# Study of the Factors Governing Water Inflow into Deeply Buried Phosphate Deposits and Prediction of Water Inflow

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**Abstract:** Deeply buried phosphate deposits face complex hydrogeological conditions and water-inrush risk. For Deposit A, with the Dengying Formation aquifer as immediate roof and sharing the same orebody as surrounding mines, water-inflow factors are analyzed. Fracture height, river leakage, and aquifer-level responses to surrounding drainage are evaluated. Well-interference test theory predicts -650 m inflows under normal and shutdown conditions; results are compared with analytical and analogy methods and validated by actual data. The Dengying aquifer is the main direct source, easily affected by surrounding mining; surface water and precipitation leak via faults, while vertical recharge is minor. Well-interference theory yields smaller errors and is applicable for deep phosphate mine inflow prediction.
***Keywords:*** phosphate mine; water-inflow factors; water-inflow prediction

## 1. Introduction

Phosphate ore ranks second globally[1-3]. As mining deepens (1000-2000 m [4]-[9]), complex hazards[10] become hard to prevent[11], varying with depth, mining[12]-[13], and excavation-induced failure[14]. Research has overlooked deep phosphate mines with multi-mine extraction. This study at Guizhou's A mine, via surveys, monitoring, and boreholes, identifies precipitation, surface water, and aquifers as main sources. The three-zone theory is applied; river ($H_1$–$H_3$) and borehole (K0603/K0305) data show correlations with nearby drainage. Well-interference theory predicts −650 m inflows for normal and shutdown conditions, guiding deep-mine water-hazard control.

## 2. Regional Hydrogeological Overview

In the eastern Yunnan–Guizhou Plateau, a gently dipping phosphatic sequence hosts Deposit A (1400-1750 m) within the same orebody as adjacent mines. NNE/NEE faults and Yangshui-anticline karst form low–middle mountains (1223.5-970 m). A temperate-subtropical climate brings a May-Oct rainy season (mean 1194.8 mm). Surface water: Yangshui (47,803-225,438) and Laobao (4,838-17,574 m³/d) rivers; two reverse faults divide the orebody (Blocks I-III). Karst groundwater dominates. Exposed strata: ∈3, Quaternary. Drilling reveals, downward, Shilengshui-Gaotai, Qingxudong-Jindingshan-Mingxinsi aquifer, >600 m Niutitang aquiclude, Dengying roof aquifer, Yangshui floor, Nantuo Formation.

## 3. Analysis of Water-Inflow Factors for the Deposit

### 3.1 Atmospheric Precipitation

Field investigations show the rainy season is May–October (low precipitation October–April) with a multi-year average of 1194.8 mm. The caving zone[15] and water-conducting fractured zone[16] heights are calculated using the 'three-zone' method from the Regulations for Coal Pillars under Pressure: Eq. (1) for dip <55°, and Eq. (2) for gently inclined orebodies with hard overburden.

$$H_m = \frac{100\sum M}{2.1\sum M + 16} \pm 2.5 \tag{1}$$

$$H_c = \frac{100M}{1.2M + 2.0} \pm 8.9 \tag{2}$$

$H_m$ and $H_c$ denote caving and fractured zone heights. Eq. (2) yields $H_c$ = 36.55–54.35 m and $H_m$ = 35.47–40.47 m, with a combined influence of 72.02–94.82 m. These pathways are blocked by the >600 m Niutitang aquiclude, so vertical recharge is largely intercepted; unsealed boreholes may still act as paths. Thus, atmospheric precipitation is an indirect source.

### 3.2 Surface Water System

Based on the 2022 long-term $H_1$ data, the perennial precipitation-fed river was monitored at the Dengying Formation entrance ($H_1$), exit ($H_3$), and a tributary confluence ($H_2$). Discharge at $H_1$ ranged from 47,803 to 225,438 m³/d (variation coefficient 4.72), while river leakage averaged 38,275 m³/d (range 17,206–62,092 m³/d), with an average leakage intensity of 10.34 m³/(d·m).

2023 data show surrounding mine drainage ranging from 32,438 to 68,198 m³/d, with a variation coefficient of 1.78.

As a precipitation-controlled river, leakage through karst fissures enters surrounding mines, raising drainage. Though the mine is 5 km away, intercepted leakage indirectly recharges the deposit, requiring consideration in inflow prediction and hazard control.

### 3.3 Aquifers

(1) Unconfined aquifer. The Qingxudong–Loushanguan aquifer (~561.57 m) is compared with caving/fracture heights (Section 3.1); no direct inflow is possible, so mining impact is minor.

(2) The Dengying Formation aquifer (immediate roof, main water-filling) lies at –8.95 to –612.50 m (mostly <–300 m). Subsurface karst (solution pores/fissures) is developed. Inflow is mainly roof dripping, stream-like in structural zones. Boreholes monitored: K0603 fluctuates within 0.70 m (231.71–232.41 m), 2023 ~5.5 m above 2022 (stable); K0305 declines ~6 m in 2023 (max var ~2.03 m). Jan–Mar 2024: K0603 stable; K0305 declines 8.84 m avg from 2023, small fluctuations.

Levels are directly affected by surrounding mining. The deeply buried Dengying Formation is the main karst zone, with common solution pores, vugs, and local fissures.

## 4. Mine Water Inflow Prediction

### 4.1 Water-Inflow Prediction by Well-Interference Theory

Well-interference test theory, from petroleum engineering, describes pressure interactions among wells. The Petrosky formula handles multi-well pressure response and interference, solving pressure variation in homogeneous, isotropic, infinite formations (Eq. 3).

$$P_i = P_{avg} + \sum_{j=1}^{n} \frac{Q_j}{4\pi T} \cdot \ln\left(\frac{u_i \cdot r_{ij}^2}{u_j \cdot r_{ji}^2}\right) \tag{3}$$

Where $P_i$ is water head at point i; Pavg is background natural head; $Q_j$ is pumping rate of well *j*; *T* is transmissivity (product of K and H); $u_i$ and $u_j$ are correction factors; $r_{ij}$ is distance from well *j* to point *i*, and $r_{ji}$ is the distance from point *i* to well *j*.

Using the Petrosky formula (pressure change proportional to other flow rates and inversely proportional to distance), water inflow for multi-well systems in Mine A's unit under production/injection is predicted (Table 1). By well-interference theory, normal/max inflows are 26,026.98/36,328.02 m³/d; worst-case: 49,451.26/53,084.65 m³/d.

**Table 1. Prediction results of mine water inflow**

| Reference elevation(m) | Operating Conditions | Well-interference test theory($m^3$/d) | |
|---|---|---|---|
| | | Normal inflows | Max inflows |
| -650 | worst conditions | 49451.26 | 53084.65 |
| | normal condition | 26026.98 | 36328.02 |

### 4.2 Comparison of Analytical and Analogy Methods

(1) Analytical method model.

The thick water-filling aquifer is treated as a confined system. A groundwater inflow formula for flow to a well near an impervious boundary is established (Eqs. 4-7).

$$s_1 = \frac{0.366Q}{kM} \lg \frac{R}{r_0} \tag{4}$$

$$s_2 = \frac{0.366Q}{kM} \lg \frac{r'}{r_0} \tag{5}$$

$$S = s_1 + s_2 = \frac{0.366Q}{kM} (\lg \frac{R}{r_0} + \lg \frac{r'}{r_0}) \tag{6}$$

$$Q = 2.73KMS \frac{1}{\lg \frac{R}{r_0} + \lg \frac{r'}{r_0}} \tag{7}$$

Where $Q$ is mine drainage discharge (m³/d); $s_1$ and $s_2$ are drawdowns (m) from the actual and image pumping wells; $S$ is the interference drawdown (m); $M$ is aquifer thickness (m); $r_0$ and $R$ are the reference and influence radii of the large-diameter well (m); and $r'$ is the distance between the centers of the actual and image wells (m).

(2) Calculation formula of the analogy method.

The orebodies, roof aquifer, mining method, and water-filling mode are similar to adjacent mines. The analogy method can be used for prediction, as shown in Eq. (8).

$$Q_2 = \frac{Q_1}{m\sqrt{\frac{F_1}{F_2}} \times n\sqrt{\frac{S_1}{S_2}}} \tag{8}$$

where $Q_1$ and $Q_2$ are the water inflows (m³/d) of old and new mines; $F_1$ and $F_2$ are their mining areas (m²); $S_1$ and $S_2$ are water-level drawdowns (m); and $m$, n are empirical constants (4 and 2, respectively) based on local aquifers.

The results of the calculations are presented in Table 2. Under normal drainage, the normal inflows are 19,172.53 and 20,047.42 m³/d, and the maximum inflows are 36,489.66 and 38,154.76 m³/d, by the analytical and analogy methods, respectively; these values are close. Under the most unfavorable conditions, normal inflows are 37,726.59 and 40,548.8 m³/d, and maximum inflows are 67,153.33 and 58,129.75 m³/d, respectively.

**Table 2. Prediction results of mine water inflow**

| Reference elevation(m) | Operating Conditions | Analytical method(m3/d) | | Analogy method(m³/d) | |
|---|---|---|---|---|---|
| | | Normal inflows | Max inflows | Normal inflows | Max inflows |
| -650 | Worst conditions | 37726.59 | 67153.33 | 40548.8 | 58129.75 |
| | Normal condition | 19172.53 | 36489.66 | 20047.42 | 38154.76 |

## 4.3 Verification and Analysis of Results

The three methods are applied to surrounding operating mines to calculate the water inflow of Mine A at the −650 m level, as shown in Table 3.

**Table 3. Comparison and error rate of mine water inflow prediction results**

| Method | Adjacent mine | | | | | | A mine | |
|---|---|---|---|---|---|---|---|---|
| | Predicted inflows (m³/d) | | Actual inflow (m³/d) | | Error rate (%) | | Predicted inflows(m³/d) | |
| | Normal Inflows | Max Inflows | Normal Inflows | Max Inflows | Normal Inflows | Max Inflows | Normal Inflows | Max Inflows |
| Analytical Method | 52702.45 | 70811.97 | 61000 | 89000 | 14.61 | 20.44 | 37726.59 | 47153.33 |
| Analogy Method | 56034.49 | 89888.36 | | | 8.14 | 0.10 | 40548.8 | 58129.75 |
| Well -interference Test theory | 64619.17 | 88851.36 | | | 5.93 | 0.17 | 49451.26 | 53084.65 |

Normal inflow errors: analytical 14.61%, analogy 8.14%, well-interference 5.93%; maximum: 20.44%, 0.10%, 0.17%. Similar results confirm reasonable generalization. Analytical yields lower values (data limits); analogy (adjacent drainage) is realistic; well-interference considers disturbance, matches analogy. Both methods suit deep phosphate multi-mine mining.

## 5. Conclusions

Deposit A, buried at 1400–1750 m, has the Dengying aquifer as main water source/hazard. Surface water and precipitation leak through fractured fault zones, key inrush-prevention areas. Vertical precipitation infiltration and unconfined seepage have minor effects. Well-interference theory with analytical and analogy methods predicts −650 m normal/maximum inflows of 26,026.98 and 36,328.02 $m^3/d$. Comparison confirms reasonable generalization/parameters, providing scientific basis for water hazard control.

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