Seminar 111-1

Hydromechanical model of land subsidence in the Chousui River Alluvial Fan: a site specific problem model

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Date: 2022/11/25

Outline

- introduction
- methodology
- result
- discussion
- conclusion
- future work

introduction

background

motivation

objectives

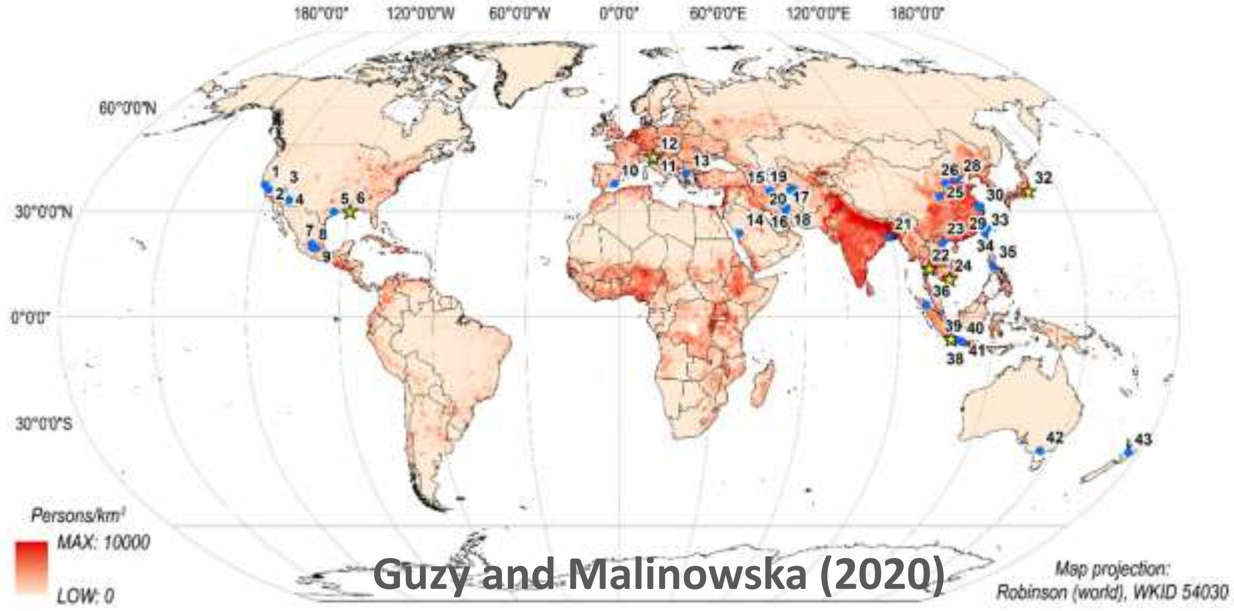
What is land subsidence?

Sudden sinking or ***gradual settling*** of the Earth's surface owing to movement of earth materials (Hoffmann et al.2003)

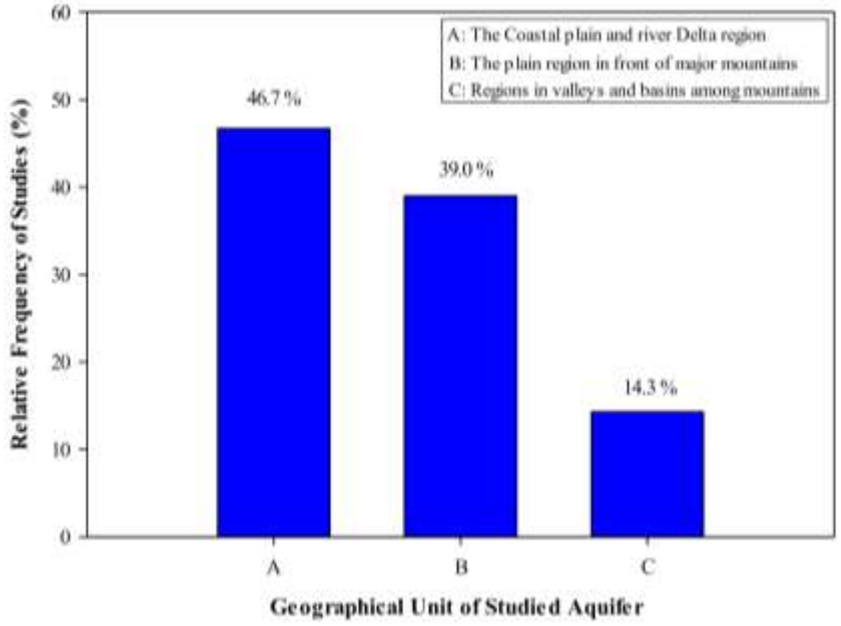
Problem related to subsidence

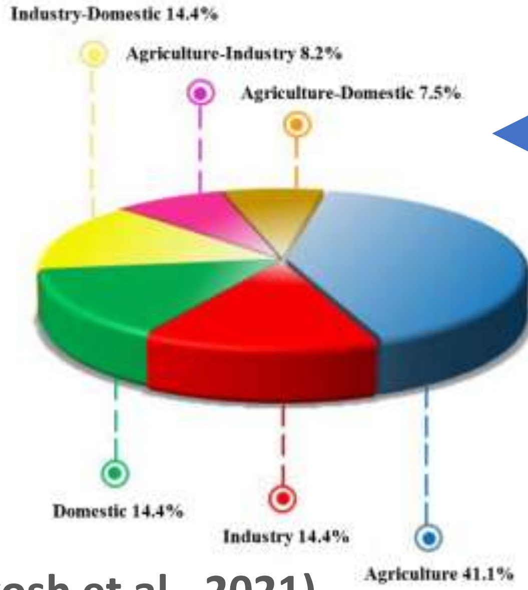
Structure failure, flooding, seawater intrusion (Galloway and Burbey, 2011)

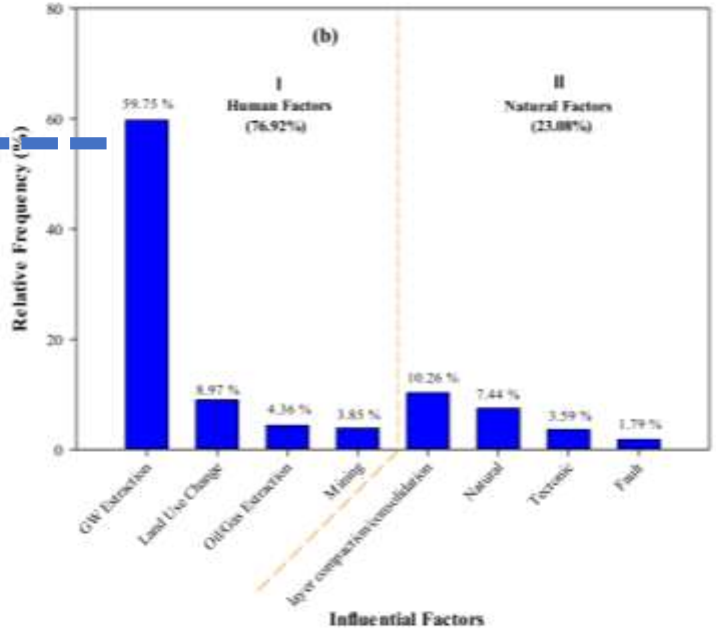
Land Subsidence as a Global Issue

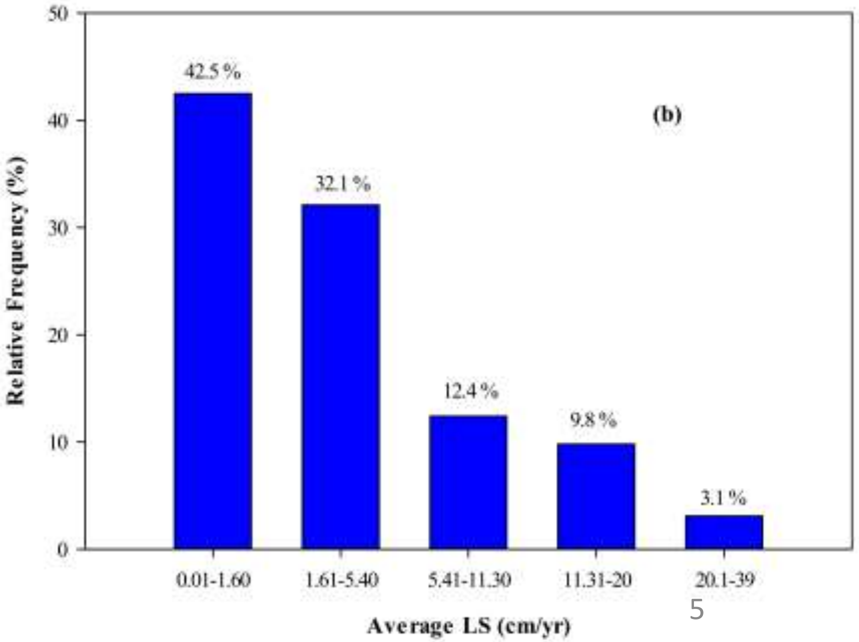


Guzy and Malinowska (2020)



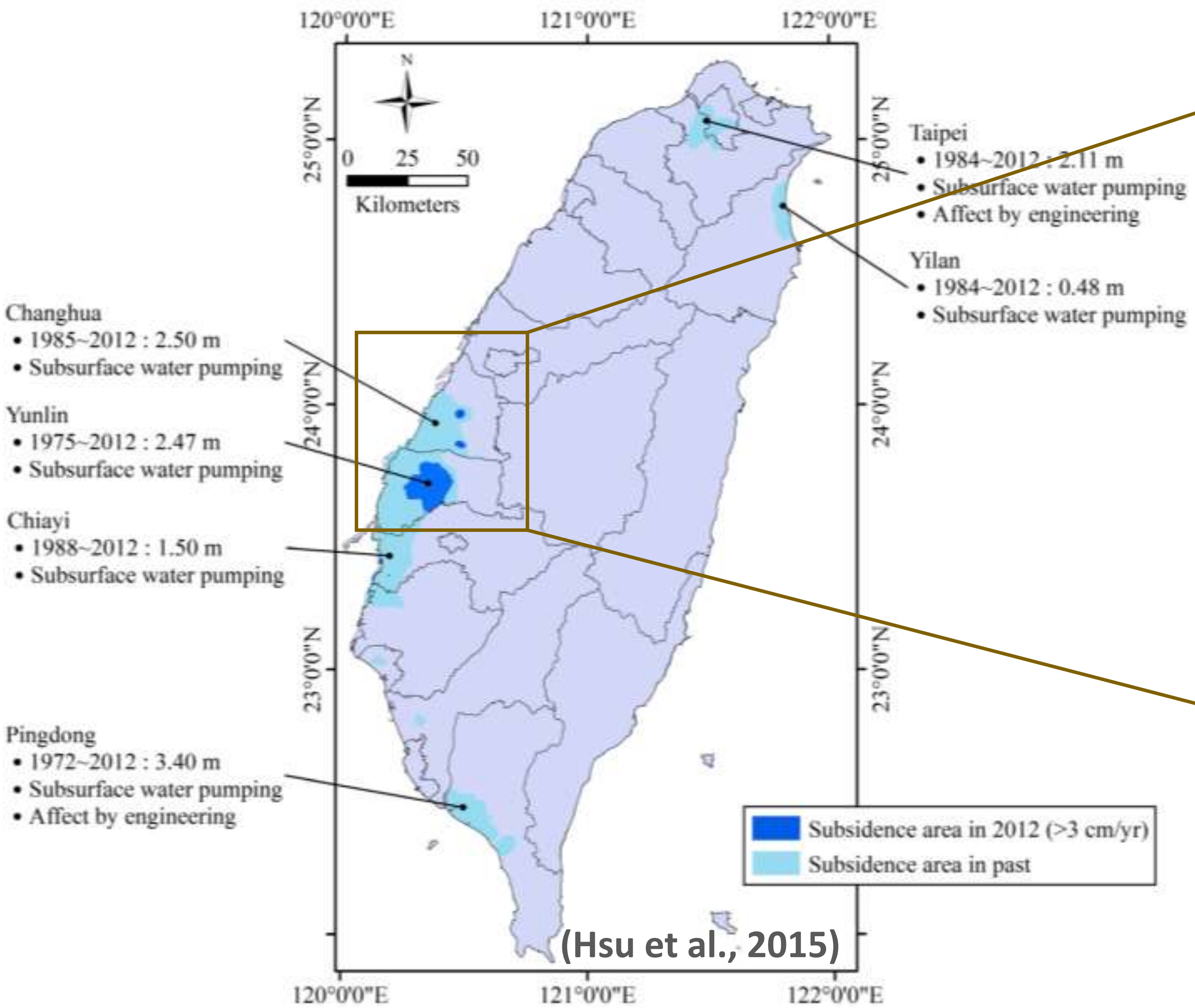




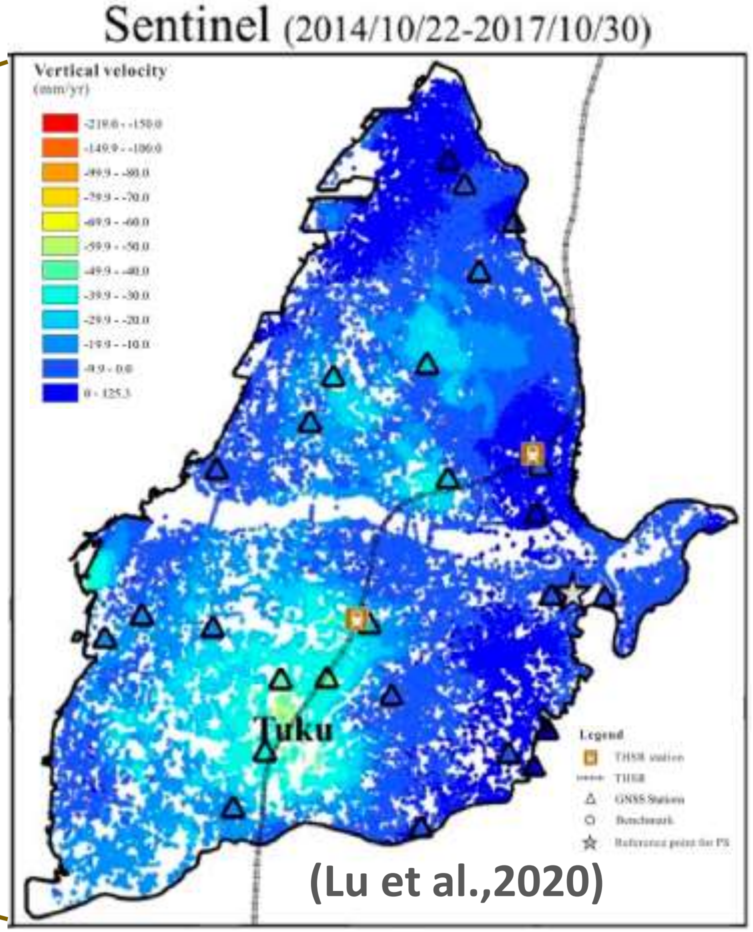


(Gavkosh et al., 2021)

Land Subsidence in Taiwan

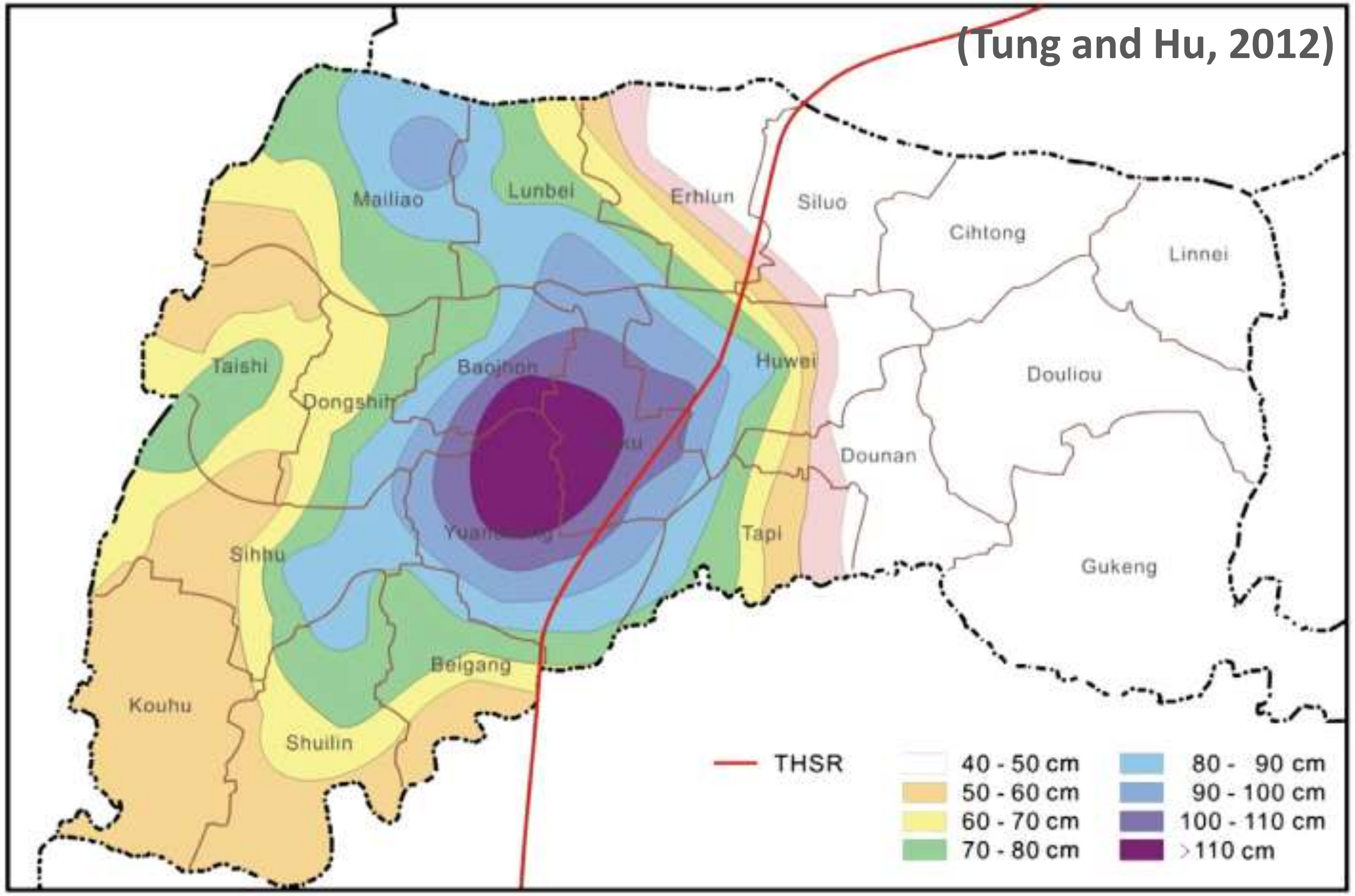


Land Subsidence in CRAF



land subsidence in Yunlin County by precise leveling from 1992 to 2007

(Tung and Hu, 2012)



the largest cumulative subsidence

> 1 meters!!

Why land subsidence in Yunlin County so high?

1.Excessive groundwater pumping

More than 100.000 well installed (745.37 million m^3)

2.Unconsolidated alluvial layer

Gravel, Sand, silt, mud and clay

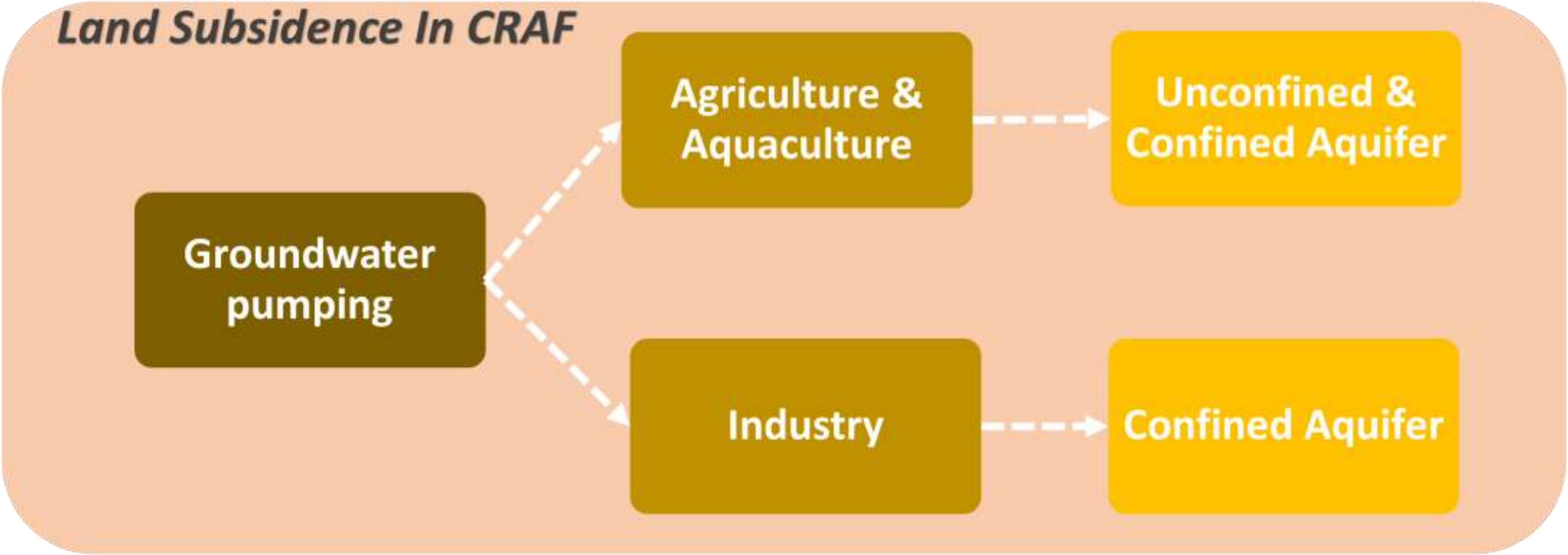
3.Groundwater recharge aren't sufficient

The rainfall in the Yunlin area varies greatly (551.89 million m^3/year)

4.Aquaculture & Agriculture

>> 4010 ha (year 2002) 471.76 million m^3(63.3 % of total withdrawal)

(Lin et al.2016, Hung et al.2010)


Land Subsidence In CRAF
Groundwater pumping
Agriculture & Aquaculture
Industry
Unconfined & Confined Aquifer
Confined Aquifer

Research Question?

Which one that can cause land subsidence significantly?

Agriculture & Aquaculture? Or Industry?

How much contribution of each layer compaction to total land subsidence?

How much the amount?

How can we reduce the amount of land subsidence?

Reduce pumping?

Motivation:

Understanding the influence of different pumping scenario in the different aquifer related to the changes of hydraulic head and total layer compaction in the site specific model

Objectives:

1. To Simulate the influence of groundwater pumping in different aquifer to hydraulic head in another aquifer
2. To Simulate the influence of groundwater pumping in different aquifer to layer compaction
3. To Calculate each layer compaction and its contribution to total subsidence

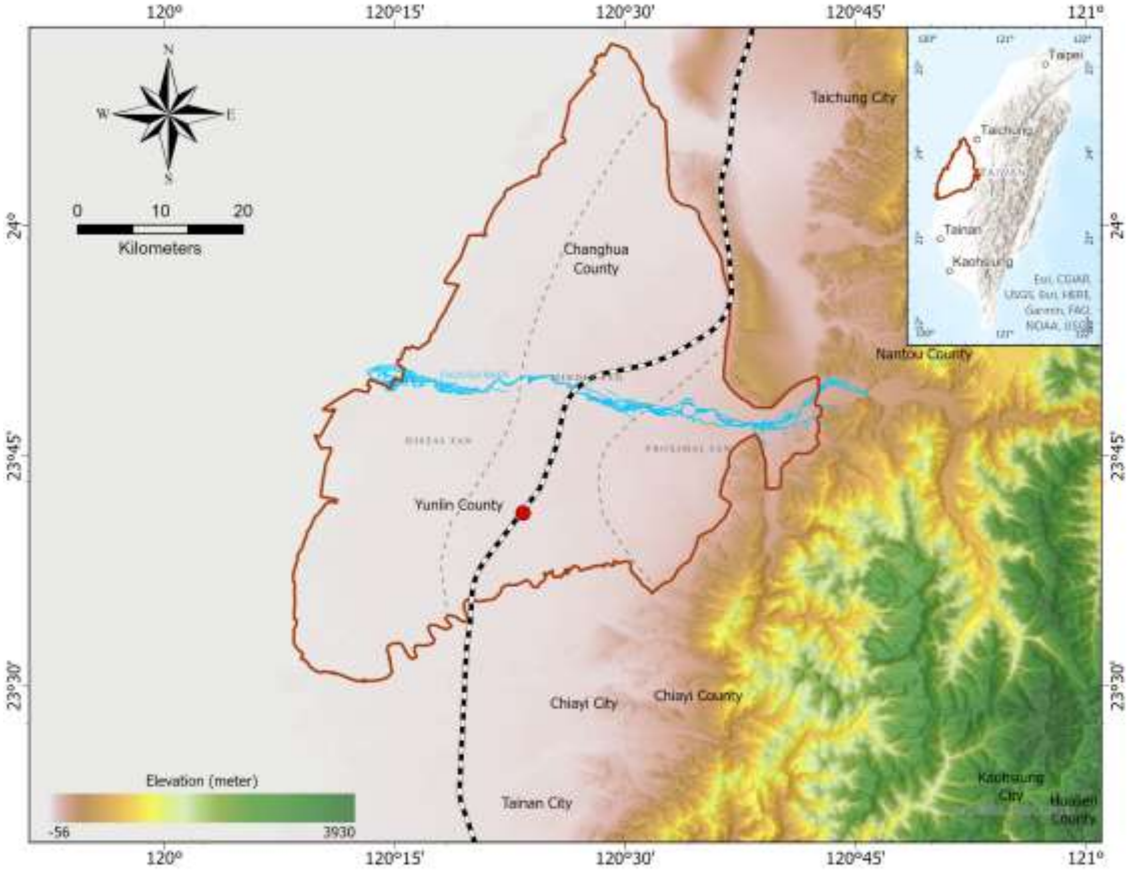
methodology

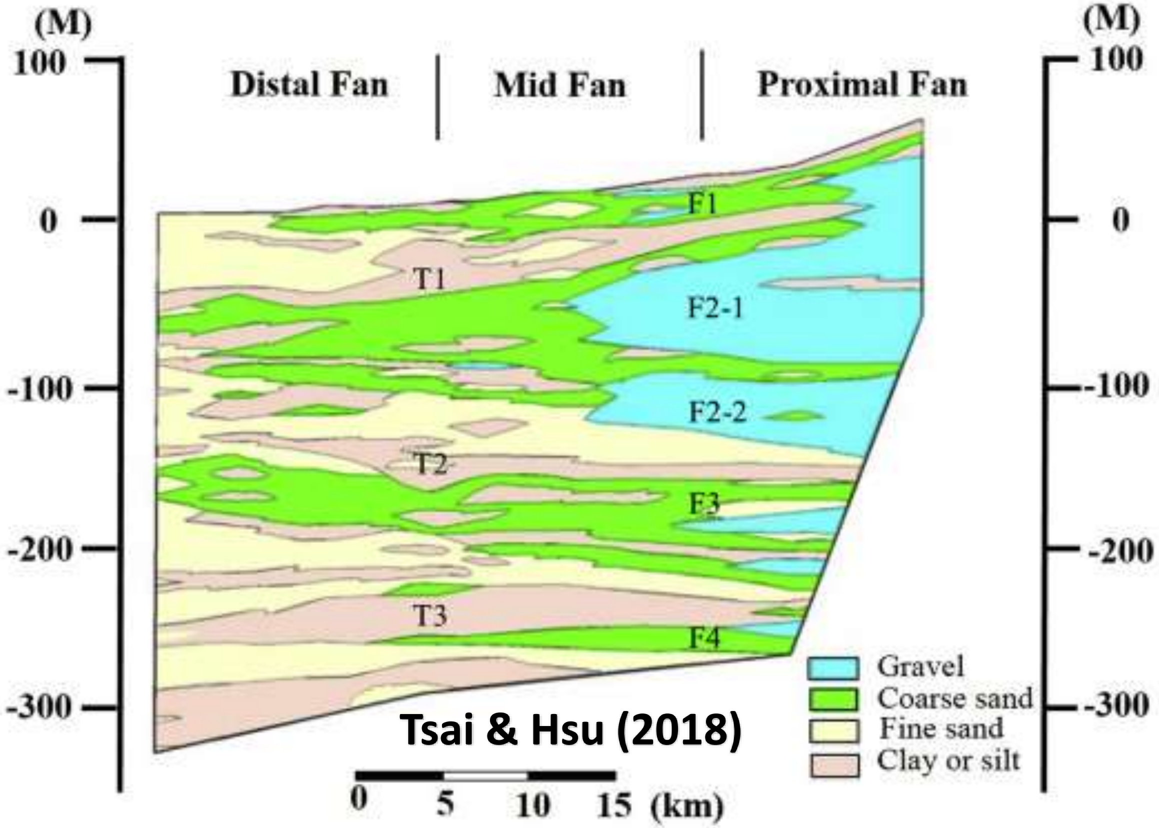
study area

data

numerical model

Study Area





Tsai & Hsu (2018)

Elevation:

0 – 100 m (asl)

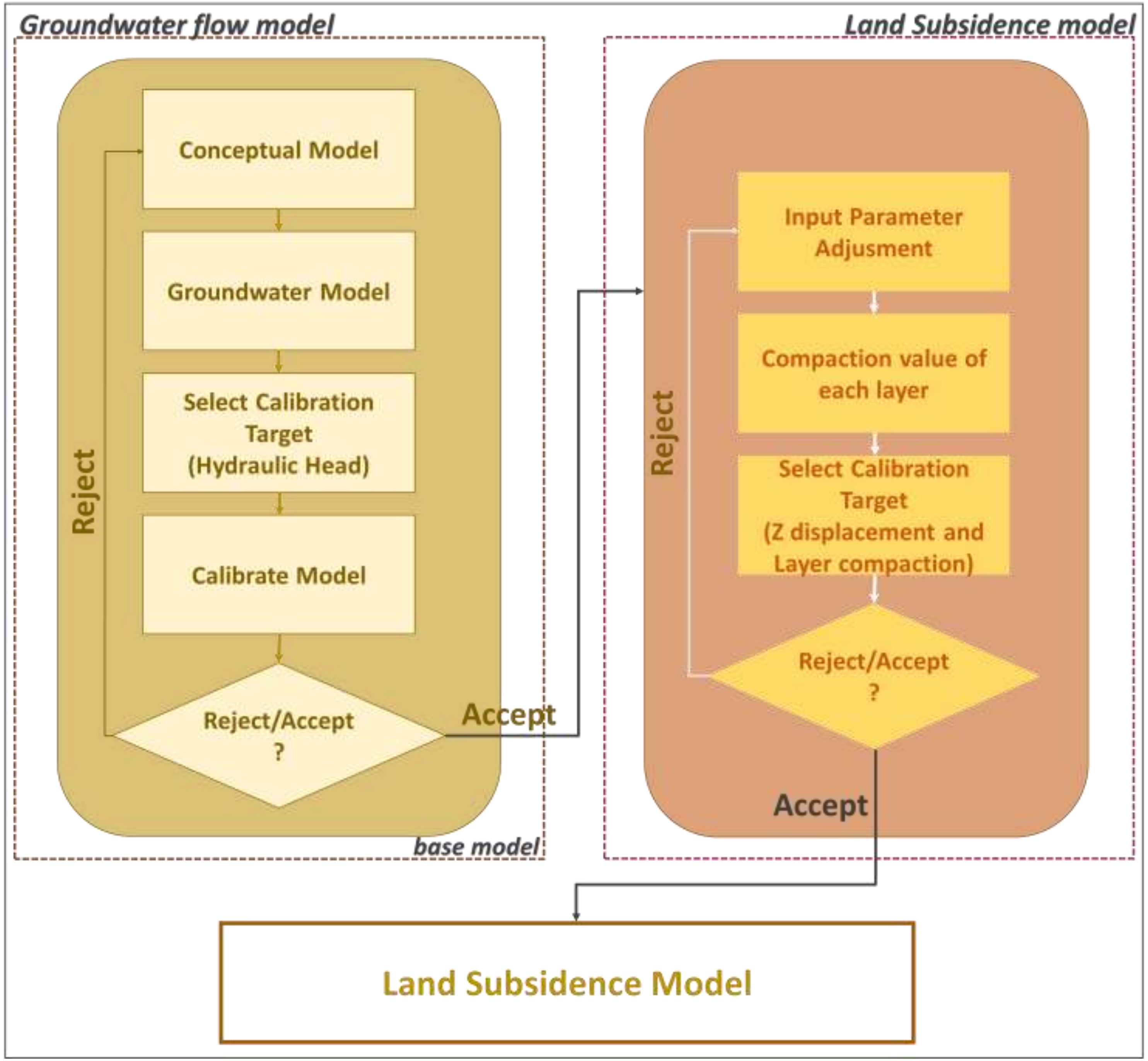
Materials:

- Gravel, coarse sand (Proximal)
- Fine-medium sand (Mid)
- Inter-bedded clay, silt (Distal)

Hydrostratigraphy:

- Four (4) Aquifer
- Four (4) Aquitard

Research Workflow



CSUB: Skeletal Storage,Compaction,Subsidence Package

(Hughes et al.,2022)

Features:

Confined & Unconfined flow systems

CSUB

Package for

MODFLOW 6

(Langevin et al.,2017)

To simulates

Vertical compaction & land subsidence→ Regional groundwater flow

CSUB simulates

1. Groundwater storage changes
2. Compaction in interbeds
3. Compaction in confining units
4. Stress-dependent in storage properties
5. Elastic & inelastic compaction

Geostatic stress → function of water table
Compaction → function of effective stress
Compressible sediment → can vary depend on saturated thickness

The three-dimensional ground-water flow equation (Harbaugh et al., 2000)

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

$\boldsymbol{x, y,}$ **and** $\boldsymbol{z}$: cartesian coordinates

$\boldsymbol{K_{xx}, K_{yy},}$ **and** $\boldsymbol{K_{zz}}$: hydraulic-conductivity tensor

$\boldsymbol{h}$: hydraulic head

$\boldsymbol{W}$: Volume of sources and (or) sinks of water

$\boldsymbol{S_s}$: specific storage of the aquifer

$\boldsymbol{t}$: time

Effective stress changes and compaction relation

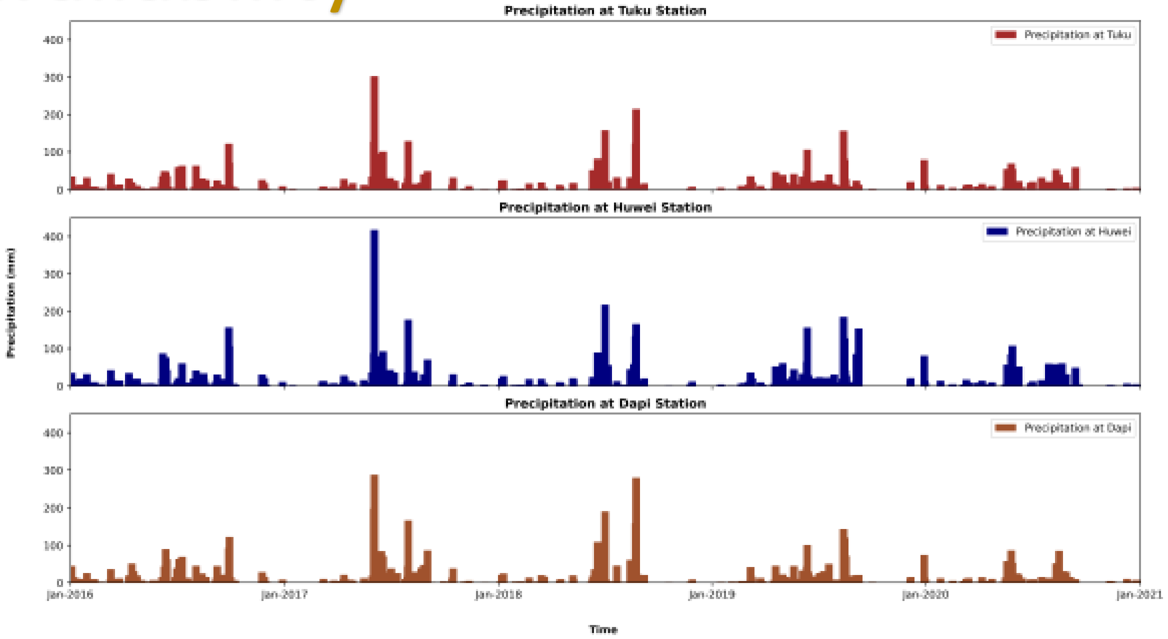
$$\Delta b = \frac{0.434 b_0}{(1+\ e_0)\sigma'}\left[C_n\left(\sigma'_n-\sigma'_{c,n-1}\right)+C_r\left(\sigma'_{c,n-1}-\sigma'_{n-1}\right)\right]$$

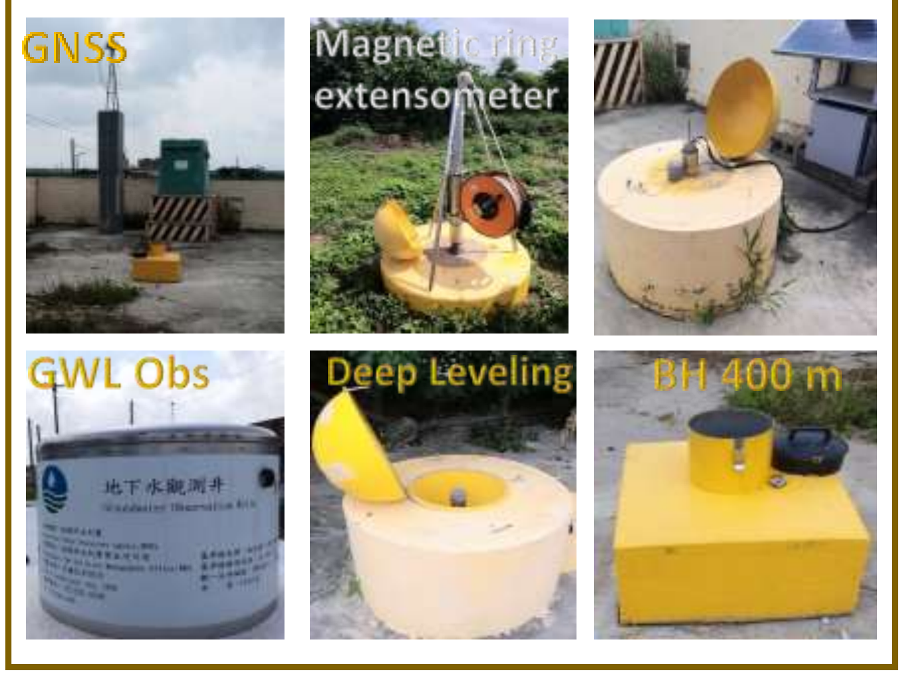
$$C_n = \begin{cases} C_c, \sigma'_n > \sigma'_{c,n-1} \\ C_r, \sigma'_n \le \sigma'_{c,n-1} \end{cases}$$

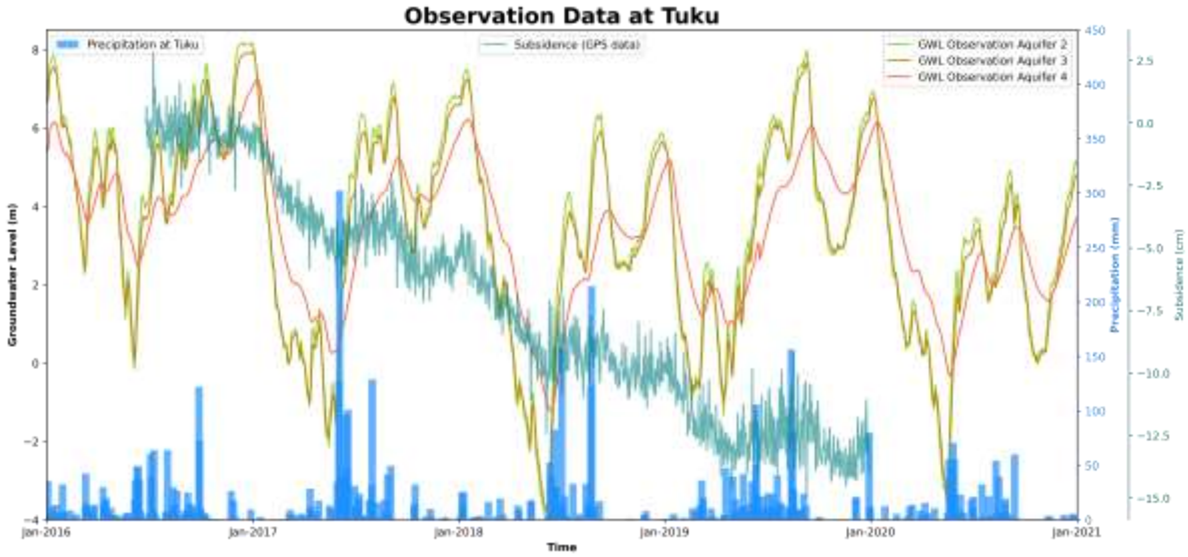
$\boldsymbol{\sigma'_{n-1}}$ and $\boldsymbol{\sigma'_n}$ are effective-stress values at times t_{n-1} and t_n

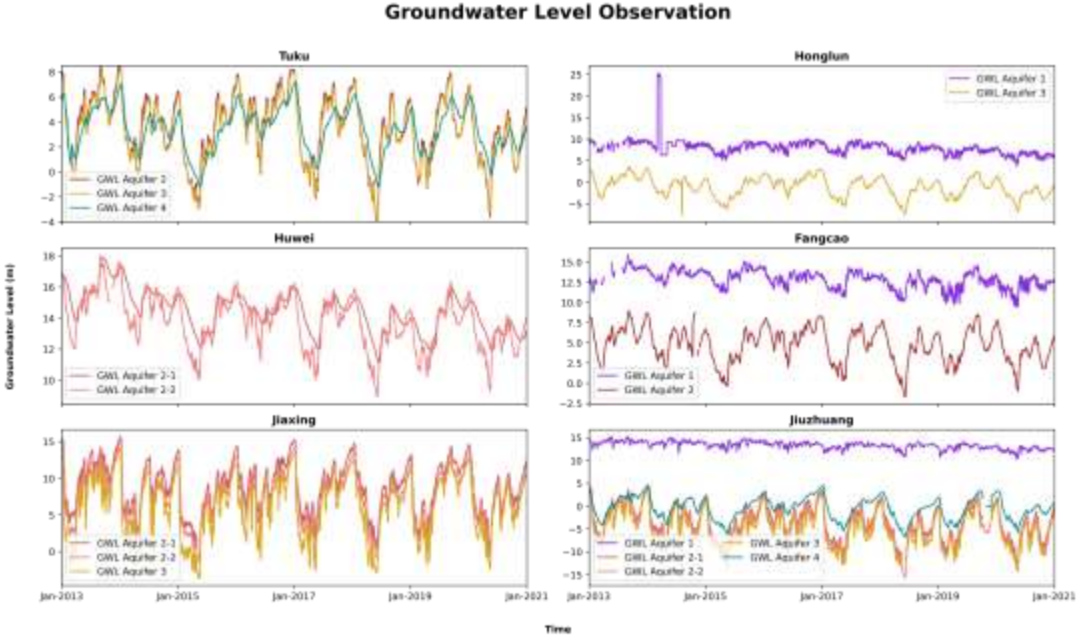
$\boldsymbol{\sigma'_{c,n-1}}$ is the preconsolidation-stress value at time t_{n-1}

Data Availability

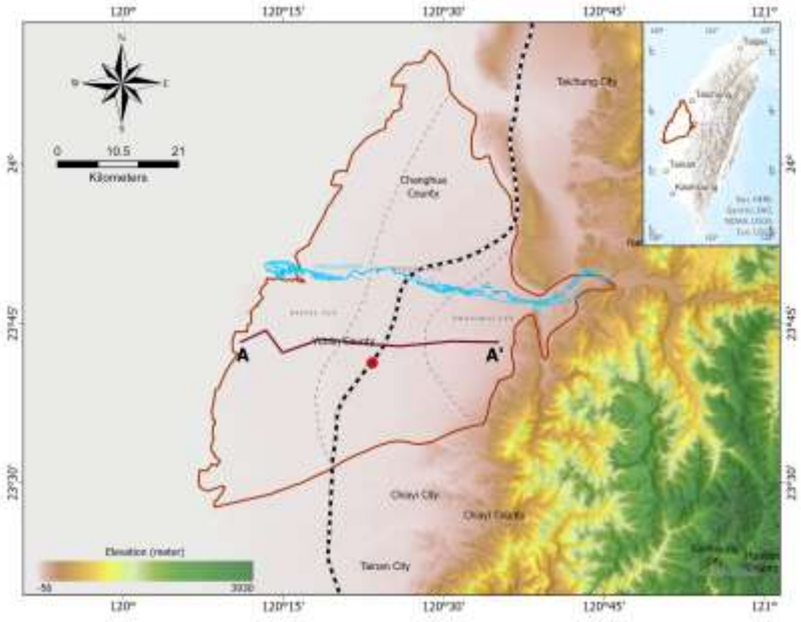


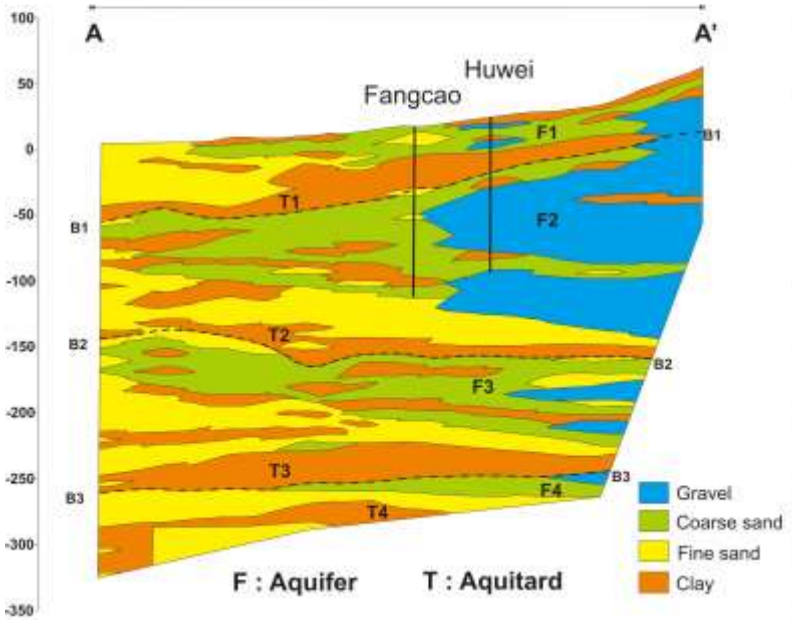


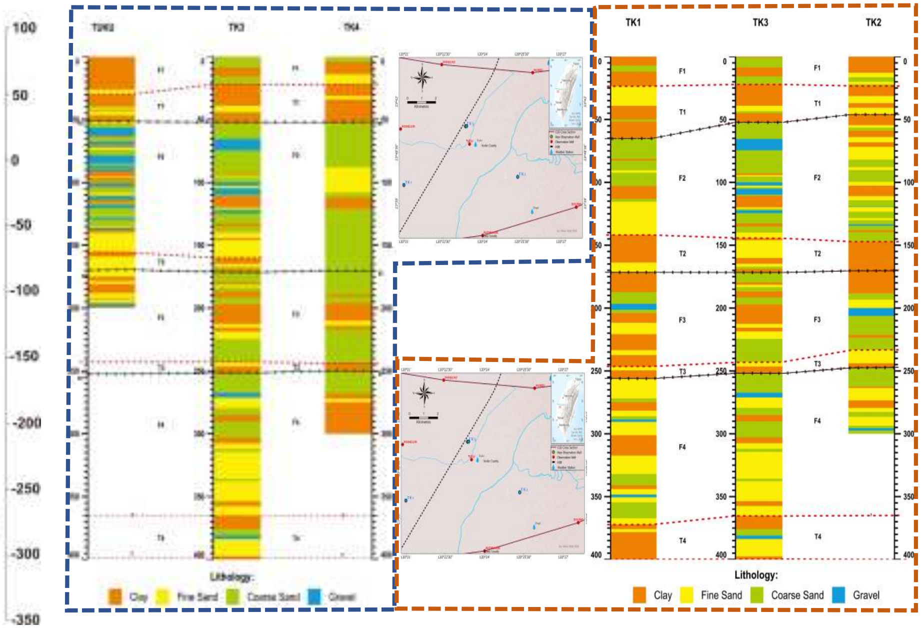


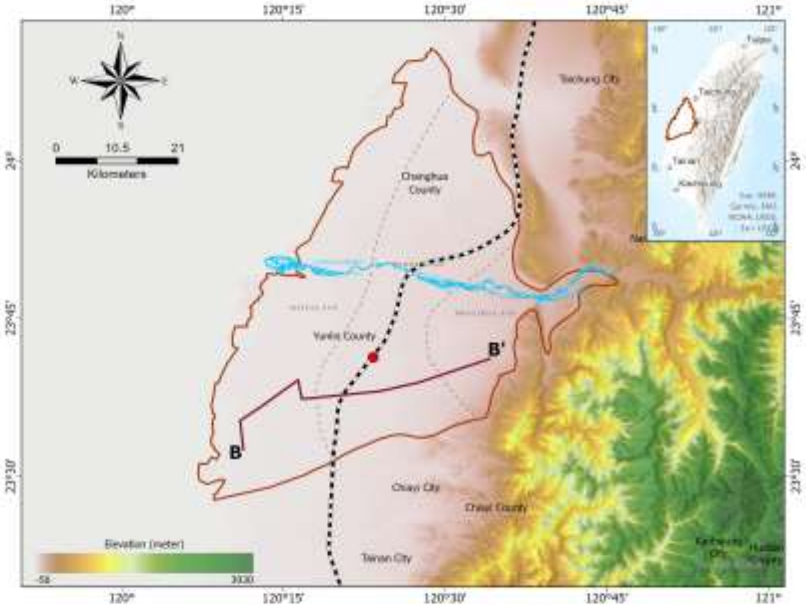


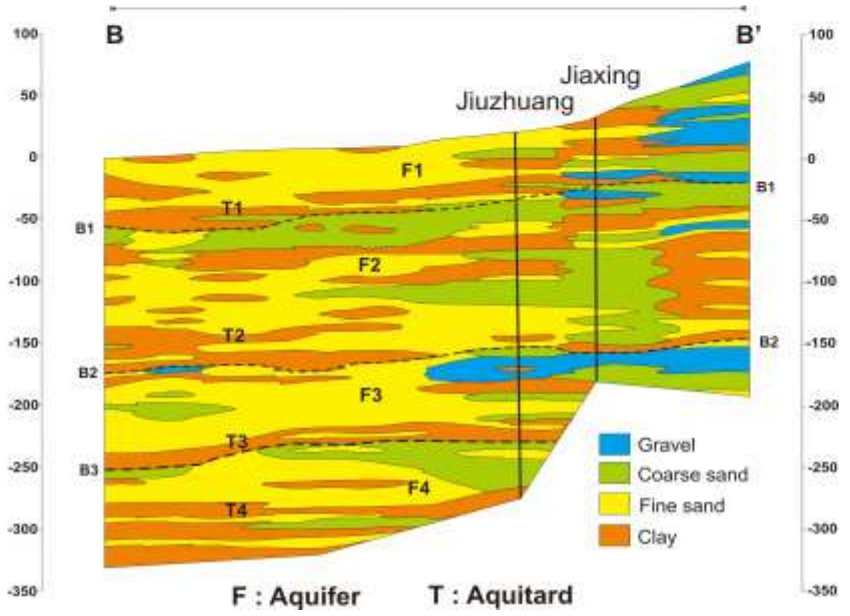
Conceptual Model: from regional to local scale

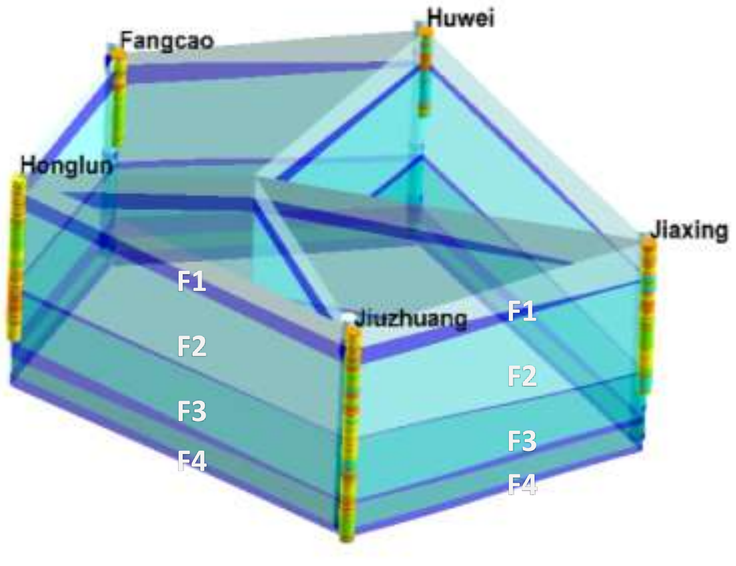


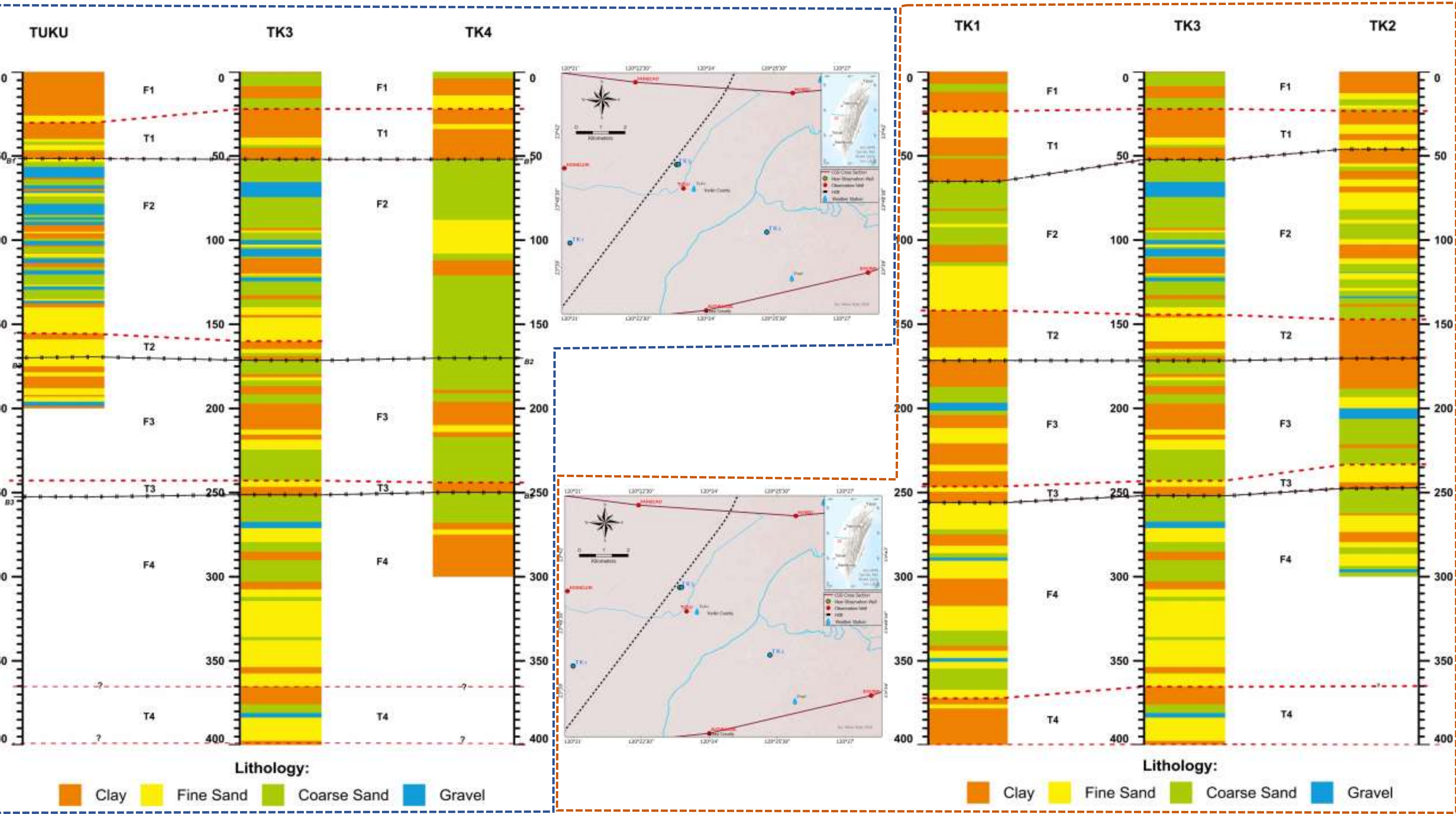




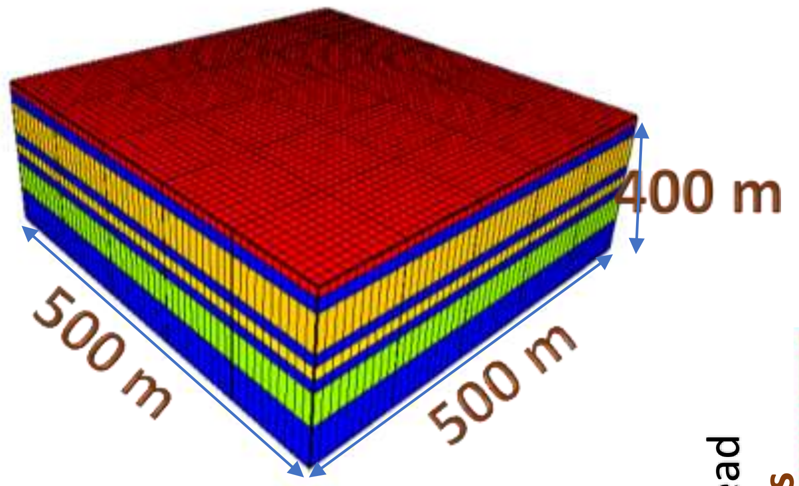




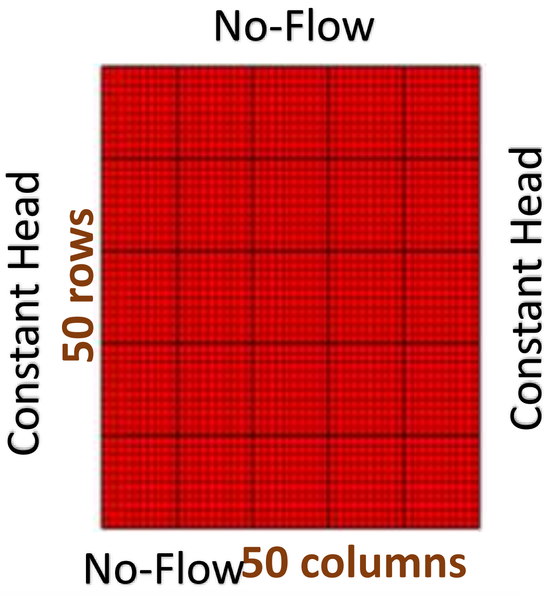


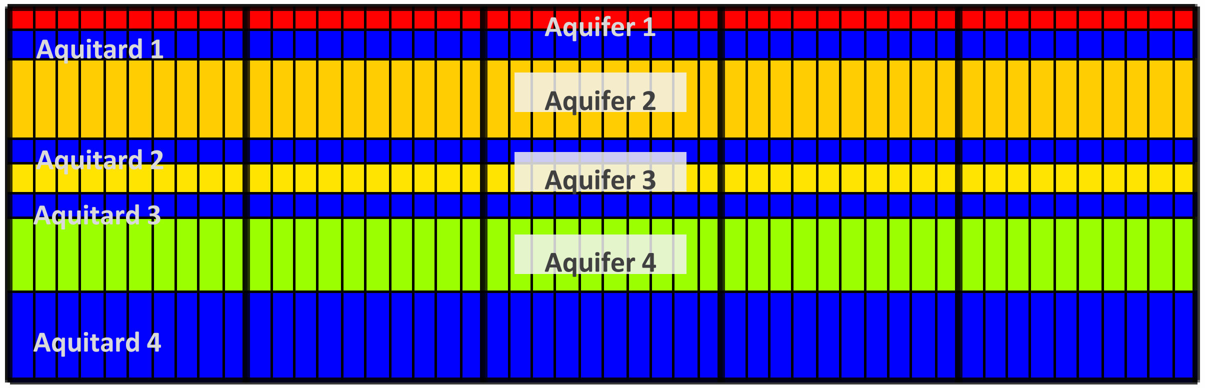


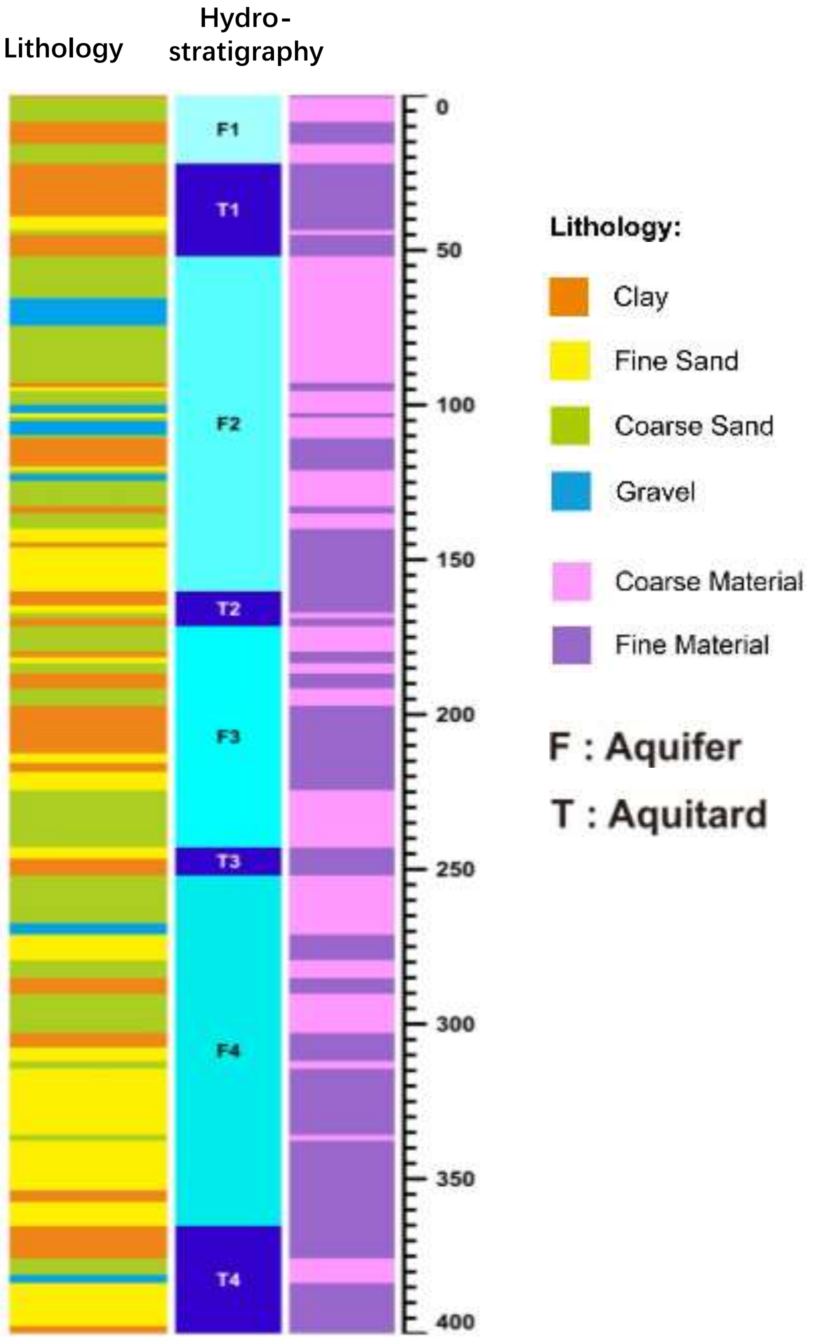
TUKU
TK3
TK4
TK1
TK3
TK2
F1
T1
F2
T2
F3
T3
F4
T4
B1
B2
B3
0
50
100
150
200
250
300
350
400
Lithology:
Clay
Fine Sand
Coarse Sand
Gravel
Lithology:
Clay
Fine Sand
Coarse Sand
Gravel



- 50 rows x 50 columns
- 10 x 10 meter grid cell size
- 8 Layer (4 Aquifer & 4 Aquitard)







CSUB Parameter

No	Layer	Elastic Specific Storage	Equivalent Number	Inelastic Specific Storage	Equivalent Thickness	Starting Compaction	Starting Head	Vertical Hydraulic Conductivity	Porosity	Ss / Sy
1	Aquifer 1	8.39E-04	1.00E+00	2.30E-03	7.00E+00	0.00E+00	6.20E+00	3.12E-03	3.00E-01	2.00E-01
2	Aquitard 1	8.39E-03	1.00E+00	2.30E-02	3.20E+01	0.00E+00	6.20E+00	5.29E-04	5.20E-01	2.00E-01
3	Aquifer 2	4.07E-04	4.00E+00	3.19E-03	4.25E+00	0.00E+00	2.10E+00	3.12E-03	3.00E-01	5.95E-03
4	Aquitard 2	3.13E-03	1.00E+00	2.51E-02	2.80E+01	0.00E+00	2.10E+00	5.29E-04	4.40E-01	1.45E-01
5	Aquifer 3	4.28E-04	3.00E+00	1.25E-02	3.00E+00	0.00E+00	2.60E+00	6.20E-04	3.00E-01	7.40E-03
6	Aquitard 3	8.39E-03	1.00E+00	2.30E-02	2.70E+01	0.00E+00	2.60E+00	7.50E-05	4.30E-01	1.63E-01
7	Aquifer 4	8.39E-04	4.00E+00	2.30E-03	4.75E+00	0.00E+00	3.20E+00	6.20E-04	3.00E-01	7.60E-03
8	Aquitard 4	8.39E-03	1.00E+00	2.30E-02	9.60E+01	0.00E+00	3.20E+00	7.50E-05	4.00E-01	1.46E-01

Aquifer	Bottom	
	Constant Head West (m)	Constant Head East (m)
Aquifer 1	6.0	6.4
Aquifer 2	2.0	2.2
Aquifer 3	2.0	2.3
Aquifer 4	3.0	3.5

Layer	Hydraulic Conductivity (m/day)	Compressible Thickness (m)
Aquifer 1	2.00E+02	7.00E+00
Aquitard 1	2.00E-01	3.20E+01
Aquifer 2	1.45E+02	1.70E+01
Aquitard 2	1.45E-01	2.80E+01
Aquifer 3	1.63E+02	9.00E+00
Aquitard 3	1.63E-01	2.70E+01
Aquifer 4	1.46E+02	1.90E+01
Aquitard 4	1.46E-01	9.60E+01

Init.Preconsolidation Stress (Hung et al, 2012):

−15 to 0 m

Void Ratio (Hung et al, 2012):

0.2 to 0.8

For S_{ske} and S_{skv}:

0.00001 to 0.1

Initial parameter input CSUB program

	Interbed Thickness	Equivalent Interbed Number	Initial Elastic Specific Storage	Initial inElastic Specific Storage	Initial Porosity	Delay Kv
Aquifer 1	7.74E+00	2.00E+00	2.30E-03	8.39E-04	3.00E-01	3.12E-03
Aquitard 1	3.00E+01	1.00E+00	2.30E-03	8.39E-03	5.20E-01	2.50E-06
Aquifer 2	2.79E+01	8.00E+00	3.19E-03	4.07E-04	3.00E-01	3.12E-03
Aquitard 2	1.13E+01	1.00E+00	2.51E-02	3.13E-03	4.40E-01	2.50E-06
Aquifer 3	3.59E+01	7.00E+00	1.25E-02	4.28E-04	3.00E-01	6.20E-04
Aquitard 3	9.10E+00	1.00E+00	2.30E-02	8.39E-03	4.30E-01	2.50E-06
Aquifer 4	7.14E+01	8.00E+00	2.30E-03	8.39E-04	3.00E-01	6.20E-04
Aquitard 4	3.48E+01	1.00E+00	2.30E-02	8.39E-03	4.00E-01	2.50E-06

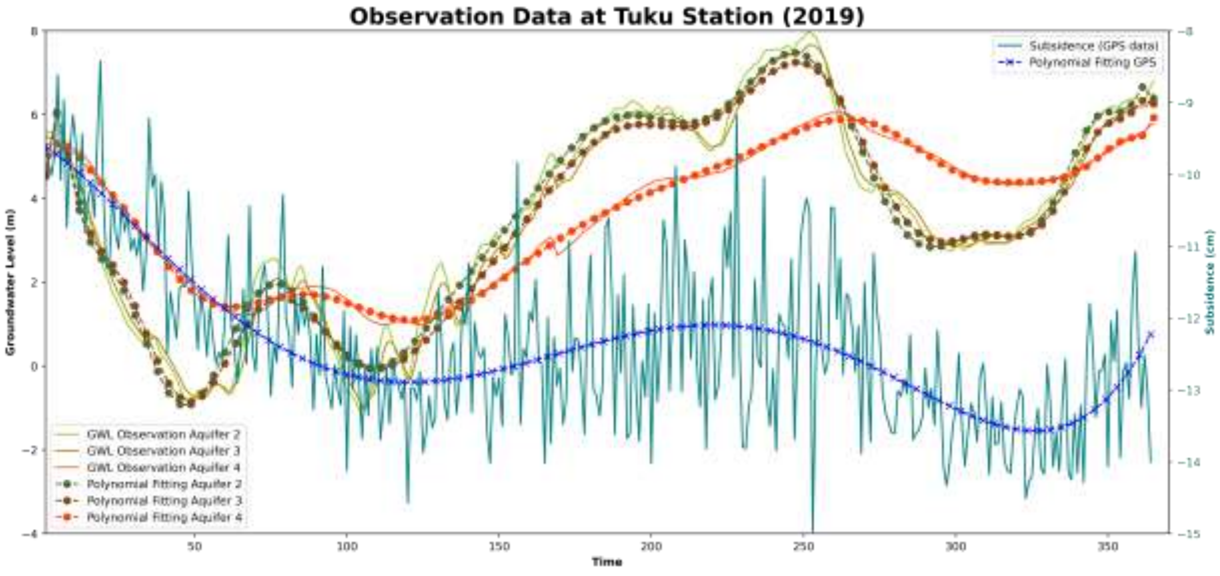
result

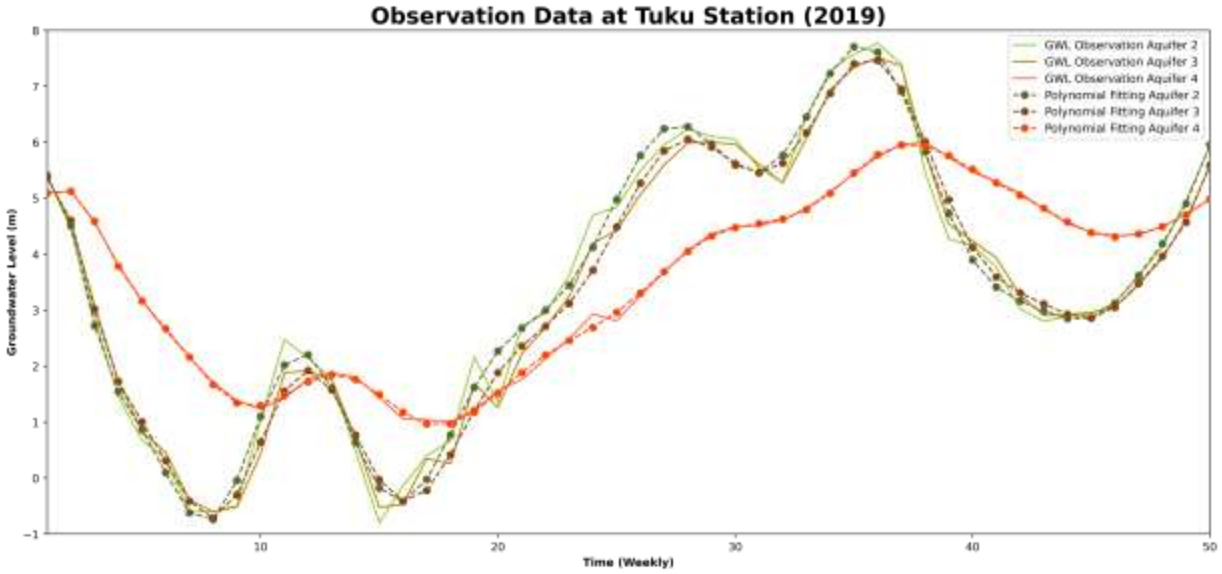
Calibration:

groundwater model

Soil mechanics model

Data Selection for Calibration

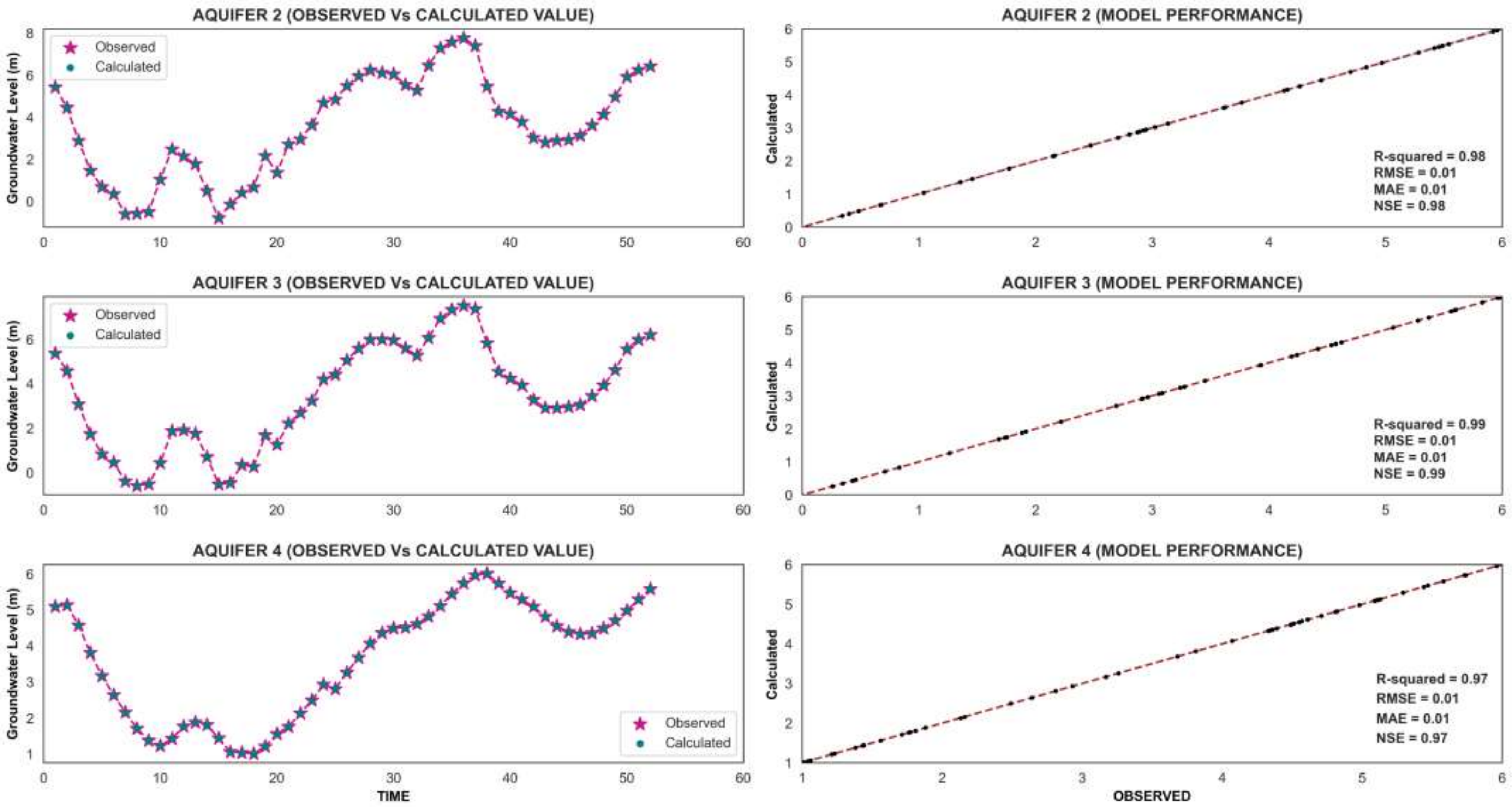




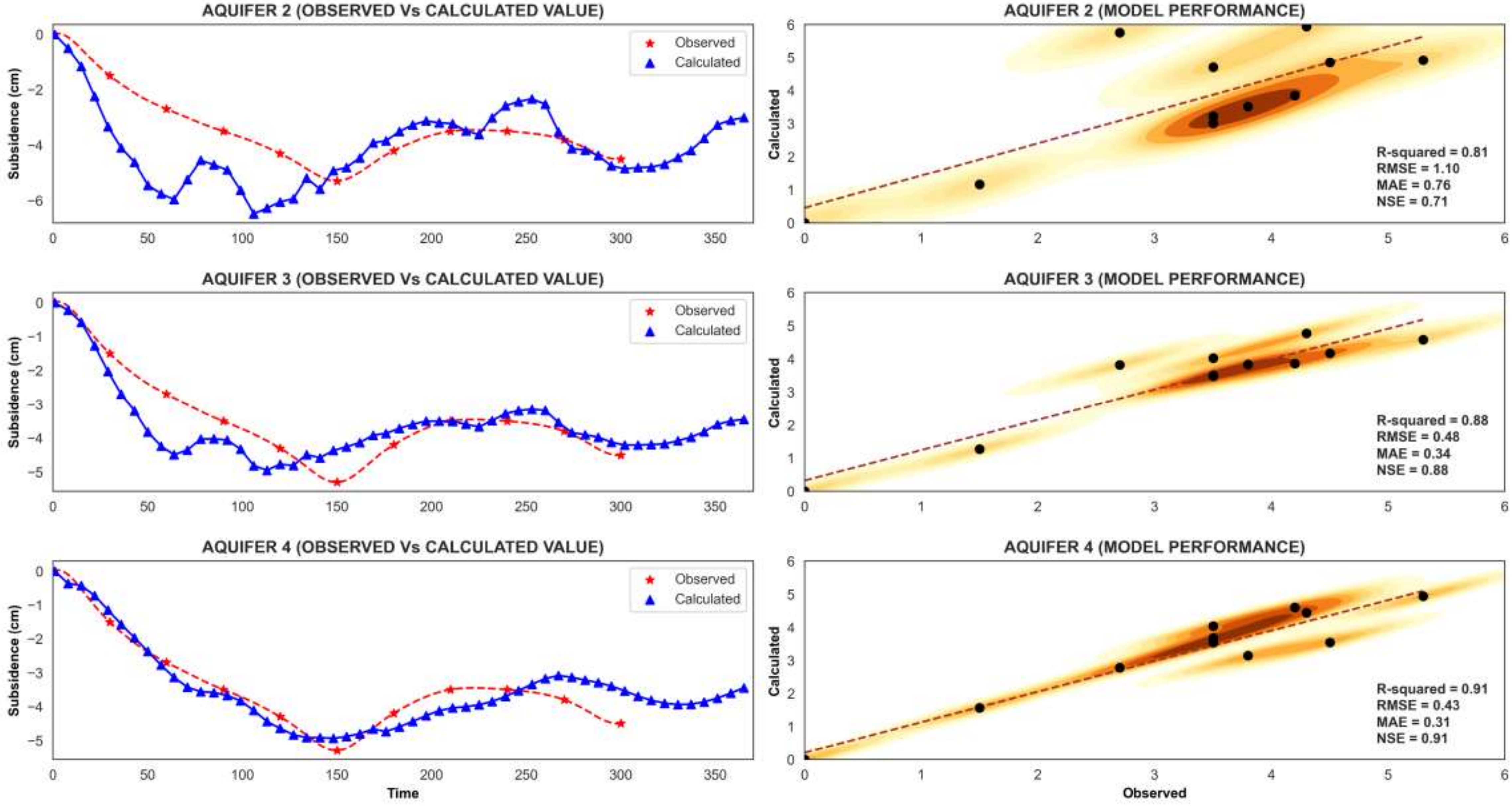
Daily Data

Weekly Data

Model Performance



Calibration Result for Subsidence



SUBSIDENCE MODEL

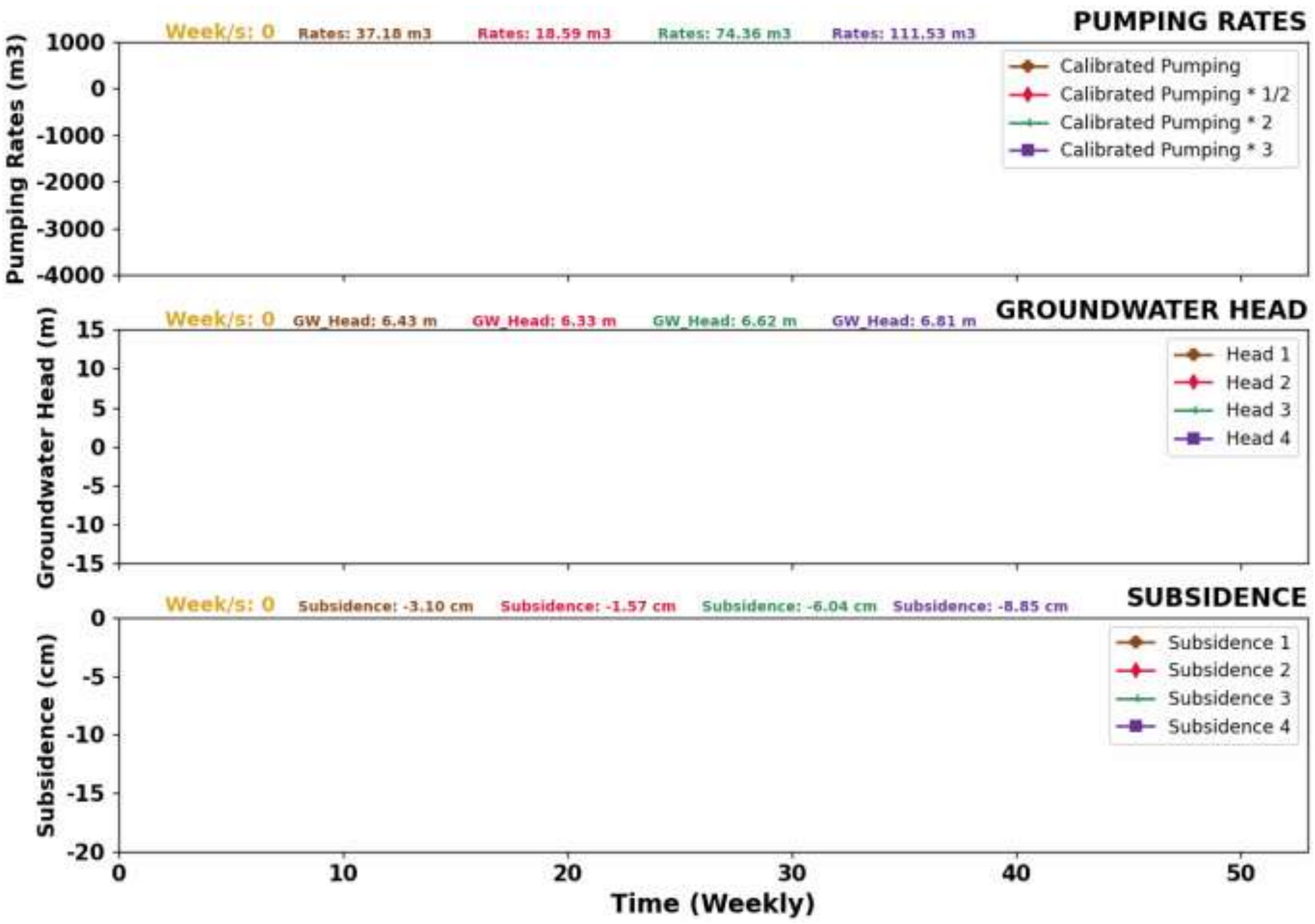
Simulate a different scenario of land subsidence

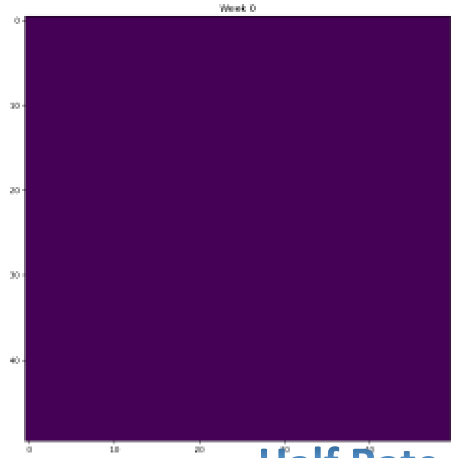
1. How large subsidence will occured if we pumped ½ , 2 and 3 times larger than calibrated pumping rate value?
2. How large subsidence will occurred, if we pump the groundwater with the same pumping rates (mean value of calibrated pumping rates of all aquifer) on each aquifer? Which aquifer that will have larger subsidence than others?
3. How large subsidence will occurred, if we have constant pumping: 500 m^3/day, 2500 m^3/day, 5000 m^3/day
4. How large subsidence will occurred, if we distribute pumping rate to 5 wells with different pumping schedule

Pumped ½, 2 and 3 Times Larger Than Calibrated Pumping Rate Value

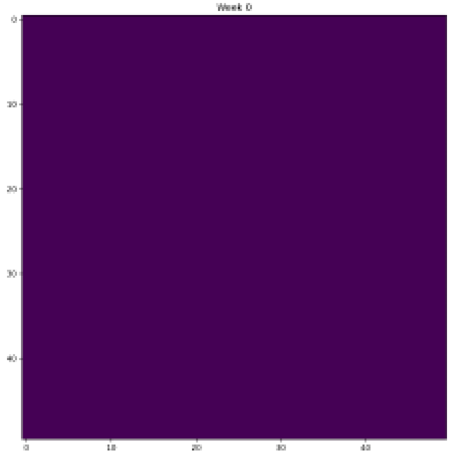
Aquifer 2

Scenario 1

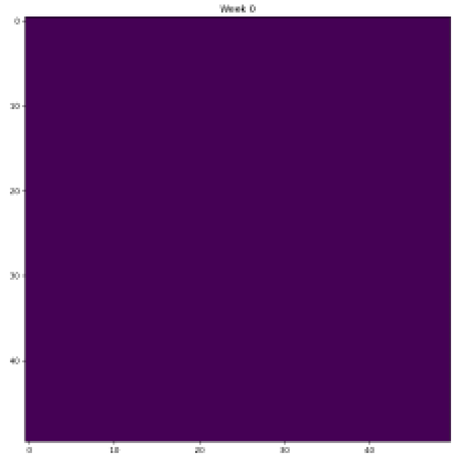




Half Rate



Tripled Rate

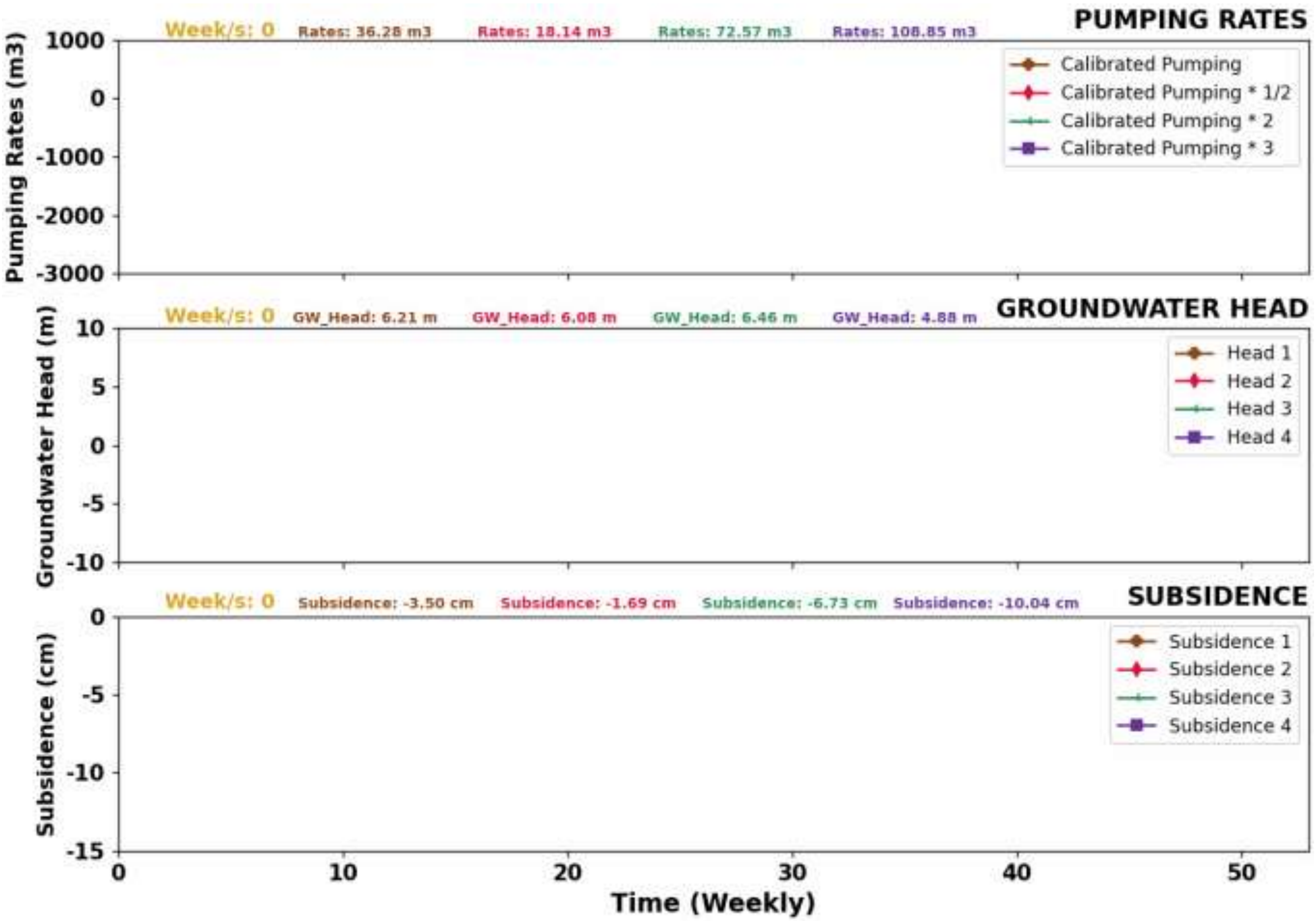


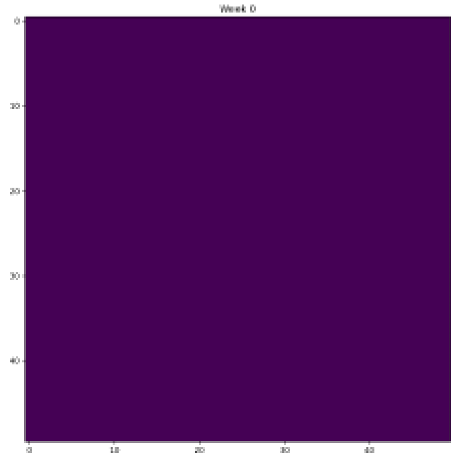
Double Rate

Pumped ½, 2 and 3 Times Larger Than Calibrated Pumping Rate Value

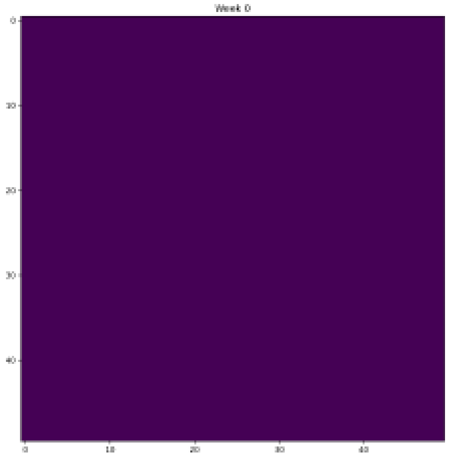
Aquifer 3

Scenario 1

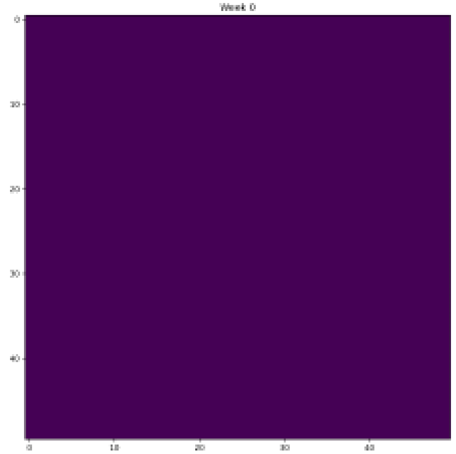




Half Rate



Tripled Rate

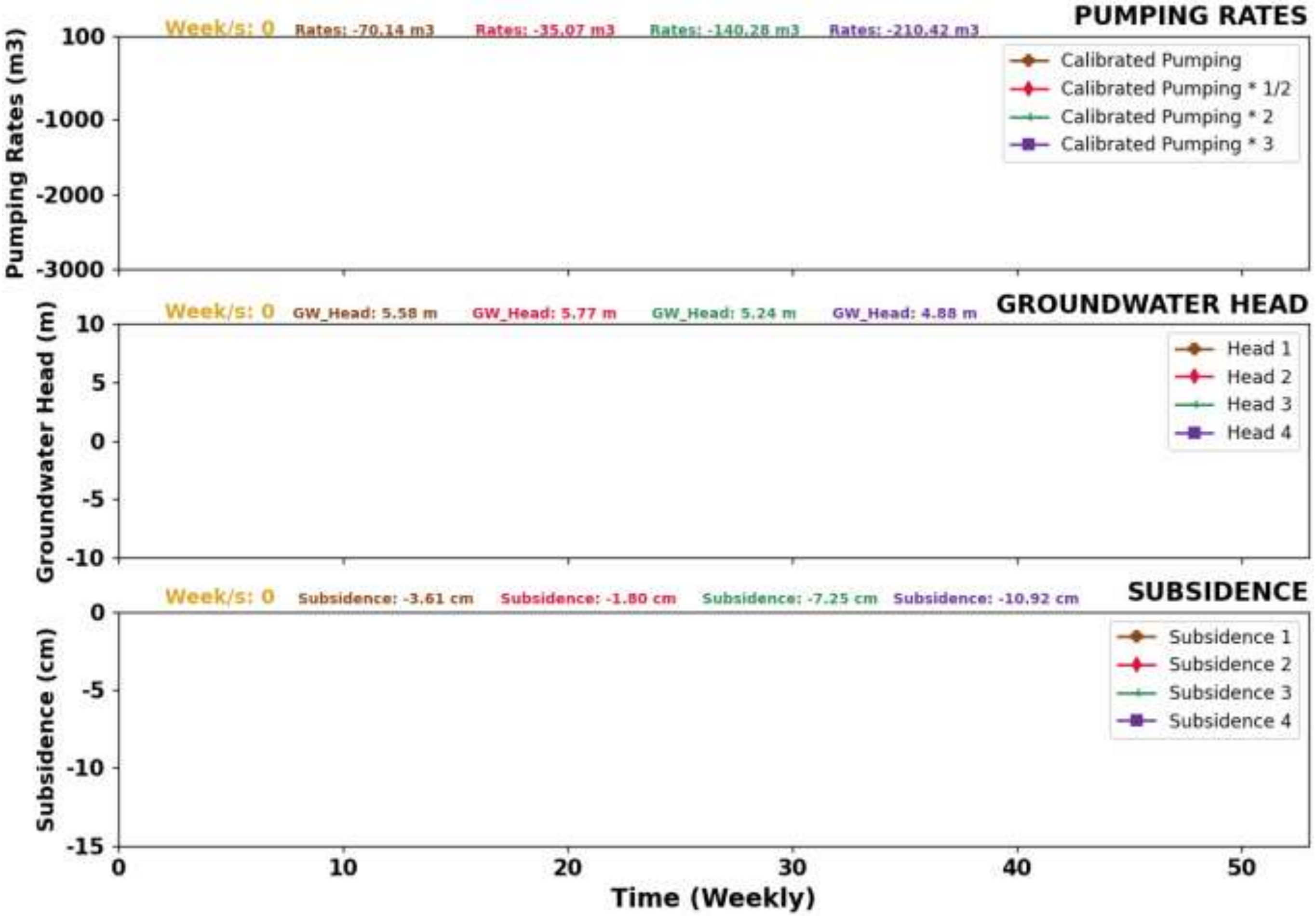


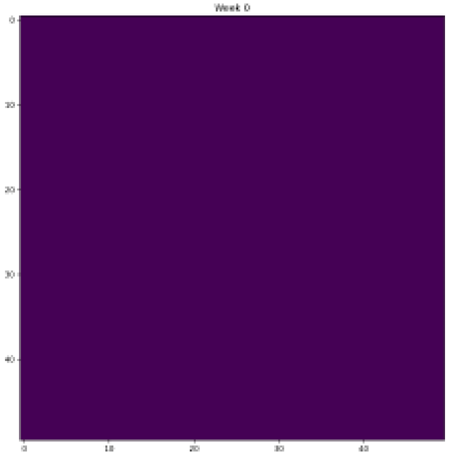
Double Rate

Pumped ½, 2 and 3 Times Larger Than Calibrated Pumping Rate Value

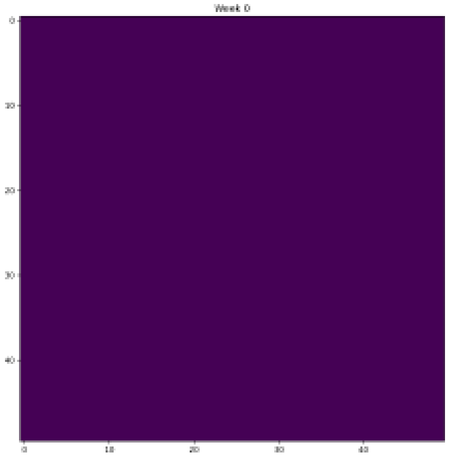
Aquifer 4

Scenario 1

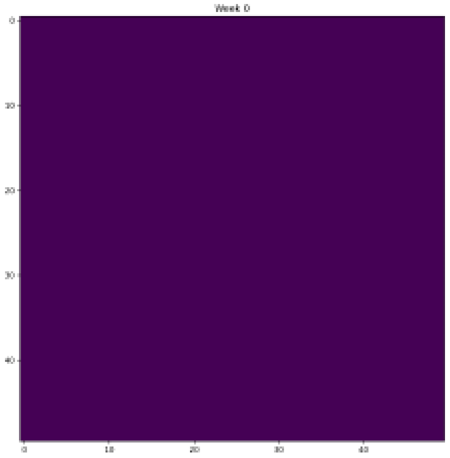




Half Rate

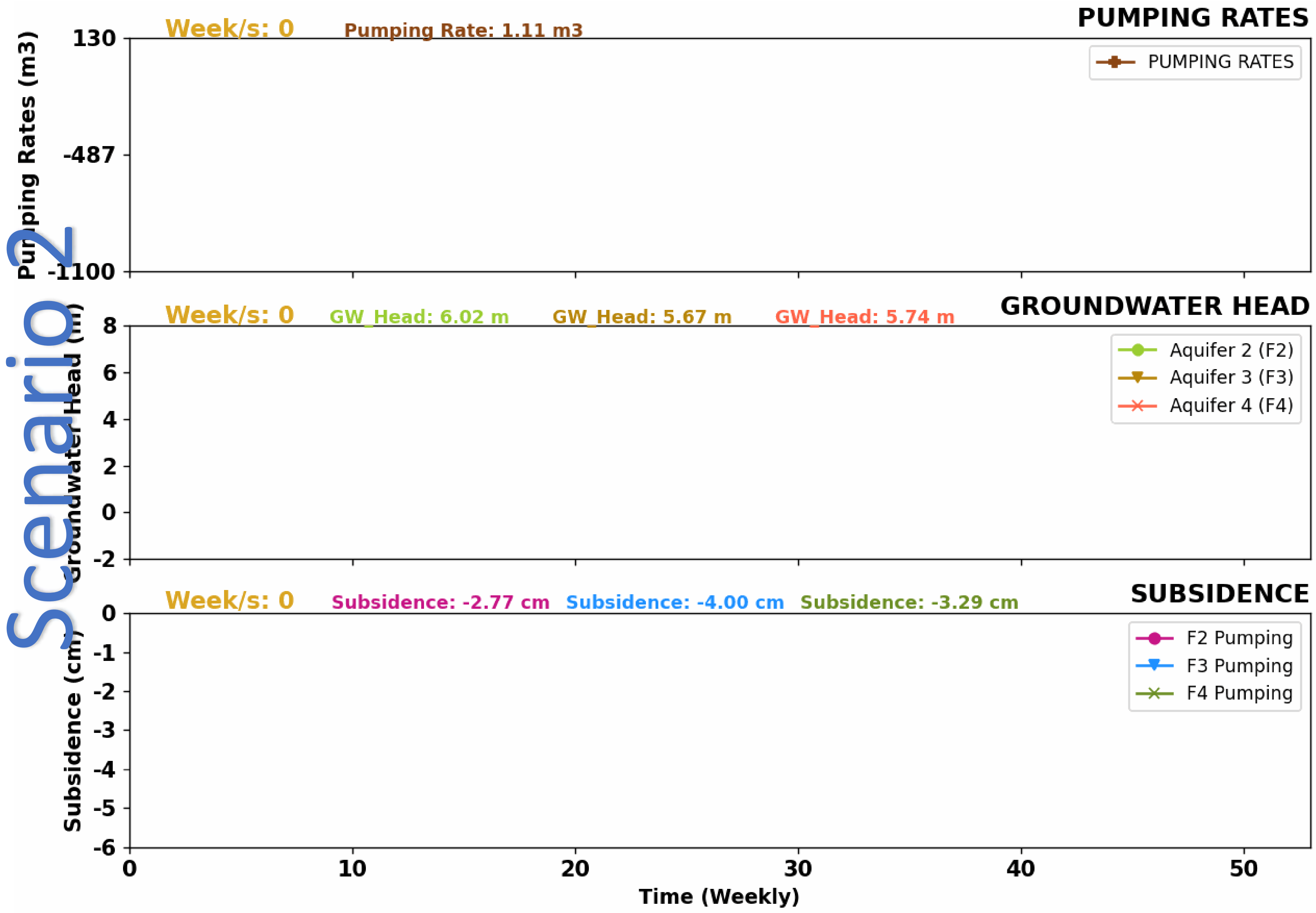


Double Rate



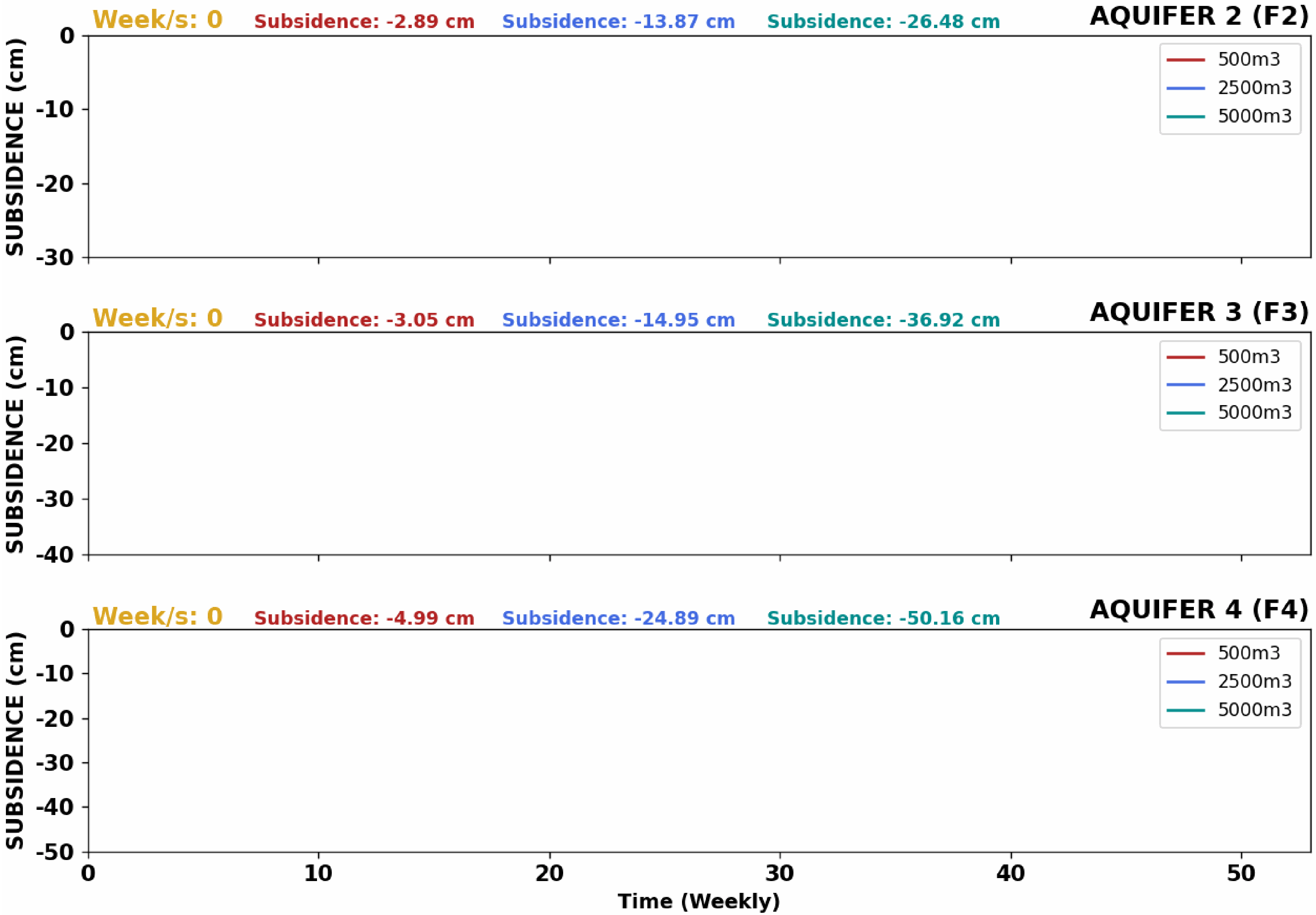
Tripled Rate

The Same Pumping Rates On Each Aquifer

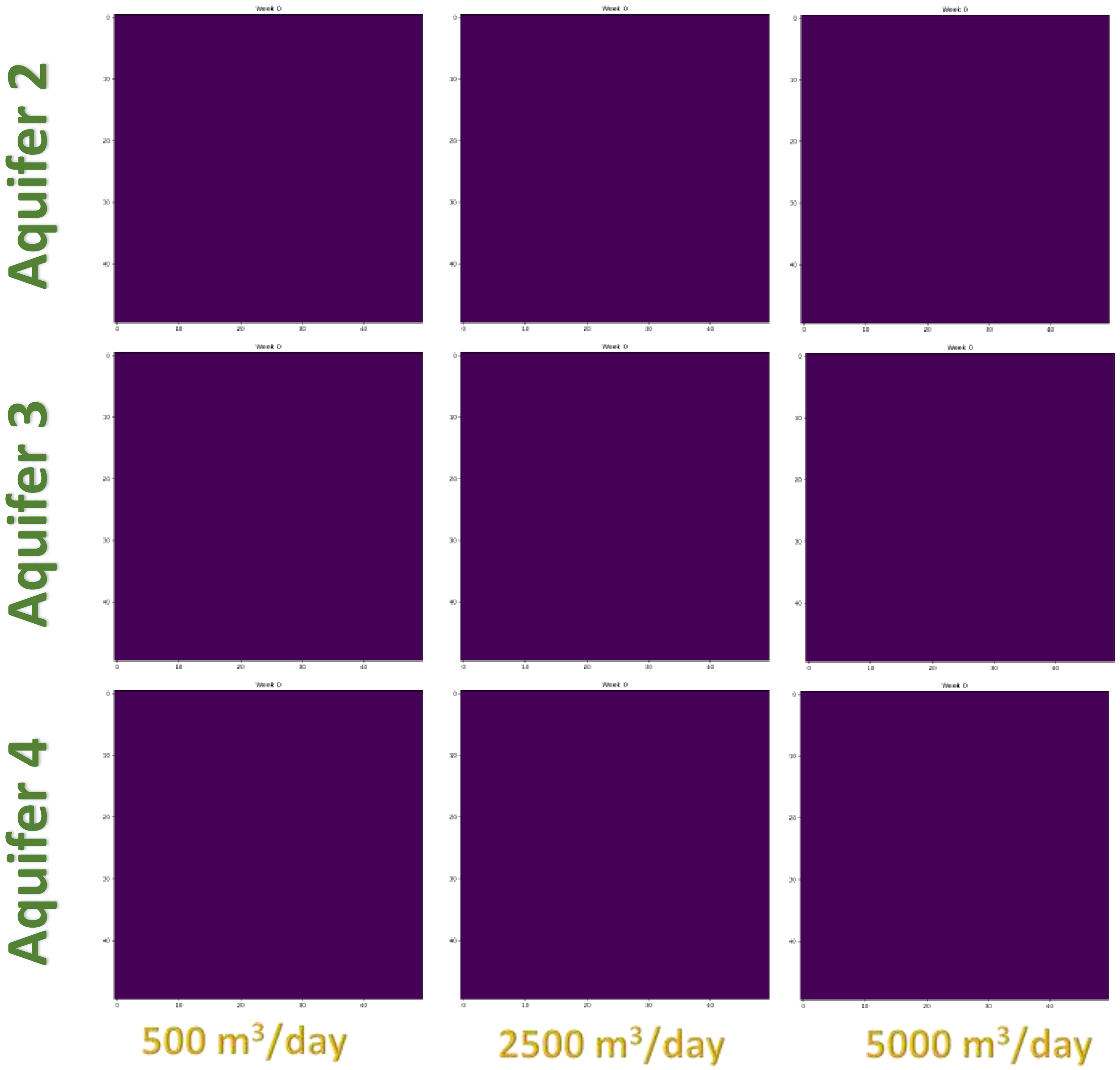


The constant Pumping Rates On Each Aquifer

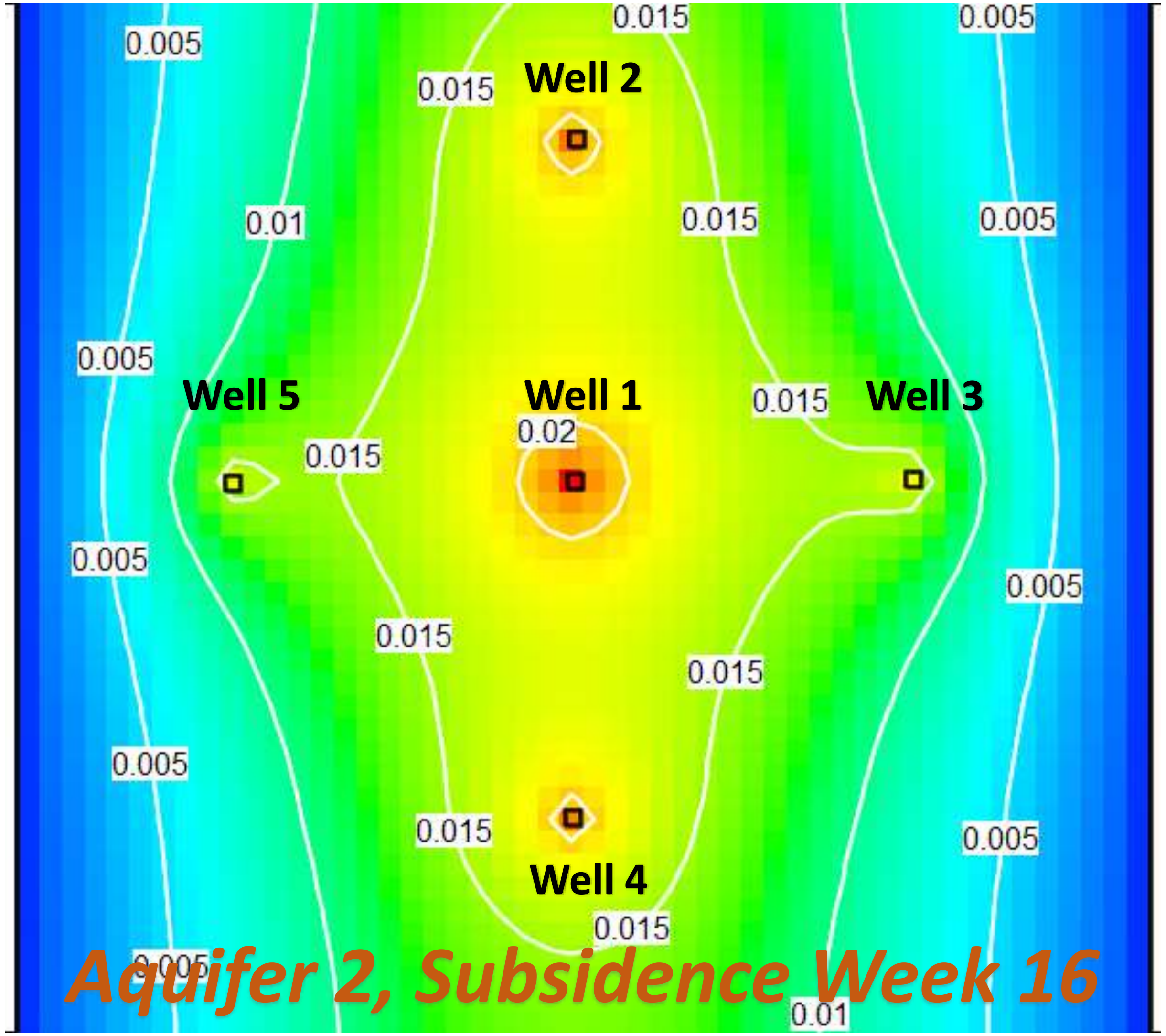
Scenario 3

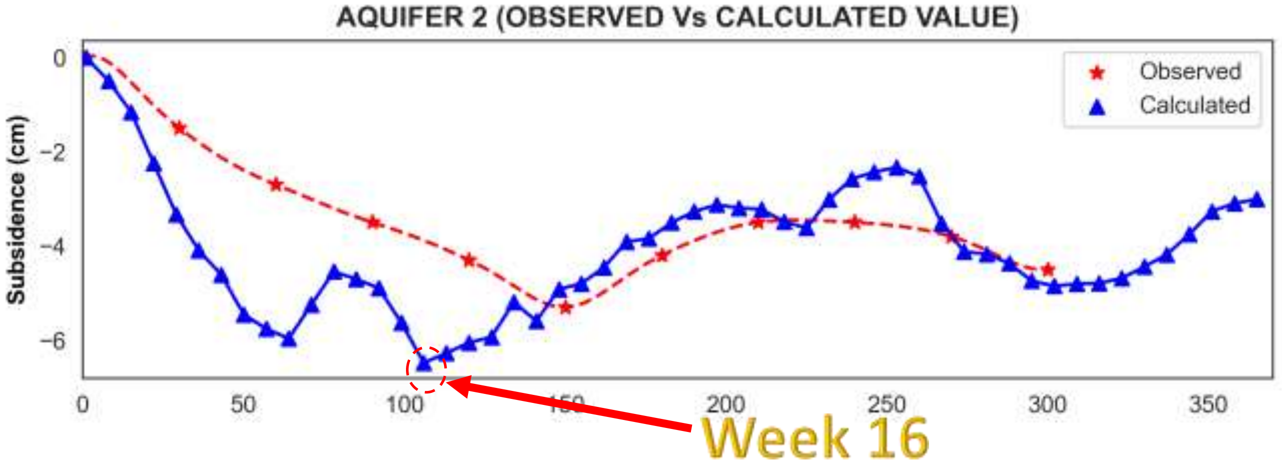


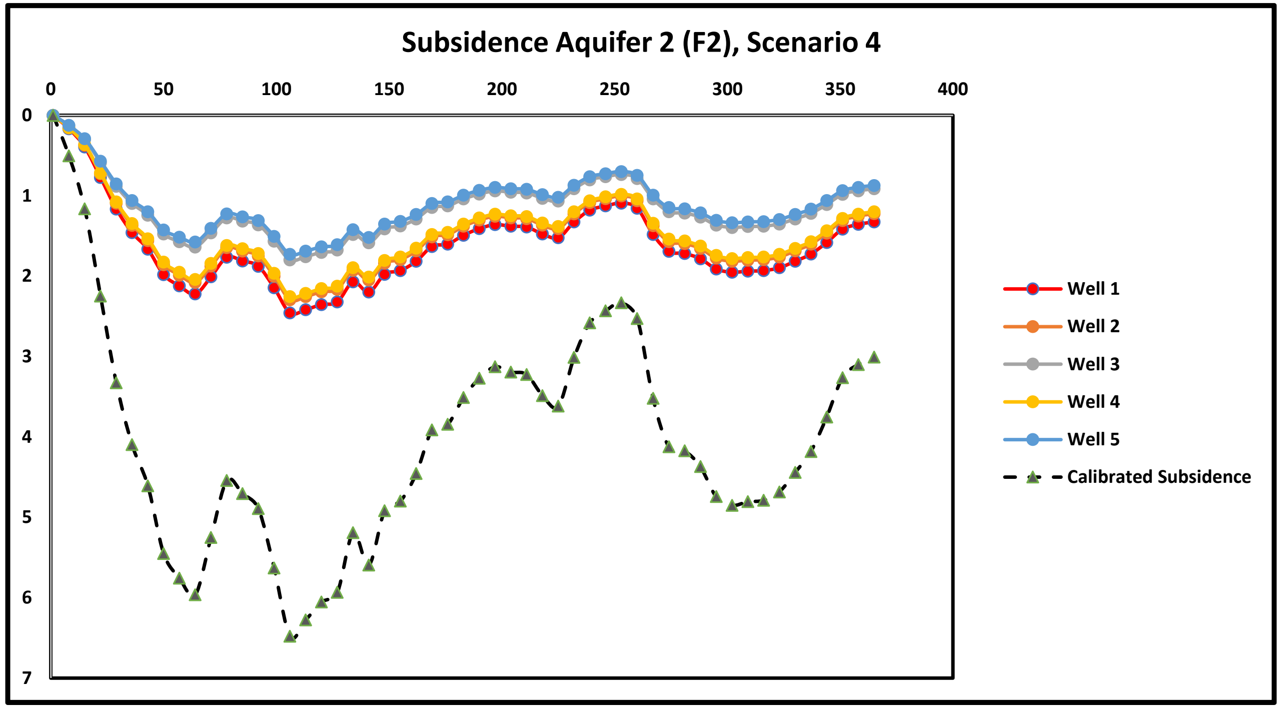
Scenario 3:


Aquifer 2
Aquifer 3
Aquifer 4
500 m³/day
2500 m³/day
5000 m³/day

Scenario 4a: Aquifer 2







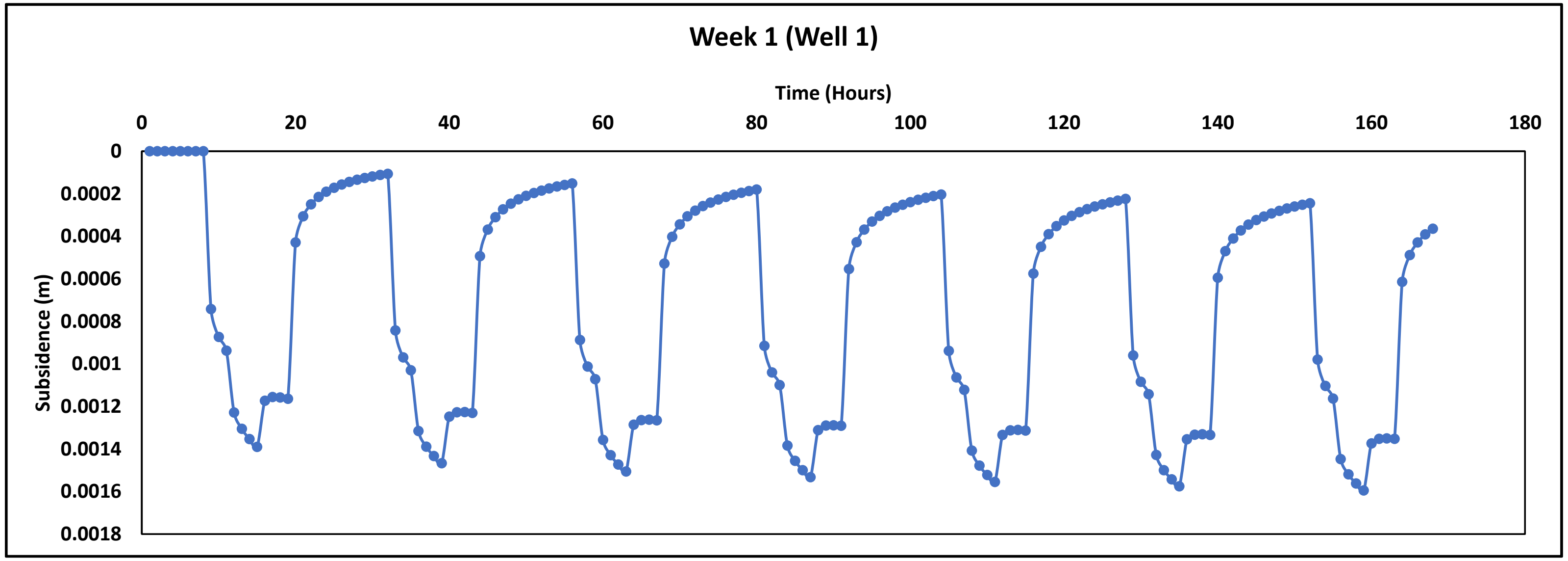
Scenario 4a: Distribute Calibrated Pumping Rate to Five Wells

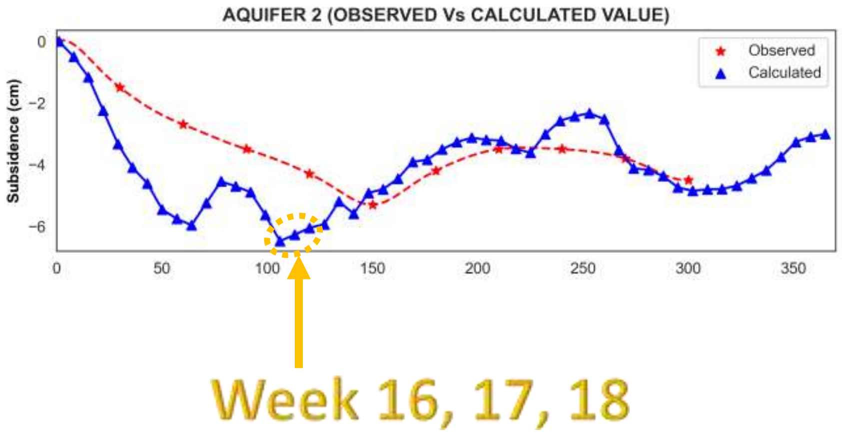
Scenario 4b: Aquifer 2

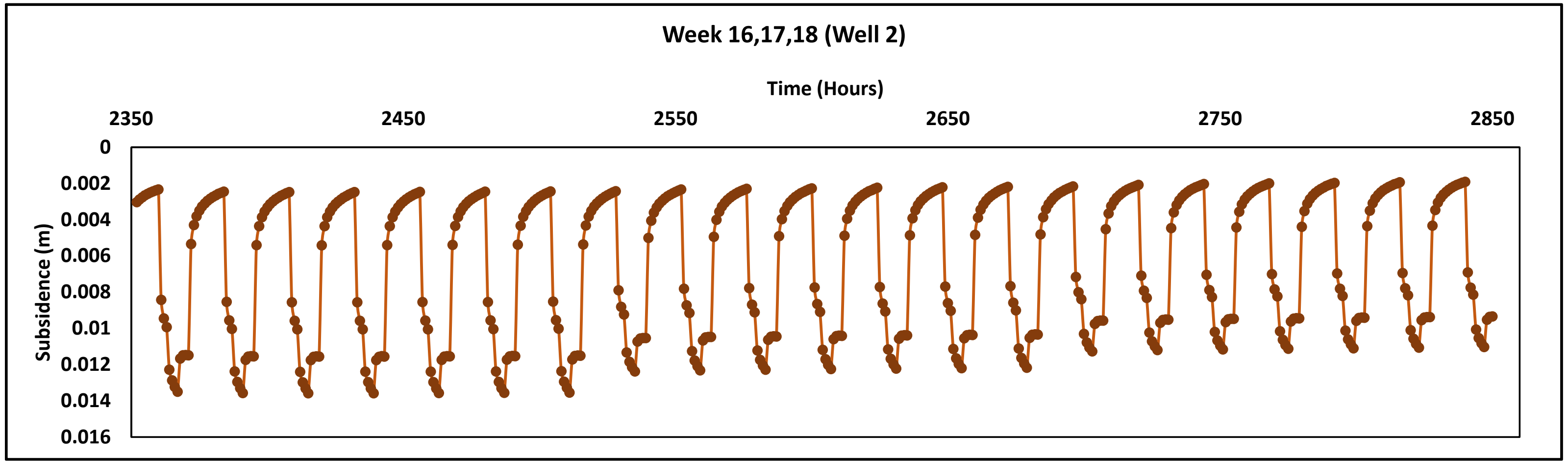
Hour		Pumping Rates
From	To	
01/01/2019 00:00:00	01/01/2019 07:01:00	No pumping
01/01/2019 07:01:00	01/01/2019 10:01:00	30 % of Calibrated Value
01/01/2019 10:01:00	01/01/2019 14:01:00	40 % of Calibrated Value
01/01/2019 14:01:00	01/01/2019 18:01:00	30 % of Calibrated Value
01/01/2019 18:01:00	01/02/2019 00:00:00	No Pumping

Scenario 4b: Rate with pumping scheduling

Scenario 4b: Aquifer 2

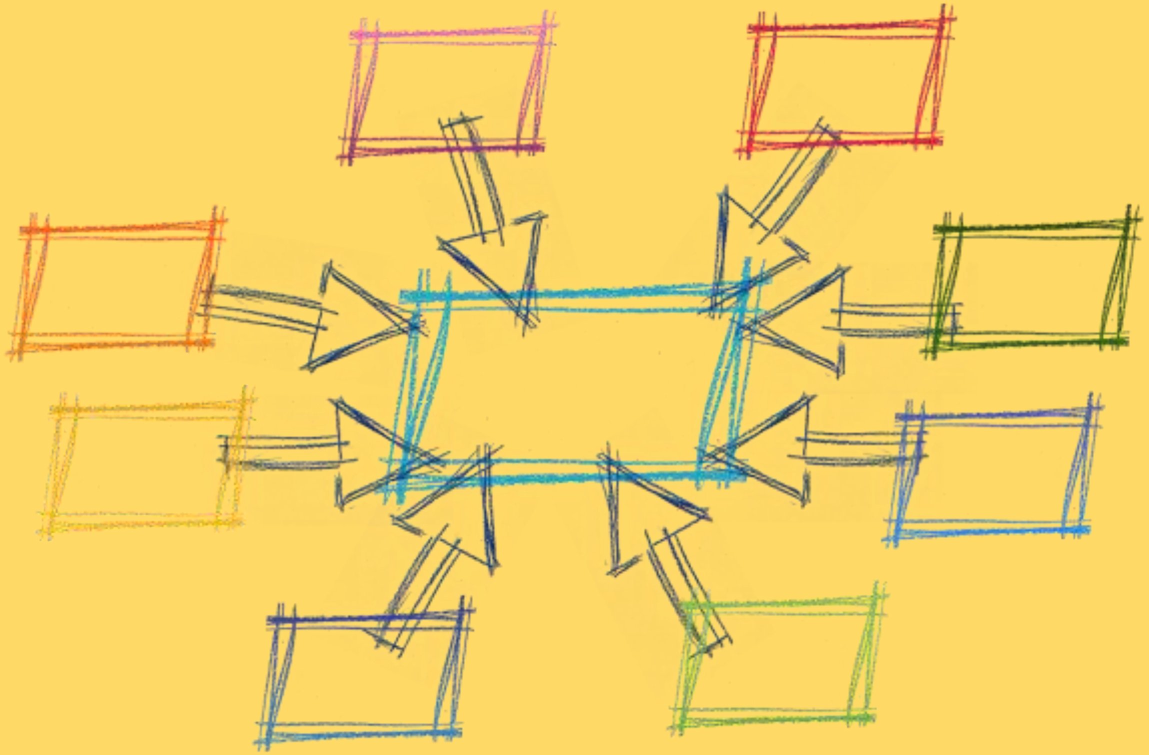






Scenario 4b: Rate with pumping scheduling

conclusion



- This study also evaluates pumping in the aquifer which will cause severe land subsidence at the study site.

- Although the simulation model cannot represent the entire complex groundwater system, it is able to match the historical head and subsidence data at the Tuku groundwater monitoring station.

- **Scenario 1** shows that aquifer 2 has the highest probability of subsidence among other aquifers.

- **Scenario 2** shows that aquifer 2 and 3 have tendency to have serious subsidence when huge amount of pumping rates were applied.

- **Scenario 3** suggest that with constant pumping rate amount in the aquifer 4 could cause the serious subsidence.

- **Scenario 1** and **Scenario 2** result looks have a reasonable output for subsidence simulation.

future work

1. calculate impact to another aquifer by pumping in certain aquifer

2. Simulate which layers that has larger compaction than others by pumping in specific aquifer

3. Calculate contribution of each layer compaction to total land subsidence

4. Analyze material that control the rate of land subsidence

Thank you
For your listening…

Land subsidence field trip at Tuku (2022)