Modeling water table drawdown and recovery during tunnel excavation in fractured rock (#78001)

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Abstract

A numerical model was created to simulate the perturbation of local groundwater systems by underground tunnel construction in Mount Mingtang, Anhui Province, China. Tunnels and other underground spaces act as conduits that remove water from the surrounding aquifer, and may lead to declines in water table elevation. These declines may have environmental impacts, including altering root zone soil moisture and changing inflows to surface waters. The main goals of this study are to predict tunnel inflows during construction and to model water table drawdown and recovery. The modeling approach focuses on managing uncertainty in parameters, since many are not known during the planning phase. The model is applied to a completed tunnel project in Mount Mingtang, China, where tunnel inflows were recorded during the construction process.

Introduction

Mount Mingtang is located in Southwestern Anhui Province between the cities of Hefei to the east and Wuhan in neighboring Hubei Province to the west. The study area has an area of approximately 183 km^2, and elevation ranging from about 206 to 1692 meters above sea level.

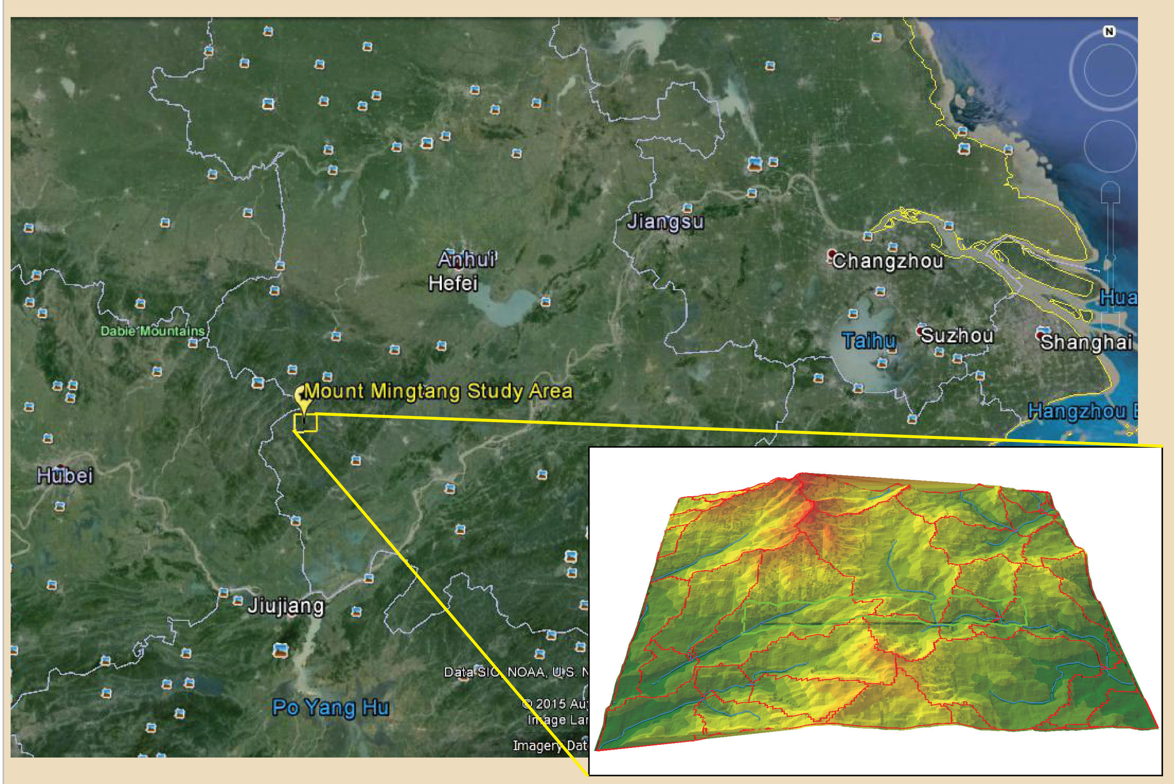

Fig 1: Mount Mingtang study area located in Southwest Anhui Province, China

Southern Anhui province has a subtropical, humid monsoonal climate:

- Temperature range: ~ -8˚to 41˚C
- Annual precipitation: 800-1,700 mm, the majority falling in the rainy season
- Ephemeral streams arise during the wet season

Land use:

- Forested with coniferous (primarily Pine) and broadleaf trees
- Some small-scale agricultural activities

Geology:

- Plutonic Felsic Granite and Gneiss, with varying degrees of weathering
- Three major fault structures, denoted by F6, F7, and F14

Mount Mingtang Tunnel:

- Total length: ~ 7 kilometers
- Tunnel depth: ~ 0 to 800 m

During excavation, several of the blasts released large volumes of pore water into the tunnel space, causing hazards and delays. In addition, it was noted that at least one groundwater extraction well and one stream in the area became dry. Unanticipated groundwater influxes and apparent environmental impacts motivate this study of tunnel-groundwater interactions.

Methods

The numerical model was constructed in ModelMuse for MODFLOW-2005 with the LPF flow package and PCGN solver.

The study area was divided into sub-regions delineated by topographic basin divides. A variably-discretized grid was used such that grid cells along the tunnel axis were fine (~0.1 m), while cells away from the tunnel were larger (~50 m) (Zaidel, Markham, & Bleiker, 2010).

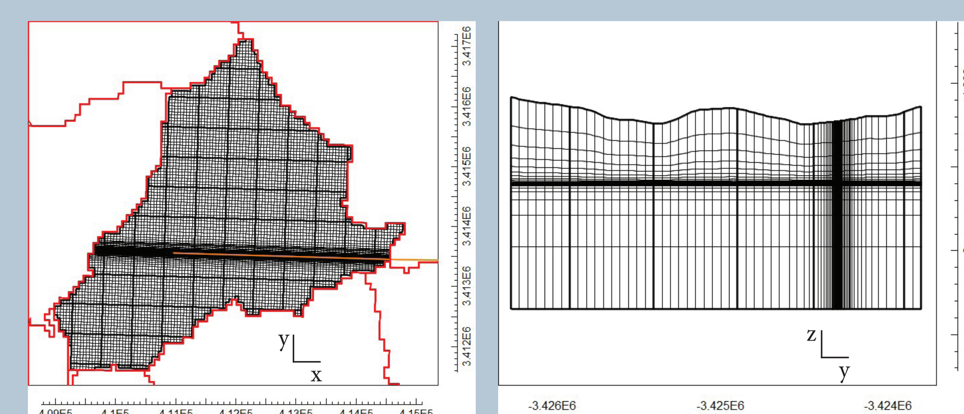

Fig 2: Left, top view of model grid. Right, cross-section view

Boundary conditions:

- No-flow basin divides
- Constant head boundaries at topographic lows on basin divides
- DRAIN boundaries representing ephemeral streams
- DRAIN boundary at tunnel wall with head equal to cell elevation
- Initial head from water table-topography regression on borehole data

Data sources:

- Geophysical surveys (seismic tomography, GPR) and boreholes
- Pumping tests
- GIS data (DEM, land cover, soil cover)
- Four nearby weather stations

Data integration:

- Basin divides delineated by topographic analysis of DEM in ArcMap
- Rock type variogram fitted using geophysical survey point clouds and boreholes
- Geophysical surveys and boreholes used in conditional indicator simulations to obtain rock type (Granite or Gneiss)
- Faults superimposed using strike and dip angles

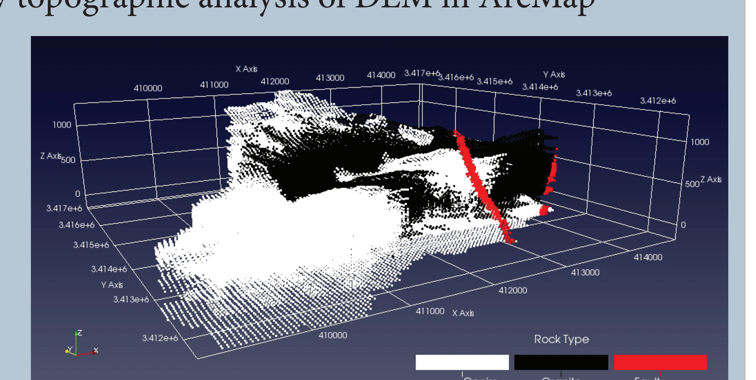

Fig 3: Rock type in the model domain from indicator kriging simulation

- Conductivities from a depth-conductivity relation, derived from regression on pumping tests in the study area, measurements in similar rock types from published studies, and other reports in China
- Recharge estimated using recorded weather data and infiltration coefficients from in-situ tests and comparable studies in the literature

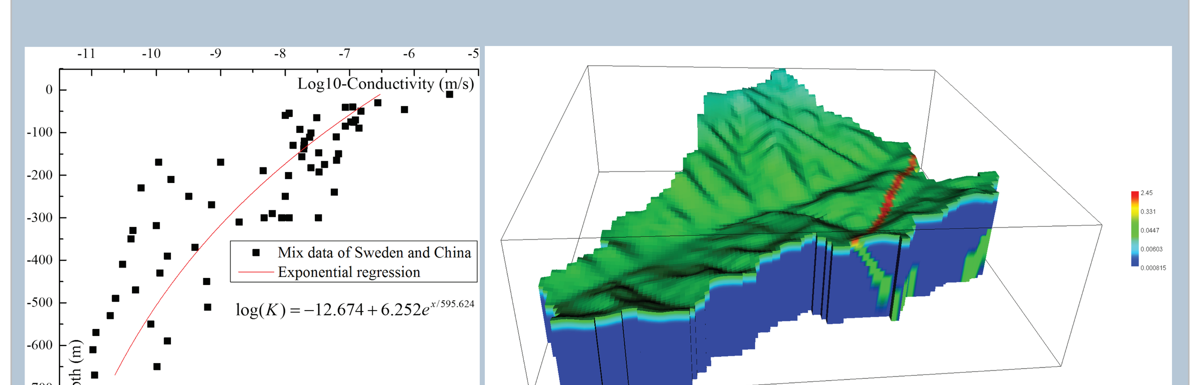

Fig 4: Left: depth-conductivity relation of Granites, from studies in Sweden and China. Right: depth-conductivity relation applied to the model domain

Results

Steady-state simulation

The tunnel partially penetrated the domain through fault F7.

Conductivity at the tunnel walls reflected conditions at the time of an inflow measurement taken during tunnel construction. Part of the tunnel was fully lined with low-permeability concrete. A section located in fault F7 was only partly lined (Fig. 5).

A uniform recharge rate of 10% of the mean daily rainfall was applied to the top model layer.

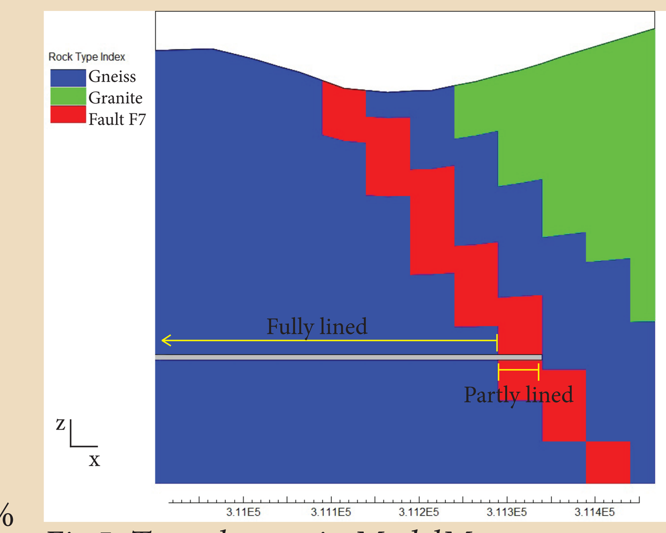

Fig 5: Tunnel setup in ModelMuse

Estimated tunnel inflows in the steady-state simulation

Tunnel section	Influx (m^3/d)	% of total
Partly lined (fault)	1050.766	63.9
Fully lined	594.5687	36.1
Total	1645.3347	-
Measured	*1500*	*9.7% relative error*

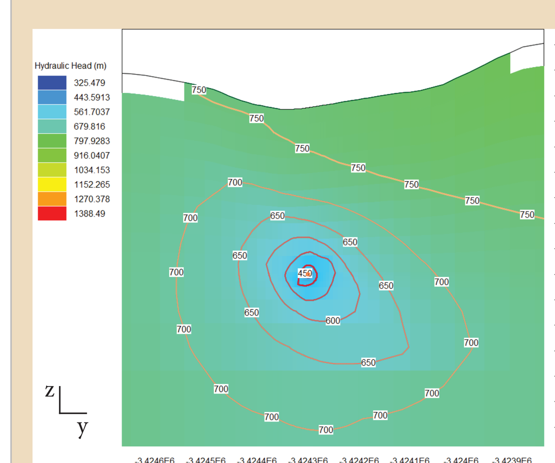

Fig 6: Cross-sectional head field around the tunnel in the fault zone

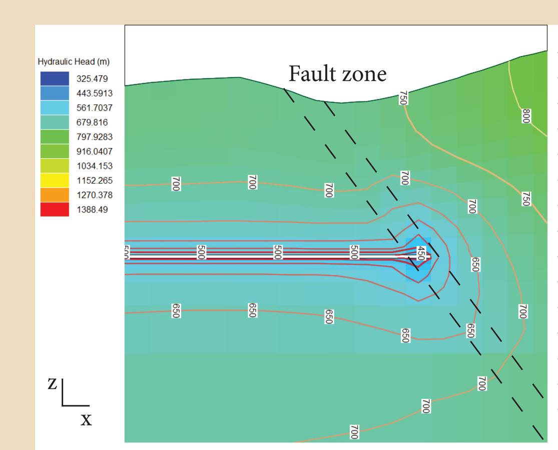

Fig 7: Longitudinal head field near the fault zone

Transient simulation

Tunnel inflows

A steady-state analysis with no tunnel feature was used as an initial condition for a transient simulation covering 60 days after tunnel construction.

From day 1 to day 30, the portion of the tunnel in the fault zone was partially lined with shotcrete and partially unlined (Fig. 5). At day 30 the entire tunnel (including the fault zone) was fully lined.

Uncertainty was explored by simulating with different values from parameter ranges. For instance, the model was run with a recharge equivalent to 10% of mean daily rainfall (Fig. 8) and with a recharge equivalent to 15% of mean daily rainfall (Fig. 9). The parameter ranges of rock and lining layer hydraulic properties were similarly explored and will be pursued further in future work.

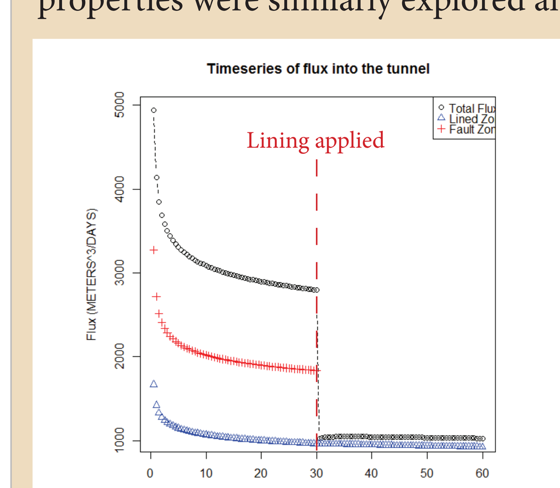

Fig 8: Tunnel inflow time series, 10% recharge coefficient

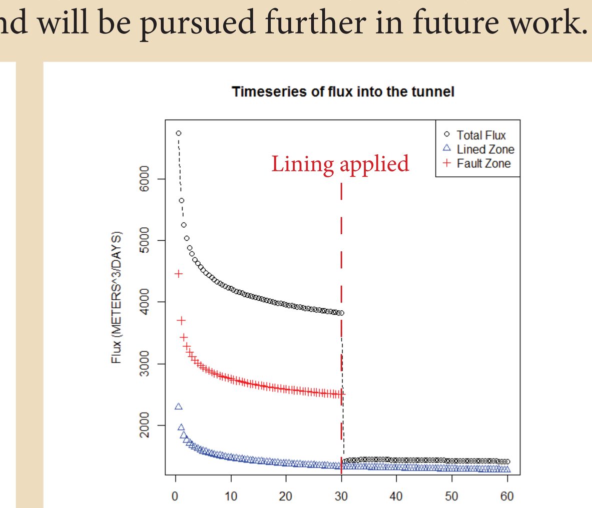

Fig 9: Tunnel inflow time series, 15% recharge coefficient

Results

Drawdown

The maximum rate of drawdown occured while the fault zone portion of the tunnel was partially lined. After full lining was applied there was a delay before drawdown began to peak and then to partially recover.

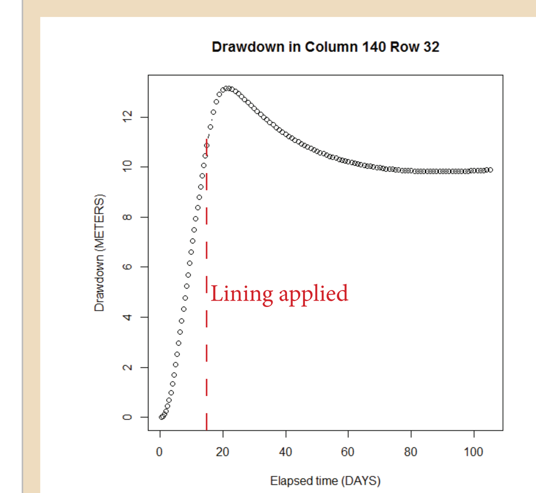

Fig 10: Drawdown at one top layer cell 10% recharge rate

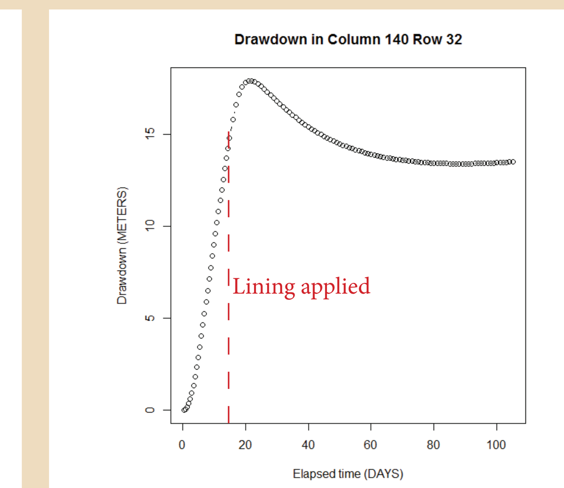

Fig 11: Drawdown at one top layer cell 15% recharge rate

Drawdown is concentrated near the fault zone and tunnel entrance (Fig 12).

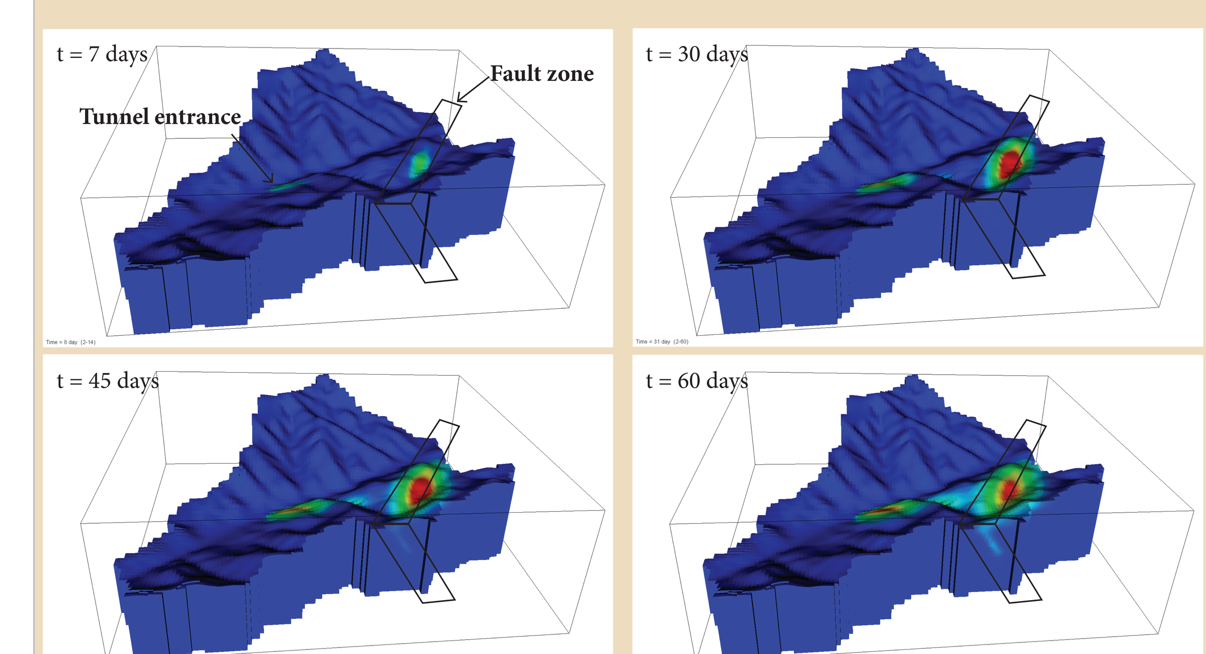

Fig 12: Drawdown with 10% recharge (blue: low, red: high)

Conclusions

Detailed MODFLOW models can be used to estimate tunnel inflows and drawdown after construction of underground spaces. They can be used to:

- Anticipate higher-than-normal groundwater inflows during construction
- Anticipate potential drawdown and recovery times in sensitive areas
- Test effects of uncertain parameters on estimated results

This work is the basis for future refinement of such models.

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