Groundwater and Diyala Governorate

By

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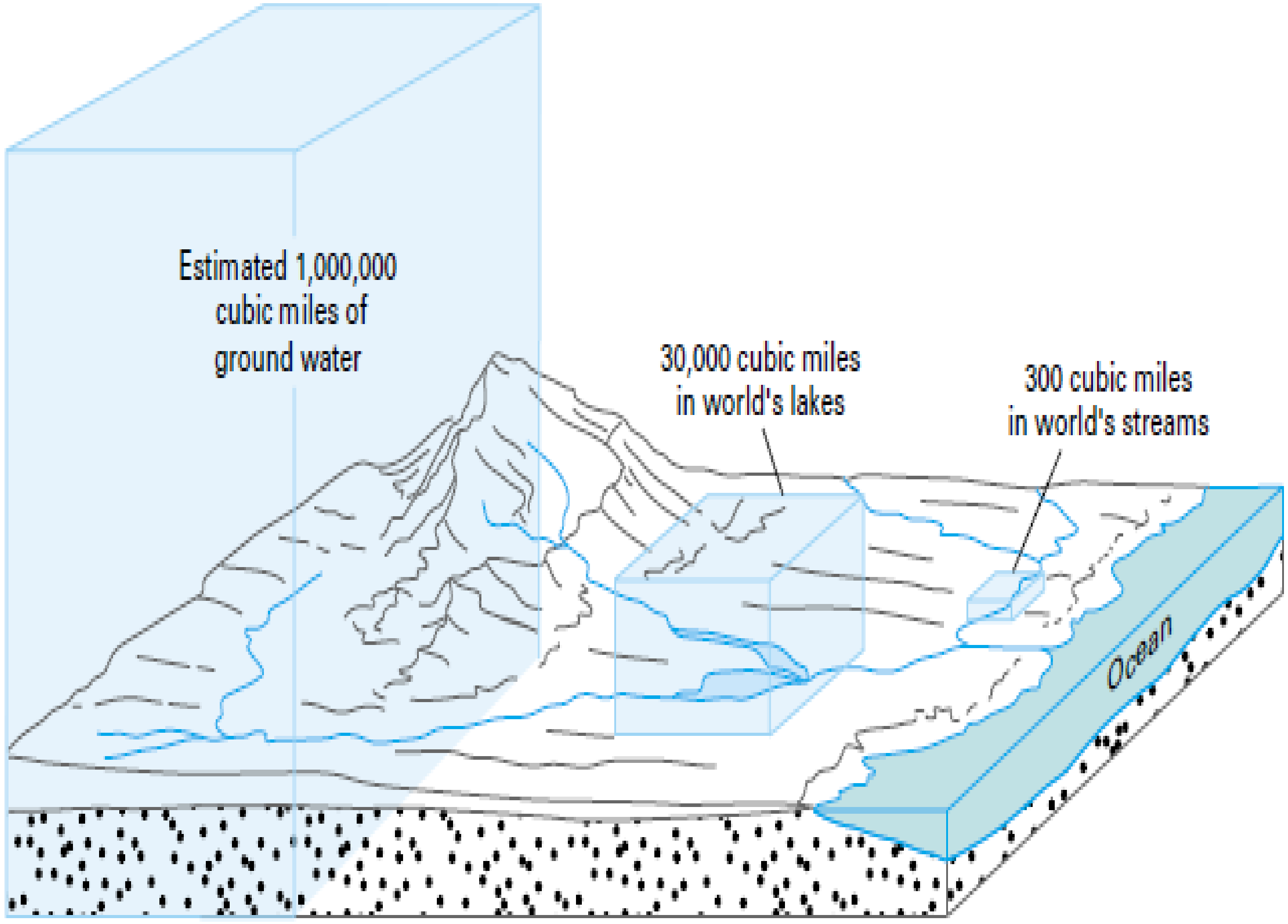
Water Springs

Pumping Wells

Water being pumped from a well

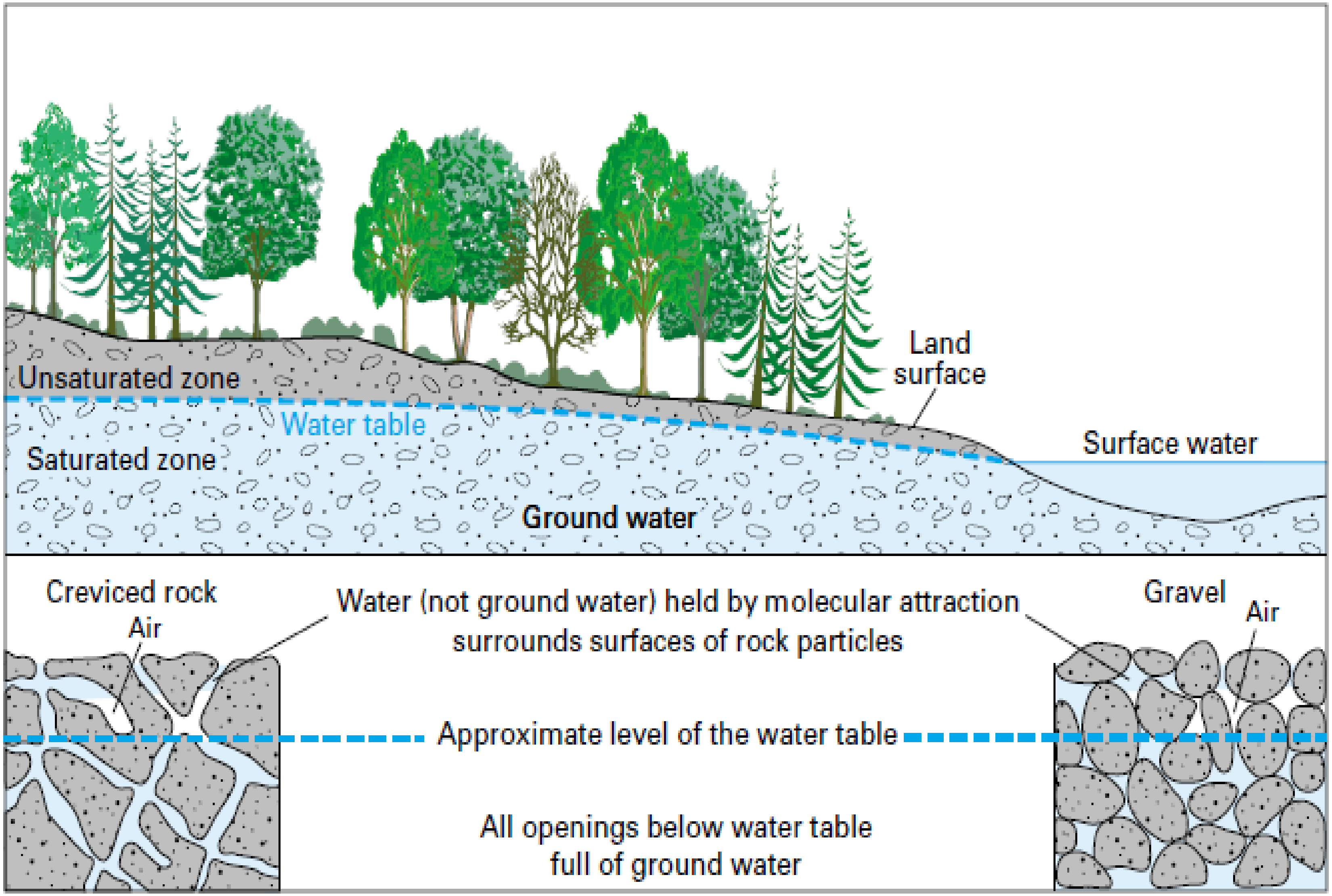
Comparison of the amount of fresh water in storage in Earth



Ground water is simply the subsurface water that fully saturates pores or cracks in soils and rocks.

It is difficult to visualize water underground

Some people believe that ground water collects in underground lakes or flows in underground rivers. In fact, ground water is simply the subsurface water that fully saturates pores or cracks in soils and rocks.

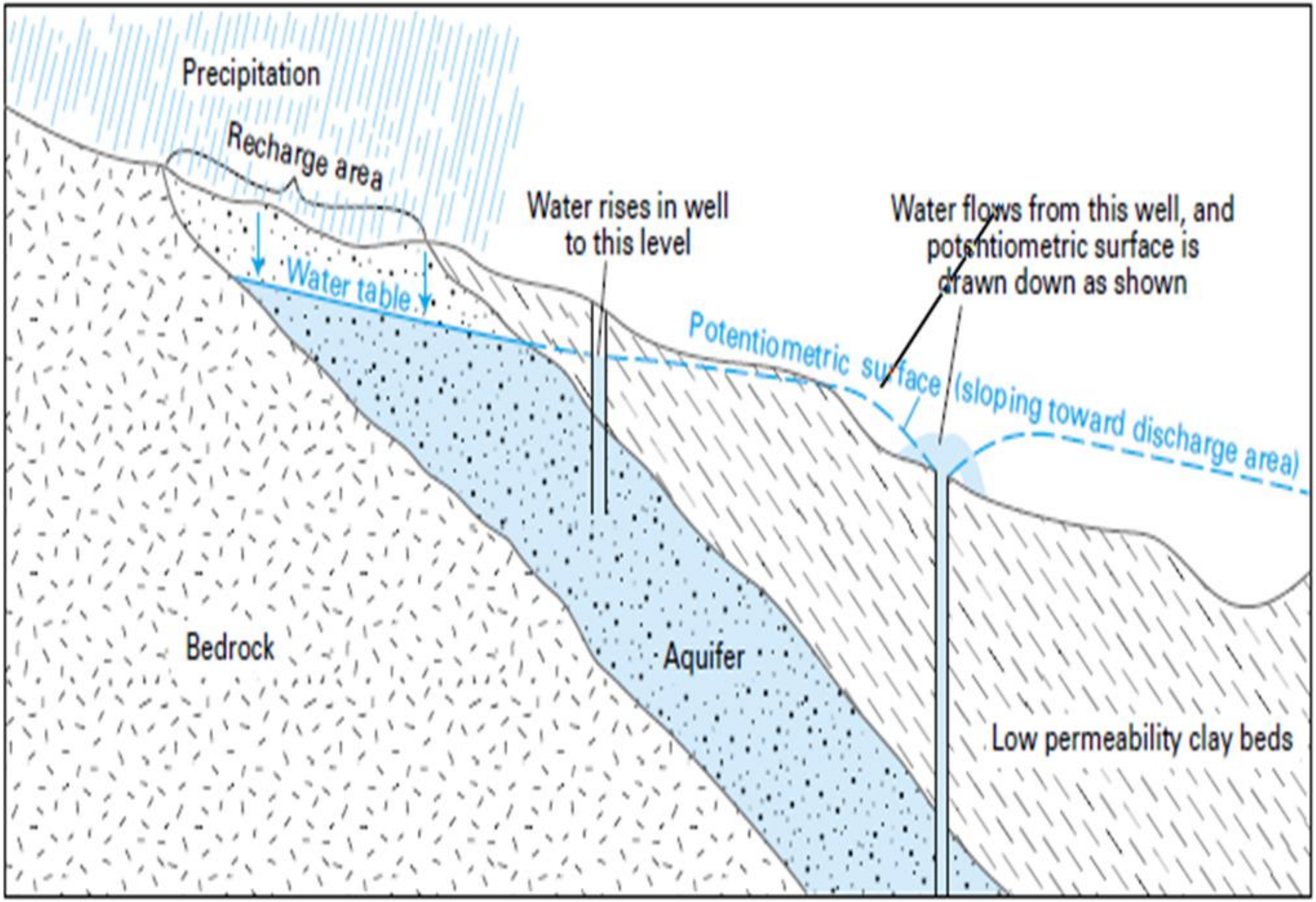

Unsaturated zone
Water table
Saturated zone
Land surface
Surface water
Ground water
Creviced rock
Air
Water (not ground water) held by molecular attraction surrounds surfaces of rock particles
Gravel
Air
Approximate level of the water table
All openings below water table full of ground water

The quantity of water at a given type of rock will hold depends on the rock's porosity

if the grains of a sand or gravel aquifer are all about the same size, or "well sorted," the water-filled spaces between the grains account for a large proportion of the volume of the aquifer

. If the grains, however, are poorly sorted, the spaces between larger grains may be filled with smaller grains instead of water.

For example, Sand and gravel aquifers having well-sorted grains, therefore, hold and transmit larger quantities of water than such aquifers with poorly sorted grains.


Precipitation
Recharge area
Water table
Water rises in well
to this level
Water flows from this well, and
potentiometric surface is
drawn down as shown
Potentiometric surface (sloping toward discharge area)
Bedrock
Aquifer
Low permeability clay beds

How does the mass of water stored in an aquifer change?

Confined Aquifer – Compression of both the material and the water

Unconfined Aquifer – Water drains out pores at the water table when the water table drops and fills pores when the water table rises. The change in store from compression is negligible.

The time derivative or change in storage term, which may be written as

$$\frac{\partial \rho n}{\partial t} = n\frac{\partial \rho}{\partial t} + \rho\frac{\partial n}{\partial t}$$

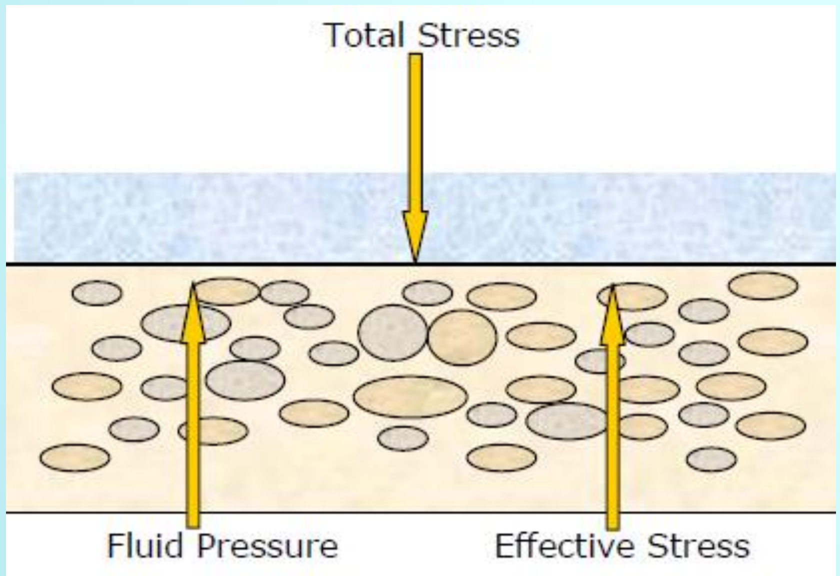
Density changes (compressibility) — Porosity changes

Overall definition: **S_s, specific storage**, (1/L) of a saturated aquifer is the volume that a unit volume of aquifer released from storage for a unit decline in head. (Volume per Volume per head change).

How can a reduction in aquifer volume occur ?

*Compression of the individual grains or rock skeleton (assumed negligible – individual grains are incompressible)•
*Rearrangement of the grains – more compact•
*Compression of the water in the pores.

We will get $Ss = \rho g \alpha + \rho g \beta n$



When pumping an aquifer the change in stress is:

$d\,\sigma_T = d\sigma_T + dP$

$$d\sigma_e = -dP = -d\rho g h$$

Water Produced from Aquifer Compaction

- Aquifer compressibility, α, $[L^2/M]$ is defined as follows (corresponds to shifting of grains and reduction in porosity.

$$\alpha = \frac{-(dV_t)/V_t}{d\sigma_e}$$

V_t is the original volume (thickness)
dV_t is the change in volume (thickness)
$d\sigma_e$ is the change in effective stress

Water Produced by the Expansion of Water

We can also define fluid compressibility

$$\beta = \frac{-(dV_W)/V_W}{dP}$$

β is the fluid compressibility - compressibility of water
n is the porosity (volume of water is total volume times n)
so, for a unit total volume, $nV_t = n(1) = n$

$$dV_W = -\beta n dP = -\beta n(d\rho g h - d\rho g z) = -\beta n \rho g dh$$

Specific Storage is sum:

$$S_s = \rho g(\alpha + \beta n)$$

It has units $[L^{-1}]$. It is volume produced per aquifer volume per head decline.

- First term is from aquifer compressibility.
- Second term is from water expansion.

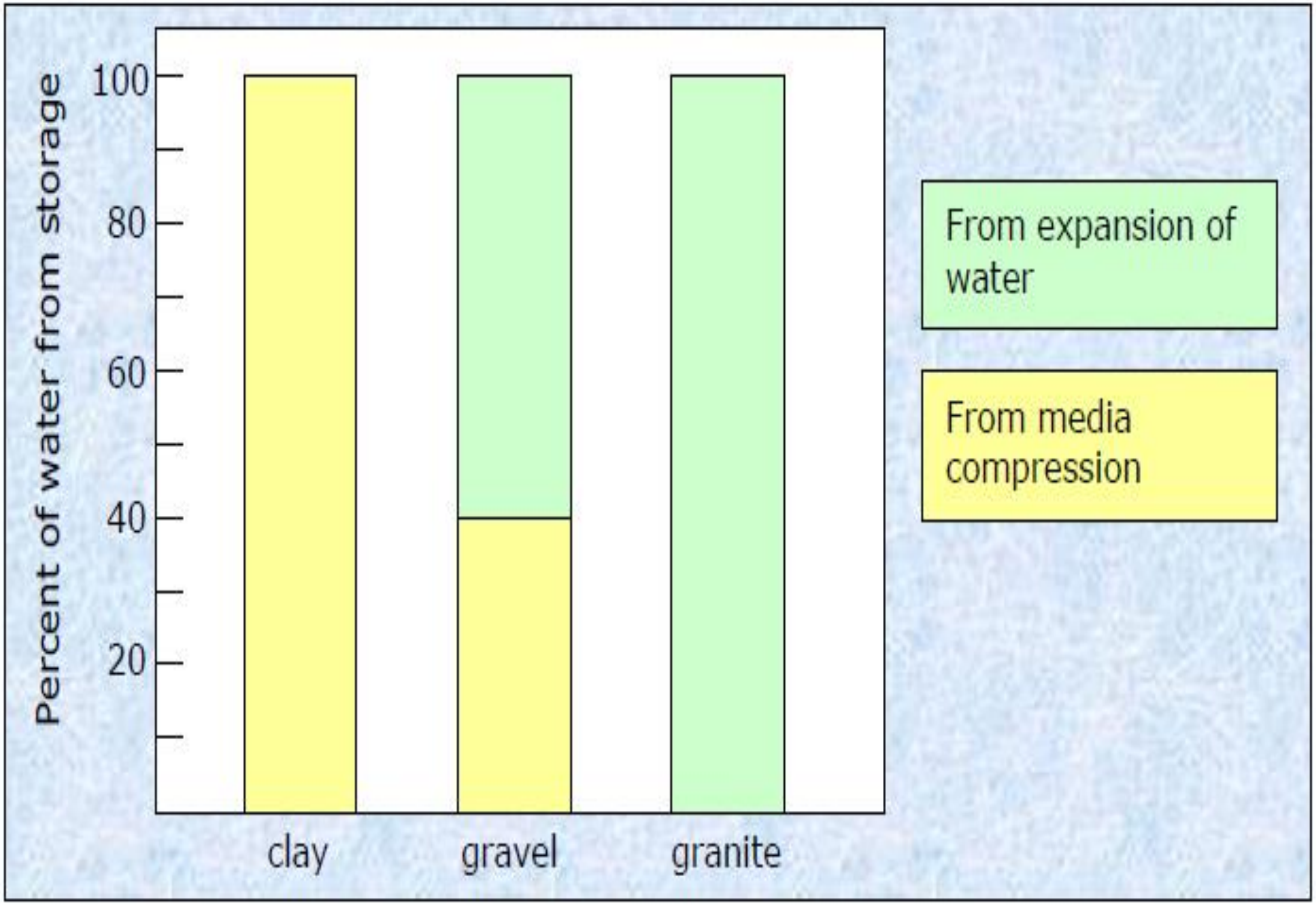
$$S_s \frac{\partial h}{\partial t} = \rho g(\beta n + \alpha)\frac{\partial h}{\partial t}$$

Where does stored water come from in confined aquifers?

Assume: $S_s = \rho g(\alpha + \beta n)$

- 10 ft of drawdown (reduction in head)
- Porosity of 30%

Compressibility (m^2/N)		Water from Storage, $S_s \times \Delta H$
Clay	10^{-6}	0.0303
Sand	10^{-8}	0.000694
Granite	10^{-10}	0.000398
Water	4.4×10^{-10}	


Percent of water from storage
100
80
60
40
20
clay
gravel
granite
From expansion of water
From media compression

With more realistic porosities, results are similar

	Porosity	Compression	Expansion	Total Water
Clay	45%	98.06%	1.94%	0.0305
Gravel	35%	39.37%	60.63%	0.00759
Granite	25%	0.90%	99.10%	0.00332

What is the nature of groundwater Flow?

* Ground water flow in a very small velocity

* Flow is considered Laminar in most cases so that Rynold"s Number not exceed 10

* DARCY LAW is applicable

Key Equations for a confined aquifer

- 3D flow equation, Homogeneous Isotropic

$$S_s \frac{\partial h}{\partial t} = K\left[\frac{\partial^2 h}{dx^2} + \frac{\partial^2 h}{dy^2} + \frac{\partial^2 h}{dz^2}\right] \quad \text{or} \quad S_s \frac{\partial h}{\partial t} = K\nabla^2 h$$

- 3D Heterogeneous, Anisotropic

$$S_s \frac{\partial h}{\partial t} = \left[\frac{\partial}{dx} K_x \frac{\partial h}{dx} + \frac{\partial}{dy} K_y \frac{\partial h}{dy} + \frac{\partial}{dz} K_z \frac{\partial h}{dz}\right]$$

- 3D Heterogeneous, Isotropic

$$S_s \frac{\partial h}{\partial t} = \left[\frac{\partial}{dx}\left(K \frac{\partial h}{dx} \right) + \frac{\partial}{dy}\left(K \frac{\partial h}{dy} \right) + \frac{\partial}{dz}\left(K \frac{\partial h}{dz} \right) \right]$$

For **Steady State,** $S_s \frac{\partial h}{\partial t} = 0$ for any equation.

For steady state:

- No water from storage
- S values doesn't matter

2D Flow Equation

- Confined aquifer, homogeneous, isotropic.

$$S\frac{\partial h}{\partial t} = T\left[\frac{\partial^2 h}{dx^2} + \frac{\partial^2 h}{dy^2}\right]$$

S = S_sb = Storativity [L^3/ L^3] ← Values like 10^{-2} to 10^{-6}
T = Kb = Transmissivity [L^2/T]   Compare values to S_y !
B = aquifer thickness [L]

- Confined aquifer, Heterogeneous, Anisotropic

$$S\frac{\partial h}{\partial t} = \left[\frac{\partial}{dx}T_x\frac{\partial h}{dx} + \frac{\partial}{dy}T_y\frac{\partial h}{dy}\right]$$

- Confined aquifer, Heterogeneous, Isotropic

$$S\frac{\partial h}{\partial t}=\left[\frac{\partial}{dx}\left(T\frac{\partial h}{dx}\right)+\frac{\partial}{dy}\left(T\frac{\partial h}{dy}\right)\right]$$

- Confined aquifer, Homogeneous, Anisotropic

$$S\frac{\partial h}{\partial t}=\left[T_x\frac{\partial^2 h}{dx^2}+T_y\frac{\partial^2 h}{dy^2}\right]$$

Mathematical Modeling

1. Govern Equations
2. Boundary conditions
3. Initial conditions
4. Set of assumption and limitations

1.Model verification → Observed data

1.Model verification → Published numerical data

2. Model Calibration + Sensitivity Analysis

Two Major problems associated with Groundwater Usability

1. Quality of Ground Water

2. Soil Subsidence Under Aquifer Mining

Quality of Ground Water

For the Nation as a whole, the chemical and biological character of ground water is acceptable for most uses

The quality of ground water in some parts of the country, particularly shallow ground water, is changing as a result of human activities.

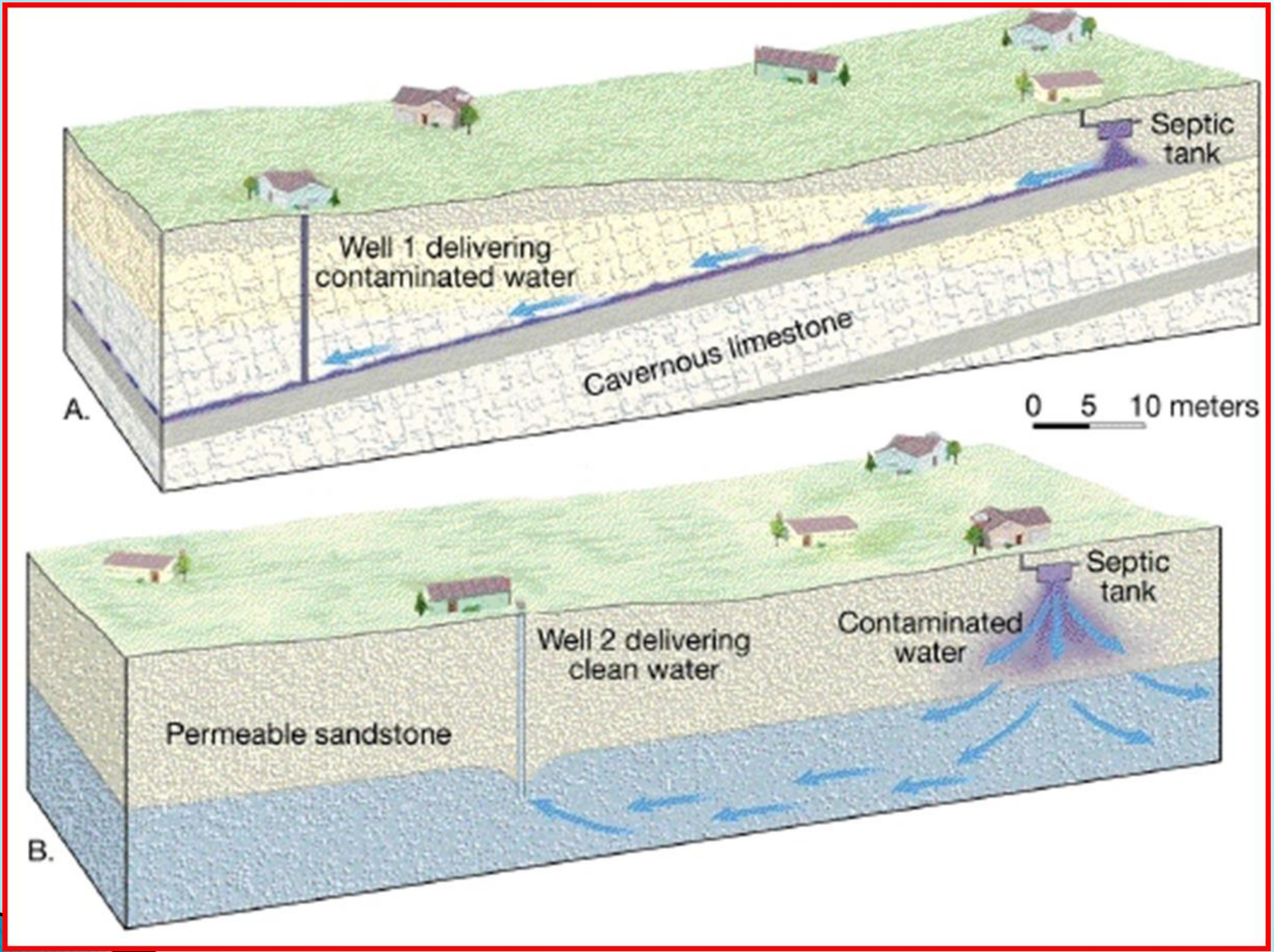
Ground water is less susceptible to bacterial pollution than surface water because the soil and rocks through which ground water flows screen out most of the bacteria. Bacteria, however, occasionally find their way into ground water, sometimes in dangerously high concentrations

Water is a solvent and dissolves minerals from the rocks with which it comes in contact

The most common dissolved mineral substances are Sodium, Calcium, Magnesium, Potassium, Chloride, Bicarbonate, and Sulfate.

In water chemistry, these substances are called common constituents. Water typically is not considered desirable for drinking if the quantity of dissolved minerals exceeds 1,000 mg/L (milligrams per liter).

Development of Contamination in Groundwater



Soil Subsides

Mainly due to heavy pumping causing aquifer severe Drawdown

Soil subsidence due to groundwater pumping

Groundwater in Diyala Governorate

Diyala Governorate extends to the northeast of Baghdad as far as the Iranian border. Its capital is Baqubah . It covers an area of 17,685 square kilometres (6,828 sq mi).A large portion of the province is drained by the Diyala River

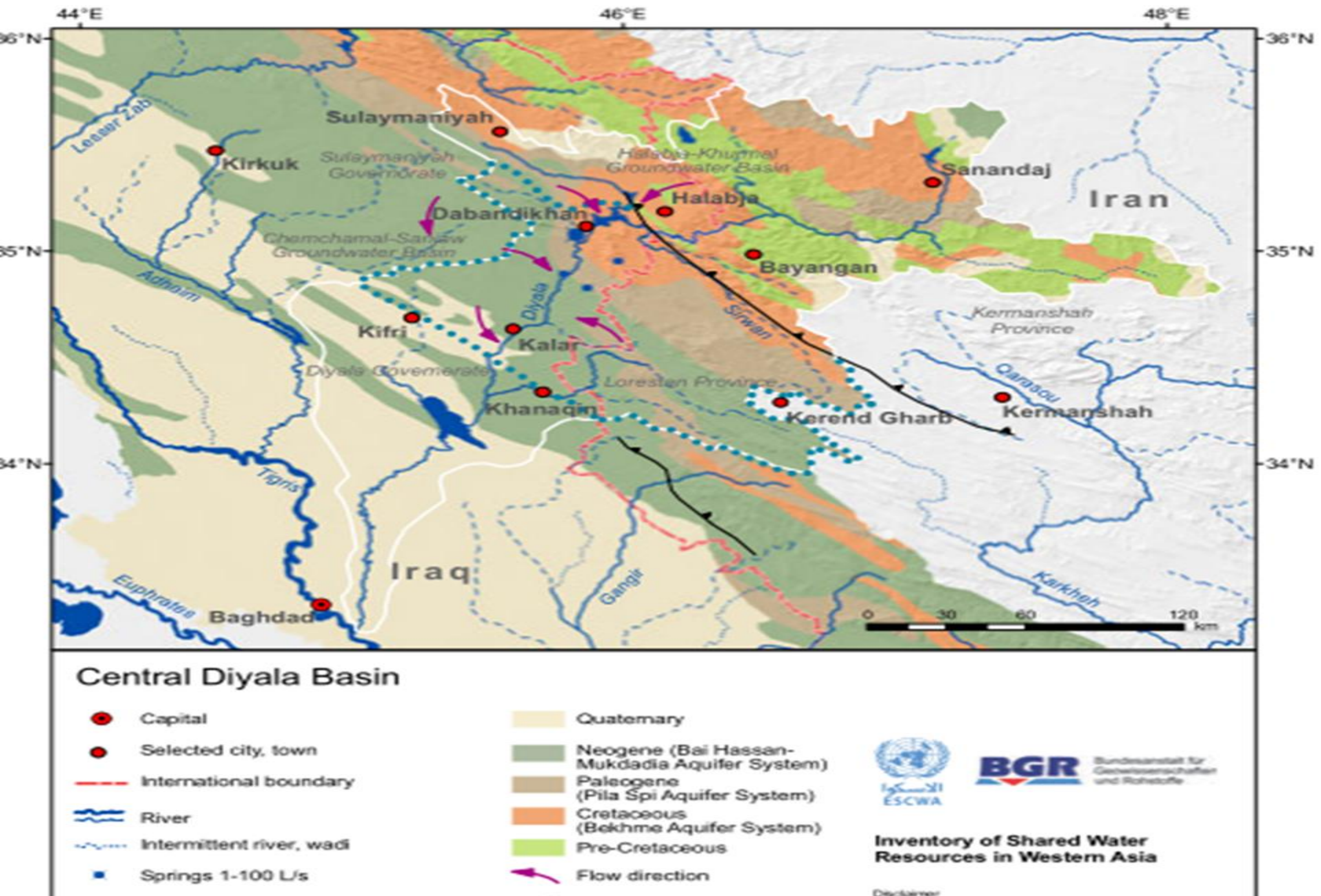
The Central Diyala Basin

The basin covers a total area of 11,760 km^2, of which 6,350 km^2 are located in Iran and 5,410 km^2 in Iraq.

The climate in the Foothill Zone is semi-arid with hot summers and mild to cold winters

Precipitation occurs mainly between September and May. The Central Diyala Basin around Khanaqin has an average annual precipitation of 330-350 mm.

The average annual temperature is 21°C, with highs around 32°C in summer andlows of 5°C in winter. Total potential annual evaporation was reported to be about 1,750 mm in 2001



44°E
46°E
48°E
36°N
35°N
34°N
Lesser Zab
Sulaymaniyah
Kirkuk
Sulaymaniyah Governorate
Halabja-Khurmal Groundwater Basin
Sanandaj
Iran
Halabja
Dabandikhan
Chemchamal-Sangaw Groundwater Basin
Bayangan
Adhaim
Diyala
Sirwan
Kermanshah Province
Kifri
Kalar
Diyala Governorate
Lorestan Province
Qaraaou
Khanaqin
Kerend Gharb
Kermanshah
Tigris
Iraq
Gangir
Karkheh
Euphrates
Baghdad
0 30 60 120 km
Central Diyala Basin
Capital
Selected city, town
International boundary
River
Intermittent river, wadi
Springs 1-100 L/s
Quaternary
Neogene (Bai Hassan-Mukdadia Aquifer System)
Paleogene (Pila Spi Aquifer System)
Cretaceous (Bekhme Aquifer System)
Pre-Cretaceous
Flow direction
ESCWA
BGR
Inventory of Shared Water Resources in Western Asia

The main aquifer in this basin is the Neogene (Bai Hassan-Mukdadia) Aquifer System. The Bai Hassan Formation is an aquifer with high potential and sometimes forms a single aquifer with the overlying Quaternary sediments, especially in the southern areas (Kalar)

The Mukdadia Formation is also considered an aquifer, though it is less promising. The exploitable saturated thickness of the Bai Hassan-Mukdadia Aquifer System is estimated at 60-200 m in different sub-basins.

The aquifer system is basically unconfined with a shallow water table. Confined conditions exist where the overlying Quaternary deposits exhibit high clay content.

Differences in lithology often cause semi-confined to confined conditions in the deeper layers.

Transmissivity values of 100 m^2/d ($1.2x10^{-3}$ m^2/s) and 350 m^2/d ($4.0x10^{-3}$ m^2/s) were reported in the Central Diyala Basin.

However, variable permeability and lateral/horizontal changes in the lithology of basin deposits often result in highly variable productivity.

Major rivers such as the Adhaim, Gangir and Lesser Zab flow through the foothill areas and may contribute significantly to direct and indirect groundwater recharge.

In the Central Diyala Basin, groundwater recharge rates were reported to range between 40 and 53 mm (11.8% of an average rainfall of 332 mm and 17.3% of an average rainfall of 308 mm)

Both in Iran and Iraq, groundwater flows mainly towards the Diyala River and storage in Iraq has been estimated at between 500 and 1,050 MCM in Iraq.

Storage in Iran is unknown.

The unconfined upper part of the aquifer is locally drained to the Diyala River. The discharge of the lower confined aquifer system is not well defined but may be connected to the upper part. A few morphological springs are reported to discharge low volumes into the Central Diyala Basin.

In general, natural discharge of the confined system seems to be limited, indicating possible upward leakage to the upper unconfined system.

Good-quality groundwater (<1,000 mg/L TDS) is found along the Diyala River and, in general, salinity increases away from the river. Deep wells contain saline water derived from the Lower Fars (Fatha) Formation but salinity rates generally do not exceed 3,000 mg/L.

GROUNDWATER USE AND SUSTAINABILITY ISSUES

Actual annual abstraction from the confined aquifer in the Central Diyala Basin is estimated at around 6 MCM from 80 wells , with very limited effect on groundwater levels . No abstraction is reported in Iran, but groundwater discharge from qanats can be assumed.

For the basin extends from Khanaqien city at the northeast toward the confluence of the Wend River with the Diyala River at the southwest. The quality of groundwater is good to medium (salinity 500 - 2000 ppm) while the yield of wells is 5 - 20 l/s.

Recently the well drilling becomes a phenomenon which cause
A severe withdrawn of groundwater in many area in Diyala Governorate
Officials in Khanqune prohibit drilling of wells unless a permission
Has to be issued.

Recent Statistics of wells in Iraq

Table 4. Number of groundwater wells drilled in each governorate in Iraq.

Governorate	Number of Wells
Duhok	410
Nainawa	1299
Erbil	1286
Sulaymaniah	423
Tameem	1093
Diyala	647
Salahaldin	1118
Baghdad	308
Anbar	608
Muthana	201
Qadisiya	6
Karbala	148
Najaf	286
Wasit	116
Mesan	80
Dhiqar	17
Basra	576
Babil	30
Total	**8752**

Thank you

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