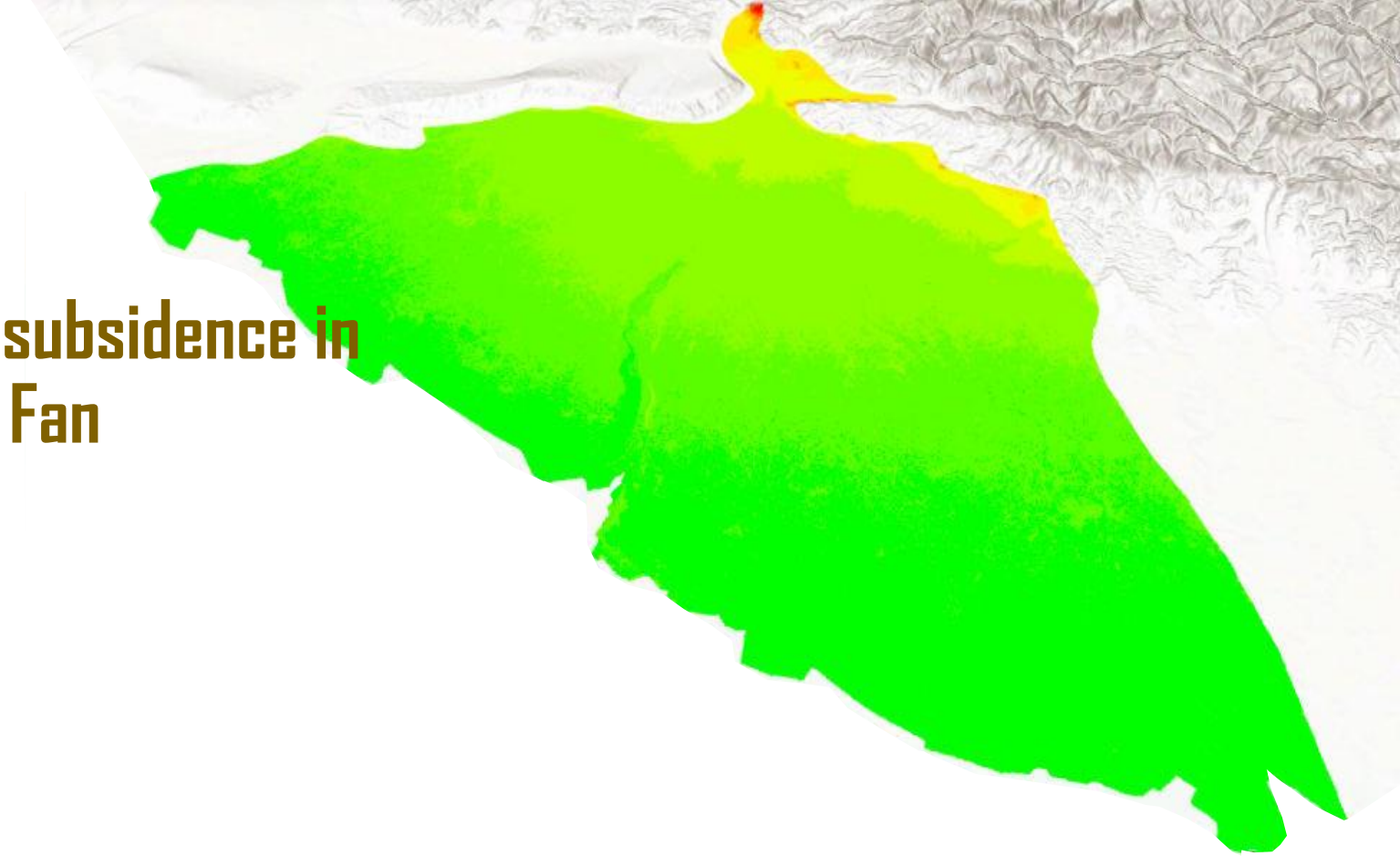
Hydromechanical model of land subsidence in Chousui River Alluvial Fan



Adviser:
Professor Chuen-Fa Ni

Presenter:
Gumilar Utamas Nugraha

Outline

Introduction

Methodology

Preliminary result

Summary and conclusion

future work

What is land subsidence?

- Land subsidence is a sudden sinking or gradual settling of the Earth's surface(Hoffmann et al.2003)
- Extend for a long period of time (months to years)

Distribution

Alluvial basins or coastal plains.

Problem related to subsidence

Structure failure, flooding, intrusion of seawater

The Causes Of Land Subsidence

- Growths of population and economy
- Surface water resources are insufficient to meet the demand

↓

- Excessive use of groundwater

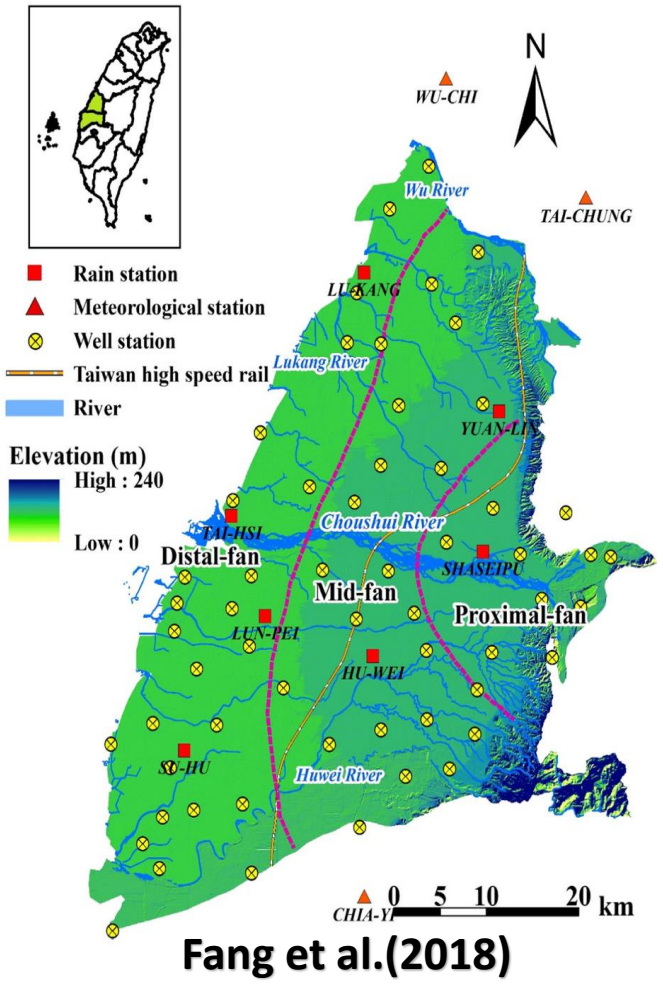
↓

- Triggered Land Subsidence

1 Introduction

background

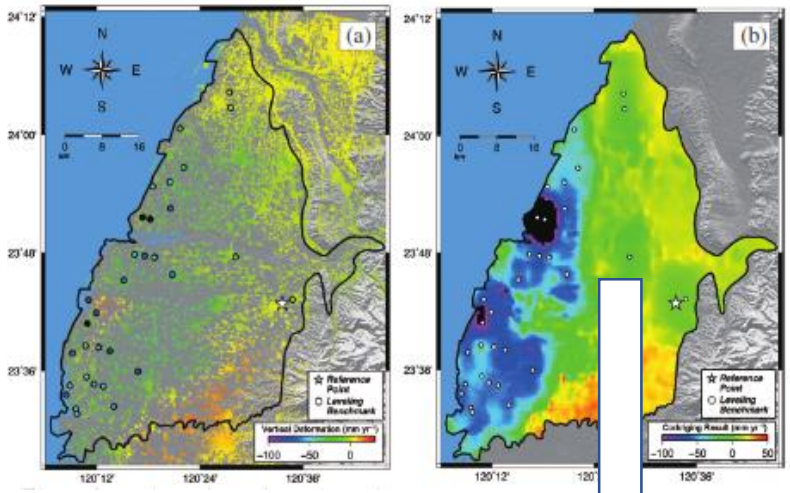
CRAF suffered severely from land subsidence



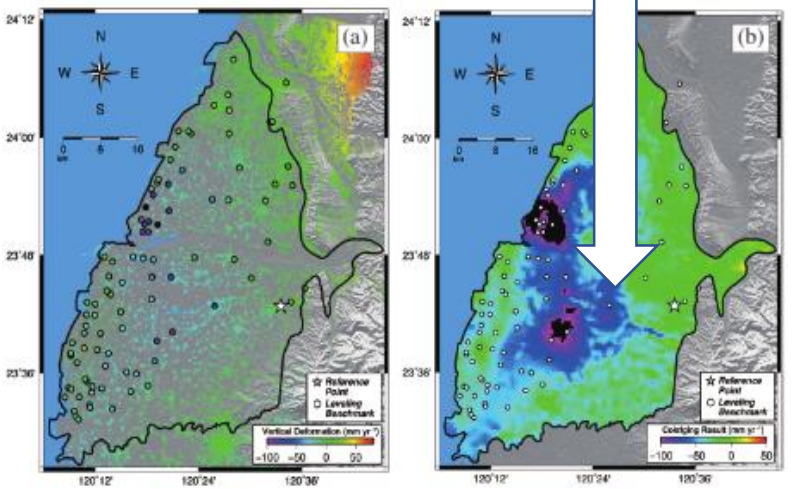
Fang et al.(2018)

The pumping of groundwater has been restricted !!!

data obtained between 1993 and 1998



Change in pattern of subsidence area

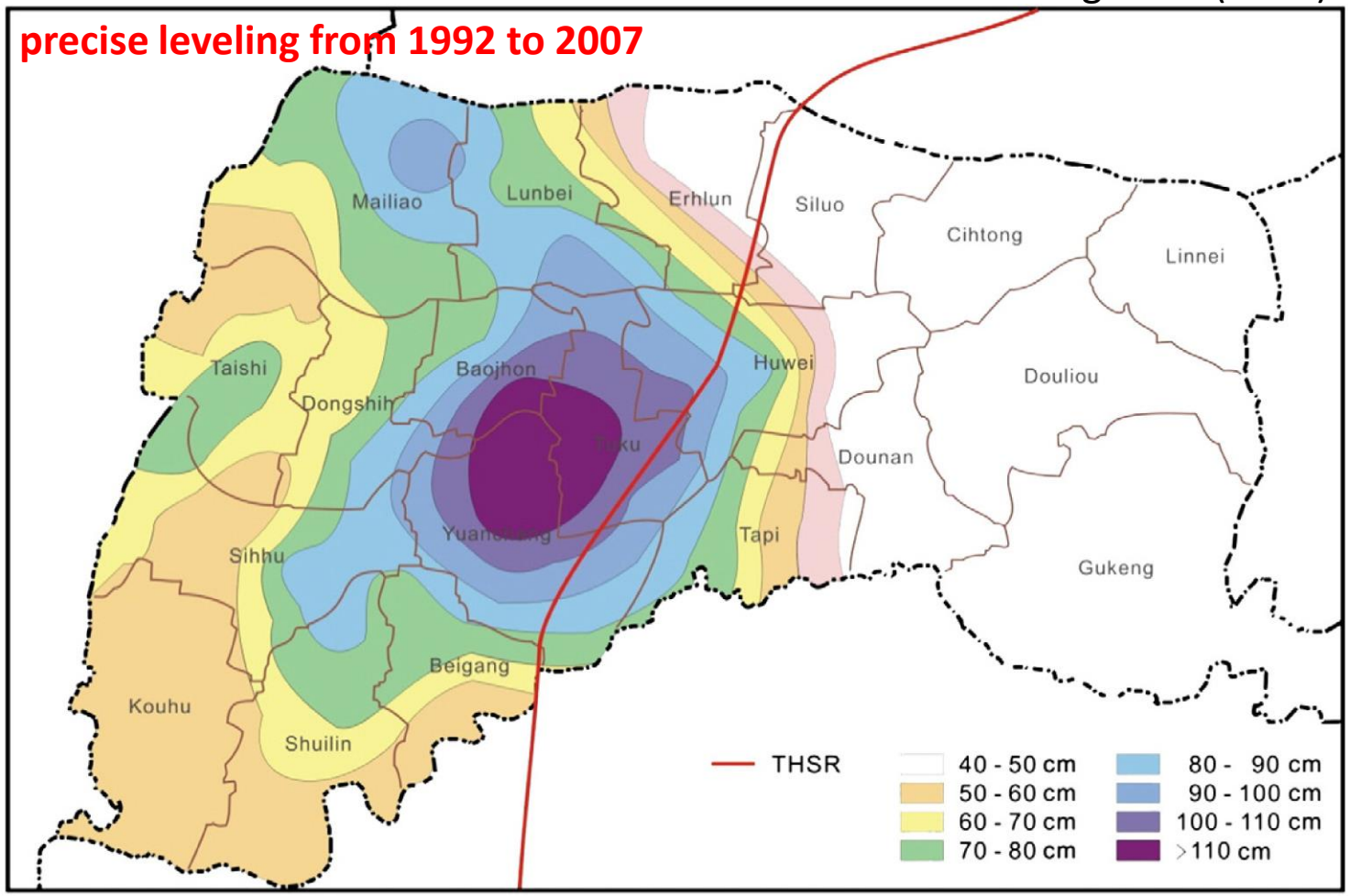


data obtained between 1998 and 2003

The high demands of agriculture, aquaculture, industry and domestic water

precise leveling and PSI → Lu et al.(2016)

Tung & Hu (2012)



Maximum cumulative land subsidence

> 110 cm !!!

1.Excessive groundwater pumping

More than 100.000 well installed

2.Unconsolidated alluvial layer

Gravel, Sand, silt, mud and clay

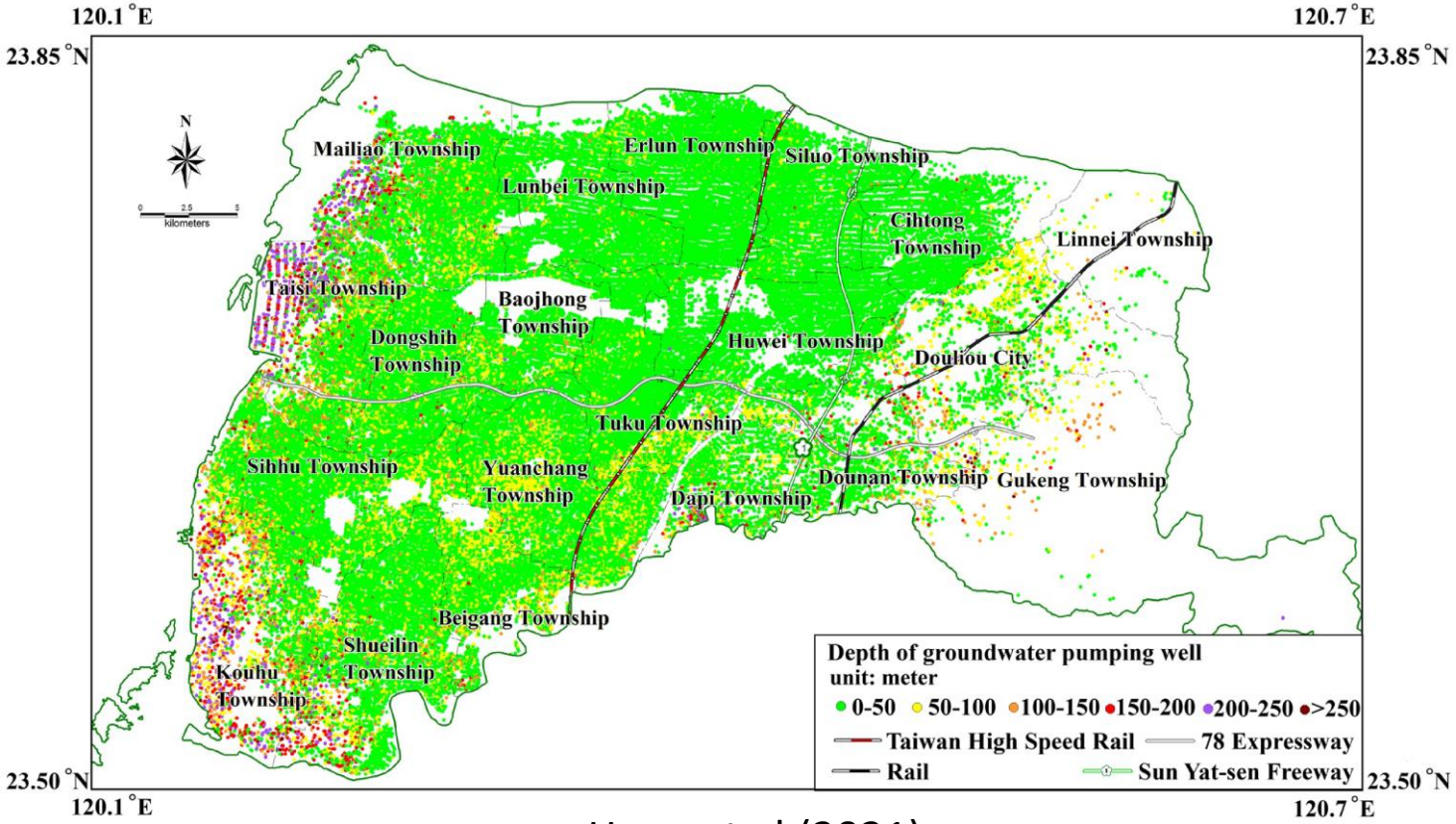
3.Groundwater recharge aren't sufficient

The rainfall in the Yunlin area varies greatly

4.Aquaculture & Agriculture

>> 4010 ha (year 2002)

Lin et al.(2016)



Hung et al.(2021)

Annual Recharge:

551.89 million m^3

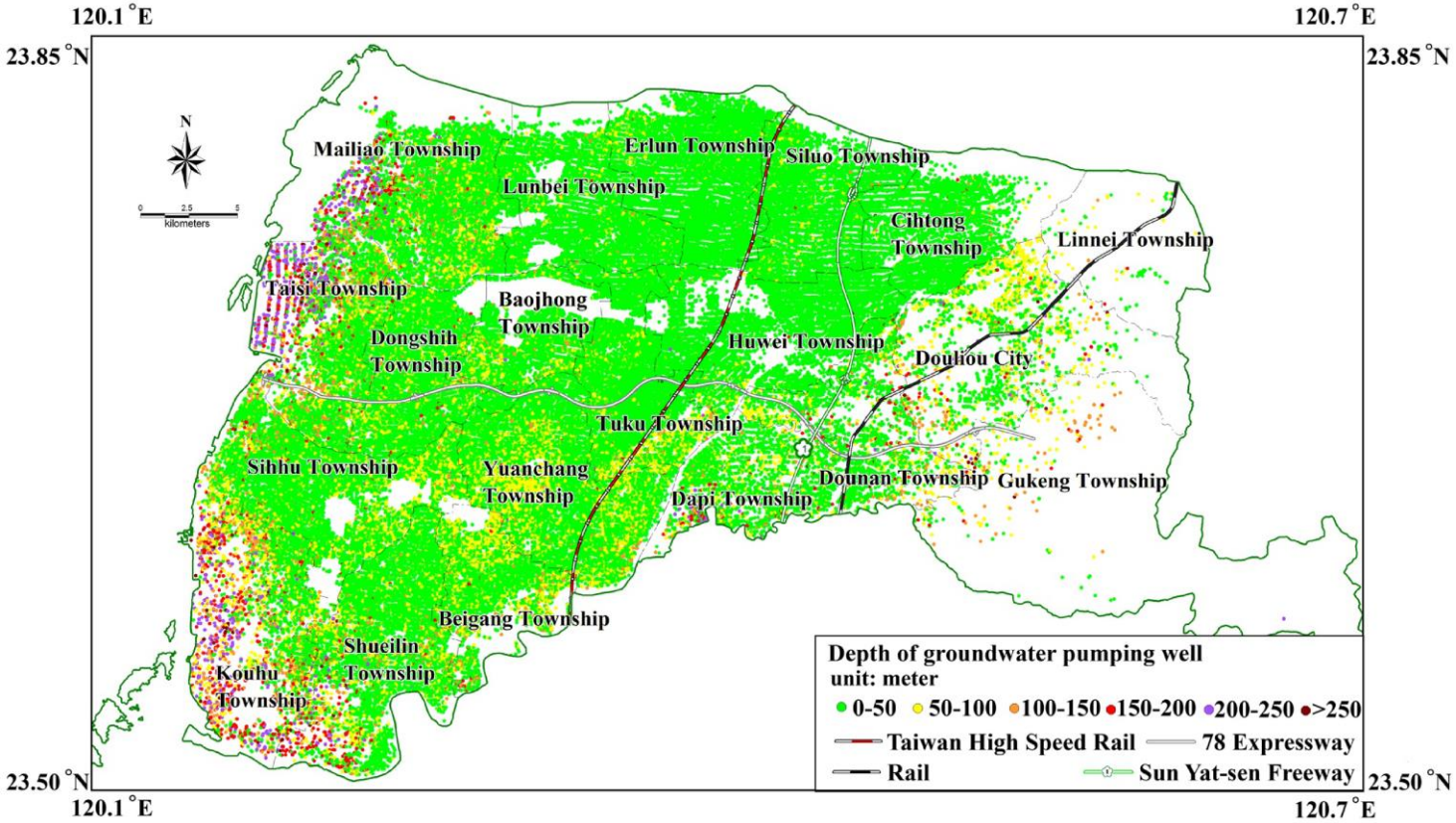
Withdrawal:

745.37 million m^3

Aquaculture:

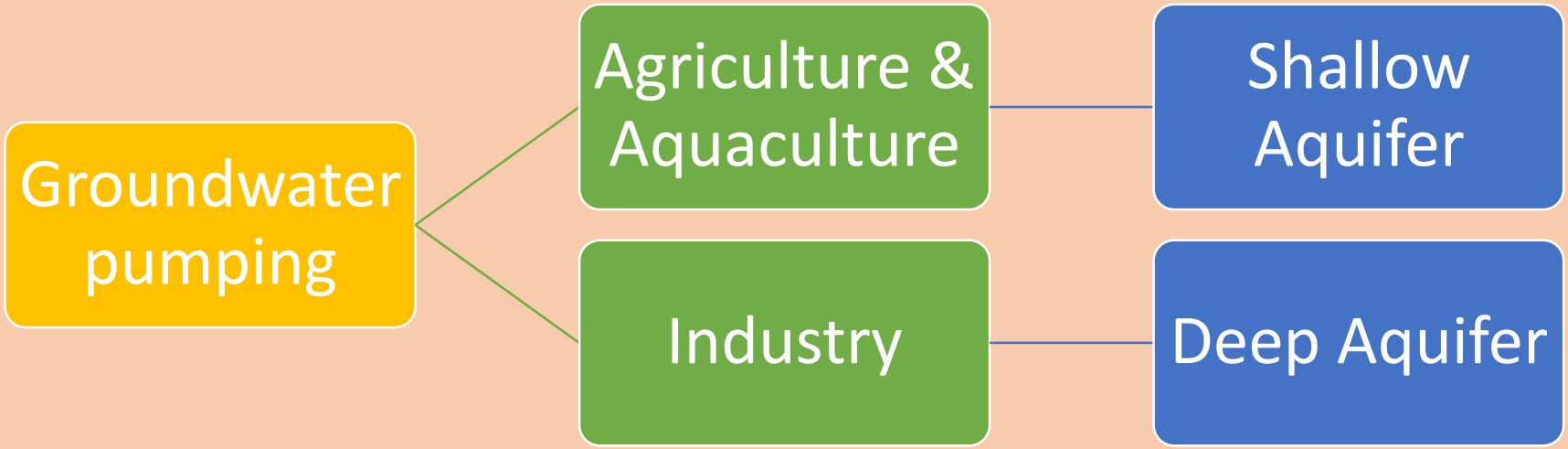
471.76 million m^3(63.3 %)

Lin et al.(2016)



Hung et al.(2021)

Land Subsidence



Agriculture & Aquaculture? Or Industry?

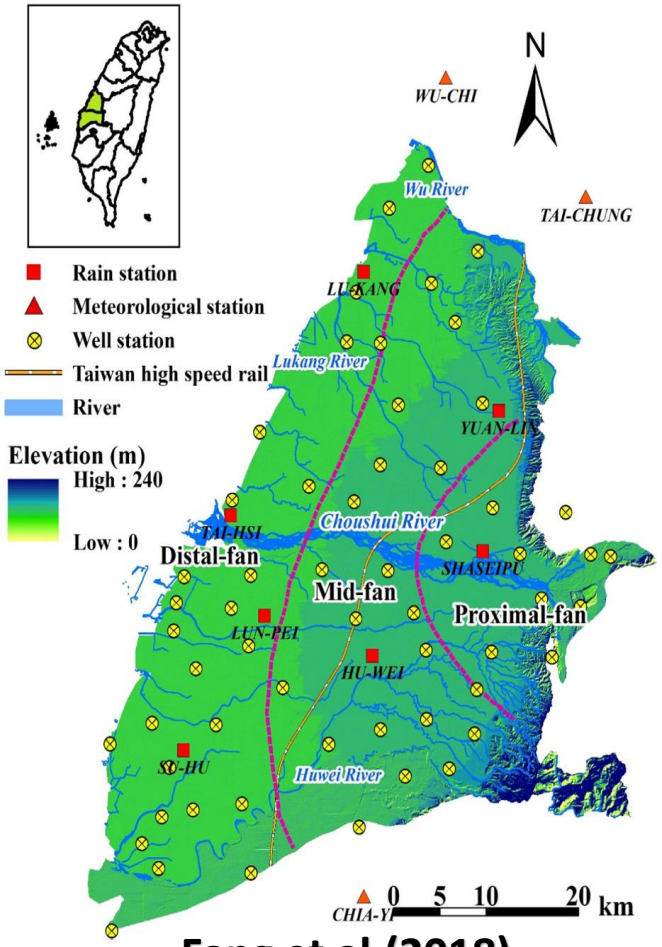
Shallow aquifer pumping? Or Deep aquifer pumping?

Motivation:

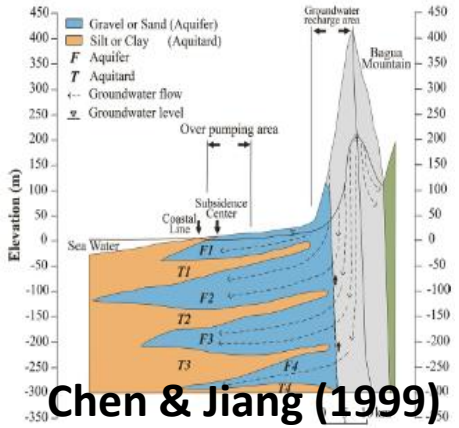
Understanding the contribution of shallow aquifer pumping to exsisting land subsidence in the chousui river alluvial fan

Objectives:

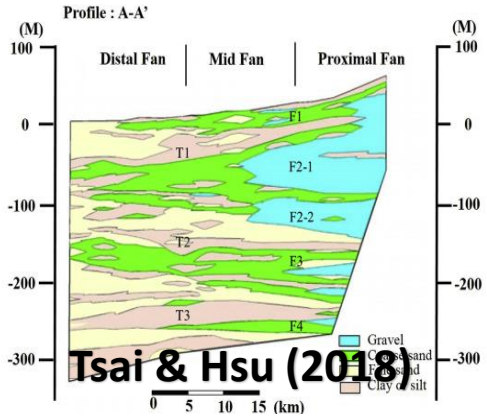
1. Build a numerical model to simulate subsidence and aquifer-system compaction for water-table
2. Calculate each layer compaction and its contribution to total subsidence



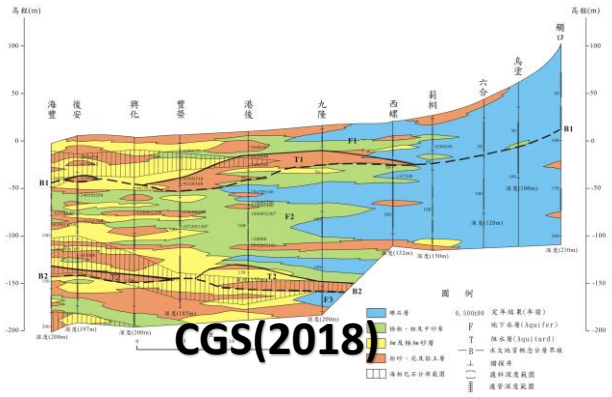
Fang et al.(2018)



Chen & Jiang (1999)



Tsai & Hsu (2018)



CGS(2018)

Elevation:

0 – 100 m (asl)

Materials:

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

Hydrostratigraphy:

- 4 Aquifer (F1, F2, F3, F4)
- 4 Aquitard (T1, T2, T3, T4)

2 Methodology

MODFLOW 2005-(Harbaugh,2005)

Modflow-SUB_WT

SUB-WT(Leake and Galloway, 2007)

Features:
Unconfined flow systems

SUB-WT

Package for
MODFLOW

To simulates

Vertical compaction → Regional groundwater flow

SUB-WT simulates

1. **Groundwater storage changes**
2. **Compaction in interbeds**
3. **Compaction in confining units**
4. **Stress-dependent in storage properties**

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

2 Methodology

Modflow-SUB_WT

MODFLOW 2005-(Harbaugh,2005)

SUB-WT(Leake and Galloway, 2007)

The development is based on the Terzaghi (1925) theory of one-dimensional consolidation that ignores horizontal strains and stress gradients

effective stress tensor

Kronecker delta

$$\sigma'_{ij} = \sigma_{ij} - \delta_{ij} u$$

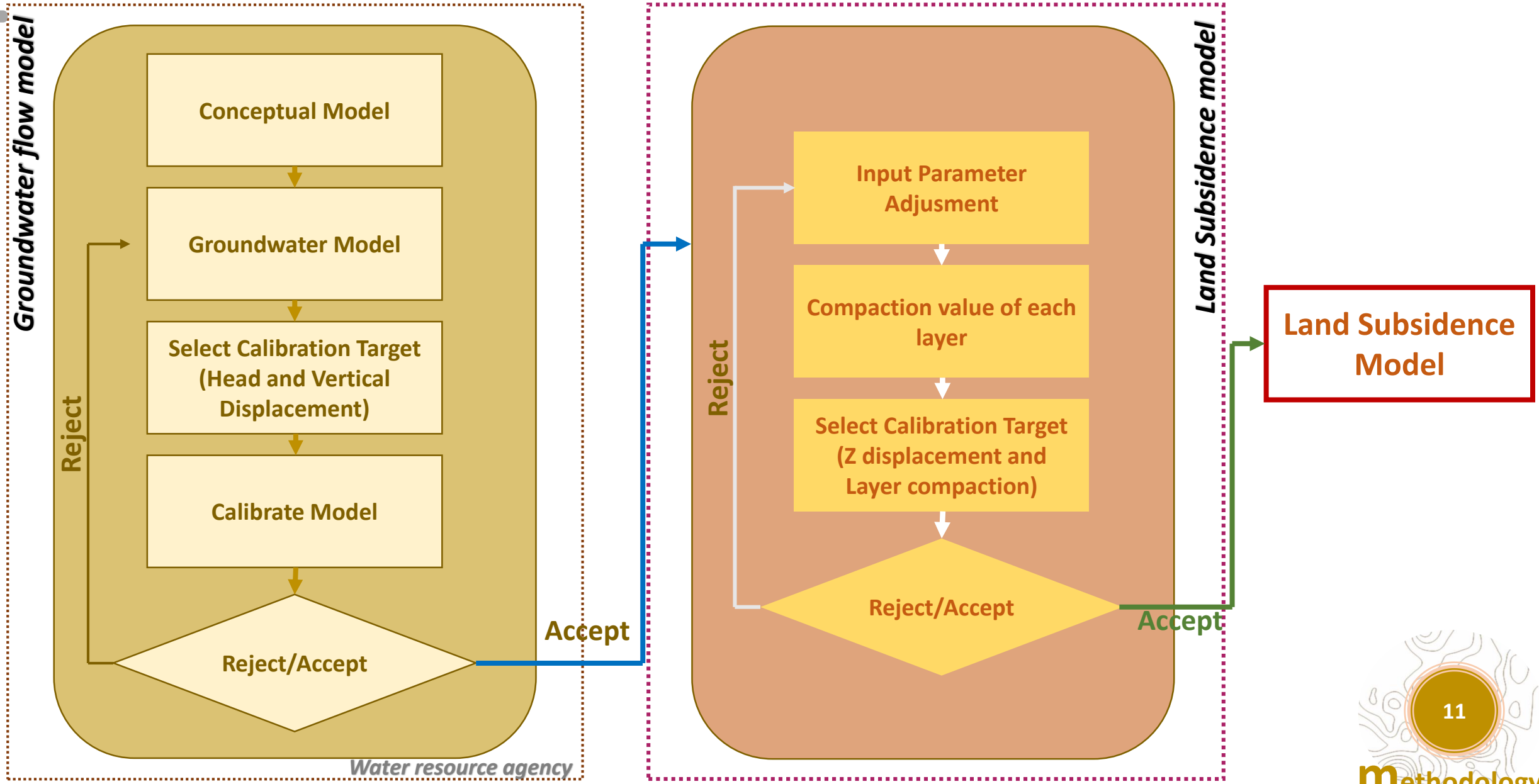
fluid pore pressure

geostatic (total) stress tensor

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

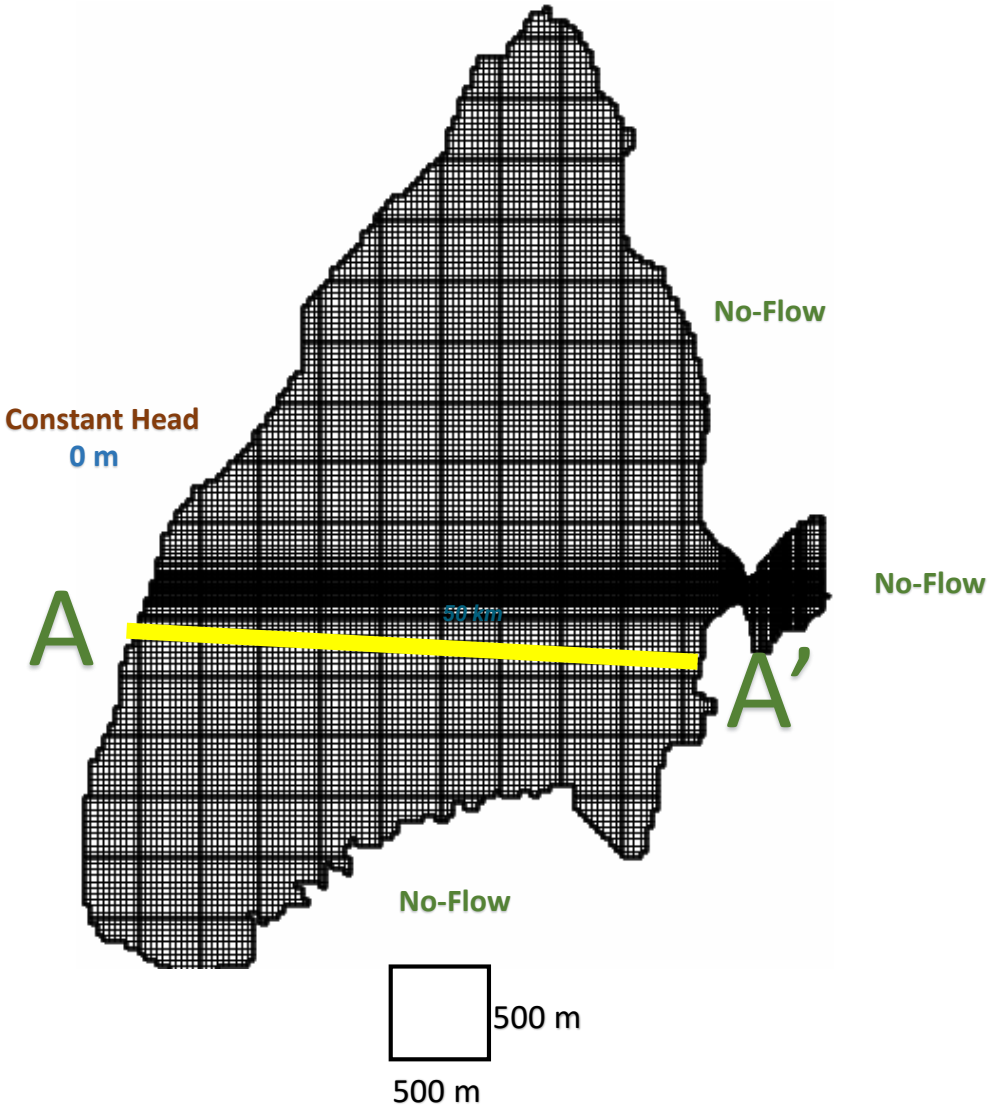
Can be approximated with finite differences

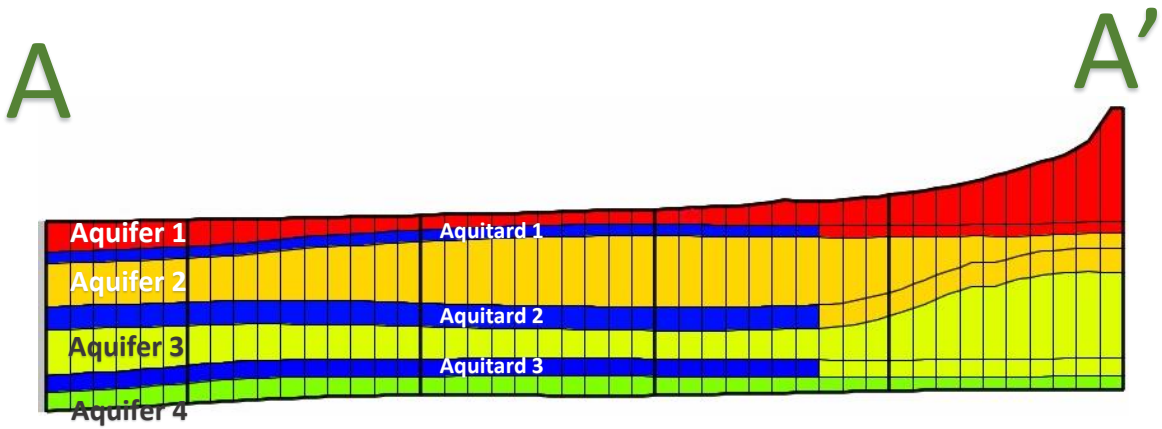
2 Methodology



2 Methodology

Model Discretization





151 Columns

189 Rows

7 Layers:

- Four Aquifer Layers
- Three Aquitard Layers

Source:

Water resource agency (2016)

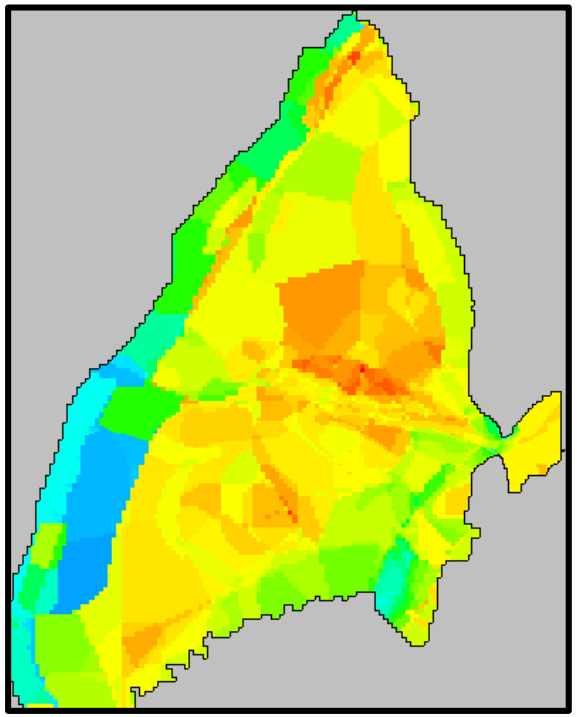
Top Elevation: SRTM Digital Elevation Model (DEM)

Layer Elevation: Central Geological Survey (1995)

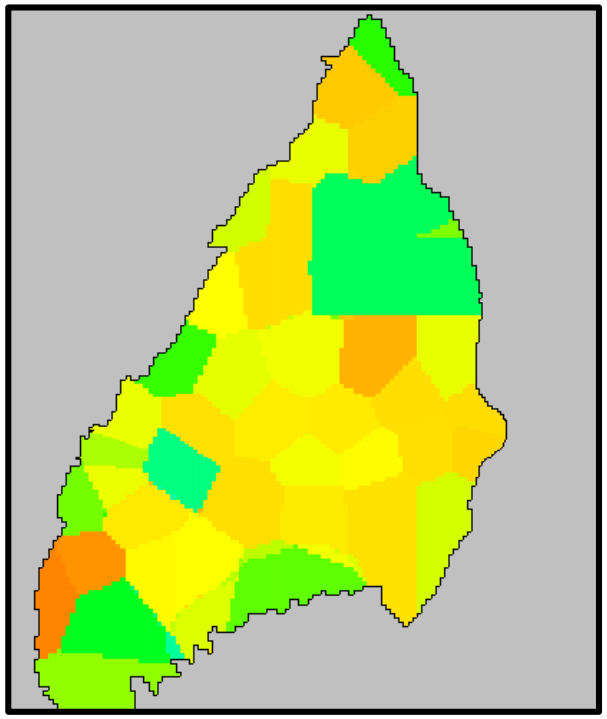
Boundary Condition: Central Geological Survey (1995)

Hydraulic Conductivity (K)

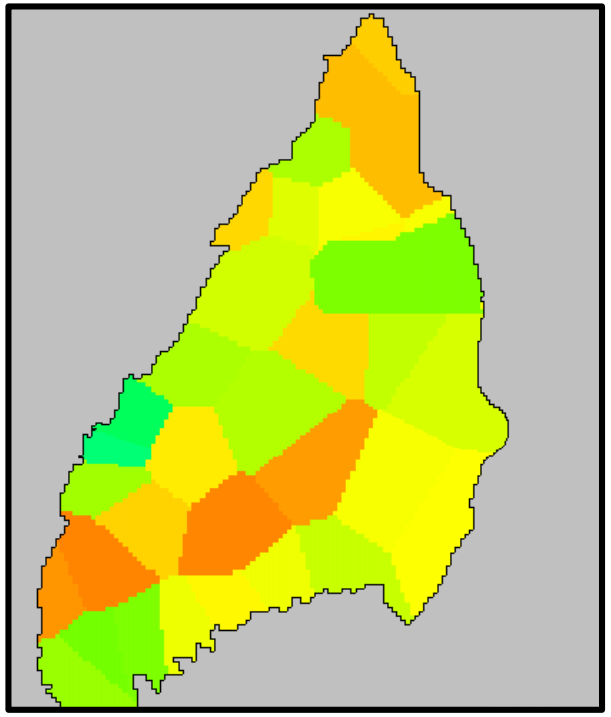
Aquifer 1



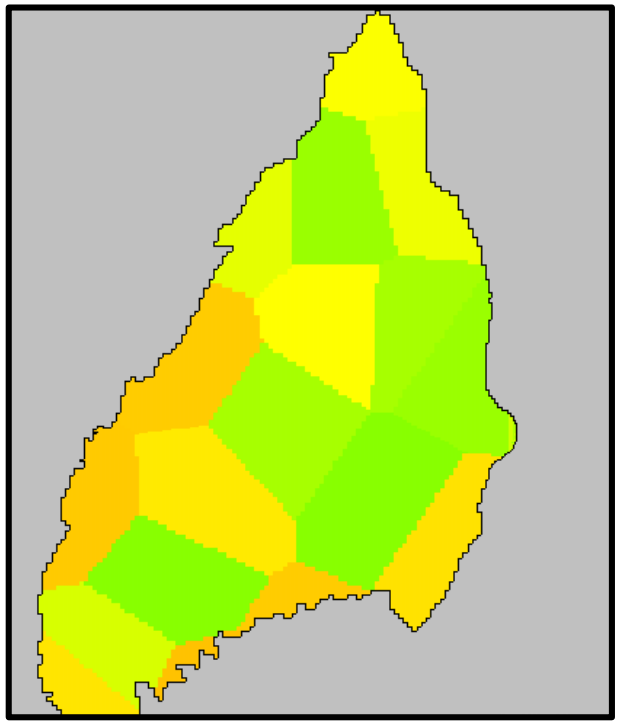
Aquifer 2

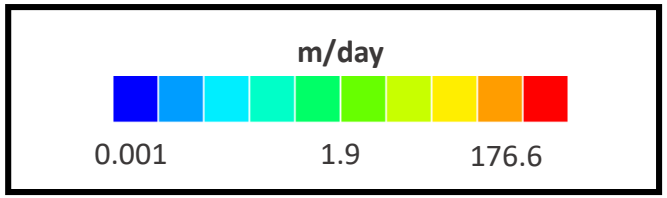


Aquifer 3



Aquifer 4

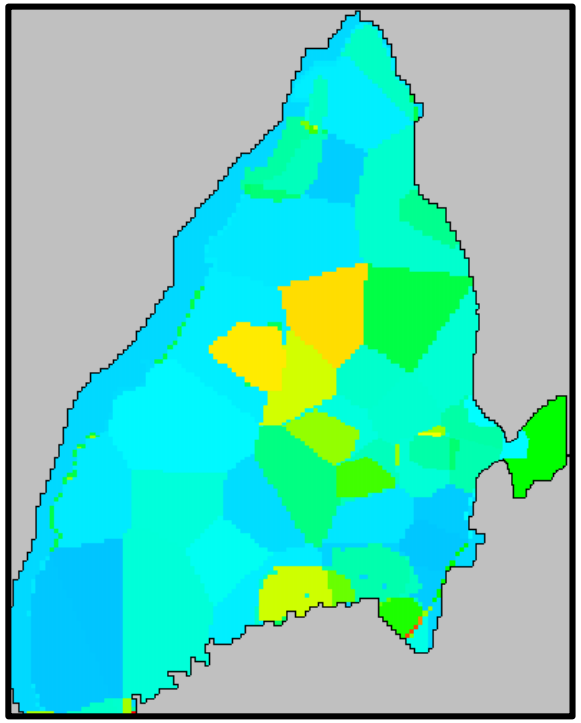


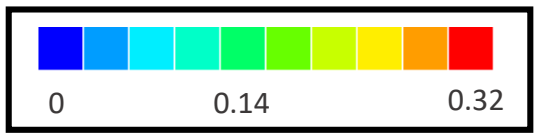


Source:
Water Resource Agency (2016)

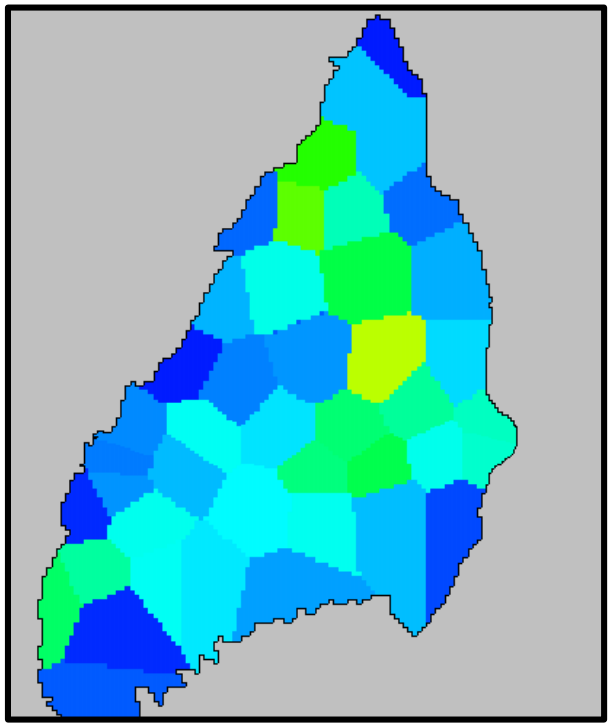
Specific Yield and Specific Storage

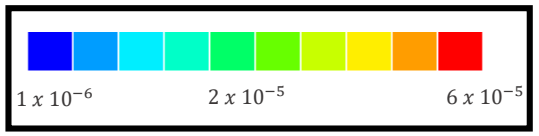
Aquifer 1



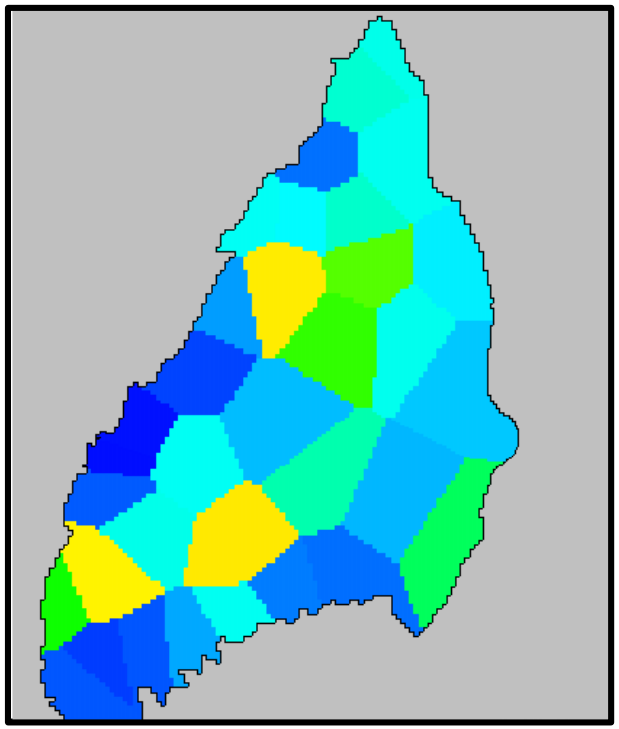


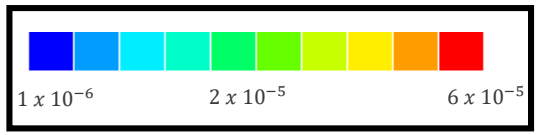
Aquifer 2



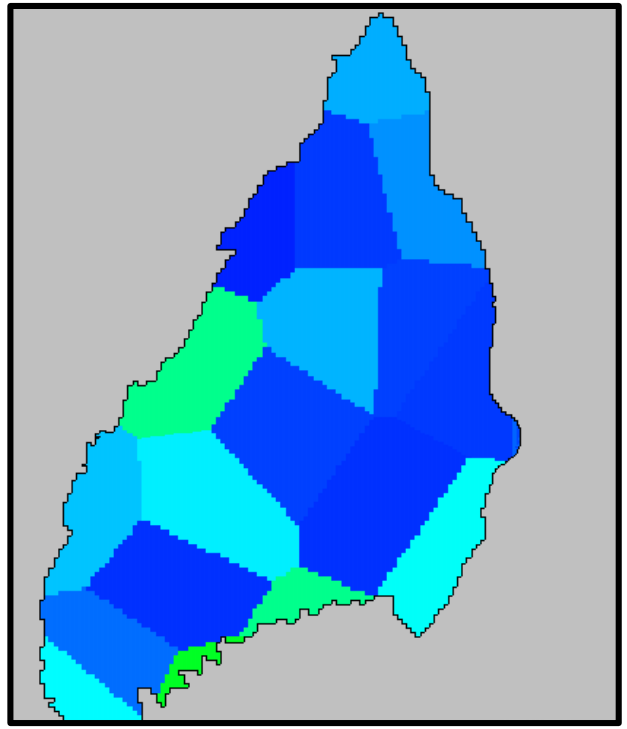


Aquifer 3





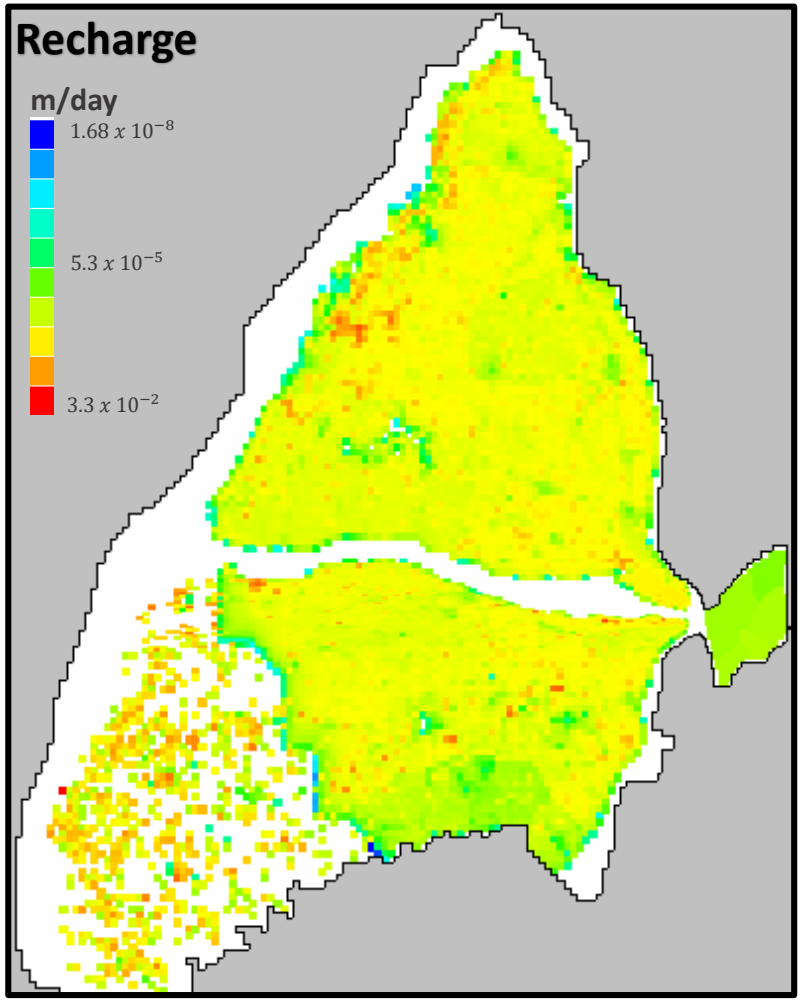
Aquifer 4

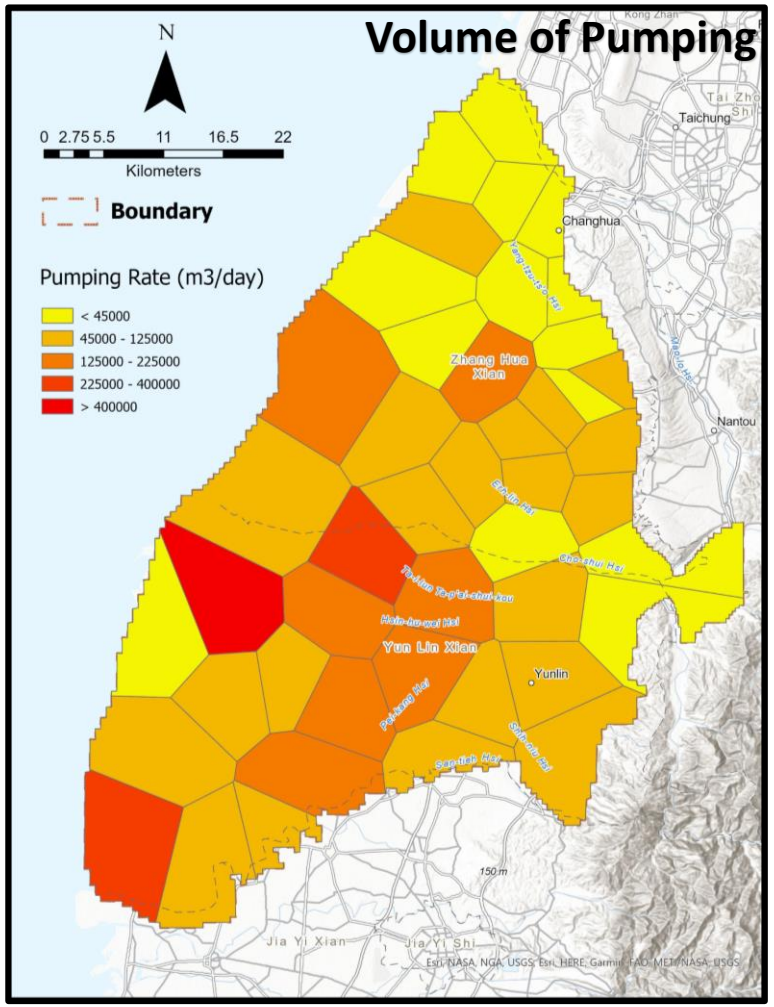


Source:
Water Resource Agency (2016)

2 Methodology

Recharge & Pumping Well

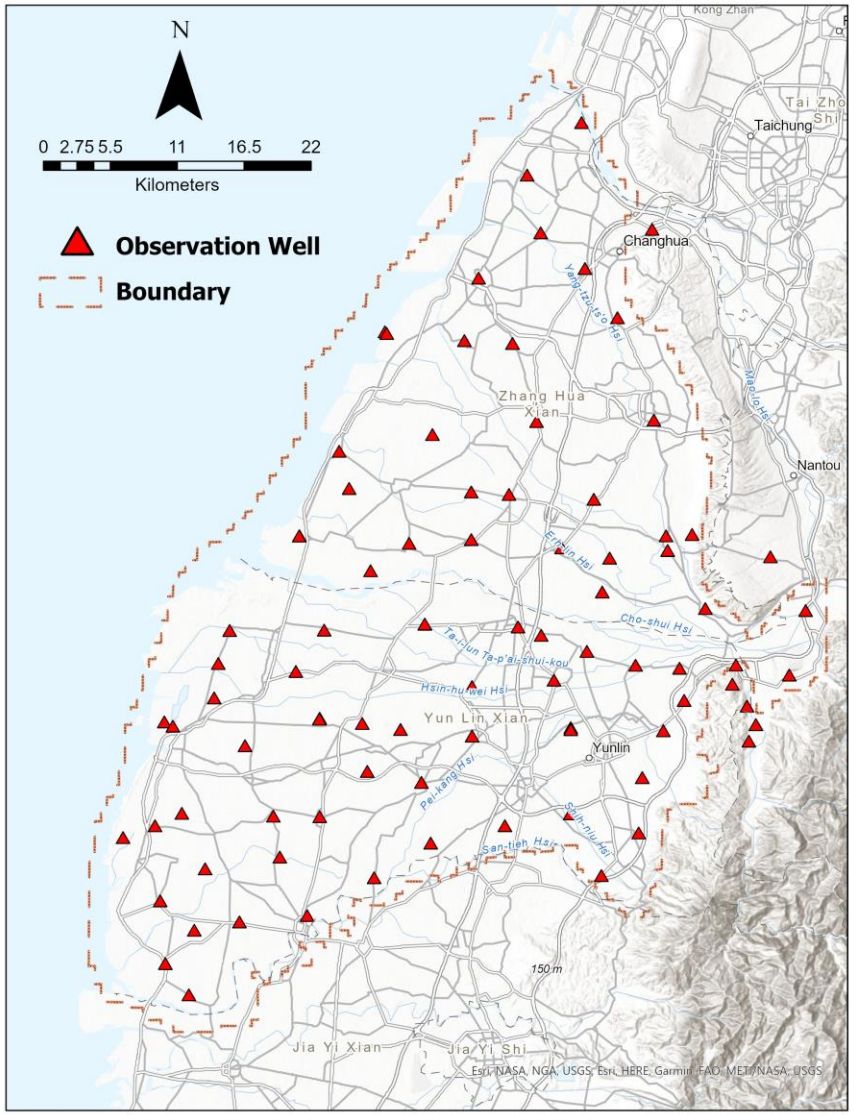


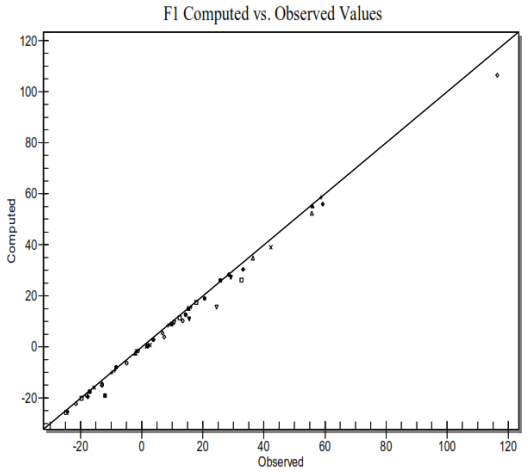


Source:
Water Resource Agency (2016)

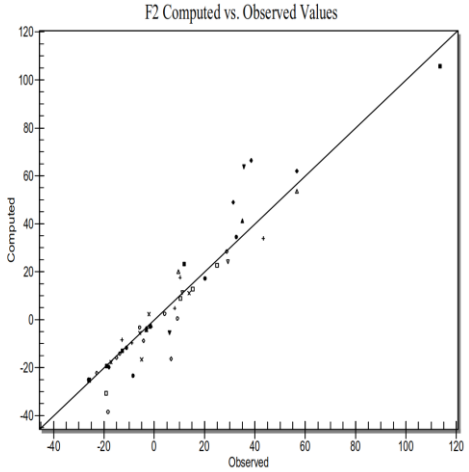
2 Methodology

Parameter Calibration

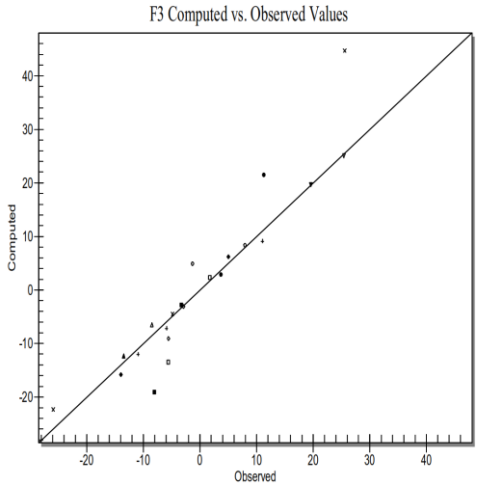




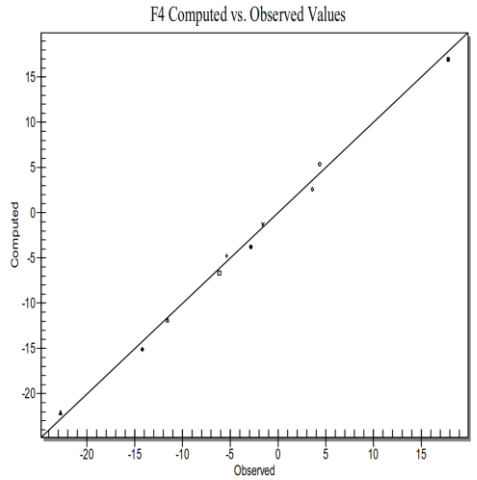
Aquifer 1



Aquifer 2



Aquifer 3



Aquifer 4

Source:
Water Resource Agency (2016)

SUB-WT Parameter

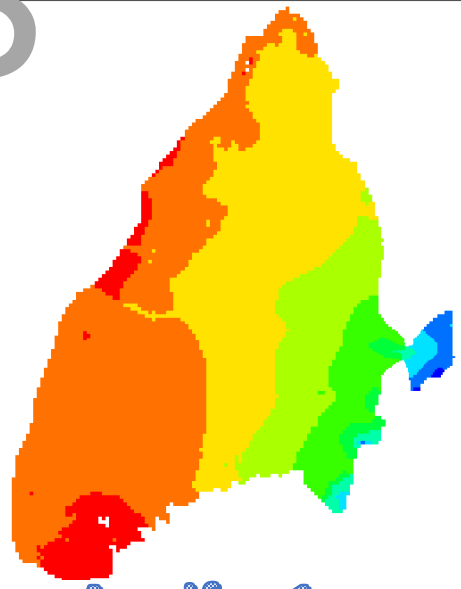
(Zhu 2012; Das, Sobhan et al. 2016; Chang, et. al. 2020)

Geostatic Stress	Init.Preconsolidation Stress	Specific Gravity Saturated	Specific Gravity Unsaturated	Compression Index	Initial Compaction	Initial Void Ratio	Recompression Index
0.75	2	2	1.7	0.25	0	0.82	0.01

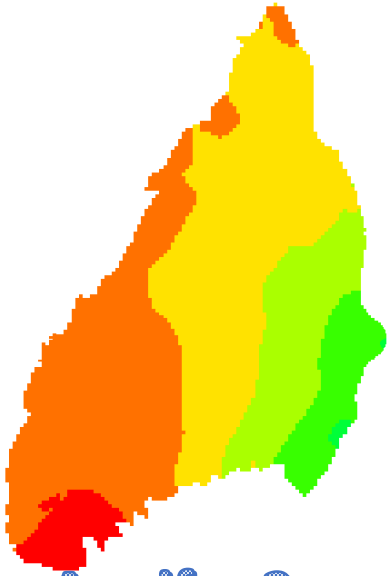
	Sske	Sskv
Layer 1	2.10E-04	9.12E-02
Layer 2	7.50E-05	7.50E-03
Layer 3	4.20E-04	1.80E-03
Layer 4	2.25E-04	2.25E-03
Layer 5	7.00E-04	4.00E-03
Layer 6	7.50E-05	7.50E-03
Layer 7	5.40E-04	3.40E-03

Focused on unconfined aquifer (layer 1)

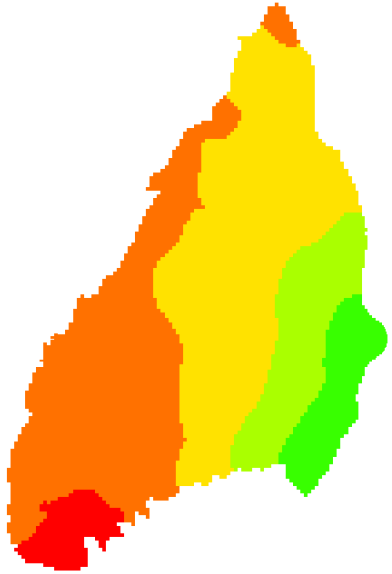
Head Distribution



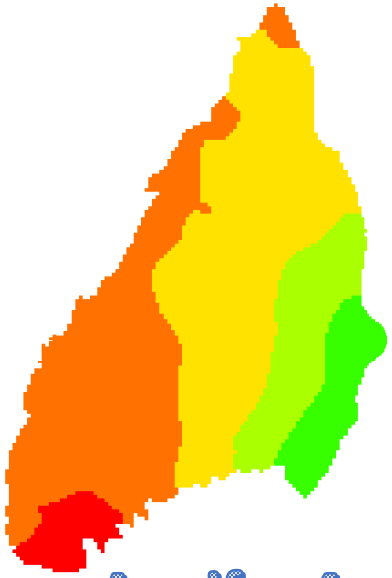
Aquifer 1



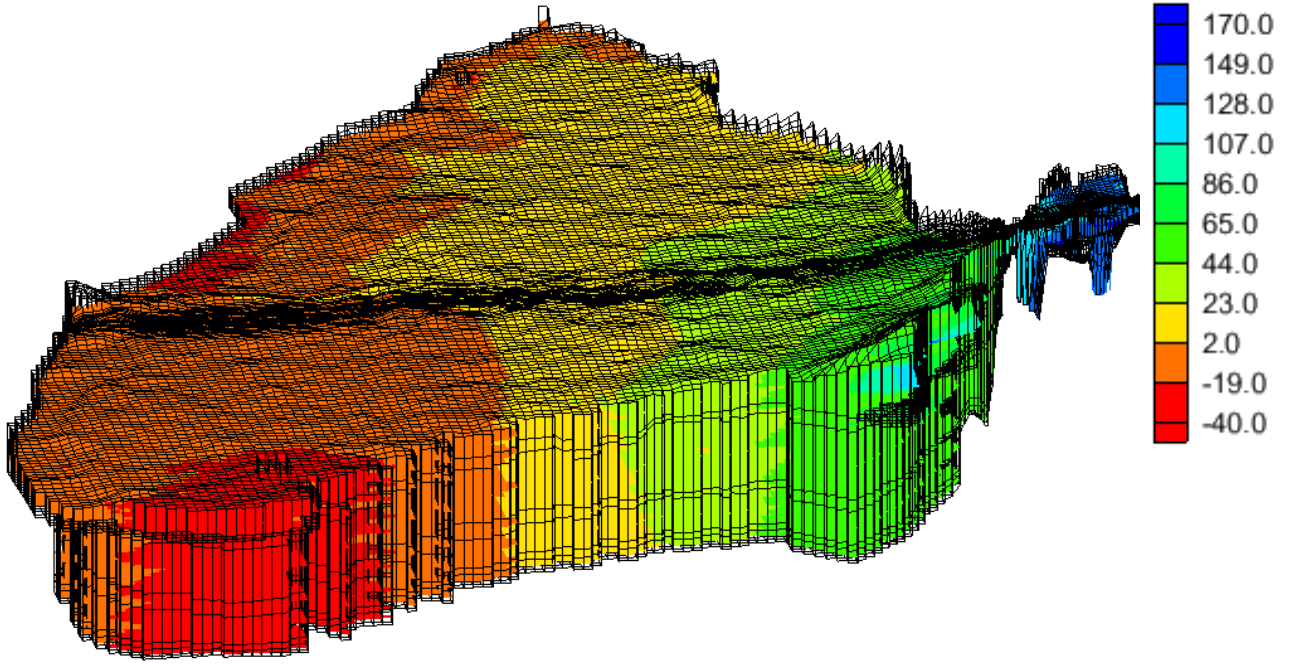
Aquifer 2



Aquifer 3



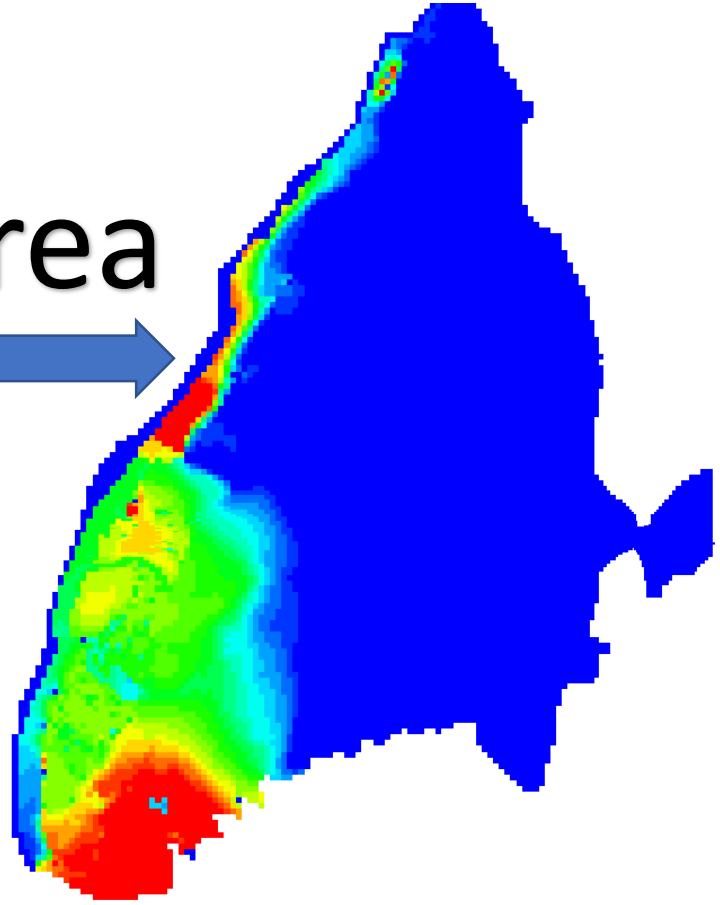
Aquifer 4

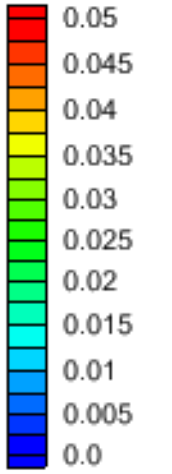


Subsidence/Compaction for Aquifer 1

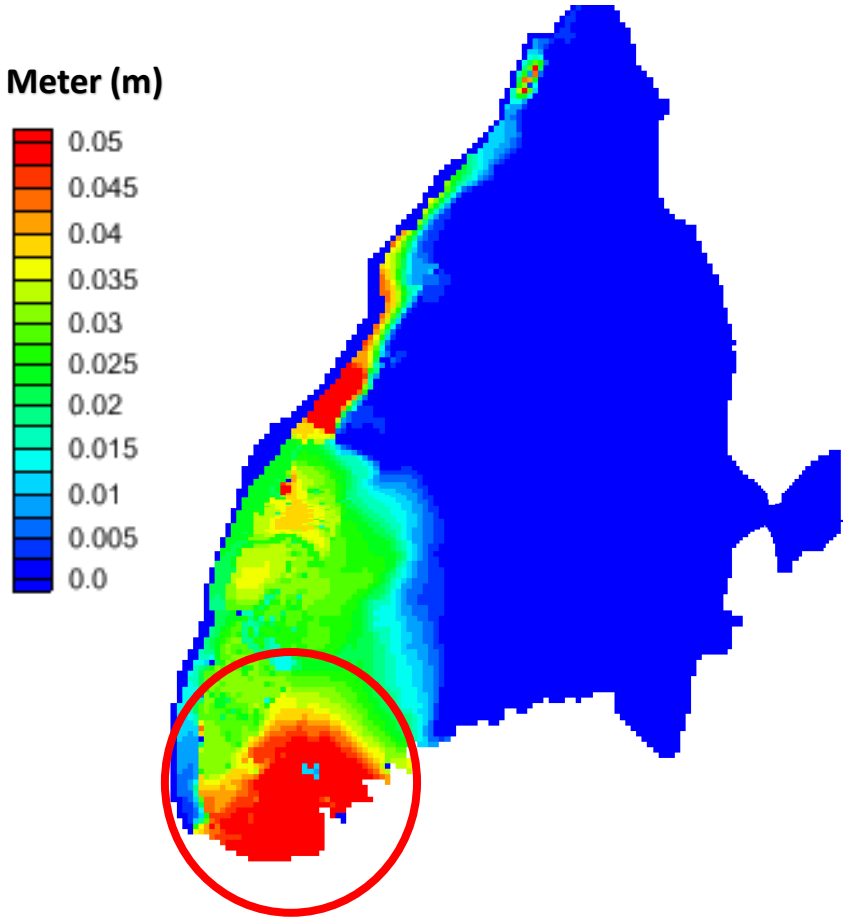
Coastal area

Intensive aquaculture activities

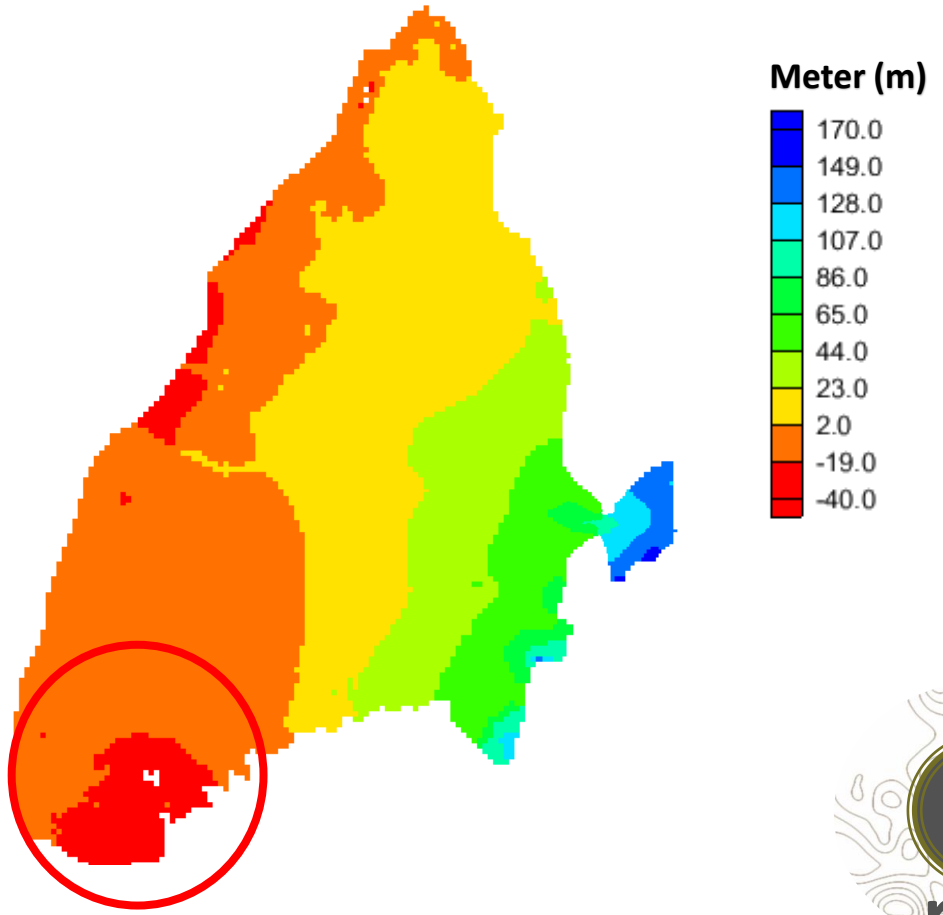




Subsidence/Compaction for Aquifer 1

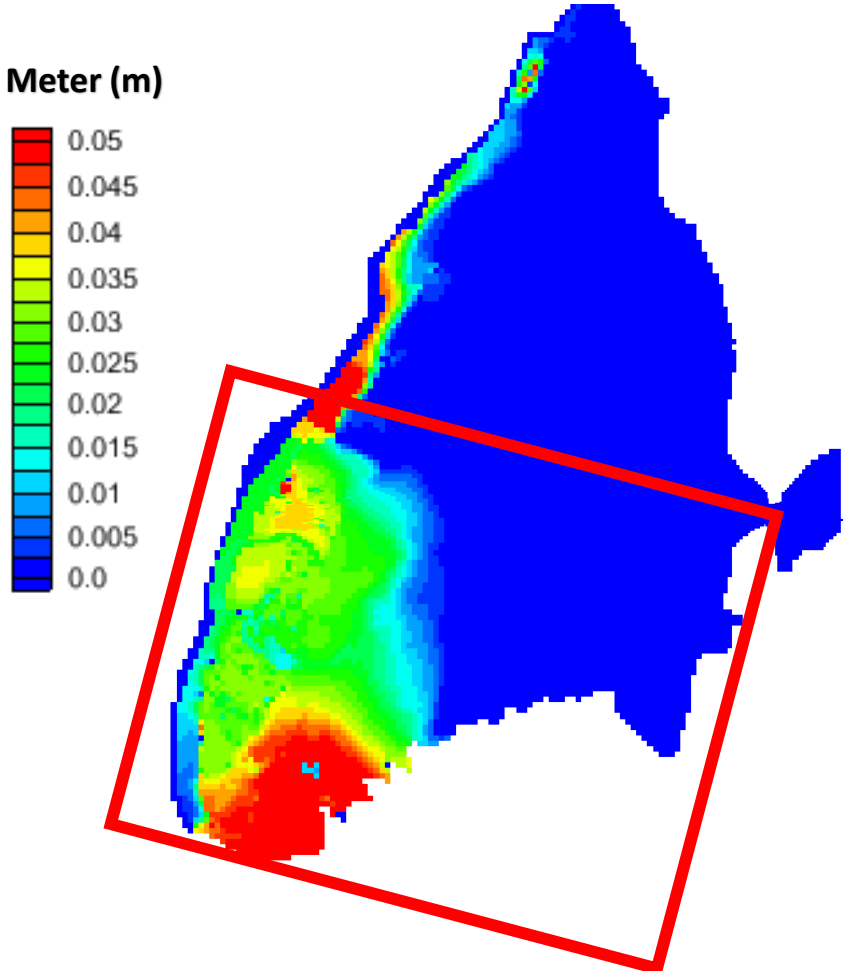


Head Distribution for Aquifer 1



Subsidence/Compaction for Aquifer 1

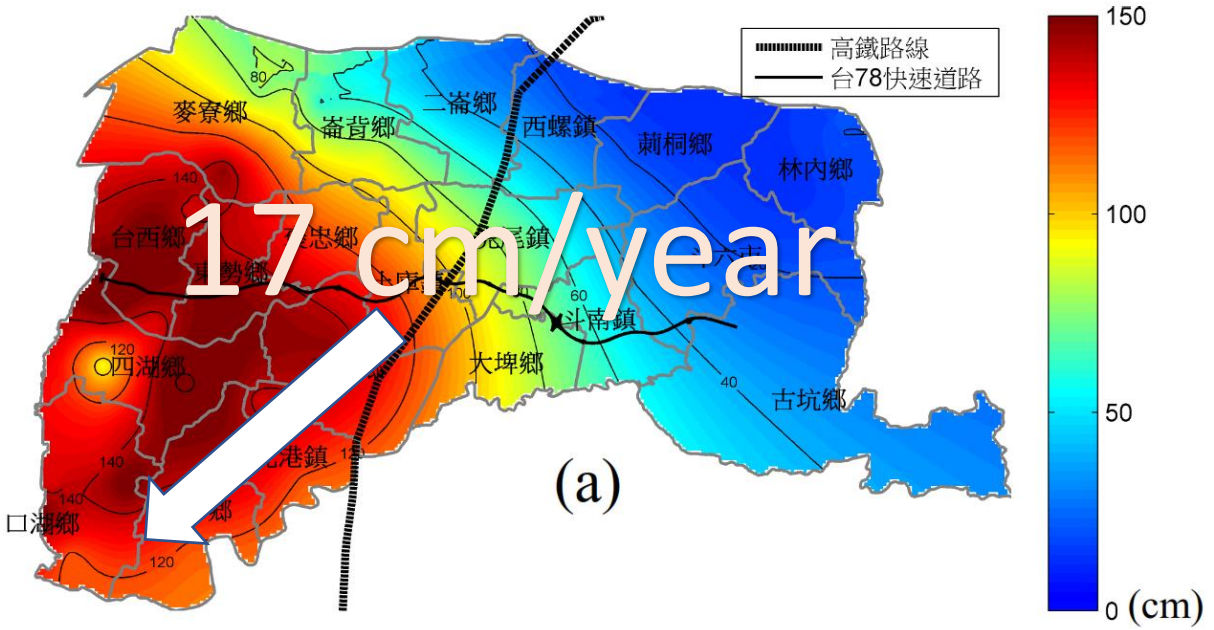
5 cm/year → **30 %**



Subsidence in Yunlin County

Lin et al.(2016)

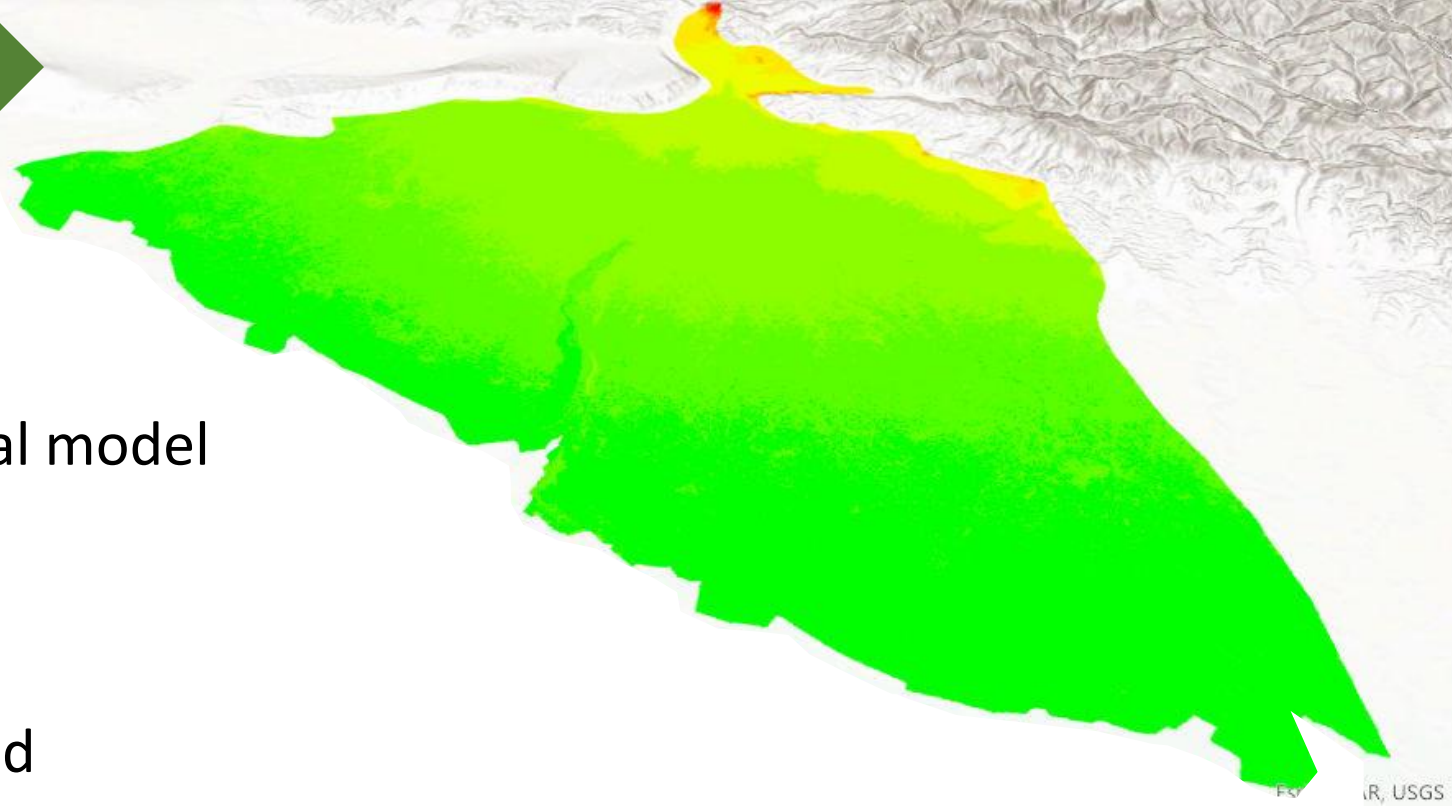
1992 to 2001



4 Summary and conclusion

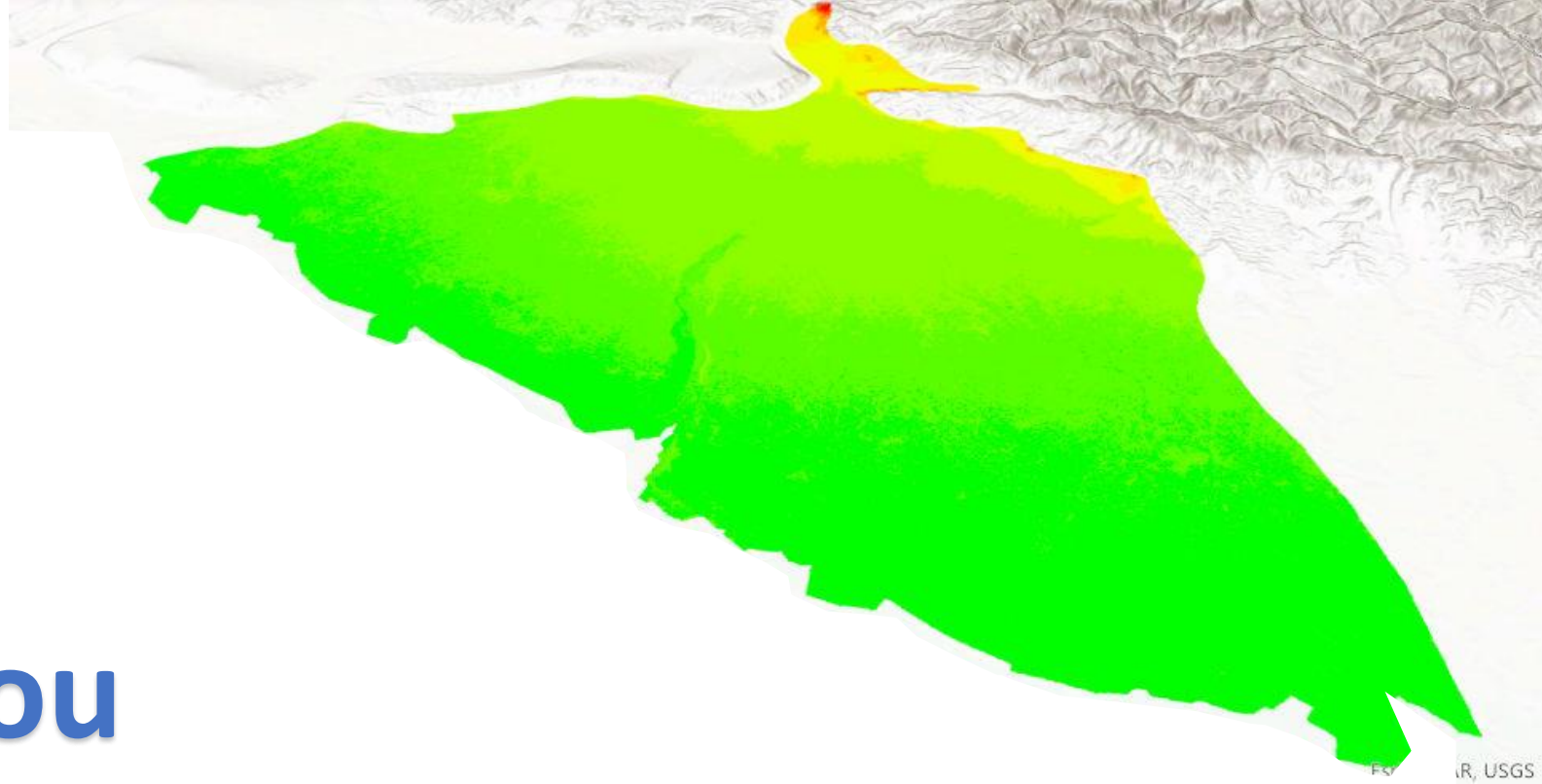
1. The subsidence in the unconfined aquifer part can be modelled using SUB-WT
2. The highest Subsidence rate reach to 5 cm/year
3. Excessive groundwater pumping in the aquaculture and agriculture area can cause serious land subsidence
4. Excessive groundwater pumping in the unconfined aquifer can contribute significantly to land subsidence

5 Future Works



- Extent the boundary of numerical model with smaller grid.

- Calibrate numerical model of land subsidence with observed data



Thank You