National Central University
Graduate Institute of Applied Geology

Paper review

Modeling aquifer-system compaction and predicting land subsidence in central Taiwan

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Date: 2022/04/22

CONTENT

Introduction

Changhua County:

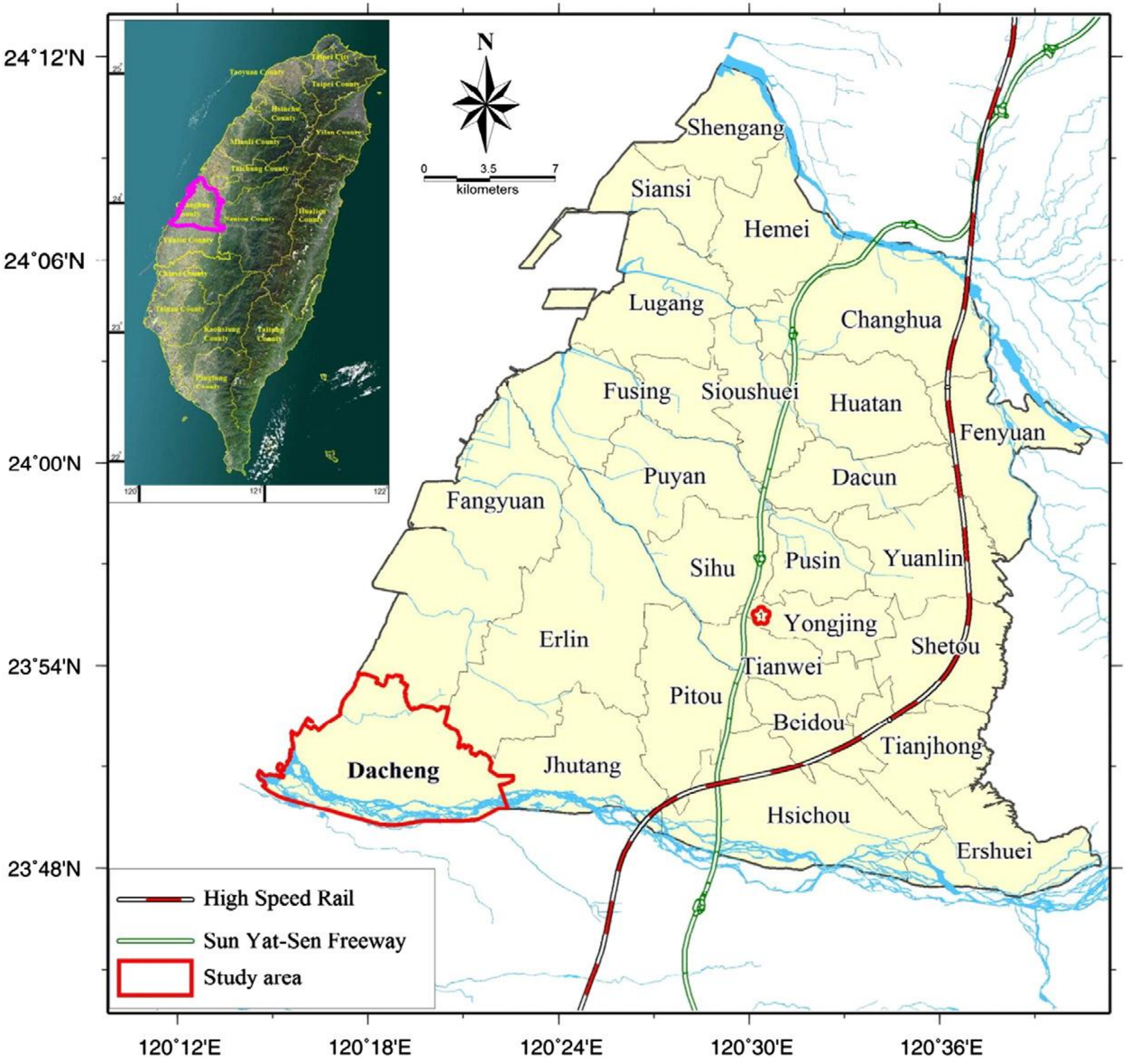
- Many major economic development projects
- Groundwater has been pumped massively, resulting in severe land subsidence
- Research land subsidence to forecast and develop an optimal GW management strategy

The study area: Dacheng Township in Changhua, Taiwan

In this paper:

- Observation (GPS, leveling, monitoring wells)

- Use a one-dimensional compaction model



Methodology

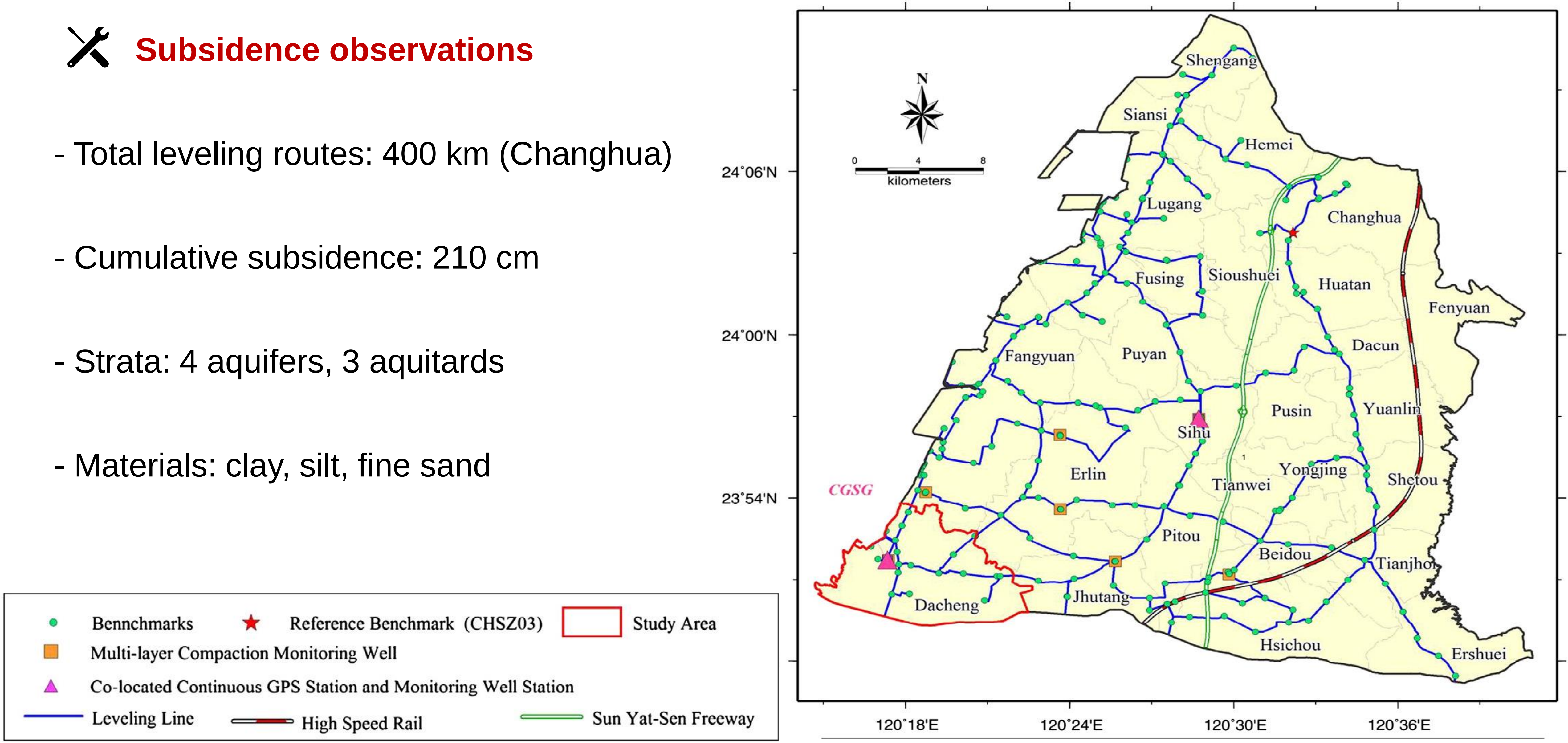
Subsidence observations

- Total leveling routes: 400 km (Changhua)

- Cumulative subsidence: 210 cm

- Strata: 4 aquifers, 3 aquitards

- Materials: clay, silt, fine sand

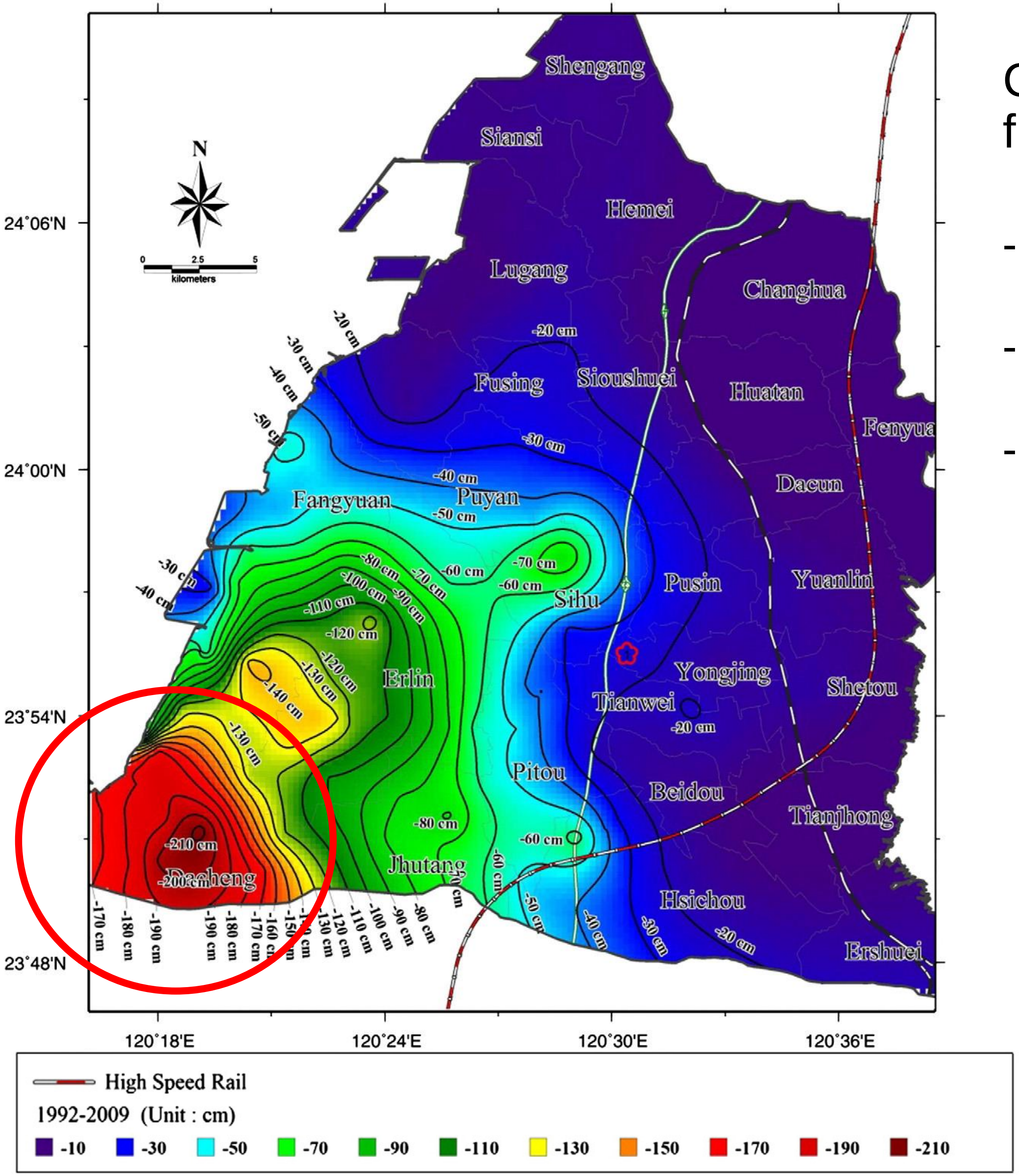


Distributions of leveling, monitoring wells and GPS station

Methodology

18 years = 210 cm

11.67 cm/year



Cumulative subsidence in Changhua from 1992-2010

- Cumulative subsidence: 210 cm
- Strata: 4 aquifers, 3 aquitards
- Materials: clay, silt, fine sand

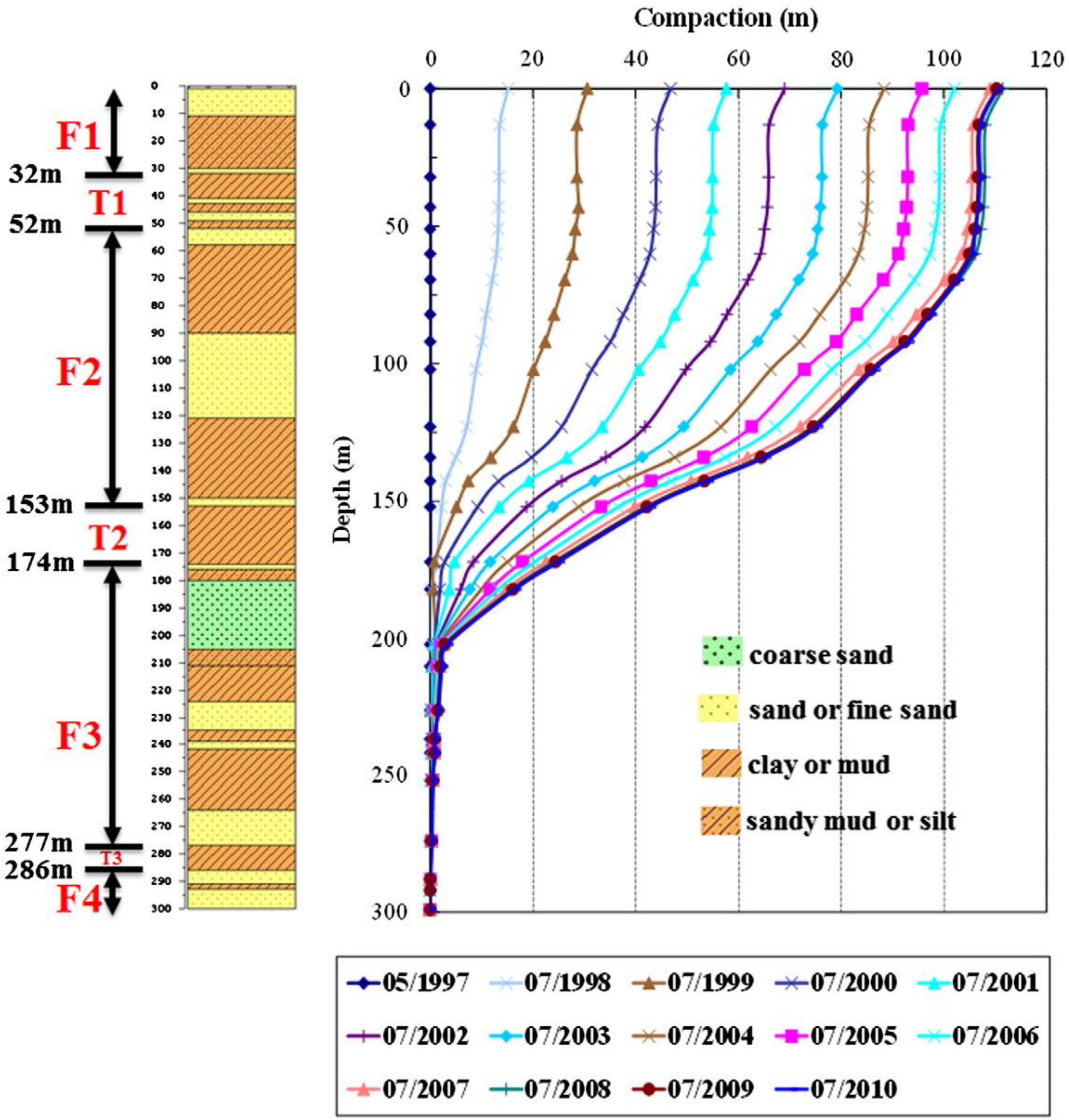
Methodology

Monitoring well information

No. of magnetic rings	25
Sediment types	(1) 0–120 m: interlayers of sand and clay (2) 120–220 m: clay with thick coarse sand interbed (3) 220–300 m: interlayers of sand and clay
Depth of major compaction (m)	50–200 m
Cumulative compaction from July 2001 to July 2007 (cm)	51.3 cm

Cumulative compactions from 1997-2010

	Depth range (m)	Compaction (cm)	Percentage (%)
Aquifer 1(F1)	0–32	3.5	3.2
Aquitard 1 (T1)	32–52	0.9	0.8
Aquifer 2 (F2)	52–153	63.4	57.3
Aquitard 2 (T2)	153–174	17.8	16.1
Aquifer 3 (F3)	174–277	24.7	22.3
Aquitard 3 (T3)	277–286	0.3	0.3
Aquifer 4 (F4)	286–299	0.0	0.0
	Sum	110.6	100.00



Cumulative compactions from 1992-2010

Methodology

Stress and strain

Using Terzaghi's theory

$$\sigma_e = \sigma_T - p_w$$

σ_T : total stress

σ_e : effective stress

p_w : fluid or pore water pressure

In confined aquifer,

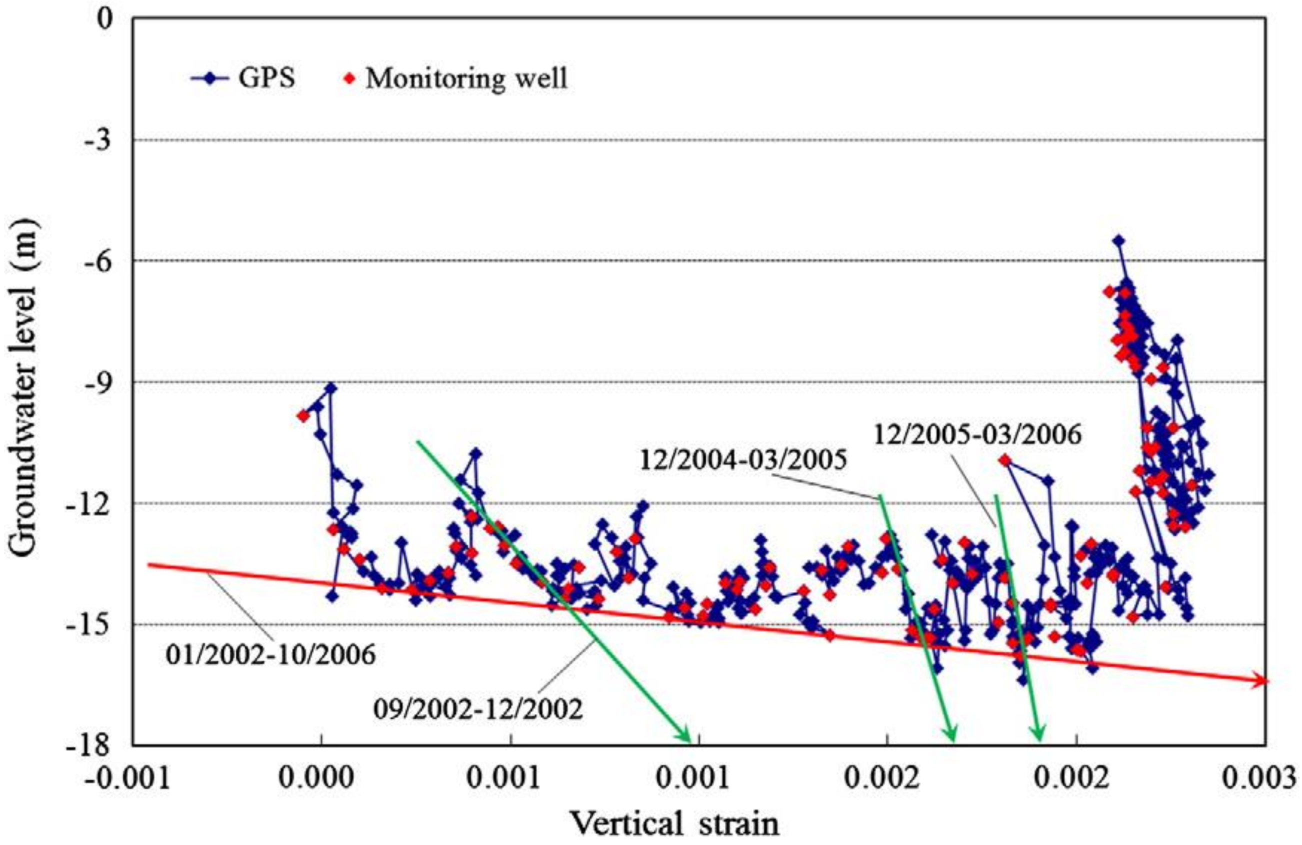
$$\Delta\sigma_e = -\Delta p_w$$

$$\Delta p_w = \rho_w g \Delta h$$

ρ_w : water density

g : gravity

Δh : various of groundwater level



The relationship between groundwater level and strains

Methodology

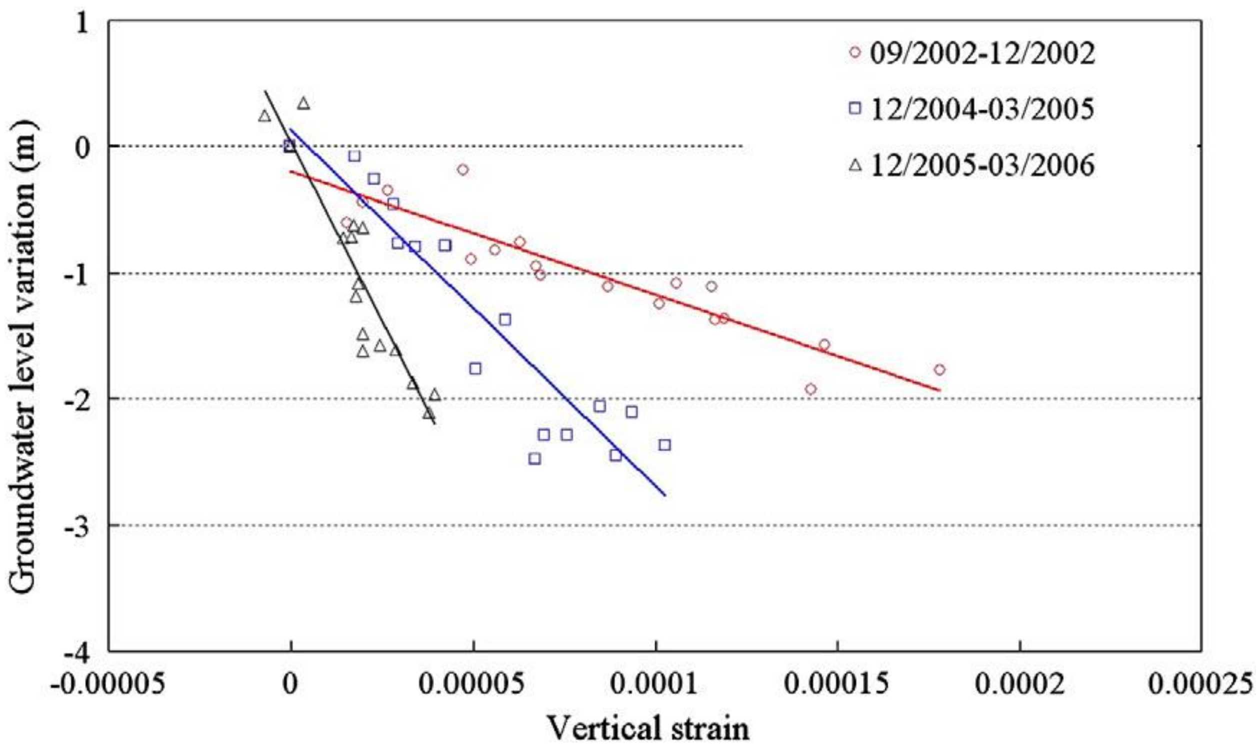
$$\alpha = \frac{-\Delta B/B_0}{\rho_w g \Delta h} = \frac{S_{sk}}{\rho_w g}$$

$$\Delta h = -\frac{\tau}{S_{sk}}$$

$$\tau = \frac{\Delta B}{B_0}$$

ΔB : compaction

B_0 : total thickness of aquifer



Relations between strain and groundwater variation

compressibility (α) ⟷ porosity (e) ⟷ skeletal specific (S_{sk})

Modeling compaction

The principle :

$$\Delta B = \Delta b + \Delta b^{'}$$

$$\Delta b = -S_{\text{ske}} b_0 \Delta h$$

$$\Delta b^{'} = N_{\text{equiv}} \Delta b^{*}$$

Δb : elastic compaction

$\Delta b'$: elastoplastic compaction

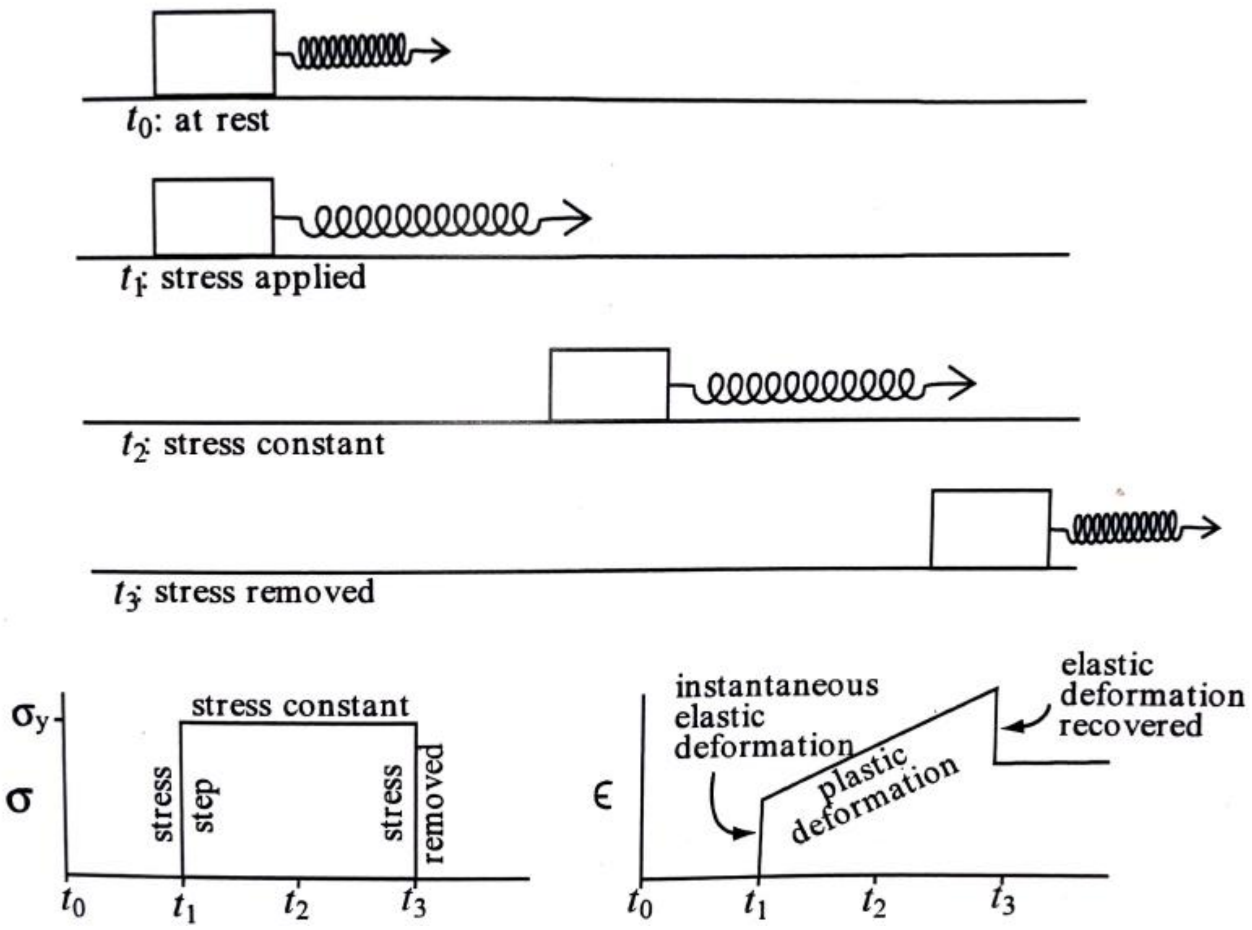
N_{equiv} : num of clay interbeds

Δb^* : fine-grained sediment compaction

S_{ske} : elastic skeletal specific storage

b_0 : total thickness

Δh : variation of groundwater level



Elastoplastic behavior demonstration

Resource: Structural Analysis and Synthesis book

Methodology

$$S_{sk}^{*} = \begin{cases} S_{ske}^{*} \text{for} \sigma_e < \sigma_{max} \\ S_{skv}^{*} \text{for} \sigma_e \geq \sigma_{max} \end{cases}$$

S_{skv}^{*} :Inelastic skeletal specific storage

S_{ske}^{*} :Elastic skeletal specific storage

Compaction of the fine-grained sediments:

$$\Delta b^{*} = \frac{\Delta z}{2}\left\{ S_{ske}^{*}\sum_{j=1}^{J-1}\left[(\Delta h_e)_j^n + (\Delta h_e)_{j+1}^n\right] - S_{skv}^{*}\sum_{j=1}^{J-1}\left[(\Delta h_v)_j^n + (\Delta h_v)_{j+1}^n\right]\right\}$$

$$(\Delta h_e)_j^n = \left(h_{prec}\right)_j^n - h_j^n$$

$$(\Delta h_v)_j^n = \left(h_{prec}\right)_j^n - \left(h_{prec}\right)_j^0$$

h_j^n groundwater level at step n

$(h_{prec})_j^0$ initial maximum preconsolidation stress

$(h_{prec})_j^n$ preconsolidation stress

Results and discussion

Estimated parameters for one-dimensional compaction

Compaction data from 01/2003 to 06/2008

Layer (depth range)	Estimated parameters			
	K_z^* (m/y)	S_{skv}^* (1/m)	S_{ske}^* (1/m)	h_{prec}^0 (m)
Aquifer 2 (52–153 m)	3.12×10^{-03}	3.19×10^{-03}	4.07×10^{-04}	−5.626
Aquitard 2 (153–174 m)	5.29×10^{-04}	2.51×10^{-02}	3.13×10^{-03}	−1.261
Aquifer 3 (174–277 m)	6.20×10^{-04}	1.25×10^{-02}	4.28×10^{-04}	−2.047

Estimated parameters → time constant

Layer	Time constant (years)
Aquifer 2	238.3
Aquitard 2	5221.6
Aquifer 3	1106.3

Model validation and compaction prediction

Observation and model cumulative compaction

Layer	Obs. total compaction (cm)	Pred. total compaction (cm)	MAPE
Aquifer 2 (52–153 m)	−14.3	−15.0	8%
Aquitard 2 (153–174 m)	−6.6	−7.2	7%
Aquifer 3 (174–277 m)	−14.6	−14.6	5%

MAPE : mean absolute percentage error

Conclusions

- This paper used the compaction model to explain the observed land subsidence. The modeling fitted well with the observations.

- The main deformation in Dacheng caused by stratum compaction occurs in the vertical direction.

- Simulation of land subsidence based on four estimated hydrogeological parameters results in an average mean absolute percentage error below 10%, so the model can be used to predict future land subsidence.

- The water management agency of Taiwan can use this model to estimate land subsidence under various situations with confidence.

Future works

1. Researching the relation of geology-hydrology and applications

2. Building a compaction model

謝謝

Thank you