On characterizing hydrogeological properties of Choshuishi Alluvial Fan, Taiwan

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Why We Need Site Characterization?

- Characterizing the subsurface system is important to understand the processes of groundwater flow, solute transport or earthquake mechanism.
- The heterogeneity of geo-material may impact the possible detection of precursors. (Kumpel, 1992)
- Site characterization is equally important to construct physically-based model

Theory of Linear Poroelasticity: linear constitutive equations

$$\varepsilon = a_{11}\sigma + a_{12}p$$

$$\zeta = a_{21}\sigma + a_{22}p$$

$$a_{11} = \left.\frac{\delta\varepsilon}{\delta\sigma}\right|_{p=0} \equiv \frac{1}{K}$$

$$a_{12} = \left.\frac{\delta\varepsilon}{\delta p}\right|_{\sigma=0} \equiv \frac{1}{H}$$

$$a_{21} = \left.\frac{\delta\zeta}{\delta\sigma}\right|_{p=0} \equiv \frac{1}{H_1}$$

$$a_{22} = \left.\frac{\delta\zeta}{\delta p}\right|_{\sigma=0} \equiv \frac{1}{R}$$

Theory of Linear Poroelasticity: governing equations

Force equilibrium

$$G\nabla^2 u_i + \frac{G}{1-2\nu}\frac{\partial^2 u_k}{\partial x_i \partial x_j} = \alpha\frac{\partial p}{\partial x_i} - F_i$$

Fluid continuity

$$\frac{\alpha}{KB}[\frac{B}{3}\frac{\partial \sigma_{kk}}{\partial t} + \frac{\partial p}{\partial t}] - \frac{k}{\mu}\nabla^2 p = Q$$

Difficulties in using physically - based model

- Parameters may be **scale-dependent** and **process-dependent**.
- Parameters may be **inhomogeneous** in spatial domain and **nonstationary** in temporal domain

Variation of Material Properties

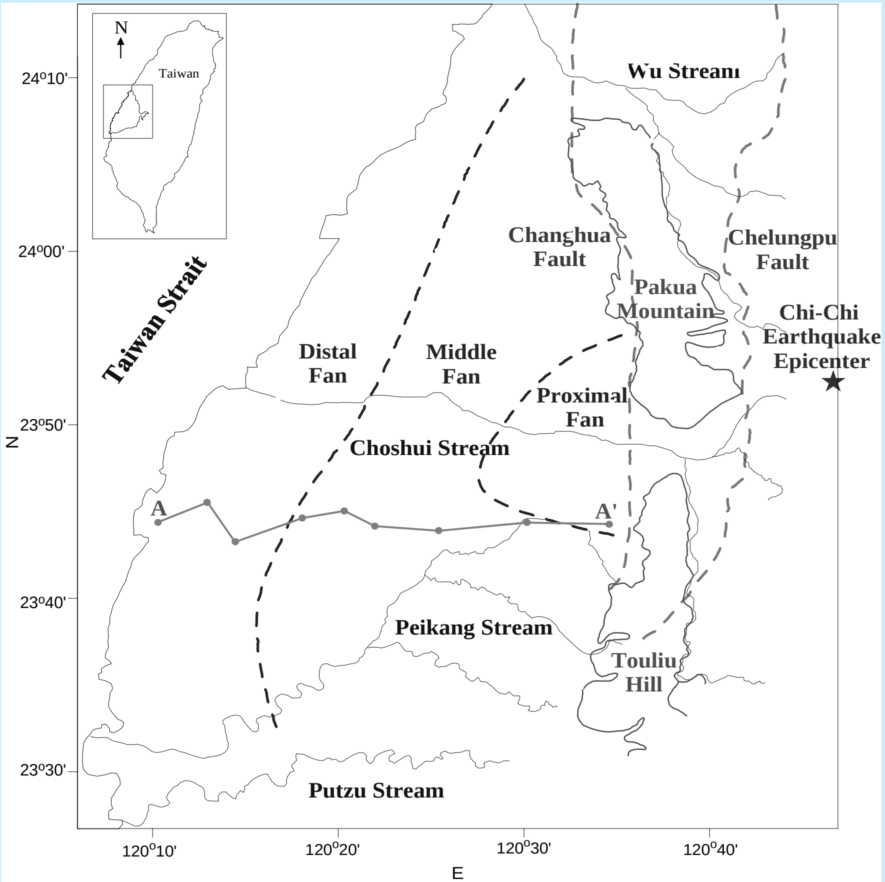
Material	*G* (GPa)	ν	ν_u	*K* (GPa)	*B*	α	*Ks* (GPa)	φ	*k* (mD)
Ruhr sandstone[1]	13	0.12	0.31	13	0.88	0.65	36	0.02	2.0×10^{-1}
Tennessee marble[1]	24	0.25	0.27	40	0.51	0.19	50	0.02	1.0×10^{-4}
Charcoal granite[1]	19	0.27	0.30	35	0.55	0.27	45	0.02	1.0×10^{-4}
Clay[2]	-	-	-	0.062	0.99	1	∞		
Clay[3]				0.001-0.1				0.34-0.6	10^{-3}-1
Sand[3]				0.01-1				0.26-0.53	10^{1}-10^{5}
Gravel[3]				0.1-10				0.25-0.38	10^{4}-10^{6}

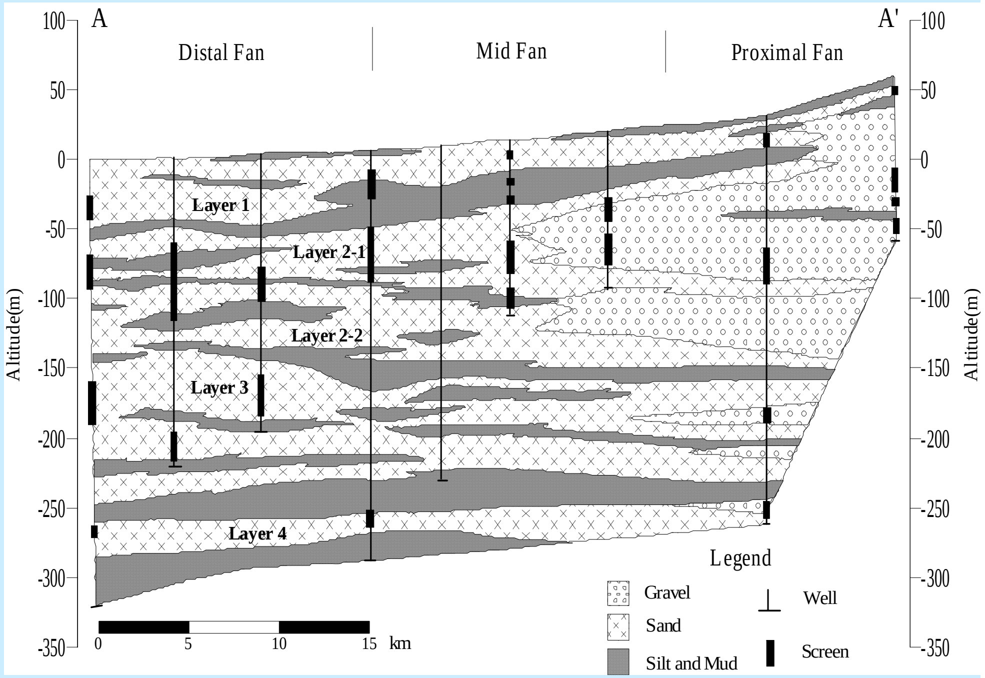
1: Detournay and Cheng (1993)

2: Domenico and Schwartz (1998)

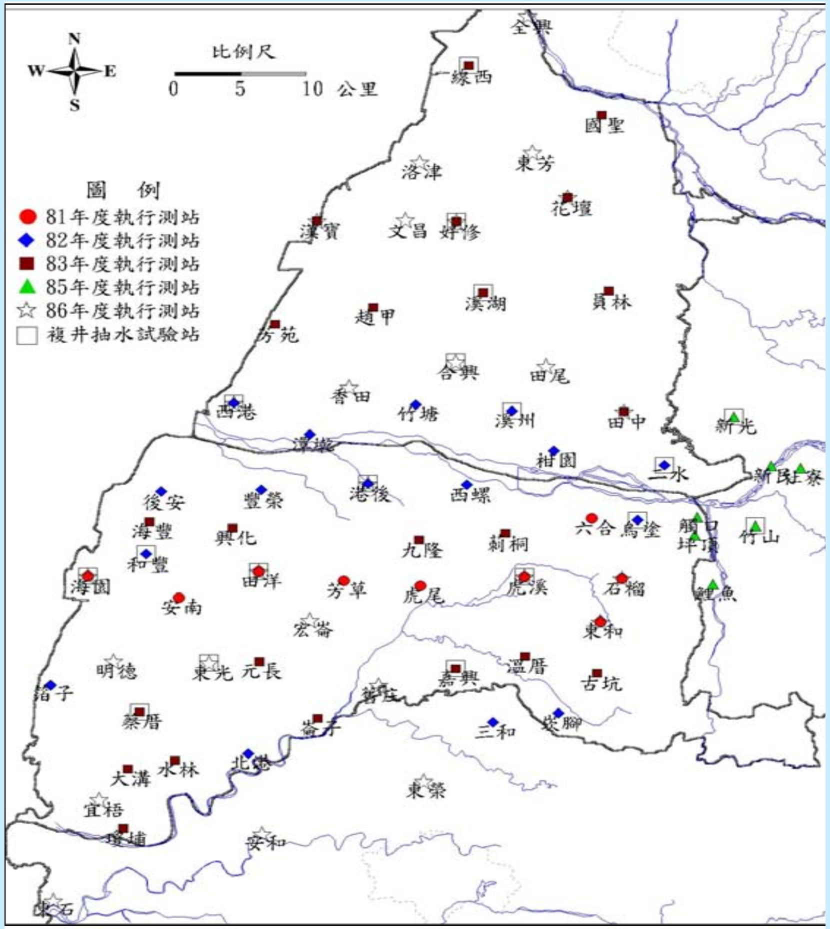
3: Zheng and Bennett (1995)

Choshuishi Alluvial Fan





Groundwater Monitoring System

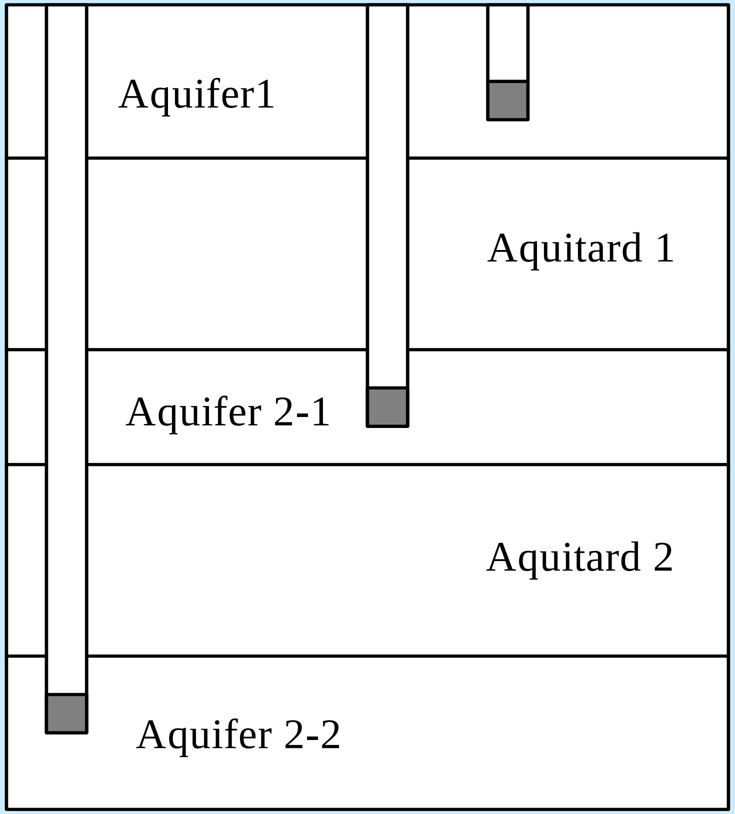


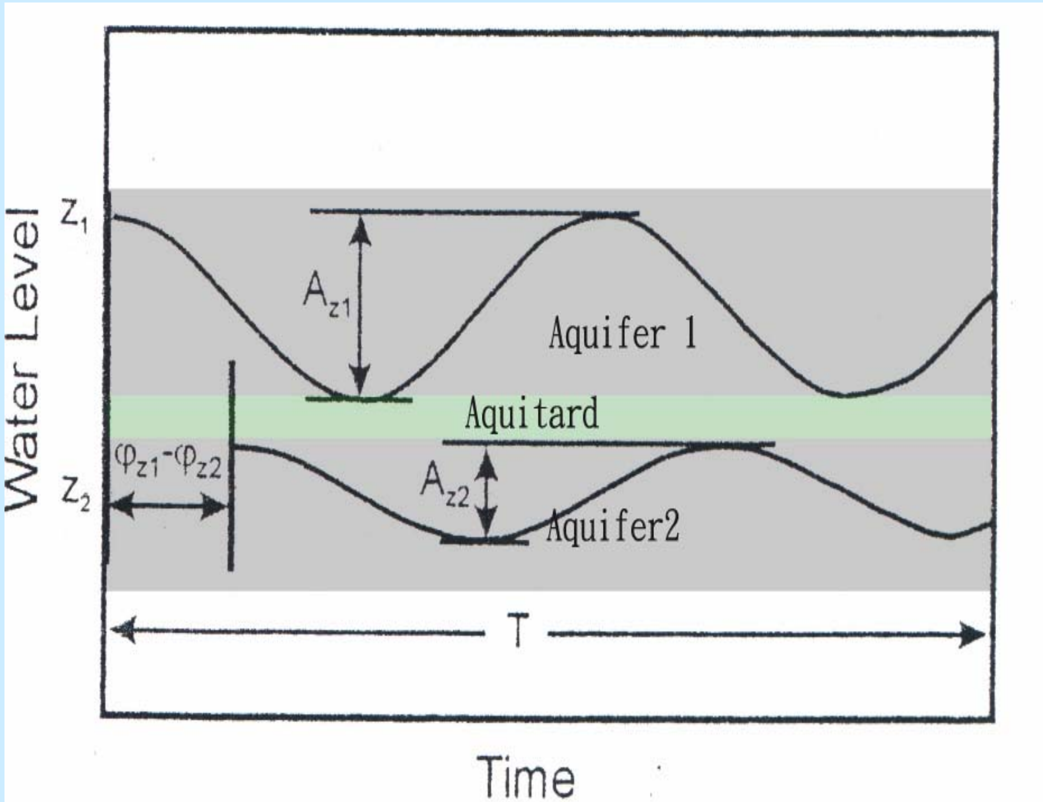
70 monitoring stations, 188 wells

Harmonic Analysis (1)

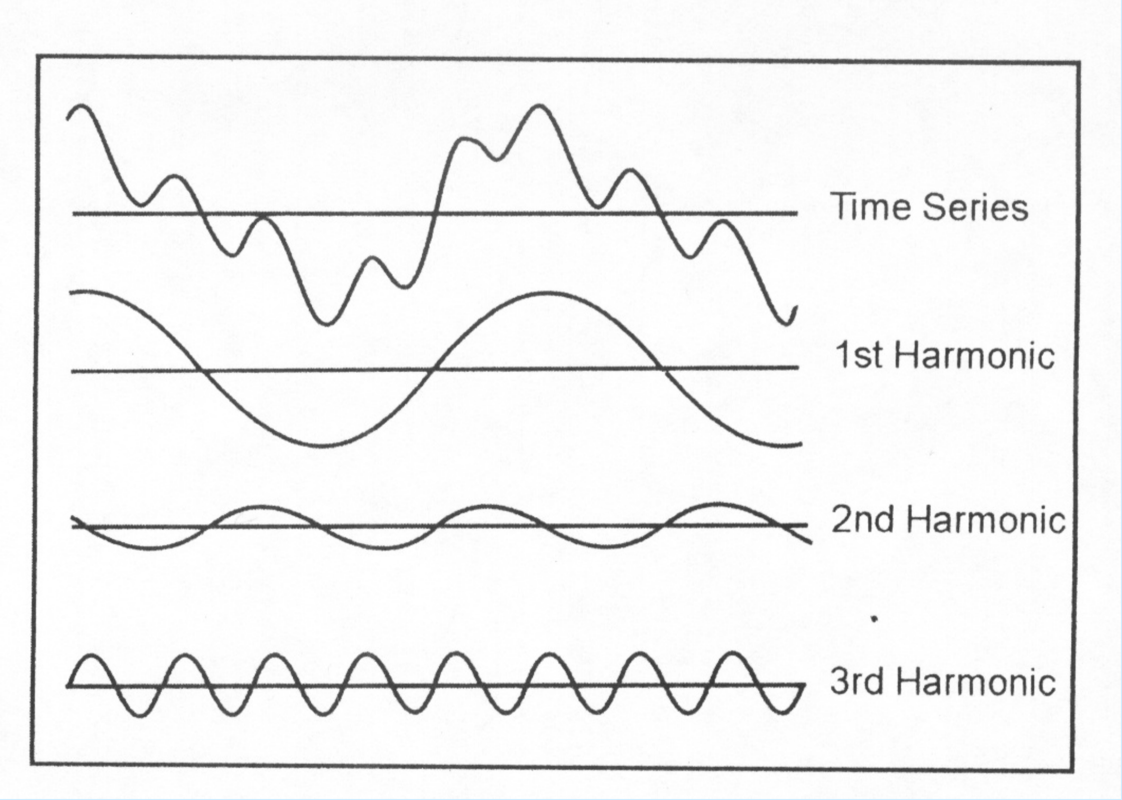
Aquifer information is abundant but aquitar data are rare!

How to estimate aquitar property ?





Harmonic Analysis (2)



$$f(t) = \sum_{k=0}^{\infty} A_k \sin(\omega_k t + \phi_k)$$

$$= \sum_{k=0}^{\infty} A_k \sin\phi_k \cos\omega_k t + A_k \cos\phi_k \sin\omega_k t$$

$$= \sum_{k=0}^{\infty} a_k \cos\omega_k t + b_k \sin\omega_k t$$

Estimating Diffusivity

For one-dimensional groundwater flow :

$$h(z,t) = Ae^{-z(1+i)\sqrt{\frac{\omega}{2D}}} e^{i(\omega t - \varepsilon)}$$

$$= Ae^{-\mathrm{k}z} e^{i(\omega t - \varepsilon - \mathrm{k}z)}$$

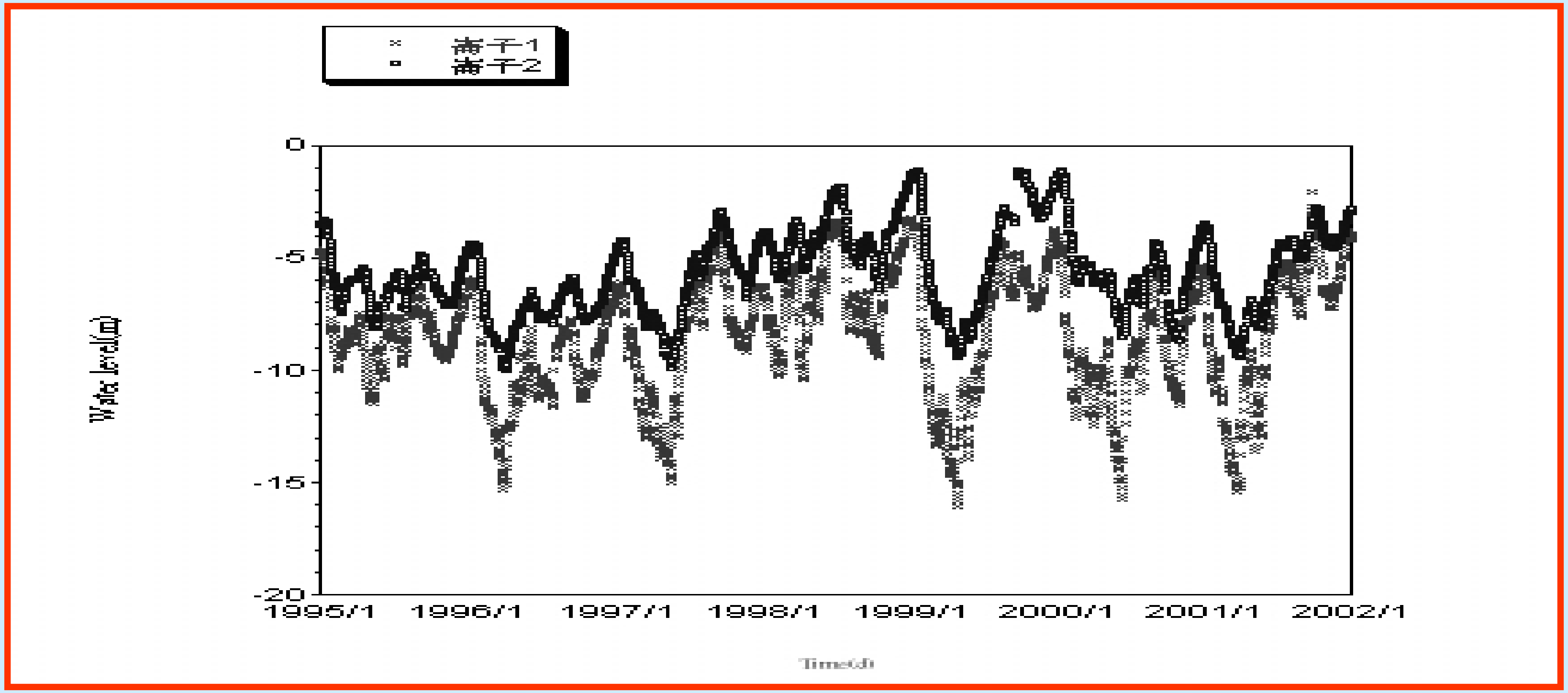
$$D = \frac{K}{S_s} = (\frac{\rho g k}{\mu}) / [\frac{\alpha}{KB}(\frac{1-\nu_u}{1+\nu_u})(\frac{1+\nu}{1-\nu})]$$

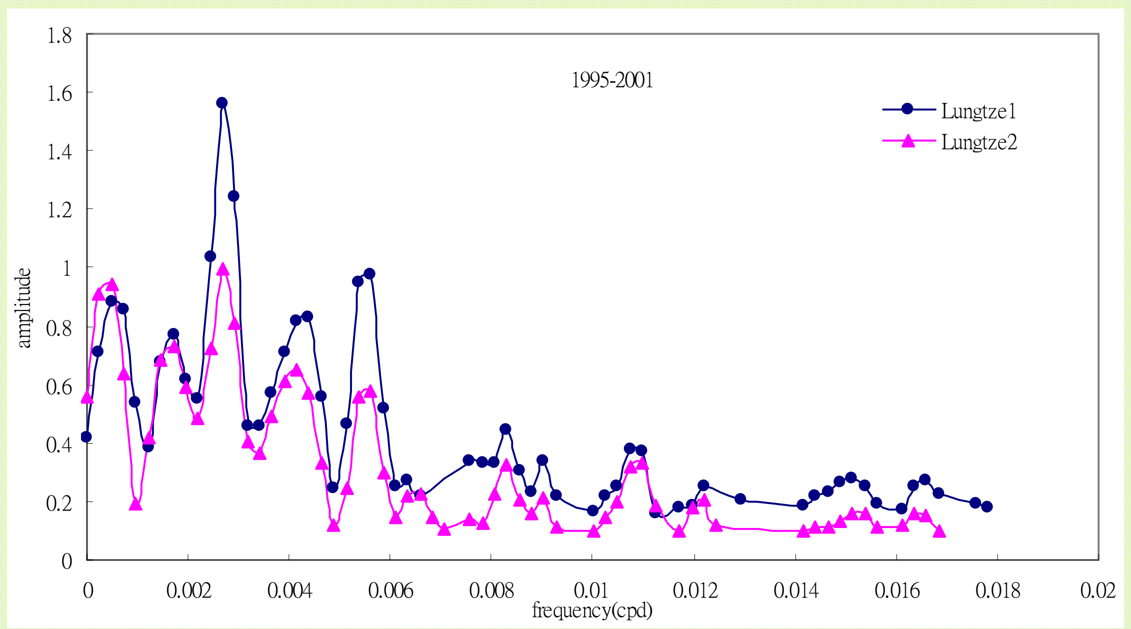
Based on amplitude :

$$D_1 = \frac{(z_2 - z_1)^2 \pi}{T}\left[\ln\left(\frac{A_{m_1}}{A_{m_2}}\right)\right]^{-2}$$

Based on phase shift :

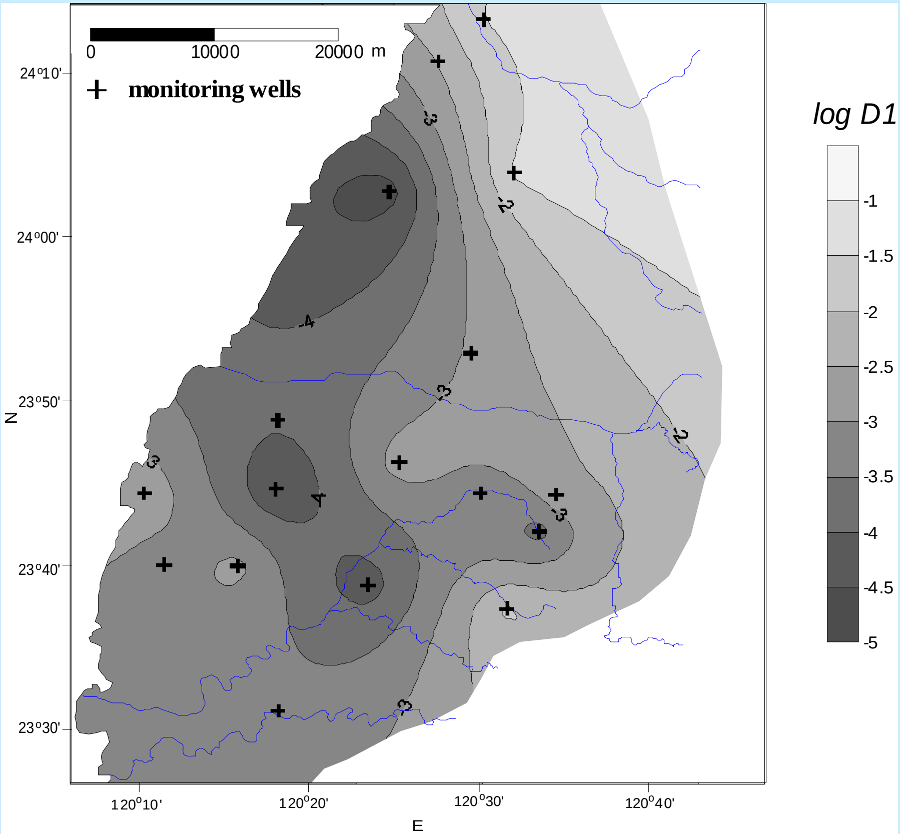
$$D_2 = \frac{\pi}{T}\left[\frac{(z_2 - z_1)}{(\phi_{z_1} - \phi_{z_2})}\right]^2$$



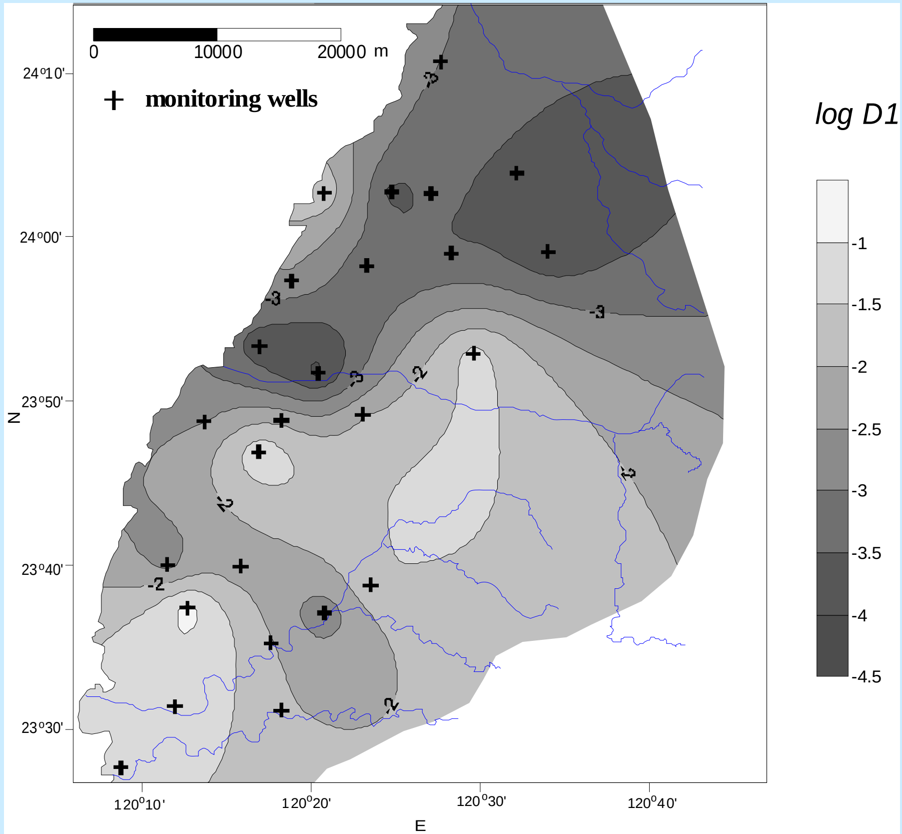


Period (day)	D_1(m²/s)	D_2(m²/s)
372	1.70E-03	2.54E-03
341	2.07E-03	2.18E-03
409	2.39E-03	2.67E-03
240	1.00E-02	1.38E-03
D_{av}	4.04E-03	2.19E-03

Result (1): Based on amplitude

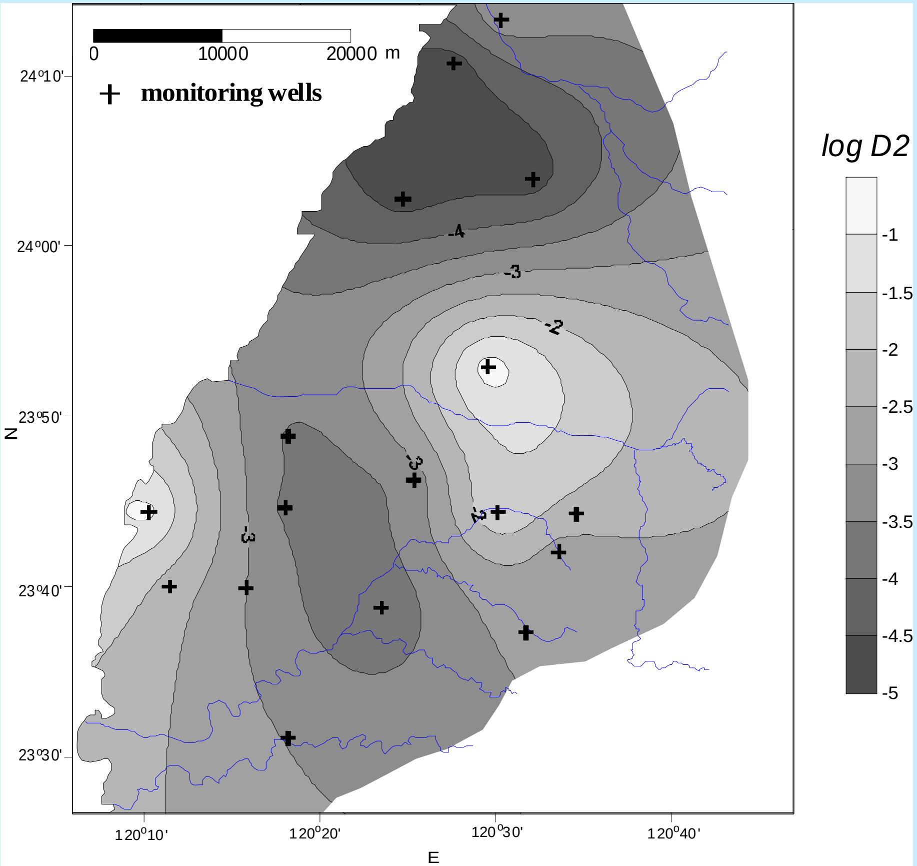


Diffusivity at Aquitar 1

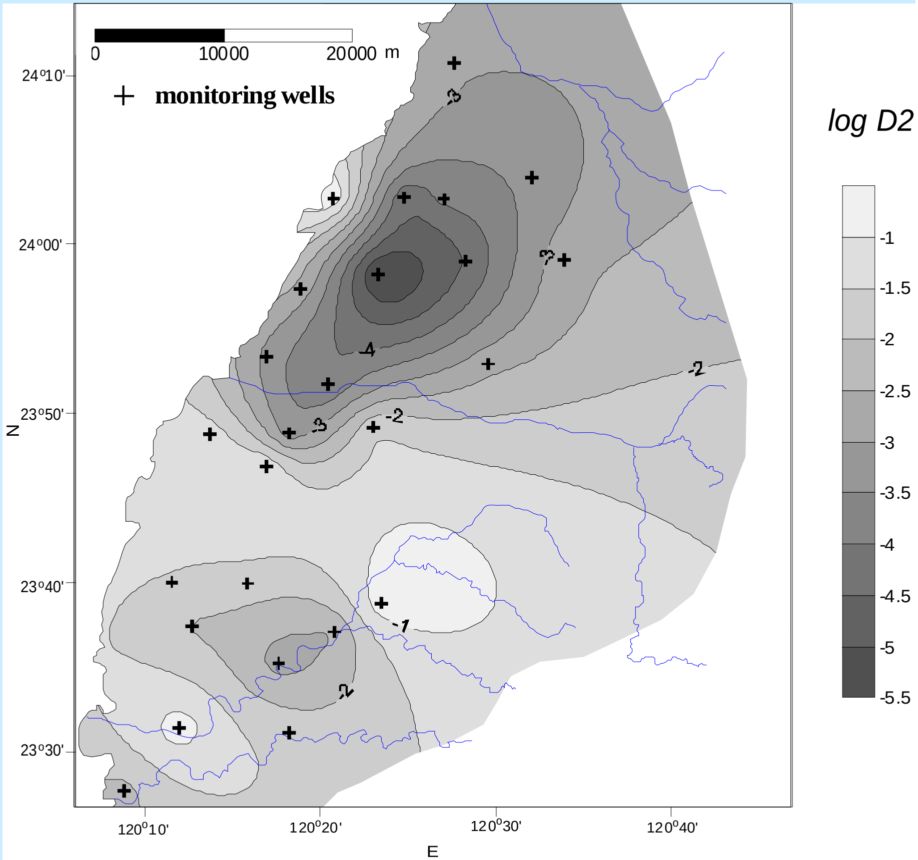


Diffusivity at Aquitar 2

Result (2): Based on phase shift

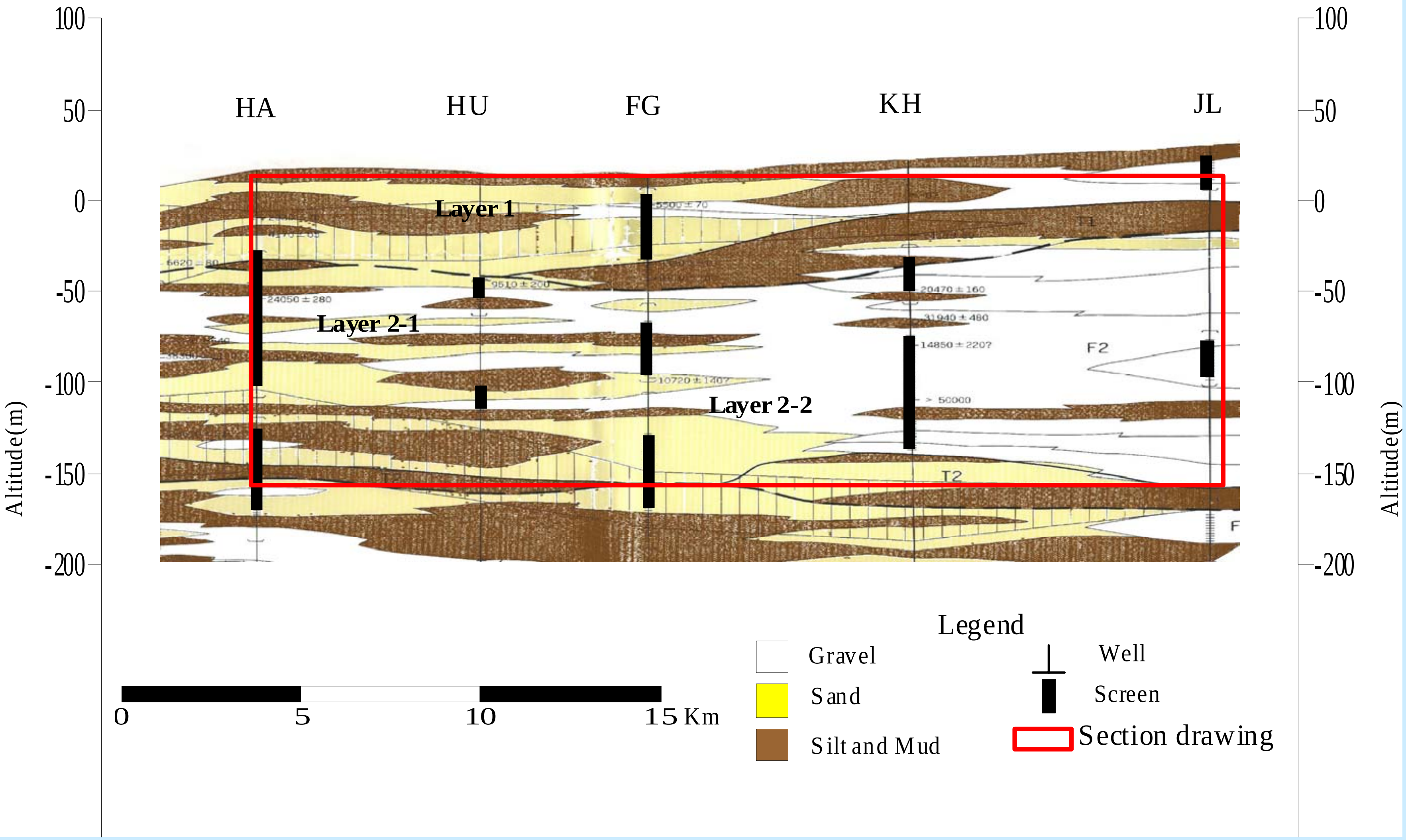


Diffusivity at Aquitar 1

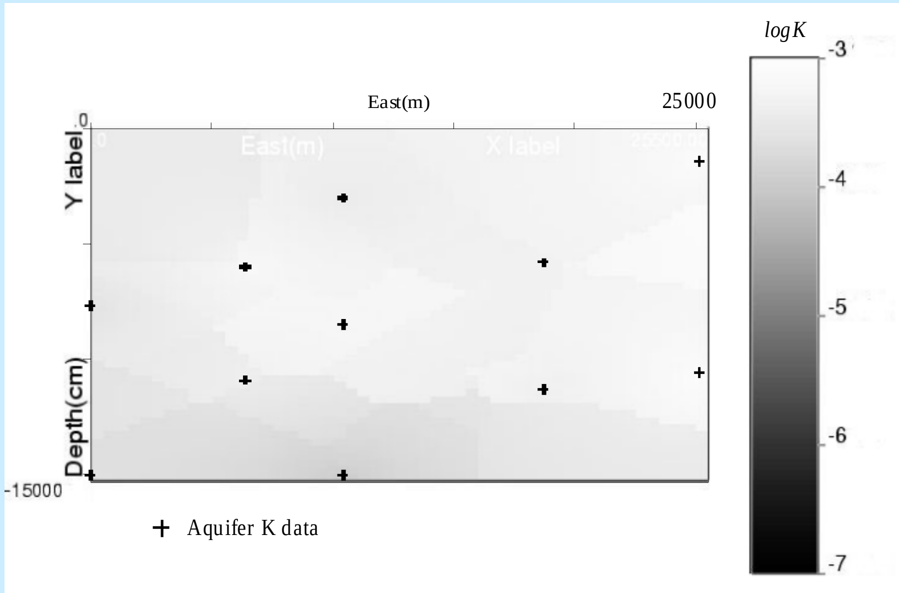


Diffusivity at Aquitar 2

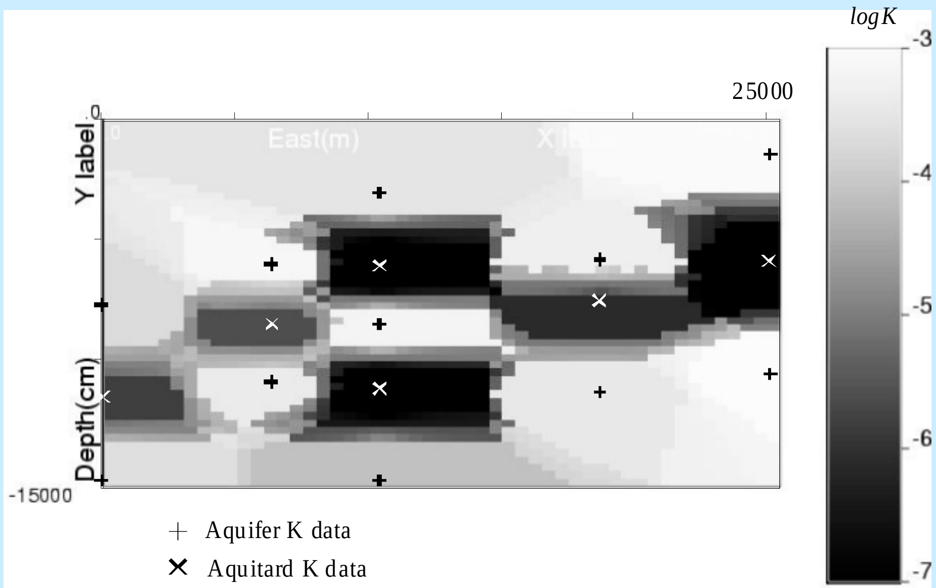
Result (3)


100
50
0
-50
-100
-150
-200
Altitude(m)
HA
HU
FG
KH
JL
Layer 1
Layer 2-1
Layer 2-2
F2
T2
0
5
10
15 Km
Legend
Gravel
Sand
Silt and Mud
Well
Screen
Section drawing

Result (4)



Only with aquifer data



With both aquifer and aquitar data

Conclusions

- Using natural forces as excitation to determine aquifer properties is **possible** and **economical**.
- The **spatial distribution** of aquitar property of the Choshuishi Alluvial Fan, Taiwan, was explored first time.
- **Without** aquitar properties, the constructed hydrogeological model may **mislead** the explanation of the processes of groundwater flow, solute transport or earthquake mechanism estimation.