0.90	0.60	1.28	0.25	-	0.40	0.95
Oct	0.90	1.20	0.53	-	0.90	0.60	1.28	0.35	0.50	0.85	0.70
Nov	0.90	1.11	0.96	-	0.90	1.00	1.28	1.10	0.77	0.75	1.05
Dec	0.90	0.58	1.06	-	0.90	1.00	1.28	0.25	1.11	-	0.95

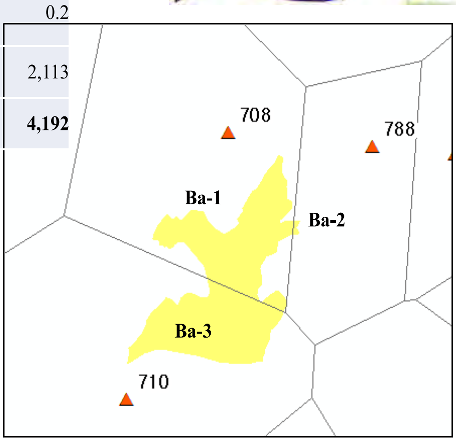
REF: RDA,RRI, FAO 56

4.2 Calculation of irrigation water requirement

(Example) Calculation of groundwater recharge



Watershed	Area (㎡)	Areal rainfall (mm)	Total amount of water ($\times 10^3$ ㎥)	Recharge rate	Recharge ($\times 10^3$ ㎥)
Ba-1	20,775,865	676	14,044	0.148	2,079
Ba-2	189,084	6	1.12	0.148	0.2
Ba-3	21,538,129	663	14,280	0.148	2,113
총 계	42,503,078	1,345	28,325		**4,192**



4.2 Calculation of irrigation water requirement

(Example) Estimation of potential water supply compared to IWR

Water budget = potential water supply – irrigation water requirements

(unit : 10^3 ㎥/year)

		Total	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Potential water supply		54,847	1,106	1,856	2,844	4,387	3,203	4,165	11,091	12,707	5,454	3,674	2,681	1,680
IWR	Total	43,312	3,058	9,944	2,941	365	1,819	1,831	2,045	1,963	4,351	1,962	3,112	9,920
	Crops from upland	3,862	104	133	184	346	403	496	759	626	299	244	158	109
	Dropwort	37,335	2,954	9,811	2,757	0	1,402	678	678	678	3,893	1,718	2,954	9,811
Water budget		13,649	-1,952	-8,088	-97	4,041	1,398	2,992	9,653	11,403	1,261	1,711	-431	-8,241

5. Conclusions

5. Conclusions

- **Understanding of the impact the climate crisis on the groundwater system is essential to stably supplying irrigation water and securing groundwater during the event of a drought.**

  - **Understanding groundwater system**
    - Hydrologic cycle
    - Subsurface distribution of water
    - Aquifer formation
    - Sustainable groundwater development
  - **Climate crisis environment**
    - Climate crisis
    - Climate change impact on agriculture
  - **Effect of drought on groundwater system**
    - Standardized precipitation index (SPI)/ Standardized groundwater level index (SGI)
    - Evaluation of drought for groundwater system
    - Determination of limit value of groundwater level
  - **Irrigation water requirement**
    - Irrigation water requirement (IWR)
    - Calculation of irrigation water requirement

Analysis of Aquifer Characteristics and Understanding Seawater Intrusion in Coastal Aquifer

Groundwater

Analysis of Aquifer Characteristics and Understanding Seawater Intrusion in Coastal Aquifer

United Nations Educational, Scientific and Cultural Organization

International Centre for Water Security and Sustainable Management

Aims and objectives

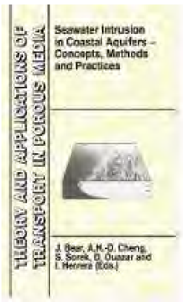
- The aims of the course are to:

  (1) understand the aquifer characteristics and groundwater model including mathematical modeling, statistical modeling and time-series modeling, and how to handle the long-term monitoring data with analysis method of them.
  (2) understand to trainees the principles of seawater intrusion and its variation according to sea level rise, and maintenance programs of groundwater with 4 steps in coastal aquifer.

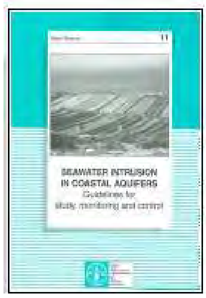
- The objectives are that trainees will understand:

  (1) aquifer characteristics
  (2) various groundwater modeling using aquifer characteristics
  (3) seawater intrusion variation according to sea level rise
  (4) maintenance program of groundwater in coastal aquifer

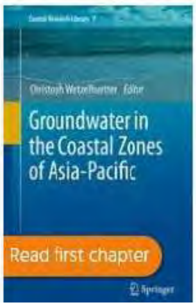
References



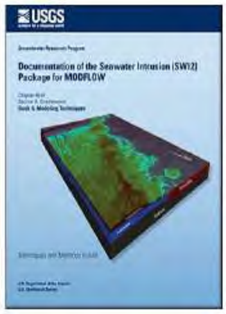
Seawater Intrusion in Coastal Aquifer-Concepts, Methods and Practices



Seawater Intrusion in Coastal Aquifers: Guidelines for study, monitoring and control by FAO



Groundwater in the coastal zone of Asia-Pacific



Documentation of the Seawater Intrusion (SWI2) Package for MODFLOW by USGS

Contents

1. Analysis of aquifer characteristics
   - Aquifer characteristics
   - Groundwater modeling
   - Characteristics of long-term monitoring data
   - Analysis method of long-term monitoring data
2. Seawater intrusion in coastal aquifer
   - Seawater intrusion (SI)
   - SI variation according to sea level rise
   - Maintenance program of groundwater in coastal aquifer
   - Seawater intrusion through coastal aquifer in Korea
3. Conclusions

1. Analysis of aquifer characteristics

1.1 Aquifer characteristics

1.2 Groundwater modeling

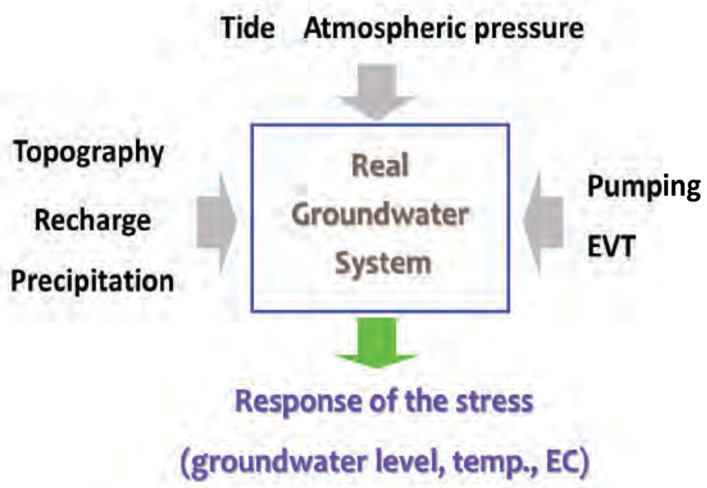
1.3 Characteristics of long-term monitoring data

1.4 Analysis method of long-term monitoring data

1.1 Aquifer characteristics

(Definition) Aquifers are characterized by physical properties including hydraulic conductivity, transmissivity and diffusivity.

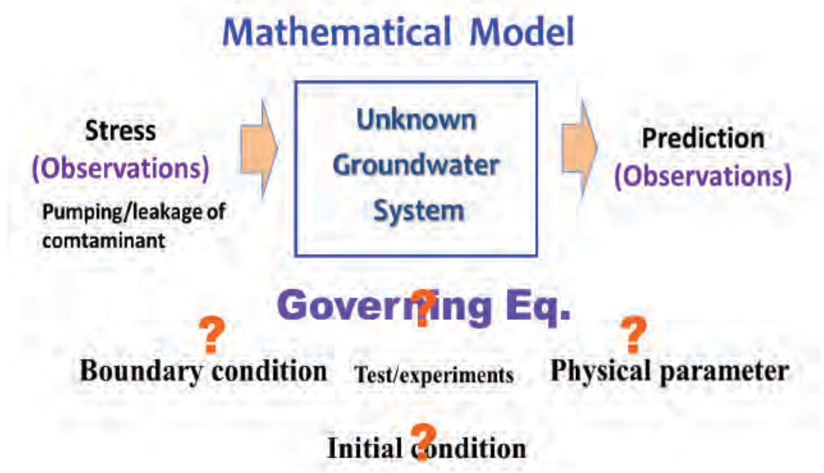
- What kind of characteristics for aquifer?
- What kind of information from the characteristics?
- What is purpose?
- How to approach to get the purpose?



1.2 Groundwater modeling

(Mathematical modeling) is a process in which real-time situation and relations in these situations are expressed by mathematics.

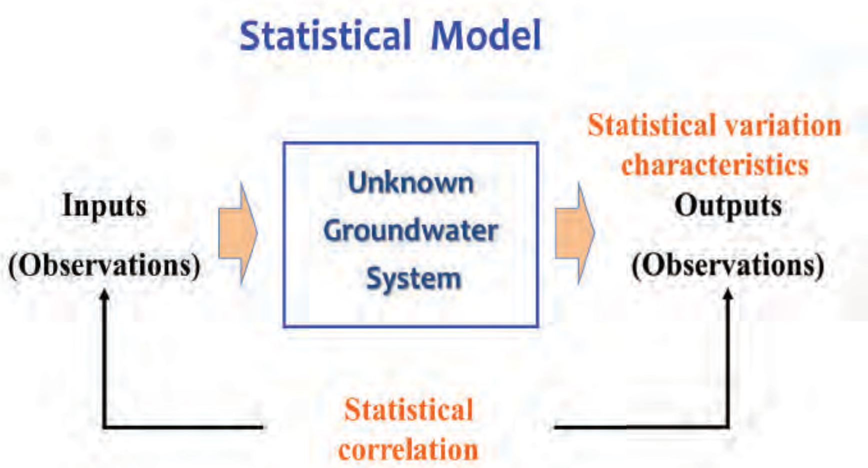
- Mathematical modeling is description of a groundwater system using mathematical concepts and language.
- Mathematical modeling is the process of using various mathematical structure including graphs, equations, diagrams, scattered plots, and etc.



1.2 Groundwater modeling

(Statistical modeling) is the use of mathematical models and statistical assumptions to generate sample data and make predictions the real world.

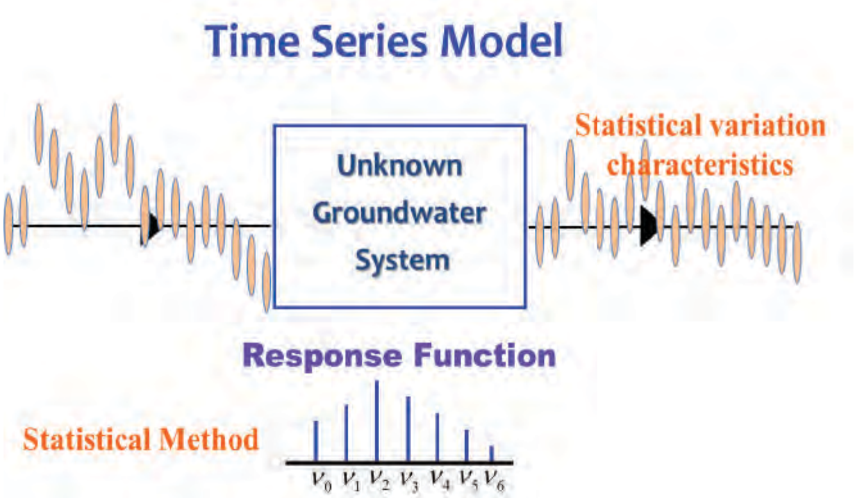
- Statistical modeling is the process of applying statistical analysis to a dataset and statistical model is a mathematical representation of observed data.
- Some common types of statistical models are correlation test, regression model, analysis of variance, analysis of covariance, and etc.



1.2 Groundwater modeling

(Time-series modeling) is used to forecast future events based on previous events that have been observed at regular time intervals.

- A time-series is a series of data points indexed in time order and a sequence taken at successive equally spaced points in time
- Time series models are widely used to predict the seasonal variability of a target variable over time, where past values are used as the input variables for the model.



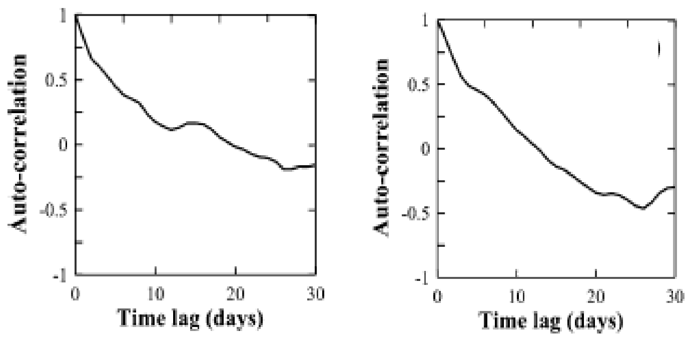
1.3 Characteristics of long-term monitoring data

(Long-term monitoring data) shows High auto-correlation due to the measurement successively

- It's necessary to be careful to use the statistical analysis because basic assumption of statistical analysis is that each data is distributed independently whereas both mean and variance are constant.

Auto-correlation function at lag k

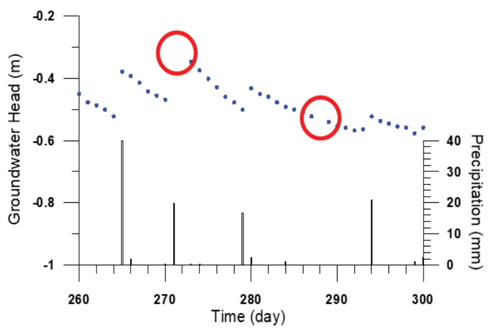
$$\rho_k = \frac{E[(y_t-\mu)(y_{t+k}-\mu)]}{\sqrt{E[(y_t-\mu)^2 E[(y_{t+k}-\mu)^2]}} = \frac{E[(y_t-\mu)(y_{t+k}-\mu)]}{\sigma_y^2}$$



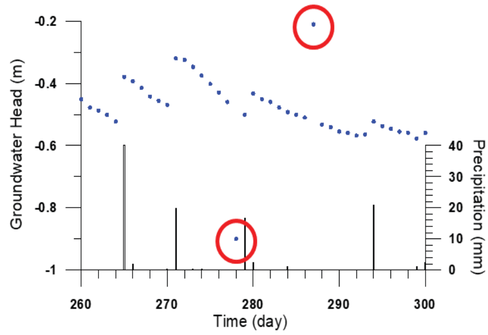
1.3 Characteristics of long-term monitoring data

(Long-term monitoring data) There are missing data and outliers from time to time.

- It's necessary to consider these because these could affect to statistics results and characteristics.
- An outlier may be due to variability in the measurement or it may indicate experimental error, the latter are sometimes excluded from the data set.



Missing data

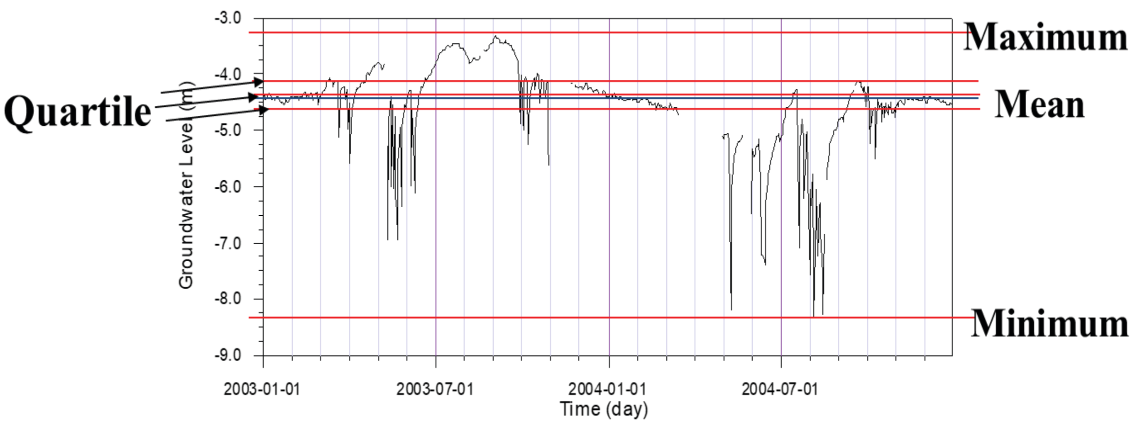


Outliers

1.3 Characteristics of long-term monitoring data

(Long-term monitoring data) Time-series data with very large fluctuations in continuous dataset

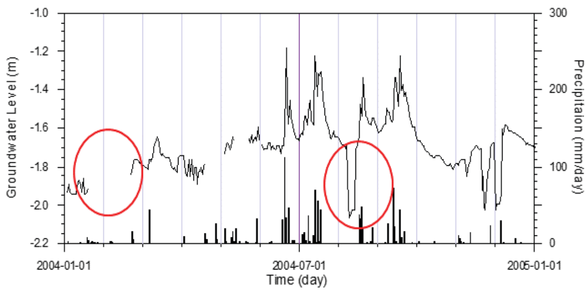
- It's difficult to indicate the variation characteristics of data with certain statistical values.
- Foe quantitative analysis of time-series data with very large fluctuation, the results of percentile analysis are highly recommended.

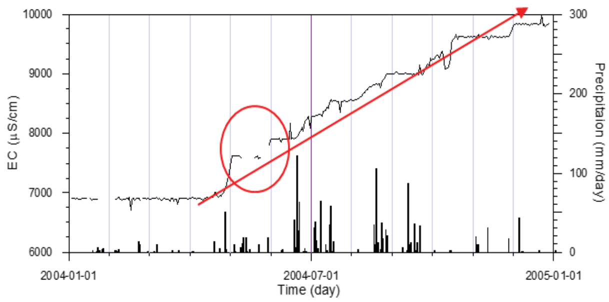


1.4 Analysis method of long-term monitoring data

(Analysis method of long-term monitoring data) Visualization with time-series graphs

- To classify with variation type
- To determine of outliers/missing data
- To display of hydrological data such as rainfall, tide, and hydrograph
- To analyze topology, geology, and so on





1.4 Analysis method of long-term monitoring data

(Analysis method of long-term monitoring data) Basic statistics

- Parametric values: maximum, minimum, mean, variance, standard deviation,,
- Non-parametric values: 1st quartile, median, 3rd quartile, and etc.
- (example) Basic statistics and non-parametric trend analysis for long-term monitoring of groundwater levels in the Waimea Plains, New Zealand

Well name	Aquifer	Periods	Groundwater level (mm, amsl)						Non-parametric trend analysis		
			Min.	Median	Mean	Max.	Range	SD	M-K[a]	Slope[b]	P
CW2	A[c]	1974-2009	4042	5208	5218	7190	3148	474	Downward	-6.75	0.00
RR	A, U[d]	1975-2009	13746	19248	19128	22010	8264	1151	-[f]	-6.37	0.11
CM	L[e]	1976-2009	-4098	2361	1852	4829	8927	1552	Downward	-25.00	0.00
ERI	L	1983-2009	309	881	860	1269	960	147	Downward	-1.80	0.03
BI	L	1983-2009	-31	975	914	1535	1566	256	Downward	-6.37	0.00
BC2	A	1995-2009	14402	17014	17094	20669	6267	1268	-	-6.13	0.74
MC	A	1997-2009	1429	2462	2478	5234	3805	298	Upward	11.83	0.04
FS	A	2001-2009	33314	33678	33696	34777	1463	177	Upward	14.21	0.04
MK	A	2001-2009	1459	29269	28875	31074	29615	3616	-	1.04	0.82
SS	A	2001-2009	23835	24398	24529	26435	2600	411	Upward	17.86	0.08
Mean			8841	13549	13464	15502	6662	935		-0.75	

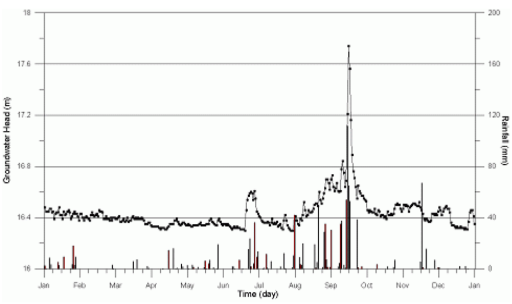
[a] Mann-Kendall test
[b] Sen's Slope median (annual)
[c] AGUA
[d] UCA
[e] LCA
[f] No judgement

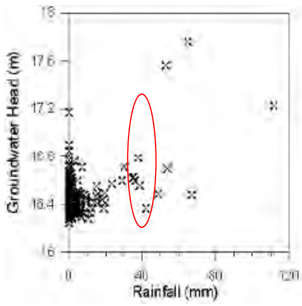
Reference: Song and Zemansky (2012)

1.4 Analysis method of long-term monitoring data

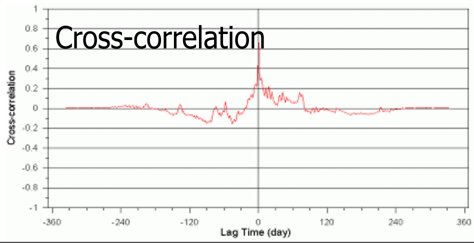
(Analysis method of long-term monitoring data) Correlation analysis

- Correlation analysis is a method of statistical evaluation used to study the strength of a relationship between the two, numerically measured and continuous variables.
- This type of analysis is useful when a researcher wants to establish if there are possible connection between variables.





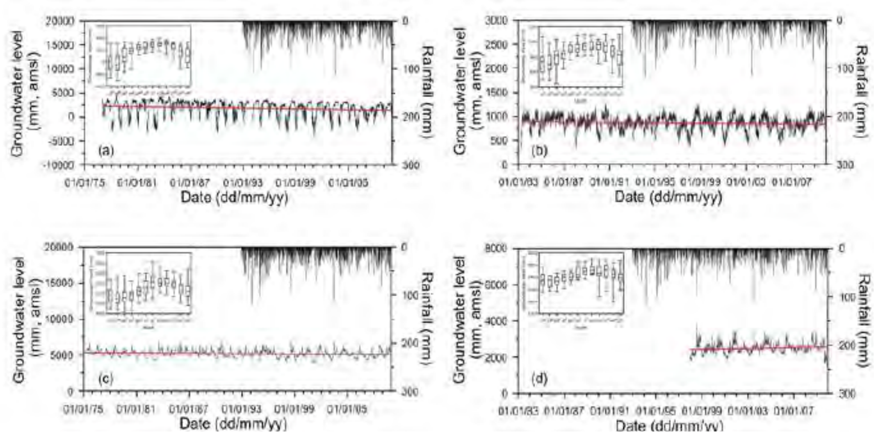
Scattered diagram: no quantitative information but trend



1.4 Analysis method of long-term monitoring data

(Analysis method of long-term monitoring data) Trend analysis

- Linear trend analysis: slope, determination coefficient fitting with line which has x-axis (time) with observation values
- Non-parametric trend analysis: Sen's test, Mann-Kendall test
- (example) Linear regression of groundwater level data for trend identification with box plot at 4 wells in the Waimea Plains, New Zealand

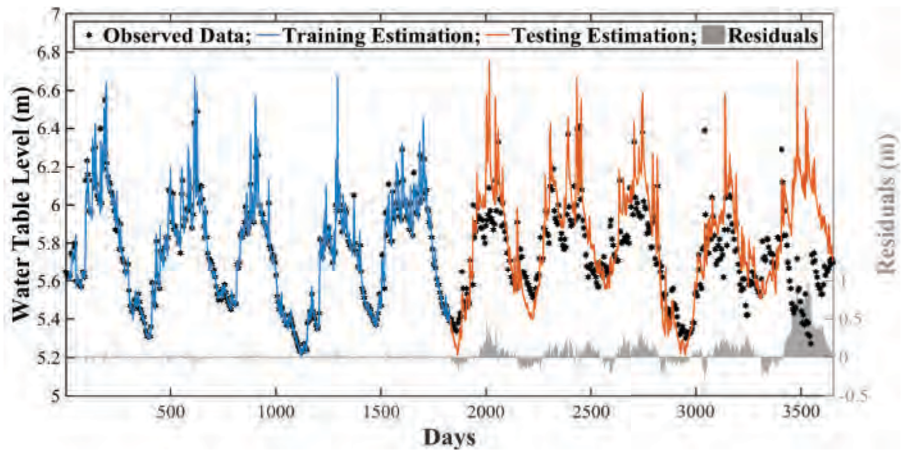


Reference: Song and Zemansky (2012)

1.4 Analysis method of long-term monitoring data

(Analysis method of long-term monitoring data) Time-series analysis

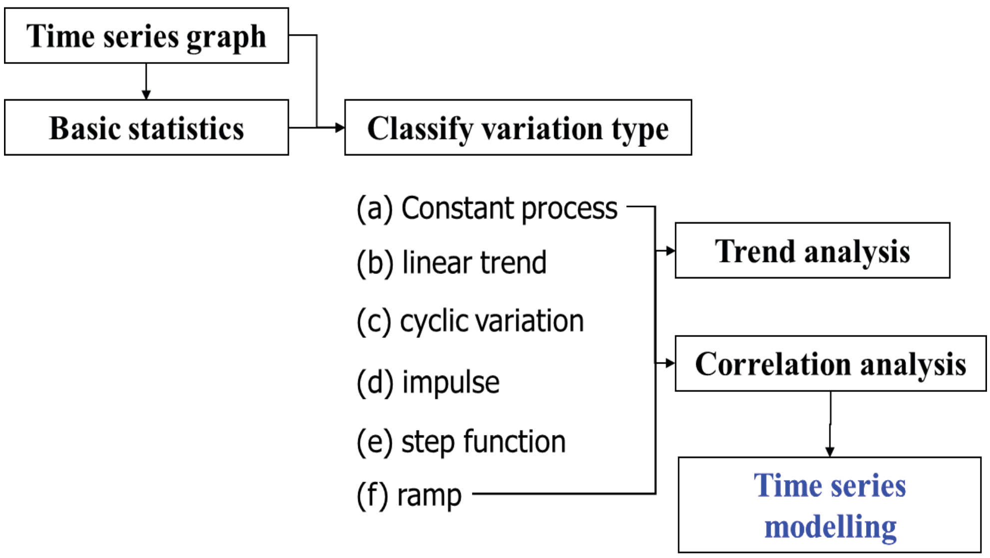
- Forecast of the future using data up to now under the assumption of sustainable variation from the past
- Understanding and controlling of system or process for the model building of system or process for the generation of time-series data



Reference: Rural Research Institute (2019)

1.4 Analysis method of long-term monitoring data

(Analysis method of long-term monitoring data) Processes



2. Seawater intrusion in coastal aquifer

2.1 Seawater intrusion (SI)

2.2 SI variation according to sea level rise

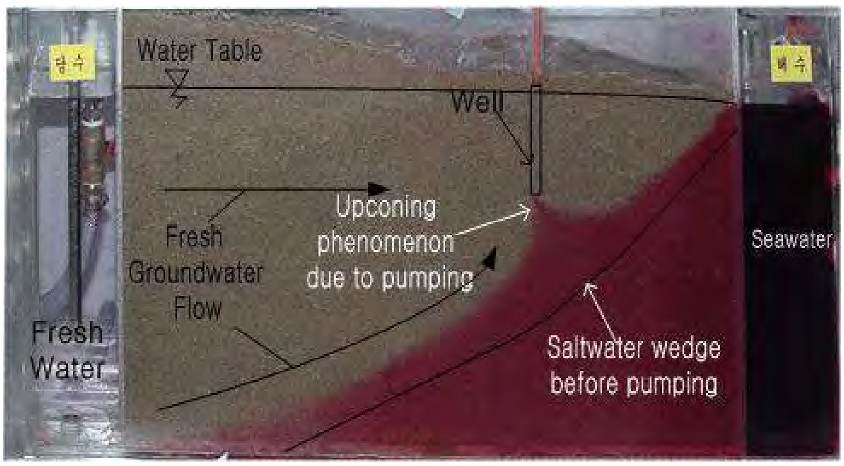
2.3 Maintenance program of groundwater in coastal aquifer

2.4 Seawater intrusion through coastal aquifer in Korea

2.1 Seawater intrusion

(Definition) Seawater intrusion is the movement of seawater into fresh water aquifers due to natural processes or human activities.

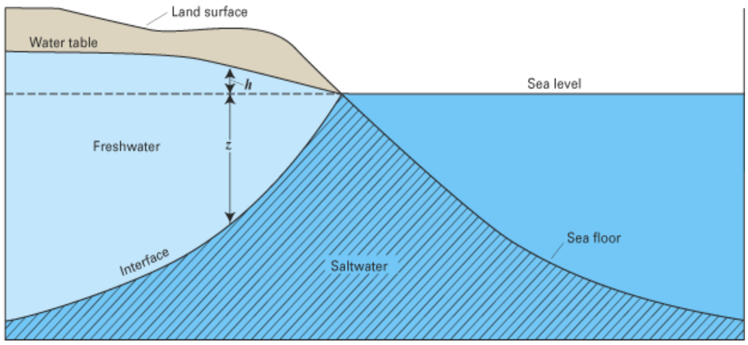
- When groundwater is pumped from aquifer that are in hydraulic connection with the sea, the gradients that are set up may induce a flow of salt water from the sea toward the well.
- This migration of salt water into freshwater aquifers under the influence of groundwater development.



2.1 Seawater intrusion

Ghyben-Herzberg relationship

- This eq. derived analytical solutions to approximate the seawater intrusion behavior, which are based on a number of assumptions that do not hold in all field cases.
- In unconfined aquifer, the thickness of the freshwater zone above sea level is represented as h and that below sea level is represented as z.
- The two thicknesses h and z are related by ρ_f and ρ_s where ρ_f is the density of freshwater and ρ_s is the density of saltwater.
- Freshwater has a density of about 1.000 g/cm^3 at 20 °C, whereas that of seawater is about 1.025 g/cm^3. Therefore, The equation can be simplified to $z = 40h$



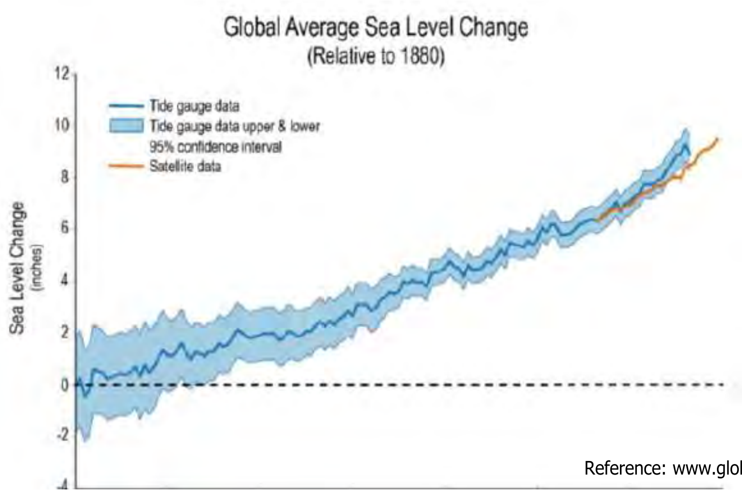
$$\rho_f g(h+z) = \rho_s g z$$
$$\rightarrow \rho_f h = (\rho_s - \rho_f) z$$

$$z = \frac{\rho_f}{(\rho_s - \rho_f)} h$$

2.2 Seawater intrusion variation according to sea level rise

(Definition) Rising global sea level is a critical consequence of climate change and ocean waters expand according to the warm of air temp., ice sheet melting, and glaciers entering into ocean basin.

- Sea level rise is caused primarily by two factors related to global warming: the added water from melting ice sheets and glaciers and the expansion of seawater as it warms.
- Global sea level has risen by about 20 cm since scientific record keeping began in 1880.



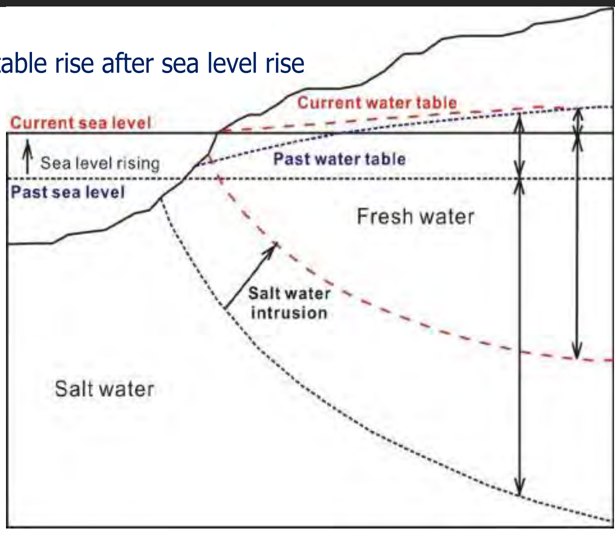
Reference: www.globalchange.gov

2.2 Seawater intrusion variation according to sea level rise

(Definition) Climate change is expected to further exacerbate seawater intrusion due to sea level rise coupled with higher temperature.

- Climate change effects are expected to substantially raise the average sea level and sea level rise influences groundwater hydraulics and in particular seawater intrusion in many coastal aquifer.
- Seawater intrusion affected by the lateral movement of seawater and the change of groundwater head.

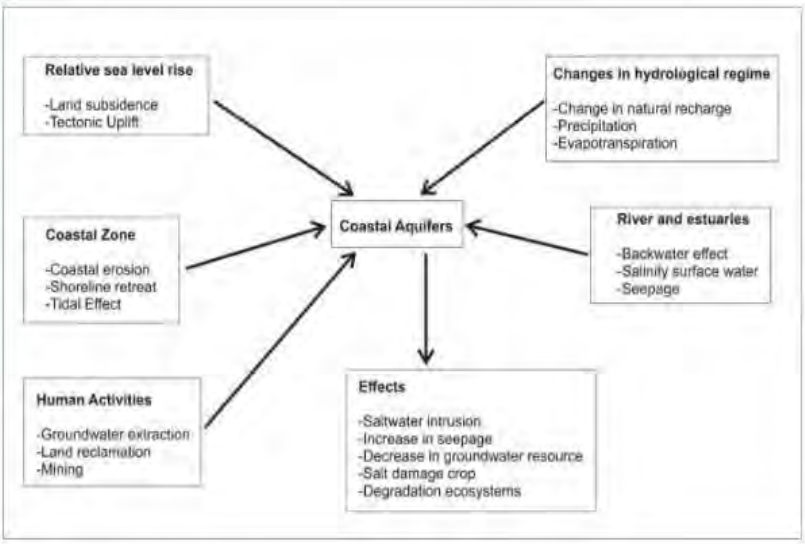
Conceptual model of groundwater table rise after sea level rise under sharp interface condition



2.3 Maintenance program of groundwater in coastal aquifer

Factors affecting the coastal aquifer and their effects

- In coastal areas, groundwater being the primary source of freshwater is exploited indiscriminately to fulfill the increasing water demands for domestic, agricultural as well as industrial usages.
- Factors affect the hydrodynamic equilibrium between the freshwater and seawater with the causes of seawater intrusion in coastal aquifer.



Reference: Kumar (2006)

2.3 Maintenance program of groundwater in coastal aquifer

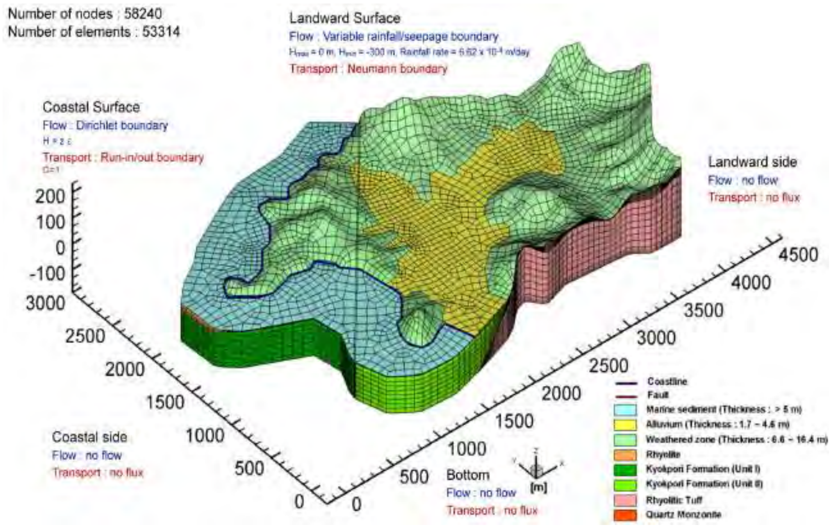
4 steps of suggestion for maintenance program of groundwater

- step 1: maximum groundwater discharge using optimal arrangement of pumping well
- step 2: additional maintenance of groundwater resources through controlling saltwater wedge
- step 3: increment of groundwater resources through ASR (aquifer storage recovery)
- step 4: maximization of groundwater utilization using underground dam

Reference: Namsik Park (2003)

2.3 Maintenance program of groundwater in coastal aquifer

step 1: maximum groundwater discharge using optimal arrangement of pumping well

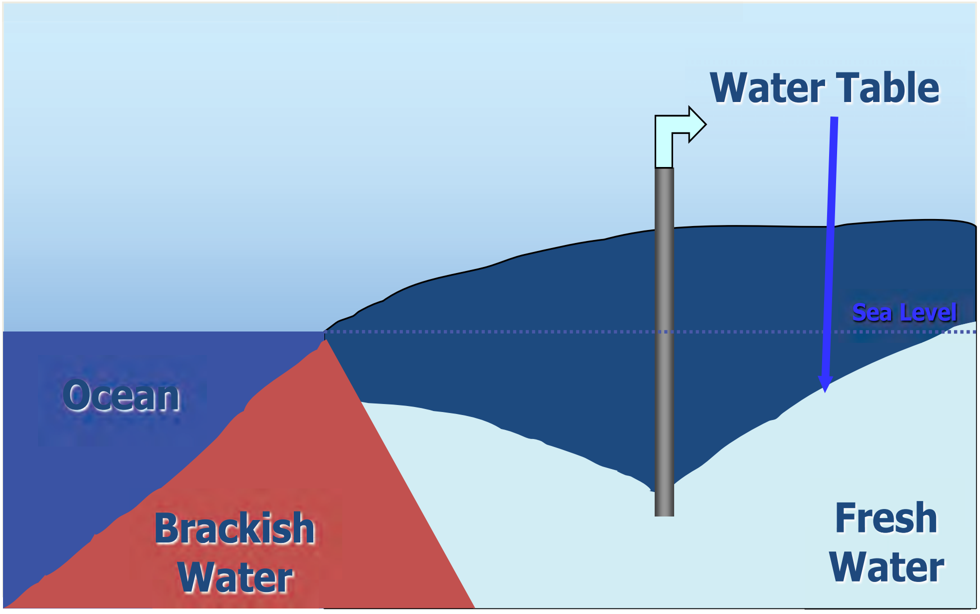


Reference: Junmo Kim (2005)

2.3 Maintenance program of groundwater in coastal aquifer

step 2: additional maintenance of groundwater resources through controlling saltwater wedge

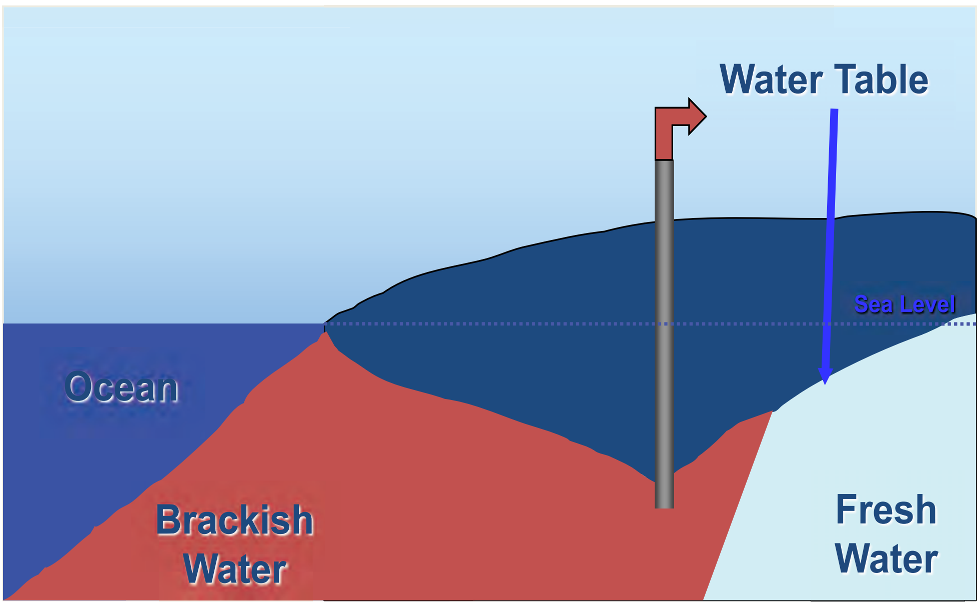
Coastal Aquifer - With Pumping



2.3 Maintenance program of groundwater in coastal aquifer

step 2: additional maintenance of groundwater resources through controlling saltwater wedge

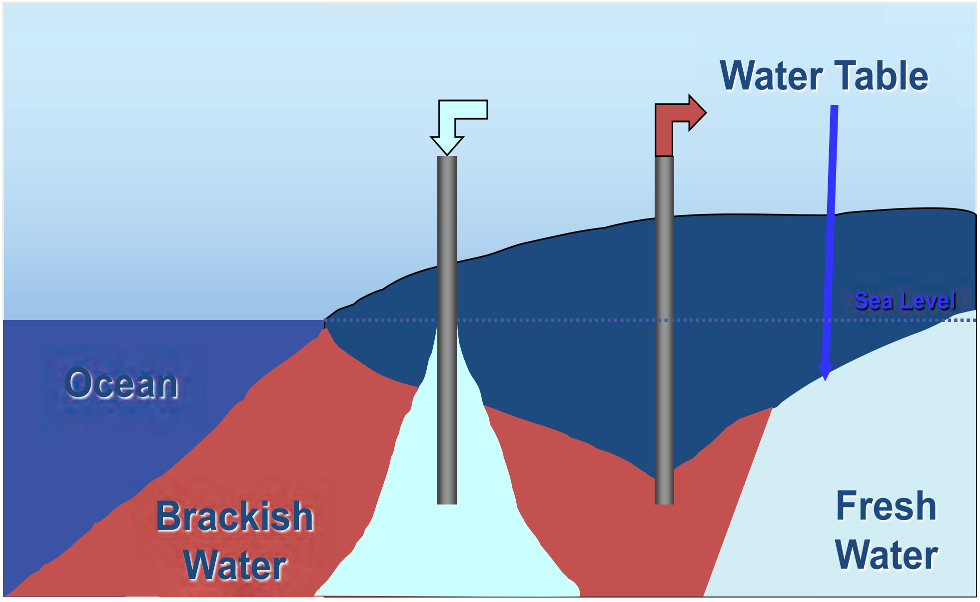
Coastal Aquifer - Intrusion Advancing



2.3 Maintenance program of groundwater in coastal aquifer

step 2: additional maintenance of groundwater resources through controlling saltwater wedge

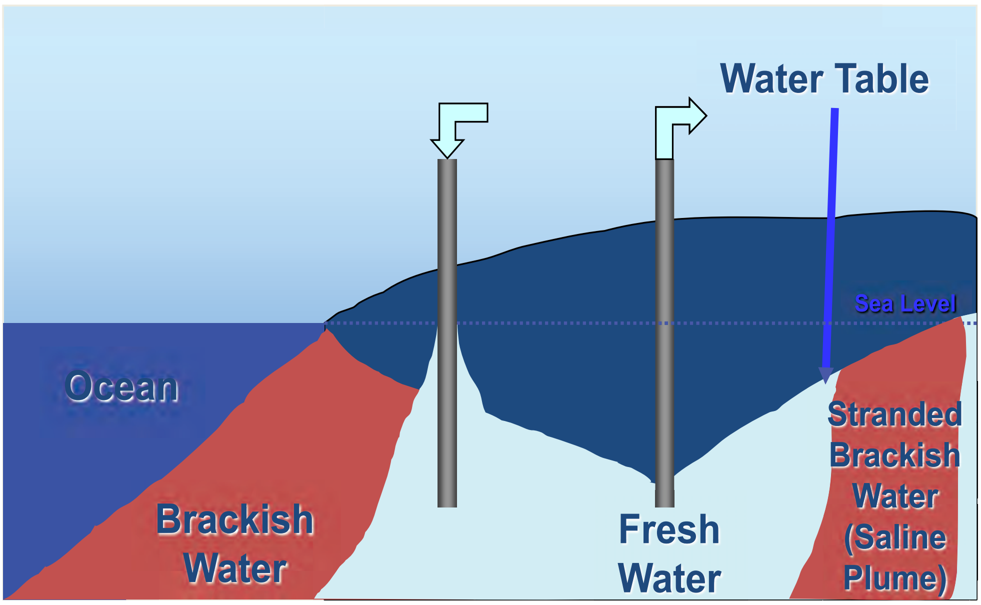
Coastal Aquifer - Pumping and Injection



2.3 Maintenance program of groundwater in coastal aquifer

step 2: additional maintenance of groundwater resources through controlling saltwater wedge

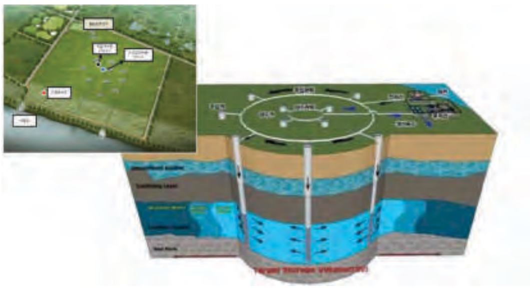
Coastal Aquifer - Pumping and Injection

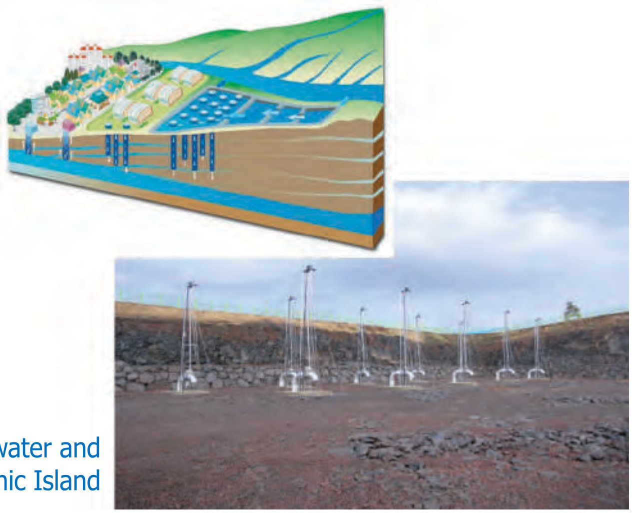


2.3 Maintenance program of groundwater in coastal aquifer

step 3: increment of groundwater resources through ASR (aquifer storage recovery)

Case 1. ASR for securing domestic groundwater in Busan



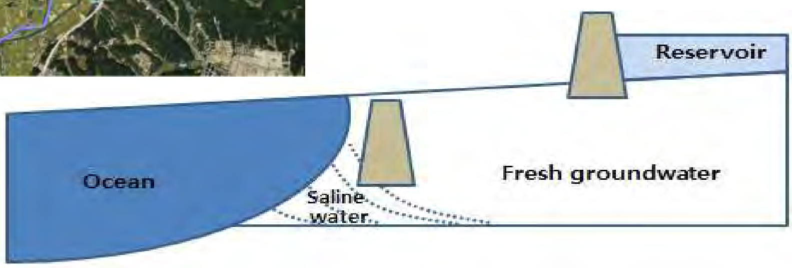


Case 2. ASR for securing groundwater and preventing flood in Jeju volcanic Island

2.3 Maintenance program of groundwater in coastal aquifer

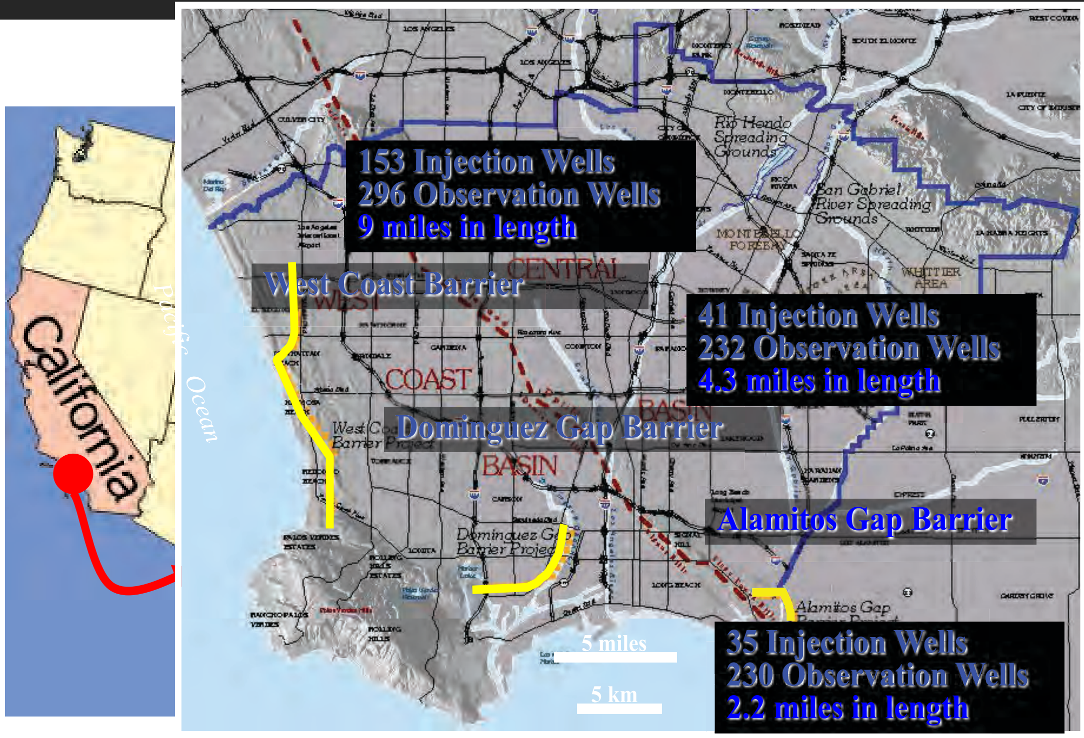
step 4: maximization of groundwater utilization using underground dam

Namsong subsurface dam in south-west Korea
(type to prevent seawater intrusion + secure additional groundwater)



2.3 Maintenance program of groundwater in coastal aquifer

step 4: maximization of groundwater utilization using underground dam



2.4 Seawater intrusion through coastal aquifer in Korea

Characteristics of groundwater in coastal area

- Decreases in the groundwater levels are mostly attributed to pumping for irrigation
- There has seldom seawater intrusion in east part of the country because high topographic elevations of the mountain adjacent to East Sea.

- From the non-parametric trend analysis, 13.3~15.6% of water level were decreasing
- Seawater intrusion is widely occurring over the west and south coasts of the country

2.4 Seawater intrusion through coastal aquifer in Korea

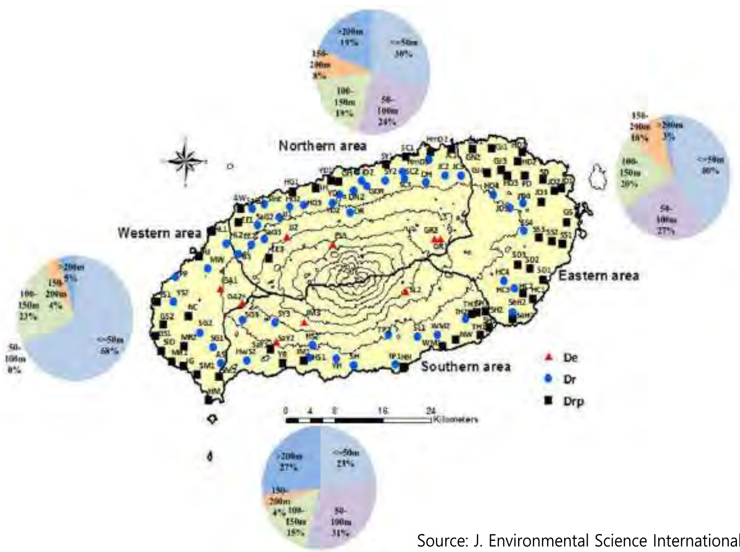
- **(Seawater intrusion monitoring networks)**
  - An around-the-clock monitoring system for seawater intrusion in coastal areas is installed to protect the hazard on farmlands by irrigating relatively saline groundwater in coastal areas.
  - The groundwater wells in SIMNs is monitoring various items: groundwater level, temperature, and electrical conductivity which are measured by multi-level sensors.

SIMNs

Multi-level sensors invented by RRI
one level sensor is placed just below the lowest groundwater level and two EC sensors are designated to be placed onto and above transition zone between saline water and freshwater, respectively.

2.4 Seawater intrusion through coastal aquifer in Korea

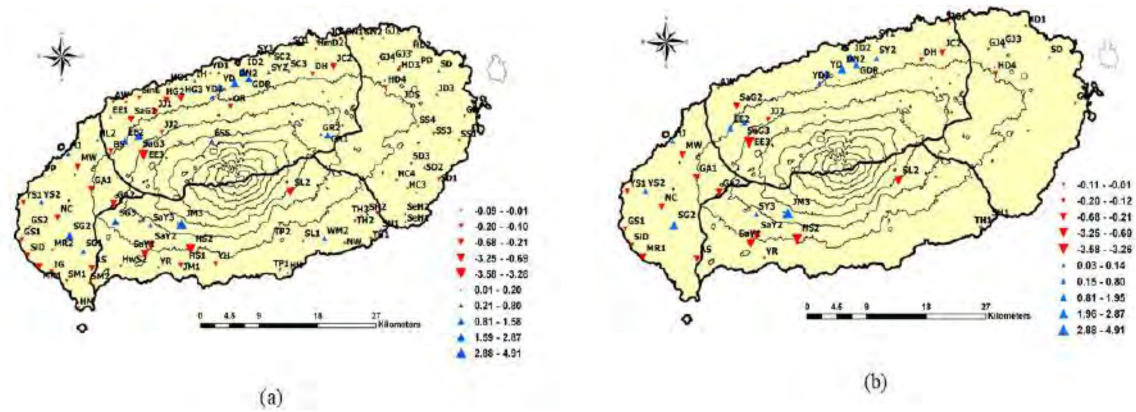
- **(Case of seawater intrusion monitoring from SIMNs in Jeju Island)**
  - Regional classification for 115 groundwater monitoring wells with three representative variation types; Dr (affected by rainfall only), Drp (affected by rainfall and pumping, simultaneously), and De (no special factors)



Source: J. Environmental Science International (Song et al., 2013)

2.4 Seawater intrusion through coastal aquifer in Korea

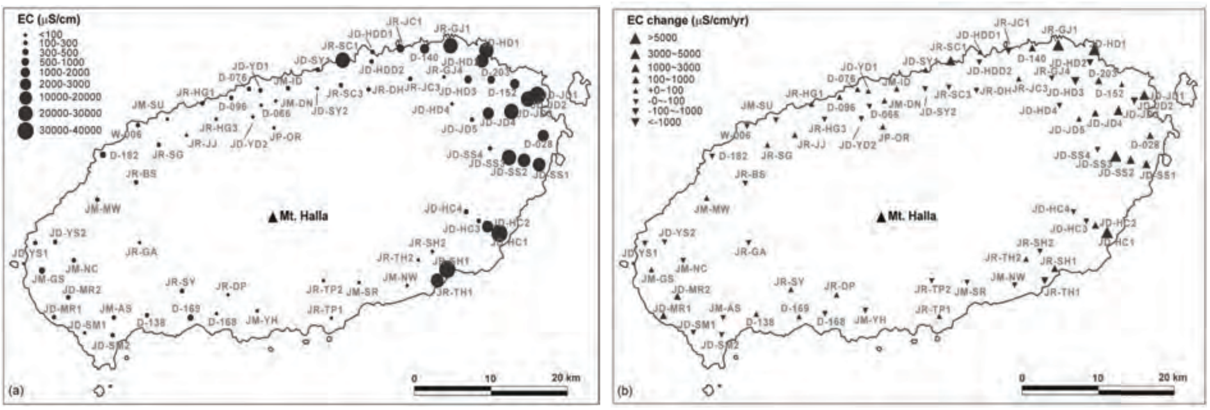
- **(Case of seawater intrusion monitoring from SIMNs in Jeju Island)**
  - Distribution of trend analysis of groundwater levels using linear regression method (a) and non-parametric method (b)



Source: J. Environmental Science International (Song et al., 2013)

2.4 Seawater intrusion through coastal aquifer in Korea

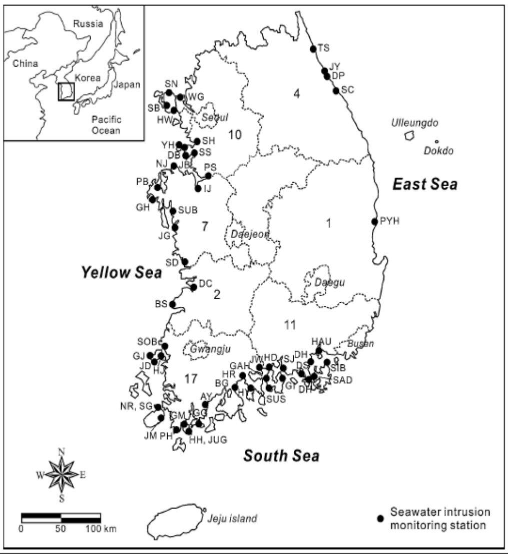
- **(Case of seawater intrusion monitoring from SIMNs in Jeju Island)**
  - Distribution of the mean of EC (a) and changing rates (b)
  - The highest EC levels (30,000-40,000 μS/cm) are observed at the eastern part.
  - The large EC values along the coast line indicate gradual encroachment of seawater.
  - Interestingly, areas with high EC levels or high EC increasing rates are not identical to those with high water level decreasing rates.

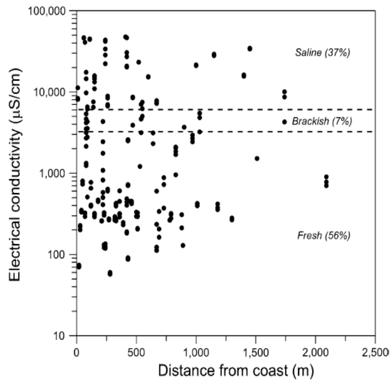


Source: J. Korean Earth Science Society (Lee et al., 2007)

2.4 Seawater intrusion through coastal aquifer in Korea

- **(Evidences of seawater intrusion in Korea)**
  - Contamination of groundwater by seawater intrusion poses a threat to sustainable agriculture in the coastal areas of Korea.
  - Seawater intrusion monitoring stations were installed in eastern, western, and southern coastal areas and have been operated since 1998.

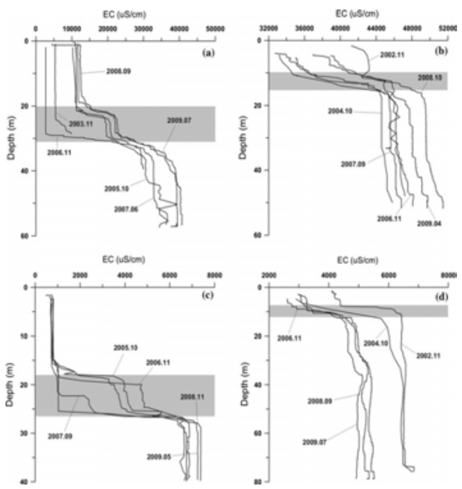




Reference: Park et al. (2012)

2.4 Seawater intrusion through coastal aquifer in Korea

- **(Evidences of seawater intrusion in Korea)**
  - To estimate the vulnerability of groundwater systems with sea level rise within coastal aquifers in South Korea, long-term groundwater data were analyzed using basic statistics, trend analysis, and correlation analysis.



Reference: Song and Zemansky (2012)

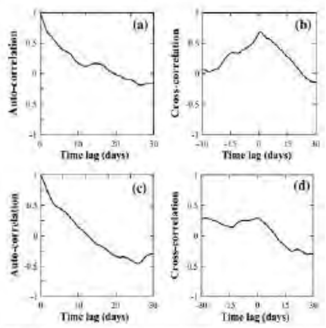


Fig. 7 Auto-correlation and cross-correlation between rainfall and groundwater levels during the dry season at monitoring well GG1 in the relatively dry year of 2008 (a, b) and during the rainy season at monitoring well GI2 in the relatively wet year of 2003 (c, d), respectively

Table 4 Results of cross-correlation analysis between cumulative rainfall and groundwater level with cyclic variation from auto-correlation analysis

Well ID	Rainfall (mm/year)	Dry season TL (days)	Dry season CC	Rainy season TL (days)	Rainy season CC	Cyclic period
Relatively dry year						
SB1	1,170	–	–	–	–	–
DH1	1,207	[illegible]	[illegible]	[illegible]	[illegible]	–
SDD1	1,207	–	–	[illegible]	[illegible]	–
GI2	1,081	[illegible]	[illegible]	–	–	–
JG1	814	–	–	–	–	–
JG2	814	[illegible]	[illegible]	[illegible]	[illegible]	–
GI2	981	[illegible]	[illegible]	–	–	[illegible]
GG1	1,180	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SG1	1,099	–	–	[illegible]	[illegible]	[illegible]
SG2	1,099	–	–	–	–	–
Relatively wet year						
SB1	1,641	–	–	[illegible]	[illegible]	–
DH1	2,714	[illegible]	[illegible]	[illegible]	[illegible]	–
SDD1	2,714	[illegible]	[illegible]	[illegible]	[illegible]	–
GI2	2,730	[illegible]	[illegible]	[illegible]	[illegible]	–
JG1	1,344	[illegible]	[illegible]	[illegible]	[illegible]	–
JG2	1,344	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
GI2	1,667	–	–	[illegible]	[illegible]	–
GG1	2,221	[illegible]	0.40	–	–	[illegible]
SG1	2,199	–	–	–	–	–
SG2	2,199	[illegible]	[illegible]	–	–	–

[a] Time lag
[b] Cross-correlation coefficient
[c] Cyclic period for dry or rainy season

Table 5 Results of cross-correlation analysis between sea and groundwater levels with hourly based data

Well ID	Data[a]	Time lag (days)	CC[b]	Sea level station
SB1	1,801	8	0.41	IC
DH1	3,251	1	0.37	TY
SDD1	2,640	3	0.25	TY
GI2	1,880	2	0.41	YS
JG1	2,191	6	0.16	BR
JG2	1,921	4	0.37	BR
GI2	2,164	3	0.08	YK
GG1	2,170	5	0.53	WD
SG1	2,105	–	–	MK
SG2	1,579	–	–	MK

[a] Number of data excluding missing period
[b] Cross-correlation coefficient

3. Conclusions

3. Conclusions

- **Understanding of the aquifer characteristics and groundwater modeling including mathematical modeling, statistical modeling and time-series modeling with long-term monitoring data, and seawater intrusion with maintenance program of groundwater in coastal aquifer**

  - **Analysis of aquifer characteristics**
    - Aquifer characteristics
    - Groundwater modeling
    - Characteristics of long-term monitoring data
    - Analysis method of long-term monitoring data

  - **Seawater intrusion in coastal aquifer**
    - Seawater intrusion
    - Seawater intrusion variation to sea level rise
    - Maintenance program of groundwater in coastal aquifer
    - Seawater intrusion through coastal aquifer in Korea


Thank you very much

Utilization of Groundwater (Geothermal Energy)

Groundwater

Utilization of Groundwater (Geothermal Energy)

UNESCO United Nations Educational, Scientific and Cultural Organization
i-WSSM International Centre for Water Security and Sustainable Management

Aims & Objectives

- The aims of the course are to:

  (1) Learn about type types of renewable energy and study the types of geothermal energy;
  (2) Study the heat exchange method of geothermal energy and understand the advantages and disadvantages of the heat exchange method
  (3) Study the efficiency according to the results of economic analysis of geothermal energy

- The objectives are that trainees will understand:

  (1) Types of renewable energy
  (2) Types of geothermal heat exchange method
  (3) Efficiency of geothermal energy using heat pump

Contents

1. Renewable energy

1.1 New and renewable energy
1.2 Alternative energy sources
1.3 Geothermal energy

1.1 New and renewable energy

◆ **(Definition) Energy used by converting existing fossil fuels or by converting renewable energy including sunlight, water, geothermal heat, precipitation, and biological organisms**

- New energy : hydrogen energy, fuel cell, coal liquefied gasification and heavy residual oil, gasification energy
- Renewable energy : solar energy, wind power, bioenergy, waste energy, geothermal, hydropower, marine energy

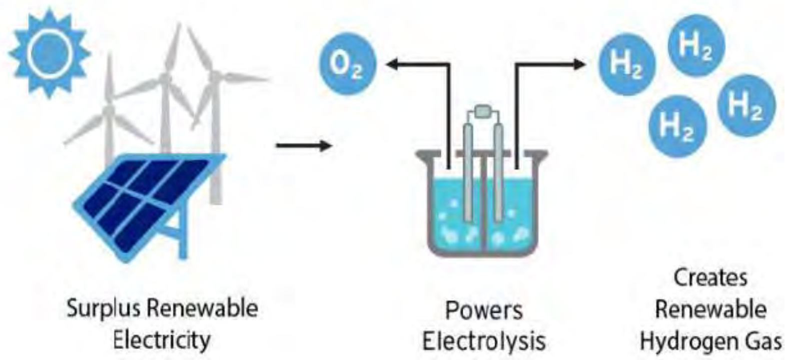
[Renewable energy]

Source : Biomass Magazine, "AEBIOM gives feedback on new renewable energy directive post-2020" Mar. 17 , 2016

1.1 New and renewable energy

◆ **(New energy) Energy that converts and uses existing fossil fuels or uses electricity or heat through chemical reactions such as hydrogen and oxygen**

- Hydrogen energy is energy that is used by decomposing or using explosive power during gaseous hydrogen combustion



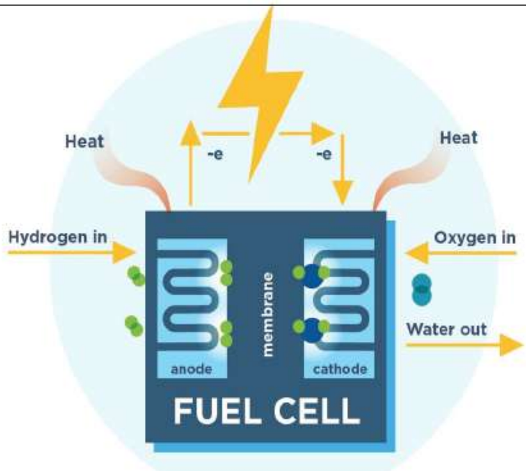
[Hydrogen energy]

Source : Fuel Cell & Hydrogen Energy Association web site

1.1 New and renewable energy

◆ **(New energy) Energy that converts and uses existing fossil fuels or uses electricity or heat through chemical reactions such as hydrogen and oxygen..**

- A fuel cell is an energy that directly converts chemical energy generated by the chemical reaction of hydrogen and oxygen into electrical energy.



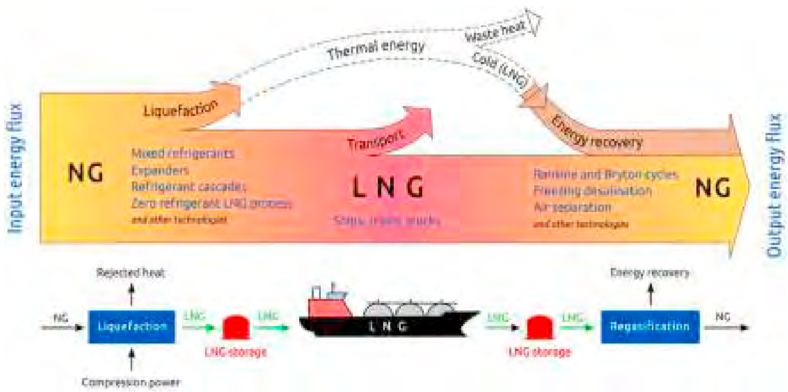
[Fuel cell energy]

Source : Fuel Cell & Hydrogen Energy Association web site

1.1 New and renewable energy

◆ **(New energy) Energy that converts and uses existing fossil fuels or uses electricity or heat through chemical reactions such as hydrogen and oxygen..**

- Energy produced by liquefying and gasifying coal and energy by gasification of heavy residual oil is energy that generates electricity by driving gas turbines and steam turbines using low-grade raw materials such as coal and heavy residual oil.



[Liquefying and gasifying energy]

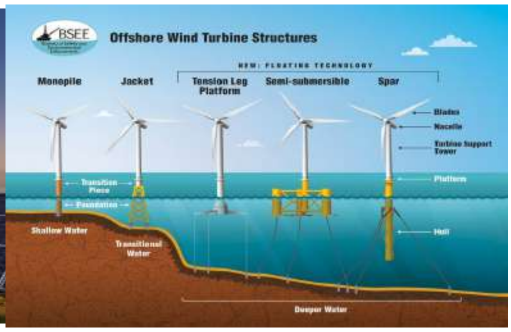
Source : renewable and sustainable energy reviews, Vol. 99, Jan 2019, pp 1-15.

1.1 New and renewable energy

◆ **(Renewable energy) It refers to energy used by converting renewable energy including sunlight, water, geothermal heat, precipitation, and living organisms.**

- Solar energy includes solar light, which produces electricity using light energy radiated from the sun and reaches the earth, and solar heat, which uses heat from the sun to produce electricity.
- Wind energy is energy that converts the power of wind into rotational power and converts it into electrical energy.

[Solar energy]



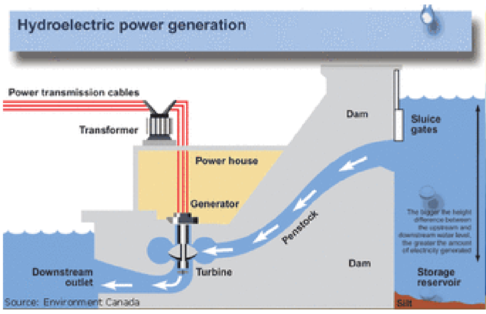
[Wind energy]

Source : ready-to-float : a permanent cost reduction for offshore wind, WPED Contributor, Sep. 27, 2021
Renewable energy market update, May, 2020.

1.1 New and renewable energy

◆ **(Renewable energy) It refers to energy used by converting renewable energy including sunlight, water, geothermal heat, precipitation, and living organisms.**

- Hydraulic energy is energy that generates electricity by using potential energy or kinetic energy of water as power.
- Ocean energy includes wave power generation by waves in the ocean, tidal power generation using sea level rise and fall, tidal power generation, and temperature difference power generation using the temperature difference between the surface and deep sea water.



[Hydraulic energy]

[Ocean energy]

Source : Hydroelectric Power : How it Works, USGS,
New technologies in the ocean energy sector, Oct. 29, 2018, E.U.

1.1 New and renewable energy

◆ **(Renewable energy) It refers to energy used by converting renewable energy including sunlight, water, geothermal heat, precipitation, and living organisms.**

- Geothermal energy is energy that uses the heat of the earth, such as water and water vapor existing underground, as heat emitted from the inside of the earth to the outside.
- Bioenergy is energy that can be obtained from all living organisms (biomass), and is used as energy by pyrolyzing or fermenting animal and plant organic matter to obtain liquid or gaseous fuel.

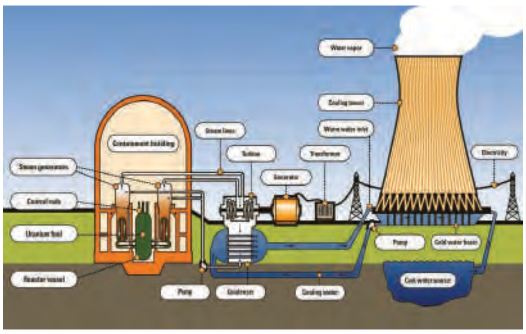
[Renewable energy]

Source : What is Geothermal energy? Feb. 4 2021, Greenesa web site
www.europeanbioenergyday.eu web site

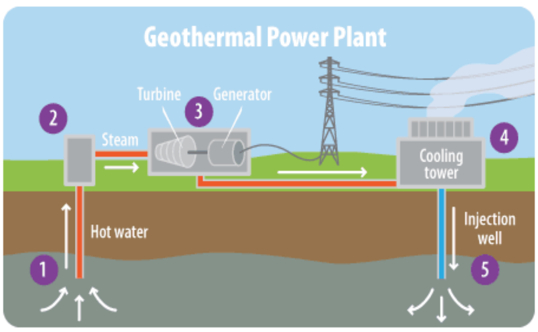
1.2 Alternative energy sources

◆ **(Definition) 90% of the energy used today in in the form of fossil fuels. Forms of energy other than fossil fuels are termed "alternative energy sources.**

- Nuclear power : clean and efficient way of boiling water to make steam, which turns turbines to produce electricity.
- Geothermal power electrical power generated from geothermal energy. Technologies in use include dry steam power station, flash steam power stations and binary cycle power stations.



[Nuclear power plant]



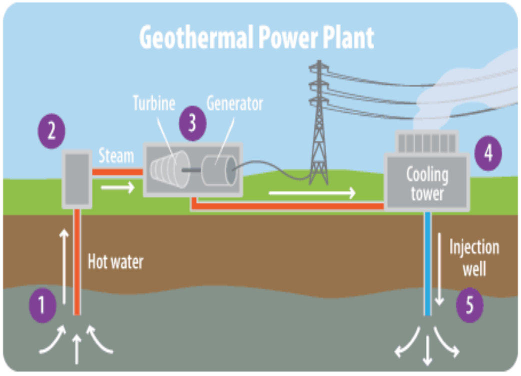
[Geothermal power plant]

Source : Fore Nuclear web site, EPA web site

1.3 Geothermal energy

◆ **(Definition) Energy that uses the heat of the earth, such as water and water vapor existing underground, as heat that comes out from the inside of the earth to the outside.**

- Geothermal heating, for example using water from hot springs has been used for bathing since Paleolithic times and for space heating since ancient Roman times.
- Geothermal power, the term used for generation of electricity from geothermal energy, has gained in importance



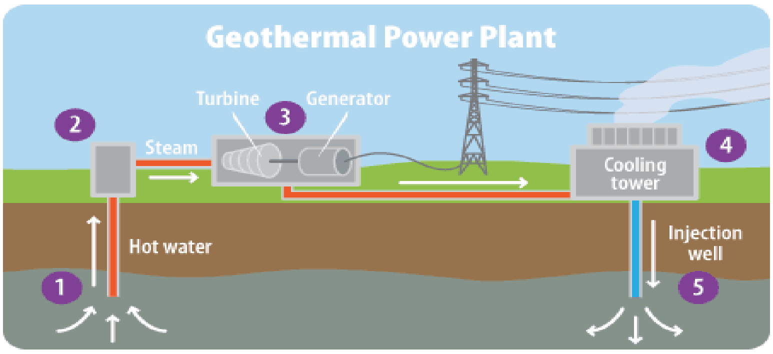
[Geothermal heating] [Geothermal power]

Source : Geothermal heat pumps in metro east Illinois, Ernst heating & cooling web site
Geothermal Energy, A Student's guide to Global Climate change, US, EPA.

1.3 Geothermal energy

◆ **(Geothermal power plants) wells are drilled 1 or 2 miles deep into the Earth to pump steam or hot water to the surface at hot springs, geysers, or volcanic activity**

1. Hot water is pumped from deep underground through a well under high pressure.
2. When the water reaches the surface, the pressure is dropped, which causes the water to turn into steam.
3. The steam spins a turbine, which is connected to a generator that produces electricity.
4. The steam cools off in a cooling tower and condenses back to water.
5. The cooled water is pumped back into the Earth to begin the process again.



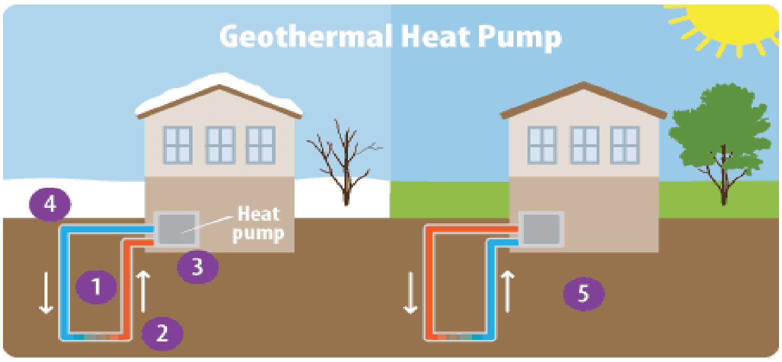
[Geothermal power]

Source : Geothermal Energy, A Student's guide to Global Climate change, US, EPA.

1.3 Geothermal energy

◆ **(Geothermal heat pump) These systems transfer heat by pumping water or a refrigerant (a special type of fluid) through pipes just below the Earth's surface, where the temperature is a constant 10 to 15°C.**

1. Water or a refrigerant moves through a loop of pipes
2. When the weather is cold, the water or refrigerant heats up as it travels through the part of the loop that's buried underground
3. Once it gets back above ground, the warmed water or refrigerant transfers heat into the building
4. The water or refrigerant cools down after its heat is transferred. It is pumped back underground where it heats up once more, starting the process again.
5. On a hot day, the system can run in reverse. The water or refrigerant cools the building and then is pumped underground where extra heat is transferred to the ground around the pipes.



Source : Geothermal Energy, A Student's guide to Global Climate change, US, EPA.

1.3 Geothermal energy

◆ **(Cost efficiency) A geothermal heat pump is worth it over the long run. Here's a quick table that summarizes the key differences between a geothermal system and a heat pump.**

- A geothermal system lasts almost twice as long as a heat pump.
- A geothermal system lasts around 25 years. And a heat pump lasts for about 15 years
- A geothermal heat pump uses 25% to 50% less electricity than a heat pump
- A 50% reduction in energy consumption over a whole year is roughly equal to $600 a year.

System	Life before it needs replacing	Electricity usage	Upfront cost
Geothermal system	25 years to 50 years	25% to 50% less than a HVAC	$3,592 – $15,578
Heat pump/HVAC	15 years	25 to 50% more than a geothermal system	$3,875 – $10,000

Source : Heat pump vs. Geothermal systems : Which is Best? Home Inspection web site

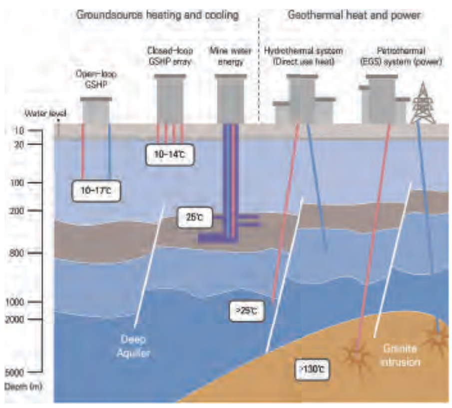
2. Geothermal heat pump

2.1 Geothermal energy source

◆ **(High vs. Low Temp.)**

- High temperature source : using hot water from the Earth as an energy source. Uses water heated from features such as geysers and volcanoes
- Low temperature low temp geothermal is becoming much cheaper to install, and the technology is already in place for it to become successful.

[High temperature source]



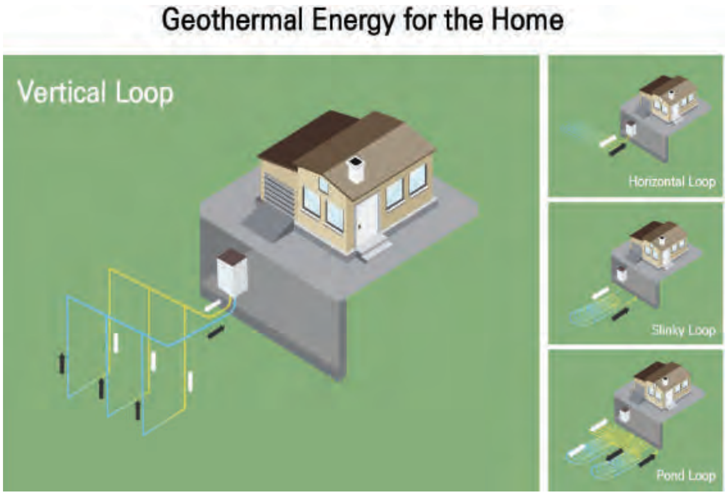
[Low temperature source]

Source : What is geothermal energy? Power Technology web site
Geothermal energy, British Geological Survey web site

2.1 Geothermal energy source

◆ **(Energy source) Heat energy from the Earth**

- High temperature : the conversion of natural heat from the Earth's interior to heat buildings and generate electricity
- Low temperature : Use of groundwater Deep wells (over 100 feet) are dug, and groundwater is used as a heat source in winter, and as a coolant in summer

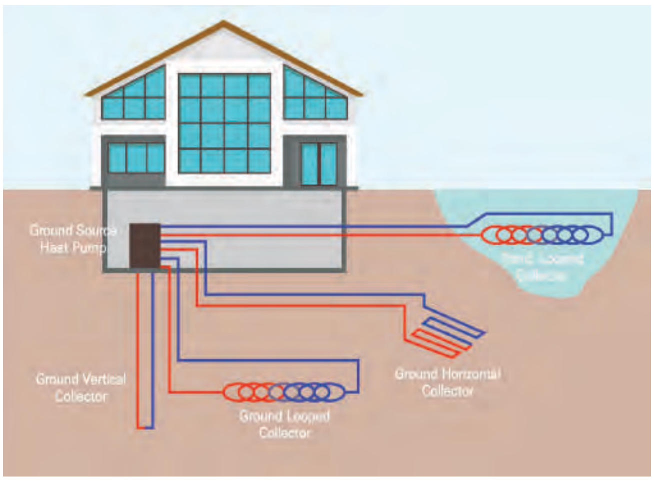


Source : Geothermal energy, Conserve Energy Future web site

2.2 Geothermal heat pump

◆ **(Heat pump) It is a device that absorbs energy from a low-temperature heat source and transfers heat to a usefully high temperature, just as a pump pumps water from a low location to a high location.**

- Using a commercially available geothermal source with a depth of 100 to 300 m,
- it absorbs and releases heat from the ground in summer for cooling,
- in winter, absorbs heat from the ground and releases it indoors for heating.



Source : Tech xplore, "Talc improves pipe performance in geothermal heat pump system, Nov. 5, 2020)

2.2 Geothermal heat pump

◆ **(Advantage) As an eco-friendly energy, it is an advanced energy that can supply infinite energy and achieve carbon neutrality.**

Eco-friendly clean energy

Eco-friendly energy that does not emit pollutant

Non-depleting energy

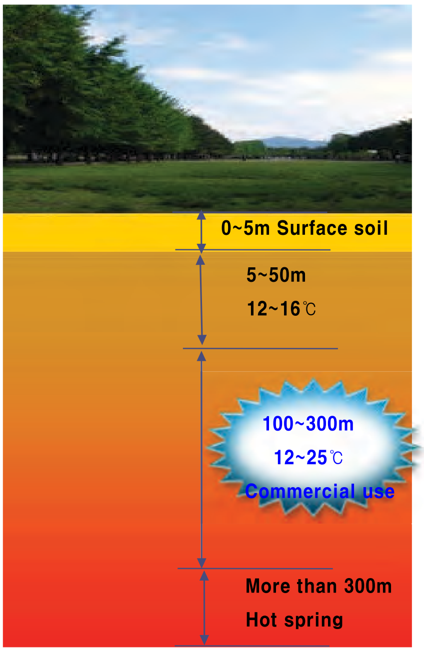
Non-depleting energy with infinite energy supply

Economical energy source

Low energy cost and aintenance cost

Flexible energy

Energy used for cooling and heating

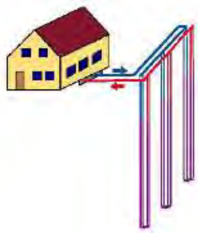


2.3 Heat exchange method

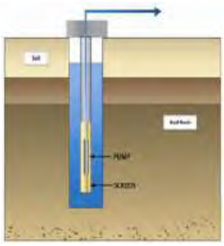
◆ **(Heat exchange) Heat exchange is a method of obtaining energy by matching the temperature of the refrigerant and the geothermal heat, and there are closed and open types.**

- Horizontal closed type

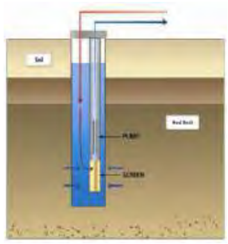
- Vertical closed type



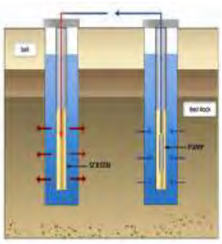
- Vertical open type



〈 Single well 〉



〈 Standing column well 〉



〈 Double well 〉

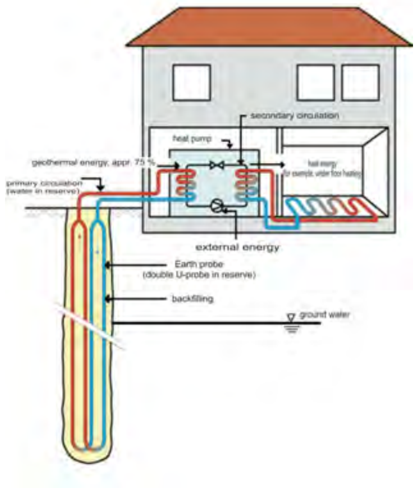
[Type of heat exchange method]

Source : Korea Institute of Geoscience and mineral resources

2.3 Heat exchange method

◆ Vertical type

- Using the energy obtained by burying a high-density polyethylene pipe by vertically drilling within 300 m underground at a constant temperature (15°±5℃)
- Circulating water inside the buried underground heat exchanger.
- Heat exchange is a method of obtaining energy by matching the temperature of the refrigerant and the geothermal heat, and there are closed and open types.

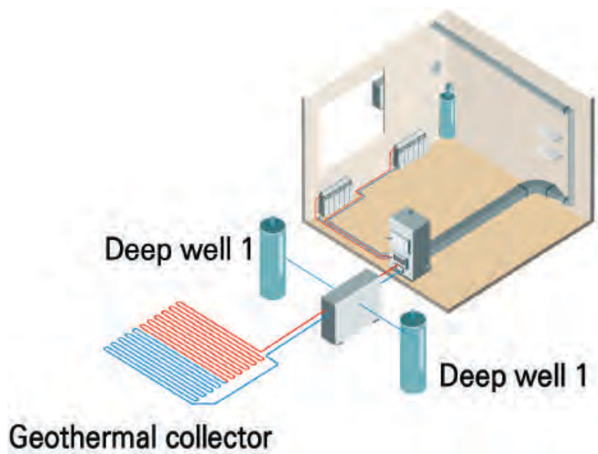


Source : Geothermal heat in a heat pump use, IOP Conf. Series: Earth and Environmental Science 43(2016)

2.3 Heat exchange method

◆ Horizontal type

- A heat pump using the energy obtained by burying a high-density polyethylene pipe horizontally within 2-5M underground using a constant temperature (15°±10°C) that exists near the surface throughout the year as a heat source
- and circulating water inside the buried underground heat exchanger. A system that performs cooling and heating by driving (HEAT PUMP)

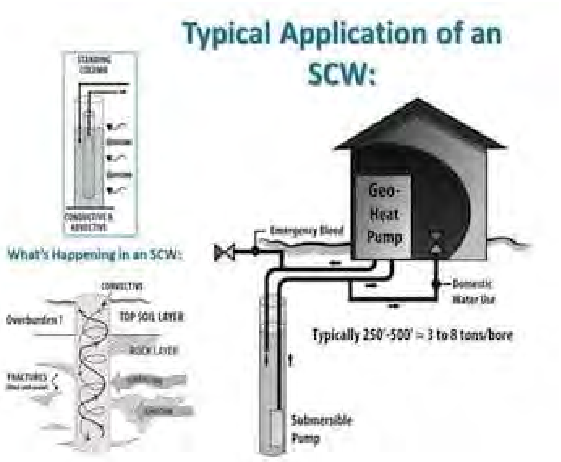


Source : Heating and Cooling systems, FEMNA web site

2.3 Heat exchange method

◆ SCW(Standing column well) type

- Install a well within 400-500M underground using a constant temperature (15°±5℃) that exists in the ground throughout the year as a heat source, insert and operate a submersible pump in the lower part, and send groundwater to a heat exchanger on the ground.
- A system that performs cooling and heating by driving a heat pump (HEAT PUMP) using the energy obtained by performing heat exchange between the two. After heat exchange, a certain amount of groundwater is discharged outside (about 10%), and about 90% is put back into the top of the well to recover thermally while circulating.

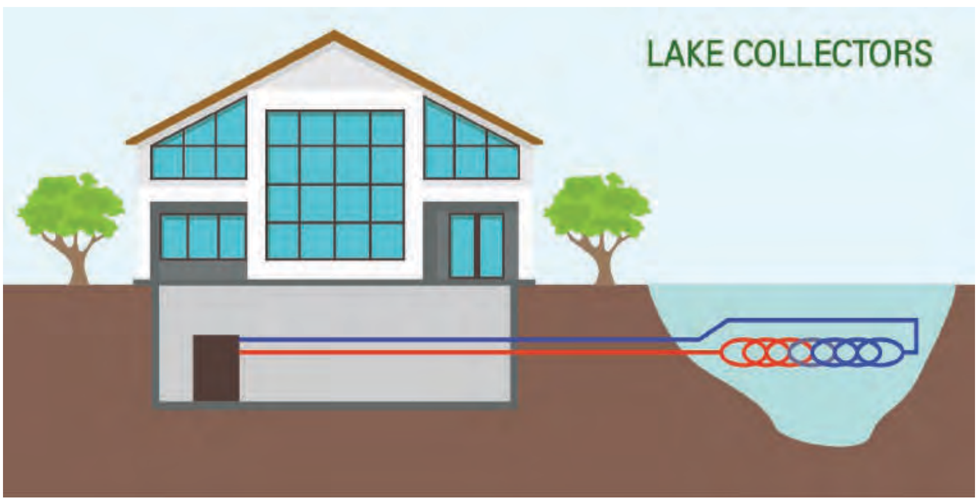


Source : Korea Institute of Geoscience and mineral resources

2.3 Heat exchange method

◆ Pond type

- A high-density polyethylene pipe is horizontally buried in a reservoir or river near a building, and a heat pump is driven using the energy obtained by circulating water inside the buried underground heat exchanger to perform cooling and heating



Source : What are the different types of ground collectors for a heat pump? Thermal Earth web site

3. Geothermal energy economic analysis

3.1 Economic analysis
3.2 CO2 emission analysis

3.1 Economic analysis

◆ **Life Cycle Cost Analysis : LCC**

- A method for assessing the total cost of facility ownership.
- It takes into account all costs of acquiring, owing, and disposing of a building system
- Cost analysis in the case of geothermal application in Korea

LCC = I + E + OM&R + R - RV

✓ I : Initial investment cost

✓ E : Energy consumption costs

✓ OM&R : Operating, Maintenance and repair costs

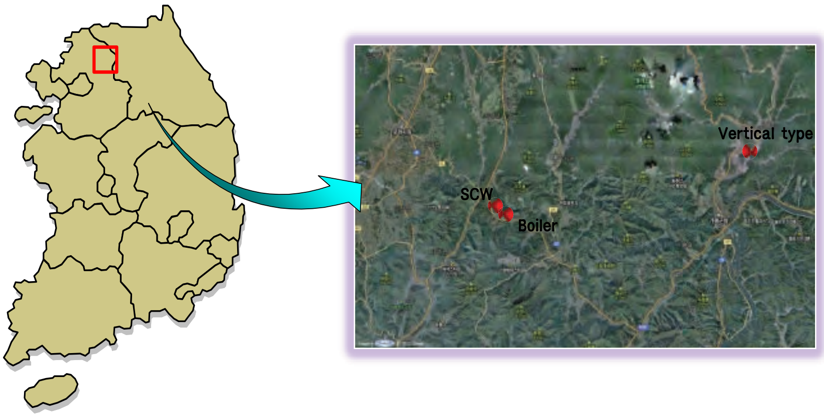
✓ R : Replacement costs

✓ RV : Residual values

3.1 Economic analysis

◆ Comparison of economic feasibility by fuel type

- Test site : The same area climatic site
- Select similar growing temperature crops :
  -> thermophilic crops : Chrysanthemum, Western Orchid, Oriental Orchid
- Comparison method : Vertical type, SCW type, Diesel boiler, Gas boiler



Source : Rural Search Institute

3.1 Economic analysis

◆ Geothermal heat pump by vertical type

- Location : Middle of Korea
- Facility area : 2,050 ㎡
- Thermal well : 157 m(depth) * 11 EA
- Heating capacity : 60 RT(30RT * 2 EA)
- Crops : Chrysanthemum, Cockscomb

Source : Rural Search Institute

3.1 Economic analysis

◆ **Geothermal heat pump by standing column well type**

- Location : Middle of Korea
- Facility area : 10,200 ㎡
- Thermal well : 330 m(depth) * 3 EA, 500 m * 5 EA
- Heating capacity : 210 RT(50RT * 3 EA, 30 RT * 2EA)
- Crops : Western orchid

Source : Rural Search Institute

3.1 Economic analysis

◆ **Geothermal heat pump by diesel boiler**

- Location : Middle of Korea
- Facility area : 4,000 ㎡
- Heating capacity : 750m000 kcal boiler 1 EA
- Crops : Oriental orchid

Source : Rural Search Institute

3.1 Economic analysis

◆ Geothermal heat pump by diesel boiler

- Location : Middle of Korea
- Facility area : 4,000 ㎡
- Heating capacity : 750m000 kcal boiler 1 EA
- Crops : Oriental orchid

Source : Rural Search Institute

3.1 Economic analysis

◆ Comparison of construction cost at each case

Case	Initial investment cost($)	Facility area(㎡)	Cost per ㎡	Note
Vertical type	222,080	2,050	108	2010 construction
SCW type	887,040	10,200	87	2009 construction
Diesel boiler	66,670	4,000	17	2012 construction
Gas boiler	100,000	4,000	25	2012 construction

Source : Rural Search Institute

3.1 Economic analysis

◆ **Comparison of energy cost at each case**

Case	Facility area(㎡)	Energy cost($)				Cost per ㎡
		Electricity	Diesel	Gas	Sum	
Vertical type	2,050	4,244			4,244	2.1
SCW type	10,200	10,525			10,525	1.0
Diesel boiler	4,000	5,230	71,501		76,731	19.2
Gas boiler	4,000	5,230		61,065	66,295	16.6

Source : Rural Search Institute

3.1 Economic analysis

◆ **Comparison of maintenance cost at each case**

Case	Maintenance cost($)	Cost for groundwater impact survey($)	Facility replacement cost($)	Note
Vertical type	3,331		179,664	
SCW type	2,674	2,680	112,676	By groundwater act
Diesel boiler	1,708		25,625	
Gas boiler	2,563		34,167	

Source : Rural Search Institute

3.1 Economic analysis

◆ Results of LCC analysis

Case	Initial investment cost($)	Energy cost($)	Maintenance cost($)	Facility replacement cost($)	LLC cost($)	Savings rate (%)
Vertical type	108	41.4	32.5	116.9	299.1	31
SCW type	87	20.6	26.1	73.3	207.0	52
Diesel boiler	17	383.7	16.7	16.74	433.7	0
Gas boiler	25	333.4	25.0	22.25	405.6	6

Life cycle cost is based on 20 years,
Geothermal system is replaced once every 15 years, the boiler is replaced once every 10 years
Calculate the saving rate in case of a diesel boiler

Source : Rural Search Institute

3.2 CO2 emission analysis

◆ Results of CO2 emission analysis

- **Annual energy consumption at 1,000 m²**

Case	Electricity (kw)	Gas (N m³)	Diesel (L)
Vertical type	47,437		
SCW type	29,602		
Diesel boiler	37,480		20,798
Gas boiler	37,480	17,967	

- **Conversion factor for CO2 emission**

Case	Total heating value (kcal)	CO2 emission factor
Electricity	2,300	0.425
Diesel	9,010	0.837
GAS (LNG)	10,430	0.637

Source : Rural Search Institute

3.2 CO2 emission analysis

◆ Results of CO2 emission analysis

- CO2 emission by fuel(TON CO2) =

TOE of each fuel(total heating value/10,000,000) * CO2 emission factor*44/12

Annual CO2 emission at 1,000 ㎡ (TON)

Case	Electricity	Gas	Diesel	Sum	Saving rate (%)	비고
Vertical type	17.0	0	0	17.0	76 %	
SCW type	10.6	0	0	10.6	85 %	
Diesel boiler	13.4	0	57.5	70.9	0 %	
Gas boiler	13.4	43.8	0	57.2	19 %	

Total heating value is Korean standard, CO2 emission factor follows IPCC report

Source : Rural Search Institute

Groundwater Management for Sustainable Use (Discussion)

Groundwater

Groundwater Management for Sustainable Use (Discussion)

UNESCO United Nations Educational, Scientific and Cultural Organization

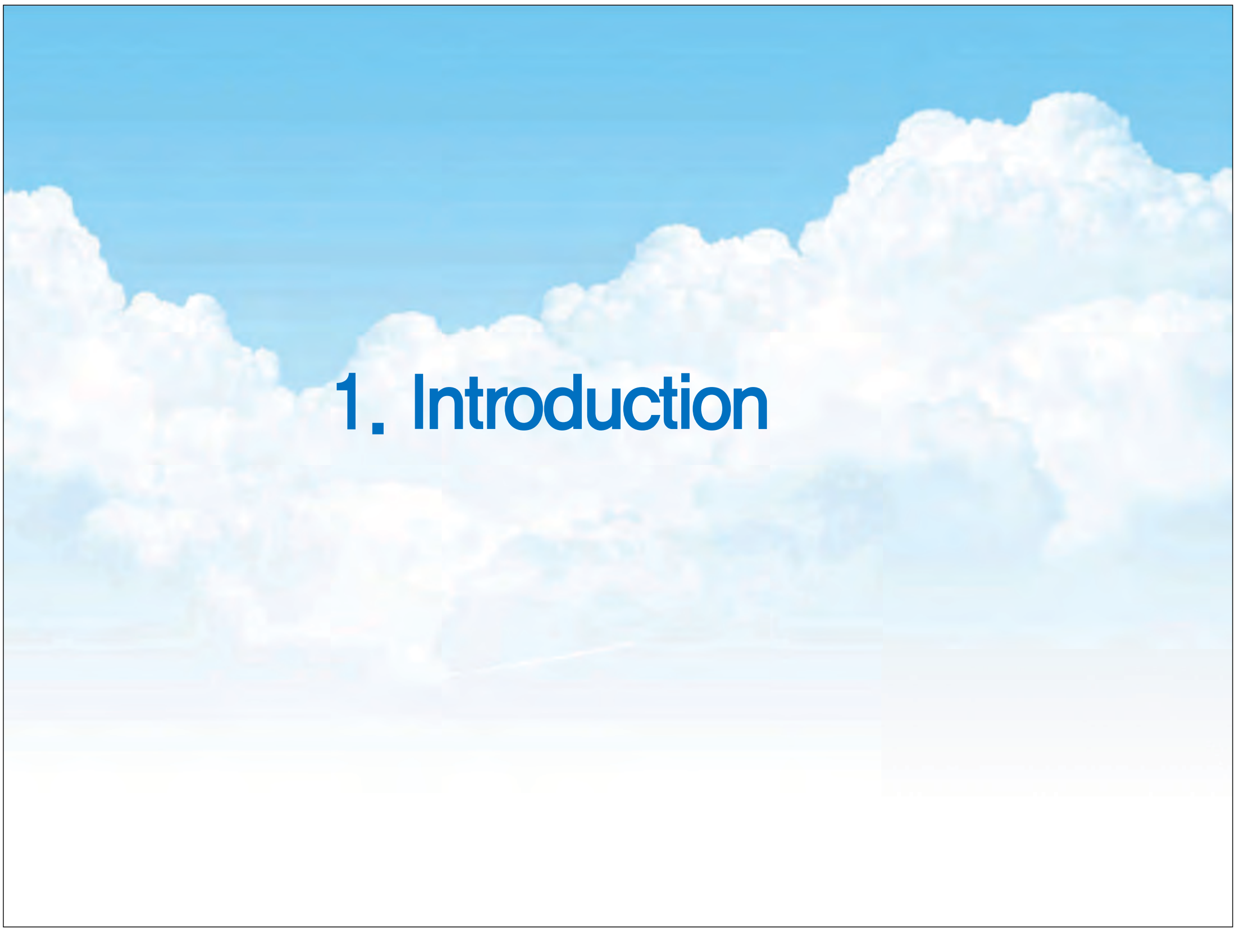
i-WSSM International Centre for Water Security and Sustainable Management

Aims & Objectives

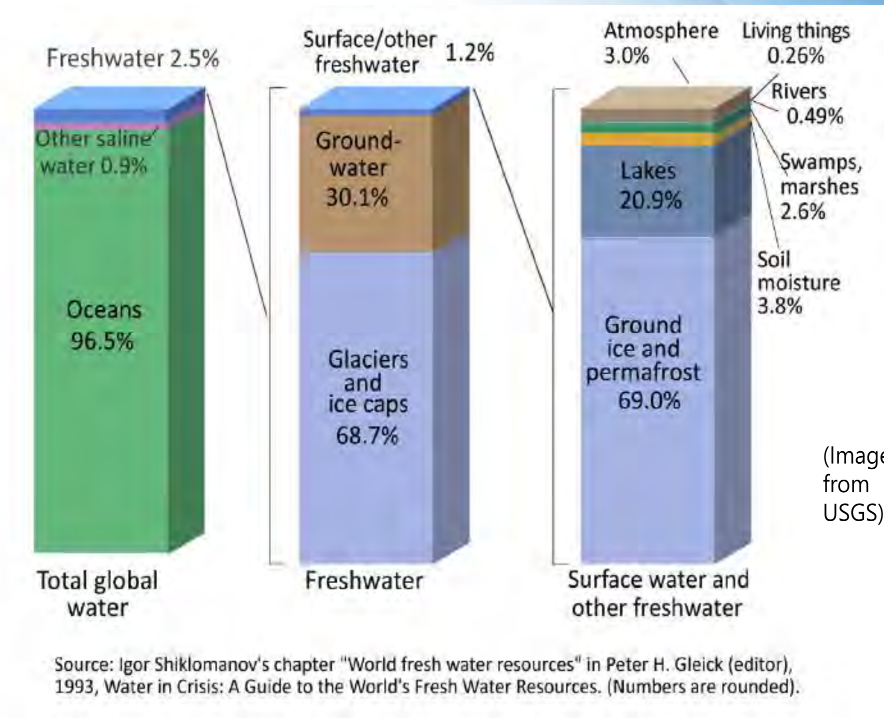
For sustainable use of groundwater, the trainees mainly discuss the following issues to clarify their awareness of the problems.

- The main issues for discussion:
  - (1) Current status of groundwater
  - (2) Water rights issue
  - (3) Overdraft and optimal pumping issue
  - (4) Groundwater quality and contamination issue
  - (5) Saltwater intrusion issue
  - (6) Water–Food–Energy Nexus issue
  - (7) Groundwater sustainability

Contents



Useful Water + Potentially Useful Water = Water Resources



(Image from USGS)

How much groundwater we can use?

OVERDRAFT:
Withdrawal over this amount.

SAFE YIELD:
Amount of water that can be withdrawn annually from a ground water basin without producing an undesired results.

UNDESIRED RESULTS:

- depletion of groundwater resources and aquifer damage
- saltwater intrusion
- intrusion of water of undesirable quality and cause groundwater contamination
- interference with existing water rights
- water level drop and deterioration of economic advantages of pumping
- excessive depletion of stream flow
- land subsidence

What will be the optimal yield?

OPTIMAL YIELD:

Hydraulic issues (safe yield) and all social and economic conditions considered

- alternative overall management plans evaluated
- cost-benefits considered
- optimal plan selected
- water rights considered

Water rights have been a source of conflict and controversy throughout the history of the world

Management of Groundwater Contamination

health risk analysis
monitoring
limit/terminate aquifer use
develop alternative water supply
import alternative water supply

remediation	remove pump and treat
containment	infiltration barrier cut-off walls hydrodynamic isolation
NAPL extraction	skimmer pumps LNAPL soil vapor extraction air sparging

in-situ bioremediation

Water, Food and Energy Nexus (1)

- The water-food-energy nexus is the key for sustainable development.
- Agriculture is the largest consumer of the world's freshwater resources
- More than one-quarter of the energy used globally is expended on food production and supply

"The inextricable linkages between these critical domains require a suitably integrated approach to ensuring water and food security, and sustainable agriculture and energy production worldwide" (from UN Water)

Water, Food and Energy Nexus (2)

72% of all water withdrawals are used by agriculture, 16% by municipalities for households and services, and 12% by industries. (UN-Water 2021)

While almost 800 million people are currently hungry, by 2050 global food production would need to increase by 50% to feed the more than 9 billion people projected who live on our planet (FAO/IFAD/UNICEF/WFP/WHO, 2017).

Global water demand is projected to increase by 20 to 30% per year by 2050. (UNESCO, 2018)

2. Share trainees' understanding and awareness of each issue

- Each trainee talks about groundwater issues in their local area and exchanges opinions with each other
- Discuss the role and potential of groundwater in relation to global water crisis

3. Take home message for groundwater conservation

- Let's discuss what each trainee can do to ensure the sustainable use of groundwater after they return to their respective countries.

4. Conclusion

- **The instructor draws conclusions based on the discussion with the trainees**

Thank you very much