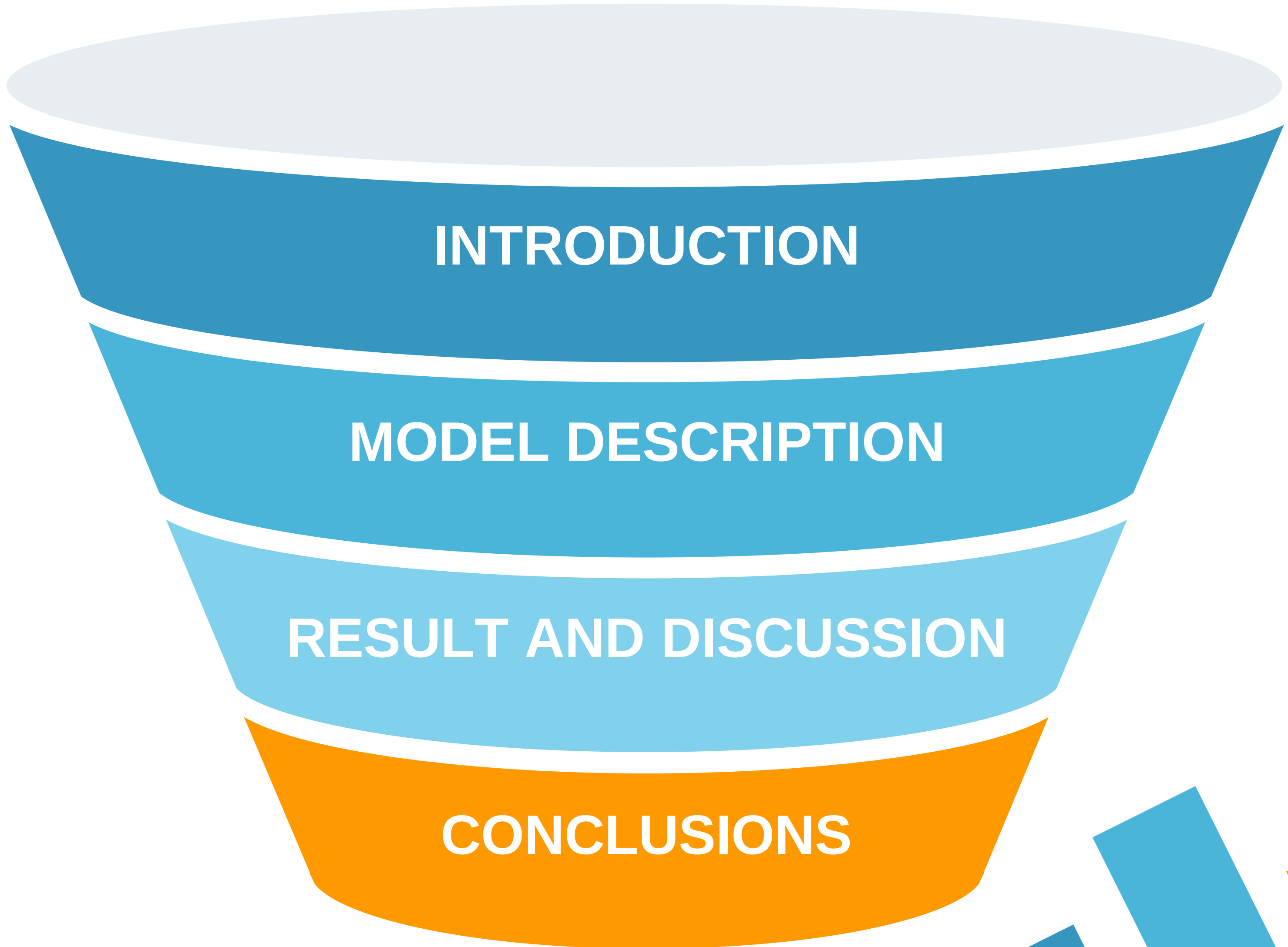
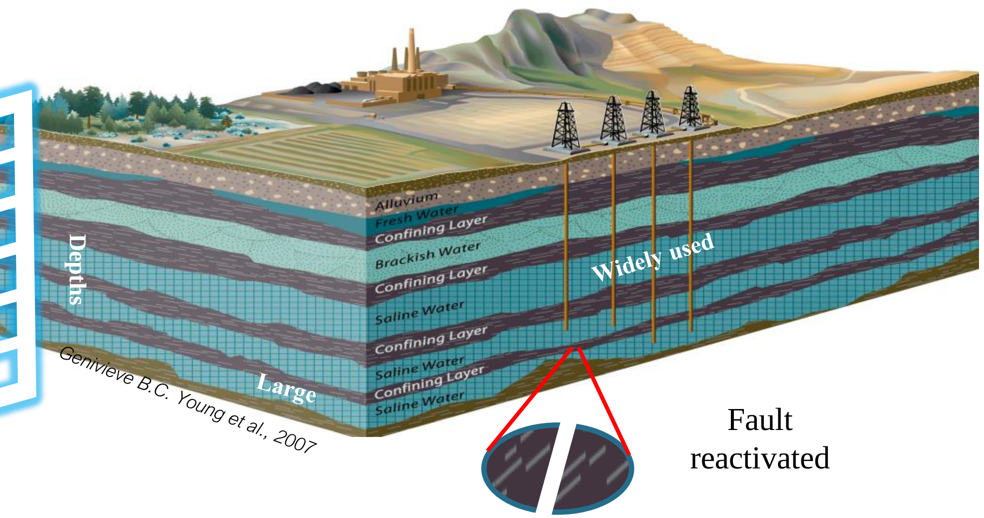
A mechanism of fluid exchange associated to CO_2 leakage along active fault during geologic storage

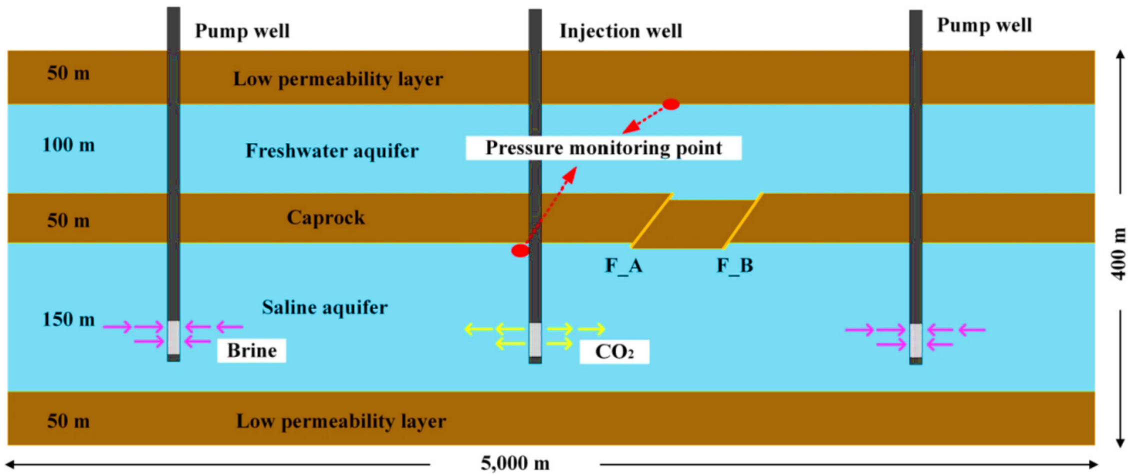
Zhang, L., Zhang, S., Jiang, W., Wang, Z., Li, J., & Bian, Y.
(2018). *Energy*.

Advisor : Prof. Jui-Sheng Chen
Student : Gia-Huy Lam
Date : 2023/11/24

OUTLINE


INTRODUCTION
MODEL DESCRIPTION
RESULT AND DISCUSSION
CONCLUSIONS





CO_2 SEQUESTRATION

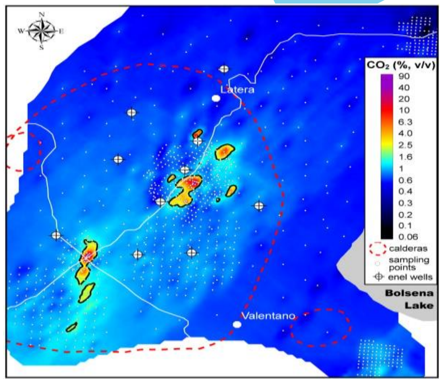
- **C**arbon **C**apture and **S**torage **(CCS)**
- Capturing carbon dioxide emissions
- The most effective way to reduce GHGs and mitigate the impacts of climate change.

- **Deep saline aquifers** is one of the main candidates to cut anthropogenic CO_2 emissions.
- **Caprock** is a natural barrier to prevent the injected CO_2 escaping from reservoirs.

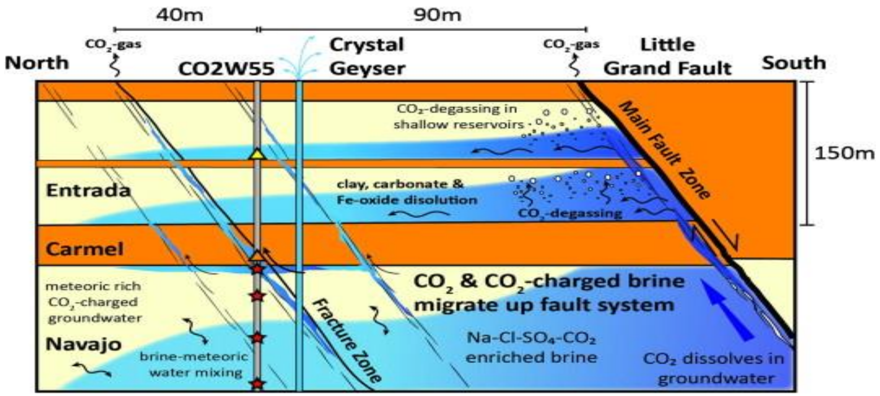
FLUID EXCHANGE

Associated to **CO_2 leakage, brine** and **freshwater** would escape or lose along the fault from their respective formation.

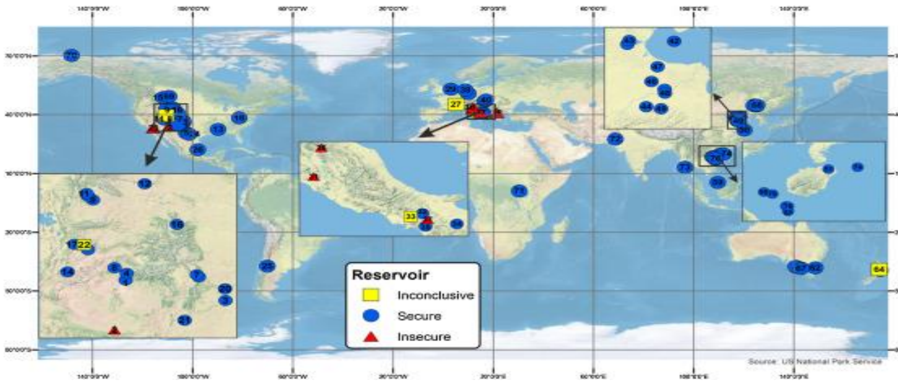
LITERATURE REVIEW



Annunziatellis et al. (2008) carried out a natural test to investigate CO_2 migration.



Kampman et al.(2014) examined the reactive fluid flow in the reservoirs, caprocks and faults during upward migration of CO_2.



Miocic et al. (2016) investigated 76 naturally occurring natural CO_2 stores in the worldwide, to understand the geologic controls on long term storage performance.

All of the authors **emphasized** that the **sealing capacity** of the fault and **the fluid exchange** need to be **evaluated and charecterized comprehensive**.

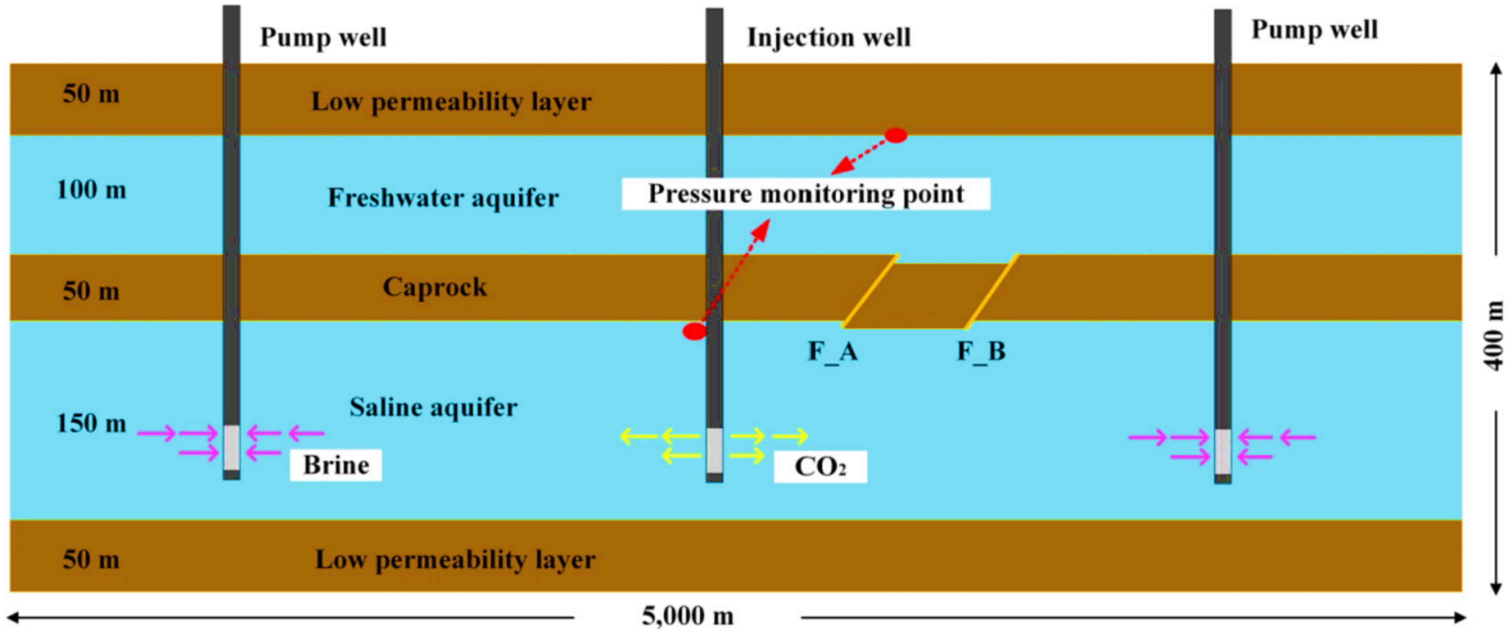
OBJECTIVE

- Employ a 3-D numerical model based on TOUGH2/ECO2N to investigate fluid exchange related to CO_2 leakage along activated faults.

- Understand the implications of fluid exchange by comparing CO_2 and brine leakage under different conditions, with and without pump wells.

- Conducts parametric analyses of leakage rates and quantities, considering factors such as fault permeability, saline aquifer permeability, and fault width

PHYSICAL MODEL

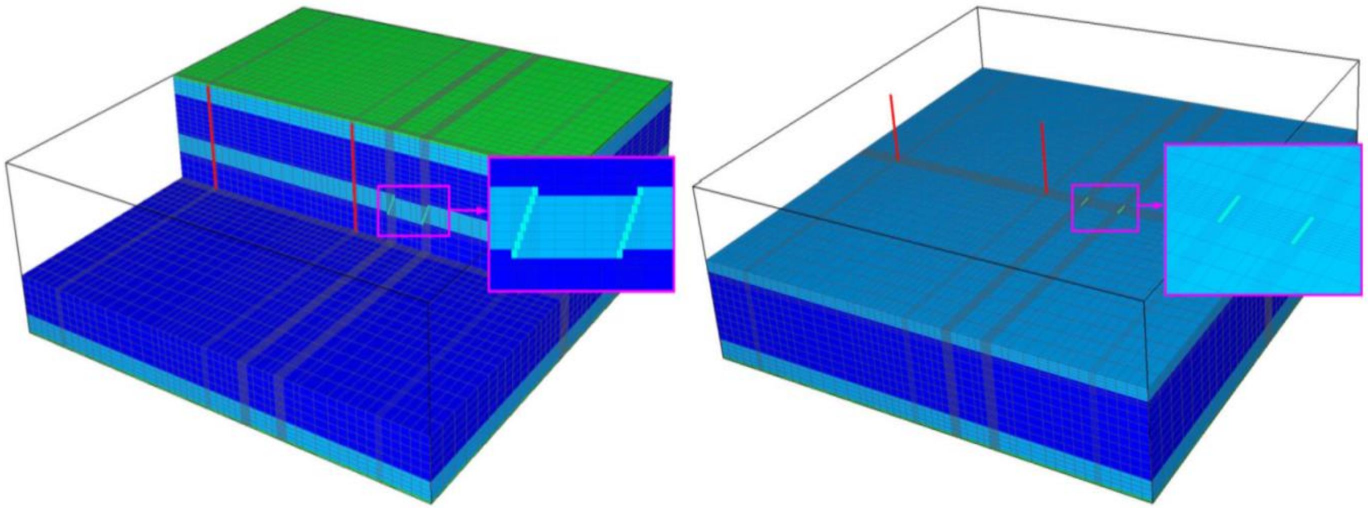


The opened or activated fault maybe exists in the caprock, which makes that CO_2, brine and freshwater would leak or lose along the fault.

A fluid exchange would certainly occur, associated to CO_2 leakage along activated fault.

- Two faults exist in the caprock:
  + Depth of 200m
  + Fault zone extents 130m and has the width of 12m
  + Dip angle 25°
- Injection well is located in the center of the physical model
- The distence between injection well and pump wells is 2000m
- The distence between F_A and the injection well is 500m

NUMERICAL MODEL



- **Grid blocks** consisted: 107,748 (73 *41 *36).
- The **mesh refinement** was carried out around the faults and injection/pump wells.
- **Isothermal conditions** were used for simplifying.

INITIAL BOUNDARY:

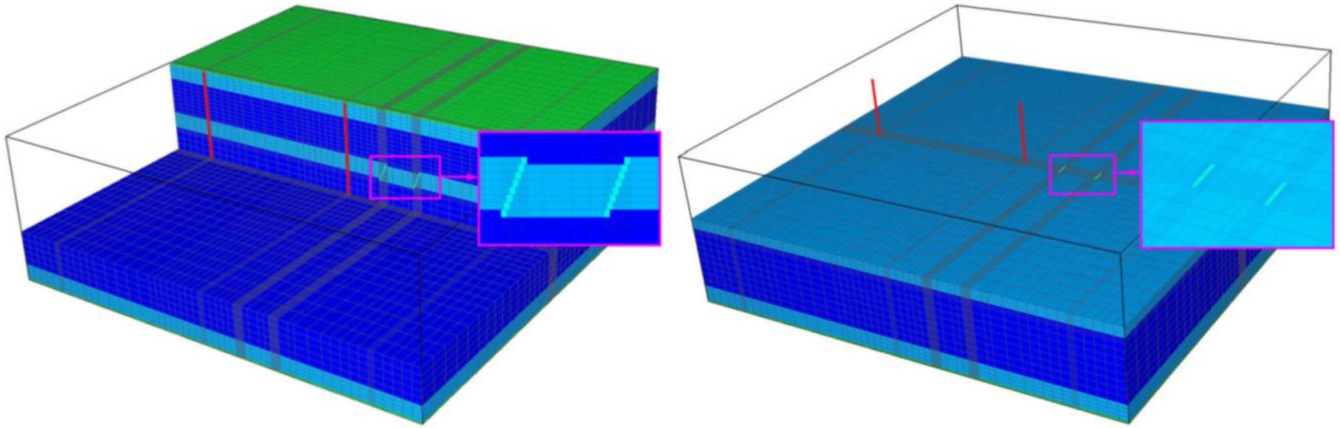
- **Impermeable boundaries** were set on the top and bottom surfaces.
- **Closed boundaries** were set at the other surfaces.

The basic mass and energy balance equations used in this model was shown as following:

$$\frac{d}{dt}\int_{V_n} M^K dV_n = \int_{T_n} F^K n d\,T_n + \int_{V_n} q^K dV_n$$

Where: V_n: an arbitrary subdomain of the flow system
T_n: the close surface of the subdomain V_n
M: quantity of mass or energy/volume.
F:heat flux between the volume elements
q: denotes sinks and sources
n : a normal vector on surface element
K : mass component

NUMERICAL MODEL



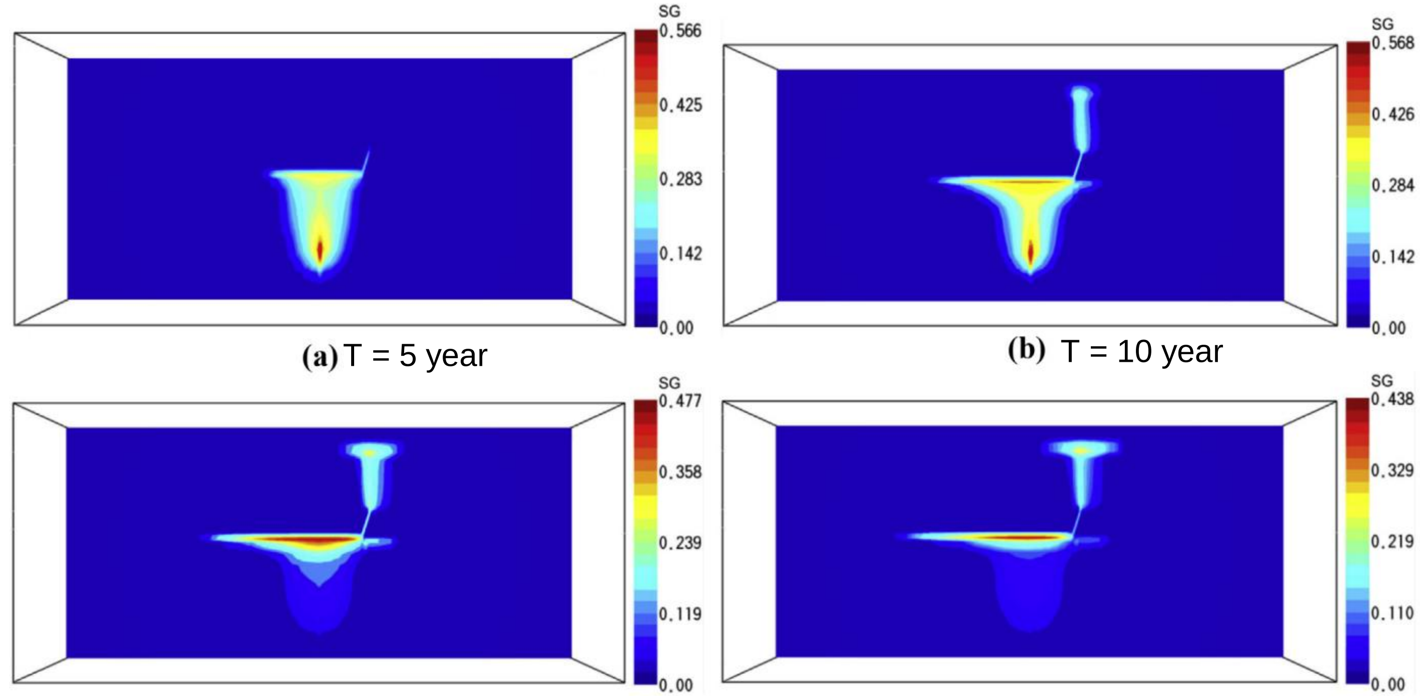
Initial conditions	Value
Temperature	49 °C
Pressure	9 Mpa
Salt mass fraction of saline aquifer	0.6%
CO_2 injected rate	10 kg/s
Brine pump rate	5 kg/s
Simulation time	20 years

Table 1
Input parameters.

Properties	Values
Rock compressibility (Pa^{-1})	4.5×10^{-10}
Rock grain density (kg/s)	2600
Rock grain specific heat (J/kg °C)	920
Formation heat conductivity (W/m °C)	2.51
λ: index	0.457
S_{lr}: residual liquid saturation	0.3
S_{ls}: maximum liquid saturation	1.0
S_{gr}: residual gas saturation	0.05
P_0: pressure coefficient (kPa)	19.59
Porosity of fault (%)	30
Porosity of freshwater aquifer (%)	15
Porosity of saline aquifer (%)	15
Porosity of caprock (%)	6
Porosity of lower permeability layer (%)	2
Permeability of fault (mD)	590
Permeability of freshwater aquifer (mD)	59
Permeability of saline aquifer (mD)	59
Permeability of caprock (mD)	5.9×10^{-4}
Permeability of lower permeability layer (mD)	5.9×10^{-5}

Mechanism of fluid exchange

MIGRATION OF GAS CO_2



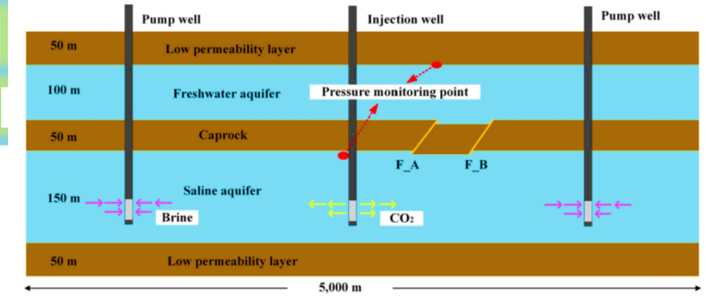
(a) T = 5 year
(b) T = 10 year
(c) T = 15 year
(d) T = 20 year

The distribution of gas CO_2 saturation.

- The CO_2 plume just reached the opened or activated fault before the 5 year.
- The **ratio of leakage amount is 1: 38,07** compare to the time before (T= 5 year).
- CO_2 leakage has just occurred along F_A, except of F_B.
- Associate to that point, the fluid exchange definitely occured.
- The maximum saturation of gas CO_2 decreases from 0.568 to 0.438 with time at the period of 10 year to 20 year.

Leakage amount	Value (Mt)
CO_2	0.413
Brine	0.021
Freshwater	0.412

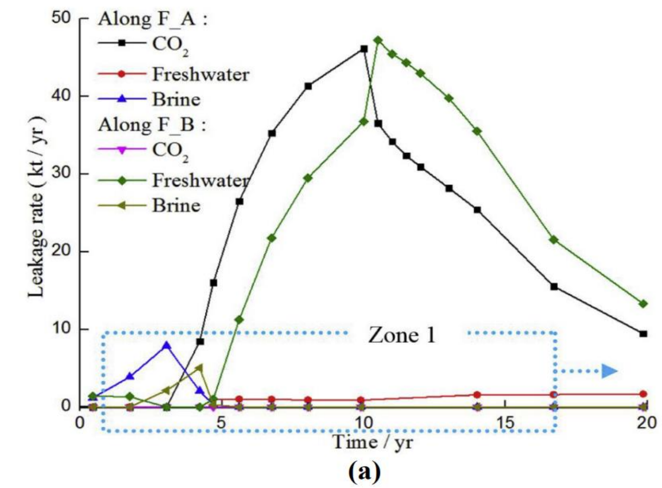
Leakage amount at 20 year



FLUID EXCHANGE MECHANISM BASED ON LEAKAGE RATE

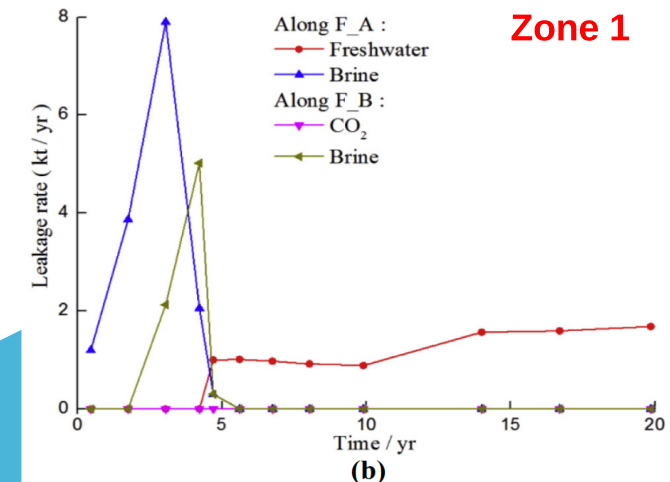
Major fluid exchange from F_A to F_B

- **CO_2 leaking occurs firstly along F_A** into freshwater aquifer, then freshwater leakage will happen.
- **CO_2** leakage and **freshwater** leakage have **increased leakage rate of each other.**
- The **fluid exchange** between CO_2 and freshwater is **disadvantageous** for **CO_2 geological storage.**
- The maximum leakage rates: + CO_2 via F_A: 46.13 kt/yr.
  + Freshwater via F_B: 47.20 kt/yr.



Minor fluid change in F_A

- The leakage of freshwater and brine slowly increased via F_A before 5 year.
- Brine leakage along F_A reach 0 kt/year at T = 6 year.

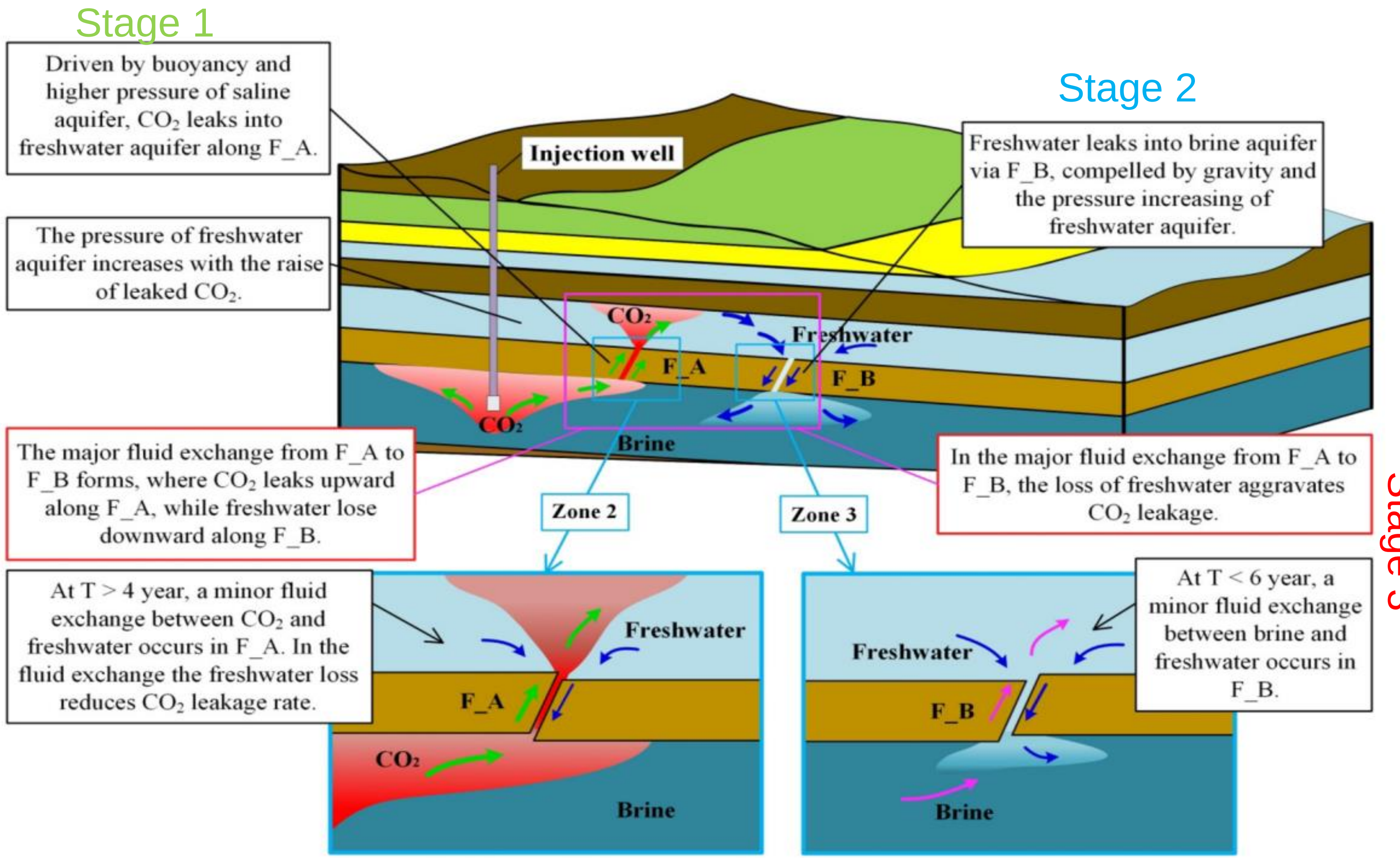


Minor fluid change in F_B

- At first time, the formation pressure near F_B increases gradually as CO_2 injecting continuously.
- A minor fluid exchange that brine leaks upward via F_B and F_A exists in F_B at T < 6 year.

Leakage rates considering different permeability of fault

Mechanism of fluid exchange



Legend:

Green arrowhead: CO_2

Blue arrowhead: freshwater

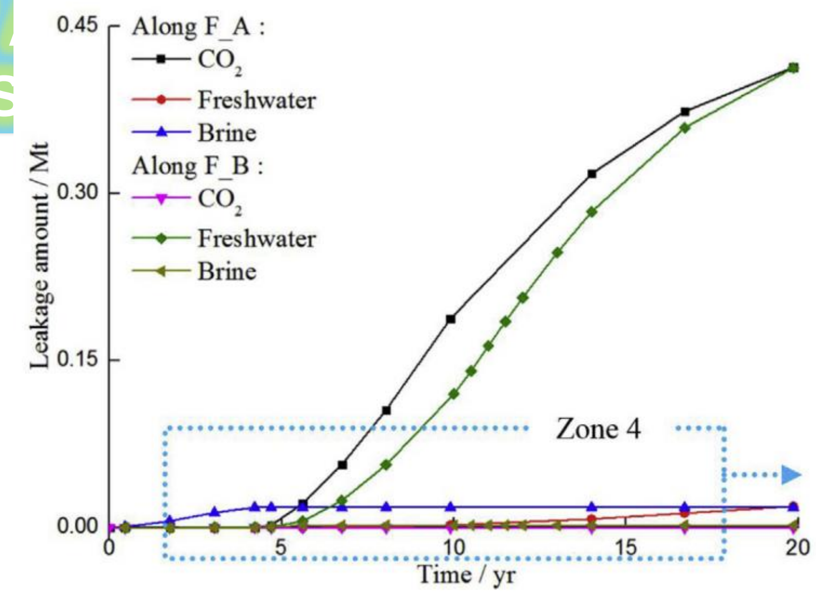
Magenta arrowhead: brine

Leakage amount in fluid exchange

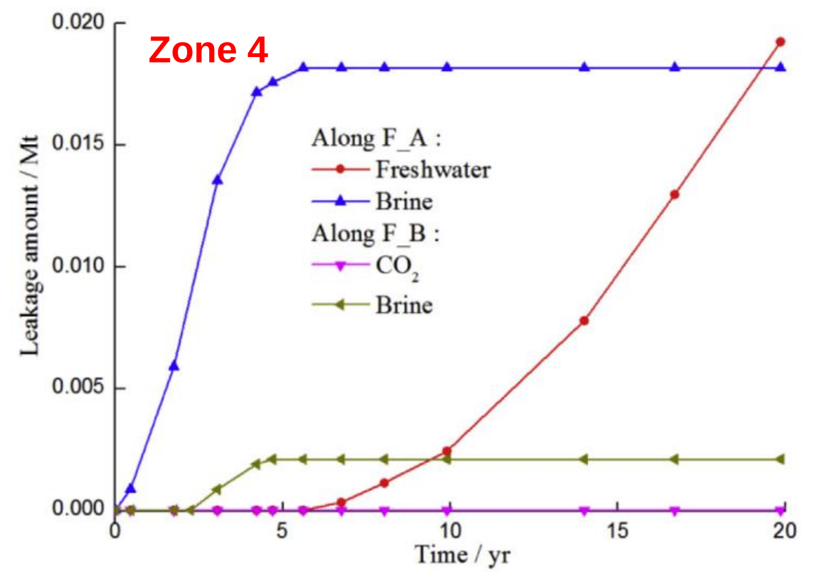
- The leakage amounts of freshwater and brine along F_A as well as the leakage amount of brine along F_B are small relatively.
- No CO_2 reaches F_B in the process of CO_2 leakage.
- CO_2 escape along F_A and freshwater loss along F_B just form the major fluid exchange from F_A to F_B, indicates the largest effect on the fluid exchange.

Leakage amount at the T = 20 year

Leakage amount	Along F_A (Mt)	Along F_B (Mt)
CO_2	0.413	0
Brine	0.018	0.002
Freshwater	0.019	0.412

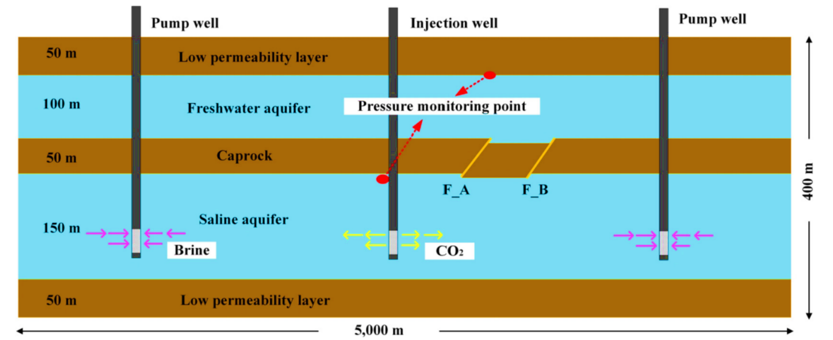


(a)



(b)

The leakage amounts of CO_2, brine and freshwater

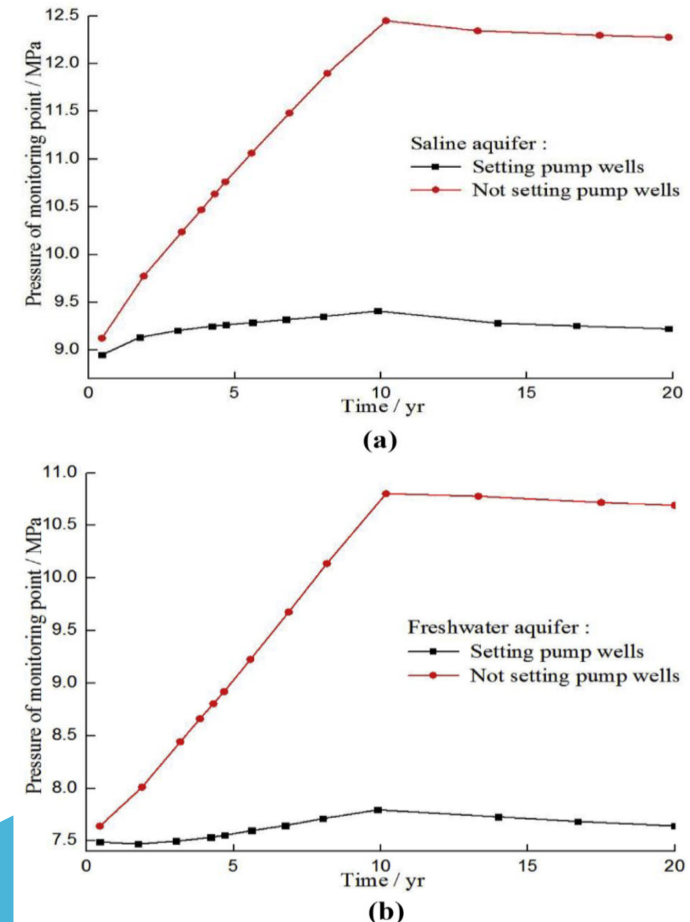


Implication from pump well

To investigate the **difference of setting and not setting pump wells** on the fluid exchange, a numerical model of not setting pump wells was developed. The **comparisons** were **focused** on **the pressure, leakage rate** as well as **leakage amount**.

Comparison of Pressure

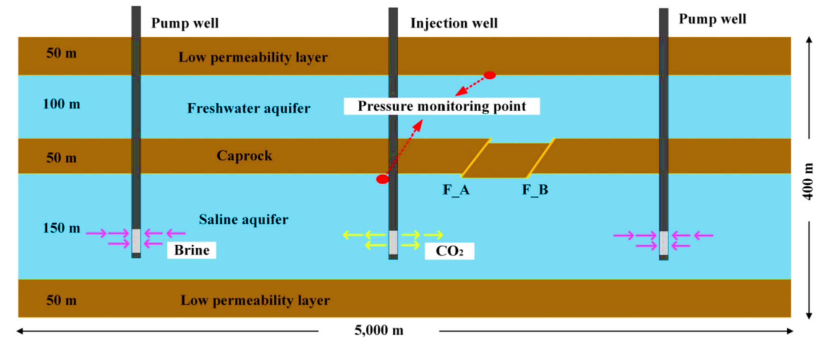
- Before 10 year, the pressure of saline aquifer for Model_nspw increases quickly, while the pressure for Model_spw increases slowly.
- **Setting pump wells** can **slow down the increasing of pressure** of saline aquifer
- For Model_nspw, **more disadvantageous** for **CO_2 geological storage.**



Pressure of monitoring point for Model_spw and Model_nspw.f

Maximum pressure at the T <10 year

Aquifer	Maximum pressure of monitoring point (Mpa)	
	spw	nspw
Saline	9.40	12.45
Freshwater	7.79	10.80

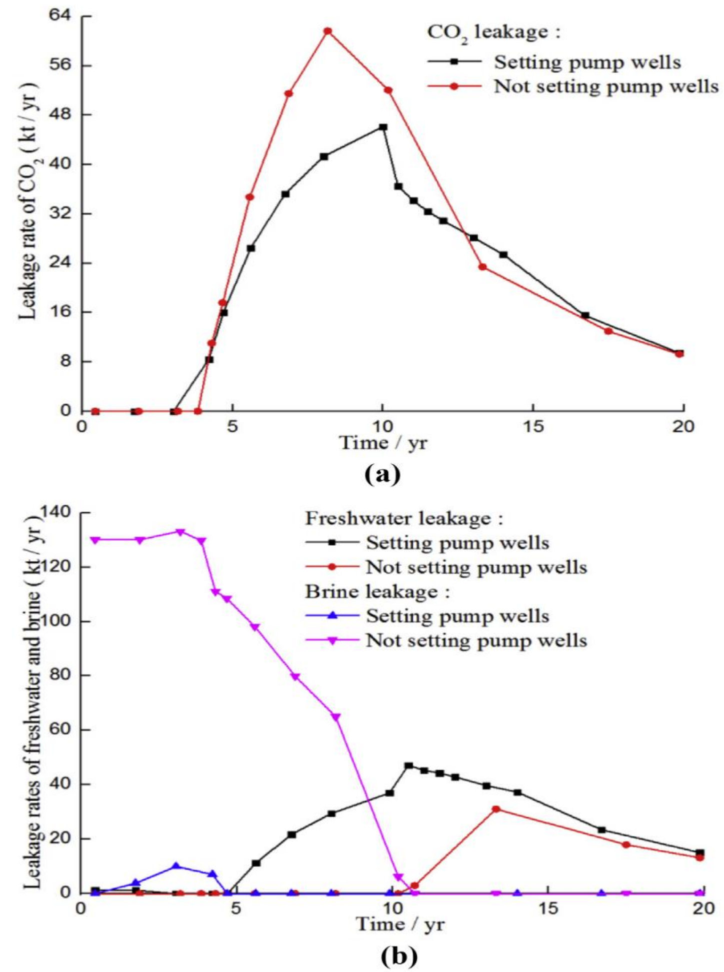


Comparison of Leakage rate

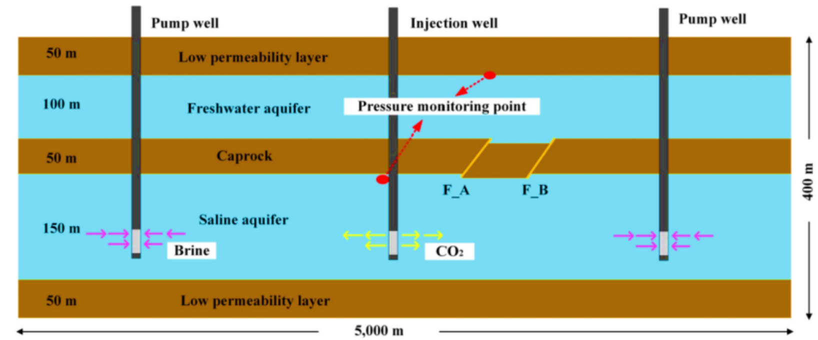
- Coresponding to pressure comparison, more disadvantageous for CO_2 geological storage.
- The leakage rate of brine remains a high level due to the pressure of saline aquifer too high.
- The pressure of saline aquifer is higher for Model_nspw, restraining the freshwater to leak downward.

Maximum leakage rate at the T < 10 year

Fluid	Maximum leakage rates (kt/year)	
	spw	nspw
CO2	46.13	62.13
Freshwater	-	-
Brine	-	131.50

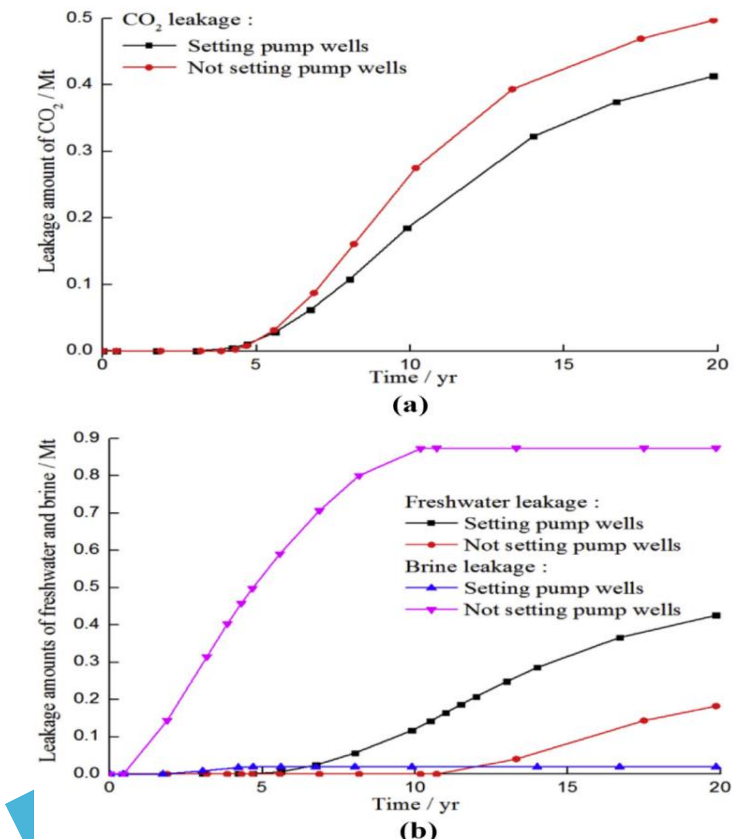


Leakage rates for Model_spw and Model_nspw



Leakage amount comparison

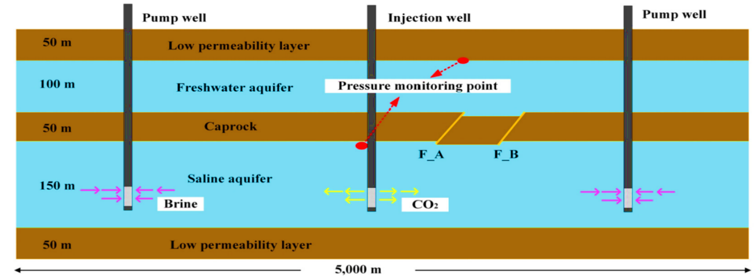
- Setting pump wells can decrease effectively the leakage amount of CO_2.
- The leakage amount of brine has an obvious decreasing of more than 95% due to setting pump wells.
- The leakage amounts of freshwater for Model_spw closely to 3 times for Model_nspw.



Leakage amount for Model_spw and Model_nspw.

Implication from pump well

- From the perspective of preventing CO_2 and brine leakages, setting pump wells can **be regarded as an important implication** for the fluid exchange associated to CO_2 leakage along fault.



PARAMETRIC ANALYSIS

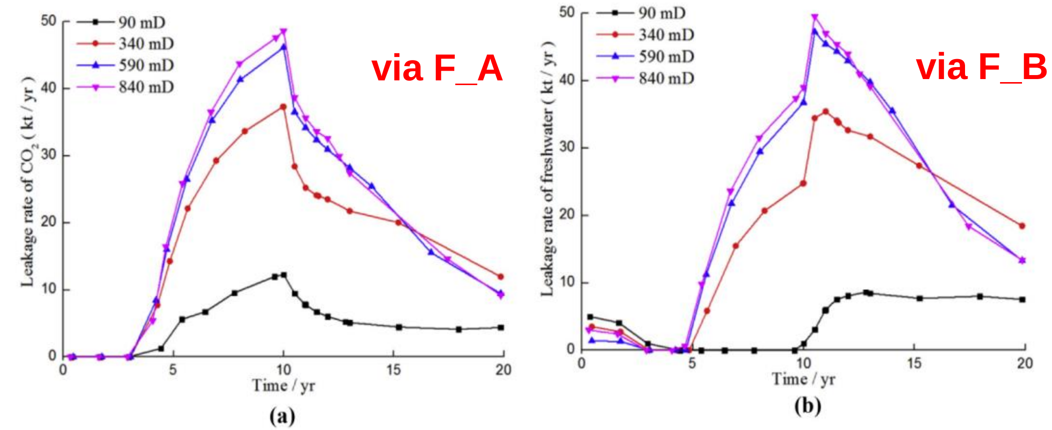
The targets investigated are **leakage rates** and **amounts of CO_2** via F_A and **freshwater** via F_B. In this parametric analysis, **other parameters** keep **constant**, while **one parameter changes**.

Effect of permeability of fault to the leakage rate and leakage amount

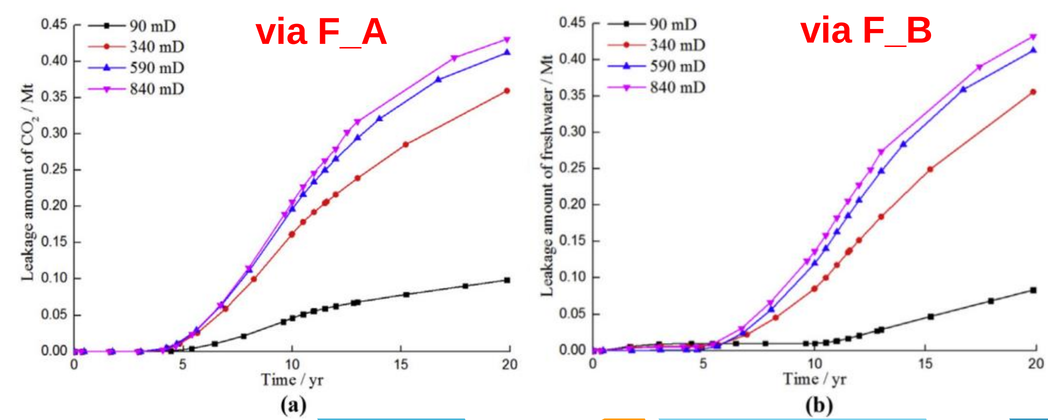
- The maximum leakage rates of CO_2 are 12.27 kt/yr, 37.31 kt/yr, 46.13 kt/yr and 48.58 kt/yr, under the fault permeability of 90 mD, 340 mD, 590 mD and 840 mD.
- Correspondingly, the maximum leakage rates of freshwater are 8.60 kt/yr, 35.42 kt/yr, 47.20 kt/yr and 49.51 kt/yr, respectively.

- Under the fault permeability of 90 mD, 340 mD, 590 mD and 840 mD, the leakage amounts of CO_2 are 0.098 Mt, 0.359 Mt, 0.413 Mt and 0.432 Mt respectively.
- Correspondingly, the leakage amounts of freshwater are 0.083 Mt, 0.356 Mt, 0.412 Mt and 0.430 Mt, respectively.

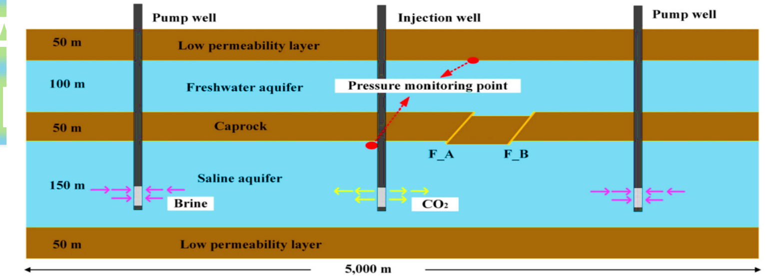
Overall, the fluid exchange is enhanced with the increasing of the fault permeability.



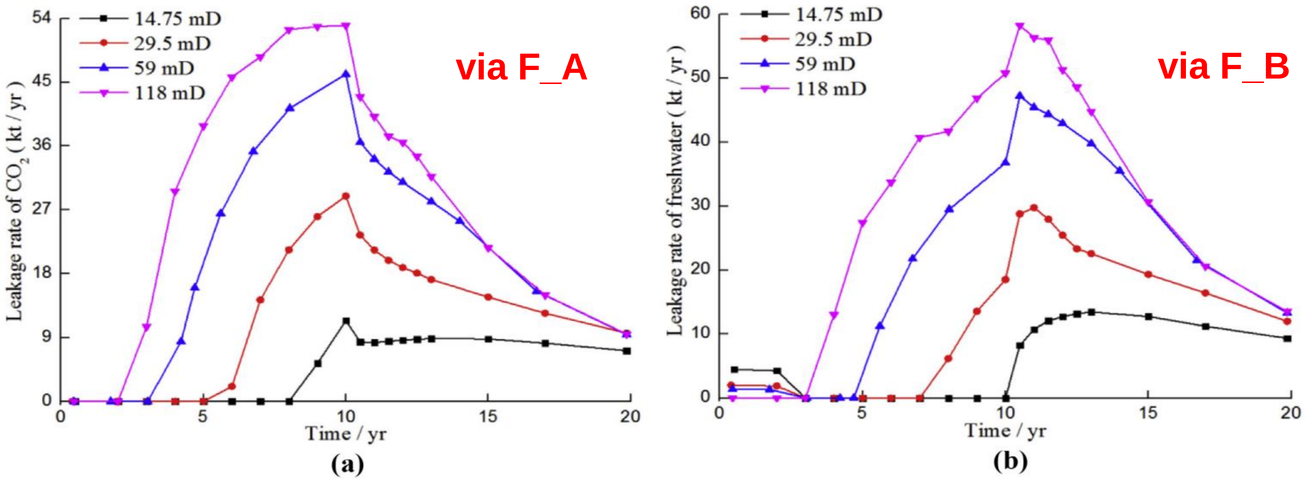
Leakage rates considering different permeability of fault



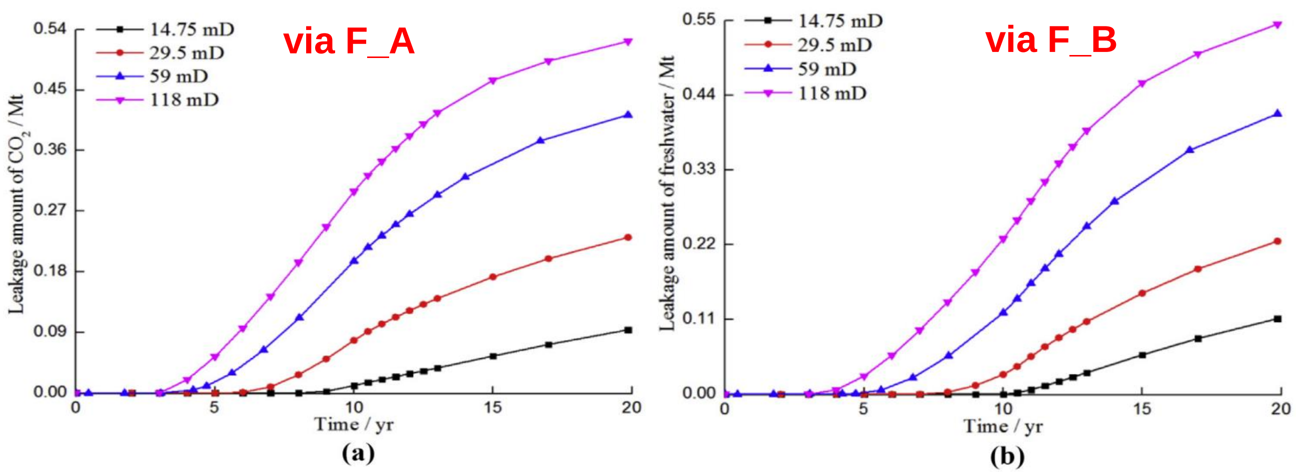
Leakage amount considering different permeability of fault



Effect of permeability of saline aquifer



Leakage rates considering different permeability of saline aquifer

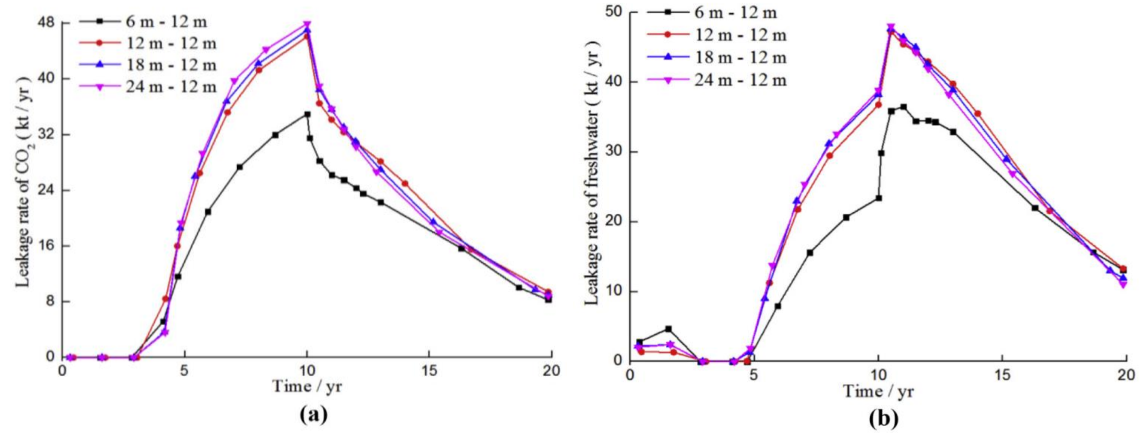


Leakage amount considering different permeability of saline aquifer

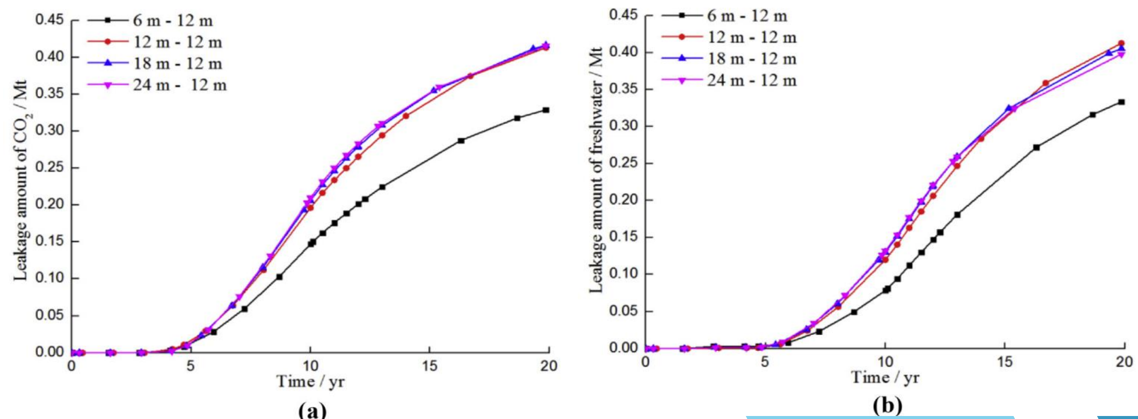
- Corresponding to the results above, the permeability of saline aquifer has a great influence on the fluid exchange. For the saline aquifer of the higher permeability, the fluid exchange is aggravated obviously.

Effect of fault width of F_A

- When changing the width of F_A from 6 – 24m, the trend of leakage rate and leakage amount is the same with results above.
- The trend of results are not too clearly at some times of the period.
- However, it can consider that the larger width will get the higher leakage rate, higher leakage amount at T = 10 year and reduce to T= 20 year and of CO_2 and freshwater.



Leakage rates considering different width of fault A,B



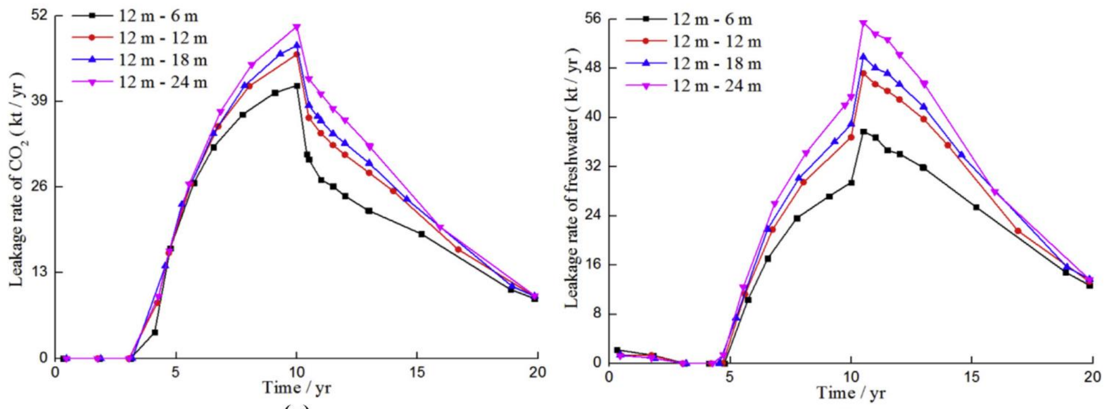
Leakage amounts considering different width of fault A,B

Effect of fault width of F_B

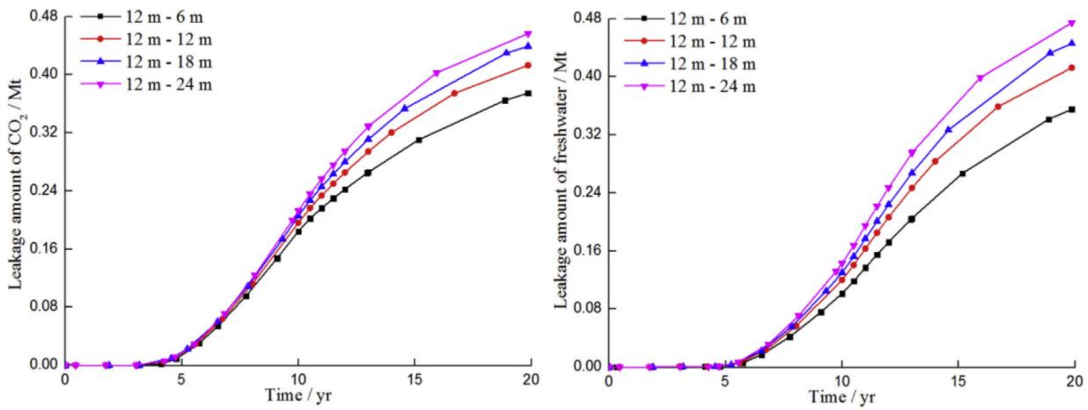
- When changing the width of F_B from 6 – 24m, the trend of leakage rate and leakage amount is the same with results above.

- The trend of results are easy to observe the different at different times of the period.

- However, it can consider that the larger width will get the higher leakage rate (T= 10 year), reduce leakage rate to T= 20 year and
- With leakage amount of CO_2 and freshwater, it can obviously observe the increasing through the period.



(a) (b)



(a) (b)

- A 3-D numerical model was developed based on **TOUGH2/ECO2N** to explore the mechanisms of fluid exchange resulting from CO_2 leakage along activated faults. The model specifically focused on **the interaction between CO_2, brine, and freshwater**.

- The fluid exchange contains **the major fluid exchange of CO_2 and freshwater from F_A to F_B**.

- As a result, setting pump wells are beneficial for CO_2 geological storage, especially when considering the two faults.

- Parametric analysis was investigated to obtain the effect of the permeability of fault, the permeability of saline aquifer and the fault width on the fluid exchange. Especially, the fluid exchange is herein reflected by leakage rates and amounts of CO2 via F_A and freshwater via F_B.

THANKS FOR YOUR LISTENING!