

HYDROLOGICAL EFFECTS OF FARMLAND DRAINAGE IN THE HUAIBEI PLAIN: AN EXPERIMENTAL STUDY

EFFETS HYDROLOGIQUES DU DRAINAGE AGRICOLE SUR LA PLAINE DE HUAIBEI : UNE ÉTUDE EXPÉRIMENTALE

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ABSTRACT

The Huaibei Plain is a typical area frequently affected by drought and waterlogging in China. As key engineering infrastructure, farmland drainage systems play a vital role in regulating regional hydrological processes and safeguarding stable agricultural production. Combining long-term field monitoring data from 1963 to 2024 and investigations at 20 representative drainage experimental sites across the Huaibei Plain, this study systematically evaluates the impacts of farmland drainage works on groundwater dynamics, soil water recession and regional hydrological characteristics through zonal experiments and comparative analysis. The effective influence range of drainage ditches on groundwater, the applicability of diverse drainage standards, and regional differentiated layouts of ditch networks are quantitatively clarified.

The results reveal that the unilateral influence scope of drainage ditches on the water table extends beyond 250 m, with the most remarkable variations in groundwater hydraulic gradients occurring within this distance. The current drainage system complies with the requirement for 5-year return period storms, which requires the water table to drop to 0.5 m below ground surface within four to five days. However, farmlands in the central-southern part are exposed to prominent waterlogging hazards when encountering extreme storms with a return period of 10 years or longer. Three dominant drainage layout patterns have been established locally, namely deep-sparse, shallow-dense, and deep moisture-conserving furrow composite, corresponding to earthwork volumes of approximately 100,000 m³/km², 60,000 m³/km² and 55,000 m³/km².

Accordingly, differentiated ditch network designs are put forward: the central-southern region adopts the three-ditch waterlogging control plus field ditch subsurface control (3-waterlogging-2-subsurface) pattern, whereas the northern region employs the 3-waterlogging-1-subsurface pattern with integrated drainage and storage functions. This study's conclusions can provide theoretical basis and practical engineering guidance for optimizing farmland drainage systems, implementing integrated waterlogging management, and promoting the sustainable use of water and soil resources in the Huaibei Plain.

Keywords: Huaibei Plain; farmland drainage; waterlogging and subsurface control; groundwater recession; ditch network layout.

RESUME

La plaine de Huaibei est une région typique fréquemment touchée par la sécheresse et l'engorgement des sols en Chine. En tant qu'infrastructure d'ingénierie clé, les systèmes de drainage agricole jouent un rôle essentiel dans la régulation des processus hydrologiques régionaux et dans la préservation d'une production agricole stable. En combinant des données de surveillance de terrain à long terme

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recueillies de 1963 à 2024 et des enquêtes menées sur 20 sites expérimentaux représentatifs du drainage dans la plaine de Huaibei, cette étude évalue systématiquement les impacts des travaux de drainage agricole sur la dynamique des eaux souterraines, la décrue de la teneur en eau du sol et les caractéristiques hydrologiques régionales grâce à des expériences zonales et une analyse comparative. L'étude précise quantitativement la portée effective de l'influence des fossés de drainage sur les eaux souterraines, l'applicabilité de diverses normes de drainage et les plans différenciés des réseaux de fossés à l'échelle régionale. Les résultats révèlent que la portée de l'influence unilatérale des fossés sur la surface de la nappe phréatique s'étend au-delà de 250 m, avec les variations les plus remarquables des gradients hydrauliques des eaux souterraines se produisant à cette distance. Le système de drainage actuel est conforme à l'exigence relative aux tempêtes avec une période de retour de 5 ans, exigeant la descente de la nappe phréatique à 0,5 m sous la surface du sol en délai de quatre à cinq jours. Cependant, les terres agricoles de la partie centrale méridionale sont exposées à des risques importants d'engorgement lorsqu'elles rencontrent des tempêtes extrêmes avec une période de retour de 10 ans ou plus. Trois plans de drainage dominants ont été établis localement, à savoir un composite de sillons «profond et clairsemés», «peu profonds et denses», et «profonds et conservant l'humidité», correspondant à des volumes de terrassement d'environ 100 000 m³/km², 60 000 m³/km² et 55 000 m³/km². En conséquence, des conceptions de réseaux de fossés différenciées sont mises en avant : la région centrale méridionale adopte le modèle de contrôle de l'engorgement dans les trois fossés ainsi que celui du contrôle souterrain des fossés de terrain (3-engorgement-2-souterrain), tandis que la région du nord utilise le modèle de 3-engorgement-1-souterrain avec des fonctions intégrées de drainage et de stockage. Les conclusions de cette étude peuvent fournir une base théorique et des conseils d'ingénierie pratique pour optimiser les systèmes de drainage agricole, mettre en œuvre une gestion intégrée de l'engorgement et promouvoir l'utilisation durable des ressources en eau et en sol dans la plaine de Huaibei.

Mots-clés : Plaine de Huaibei; Drainage agricole; Contrôle de l'engorgement et du niveau souterrain; décrue de la surface de la nappe phréatique; Plan du réseau de fossés.

1 Introduction

The Huaibei Plain constitutes the core grain production zone of the Huang-Huai-Hai Plain and plays a vital role in national food security (Yu et al., 2026). Driven by climate change and human activities, precipitation has become more uneven in time and space, and extreme heavy rainfall events have occurred more frequently. Coupled with intensive farming and variations in underlying surface properties, waterlogging has evolved into a critical bottleneck limiting crop yield stability and sustainable rural development (Zhao et al., 2021; Jing et al., 2012).

Since the 1960s, large-scale farmland drainage infrastructures have been built throughout the Huaibei Plain, forming an integrated drainage network composed of regional main canals and field ditches (Jing et al., 2009). Nevertheless, drainage works substantially modify rainfall infiltration, surface runoff generation, soil water migration and groundwater recharge-discharge processes, and consequently reshape regional water balance and hydrological cycles (Dialameh et al., 2025; Youssef et al., 2021; Kong et al., 2013). A large body of research has focused on the hydrological impacts of drainage in this region. Some studies have clarified how main ditches regulate runoff and groundwater regimes (Wang et al., 2025; Wang et al., 2013; Zhao et al., 2005); others have quantified the performance of various drainage standards in controlling flood volume and peak discharge, and developed regional hydrological models for waterlogging mitigation (Malakshahi et al., 2020; Wen et al., 2008). While previous work has offered useful insights, notable deficiencies remain. Most studies rely on short-term monitoring or single-scale observations, lacking systematic integration of long-term, multi-site and cross-regional data. The effective influence range and attenuation characteristics of drainage ditches on groundwater have not been quantitatively defined, and there are no standardized zoning layouts for ditch networks, which leads to insufficient scientific basis for engineering design and planning.

Given the remarkable north-south disparities in hydrogeology, topography and waterlogging features across the Huaibei Plain, this study uses 61 years of continuous measured data on hydrology, soil moisture and water table. It systematically analyzes the scope and intensity of farmland drainage effects

on groundwater dynamics, assesses the waterlogging control capability of existing drainage systems under storms of different return periods, compares the earthwork volume and overall benefits of alternative drainage patterns, and puts forward differentiated zoning schemes for ditch networks in the northern and southern areas. The findings provide a solid basis for the renovation of farmland drainage projects, waterlogging prevention and water resources regulation in the Huaibei Plain.

2 Materials and Methods

2.1 Study Area

The Huaibei Plain is located in northern Anhui Province, bordering Jiangsu, Henan, and Shandong Provinces, with a total area of 37,400 km². According to the China Statistical Yearbook 2022, its grain sown area and total output account for approximately 50% of Anhui Province. The region has a warm temperate semi-humid monsoon climate with distinct seasons, abundant sunlight, mean annual temperature of 14–15°C, m

Waterlogging in the Huaibei Plain is characterized by large vulnerable areas, high frequency, and strong spatiotemporal concentration: waterlogging-prone farmland accounts for 83.1% of Anhui Province, and the average annual affected area is 25% of provincial farmland. Disasters concentrate in the flood season (June–September), peaking in July–August, with low non-flood season risk. Spatially, central-southern areas face high waterlogging risk, while northern areas are relatively mild, providing natural experimental conditions for zonal drainage layout research. The study area and 20 experimental sites are shown in Figure 1.

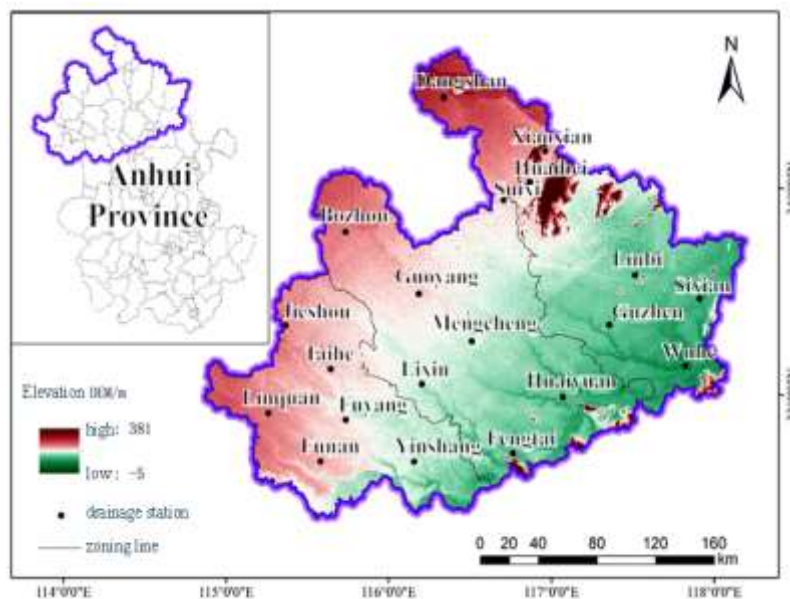


Figure 1. Overview of the study area and site locations

2.2 Experimental Design

Since 1963, continuous field investigations of farmland drainage have been conducted across the Huaibei Plain, with 20 experimental sites established in Guzhen (Bengbu), Mengcheng (Bozhou), and Xiaoxian (Suzhou), covering diverse landforms, hydrogeology, and agricultural zones (Figure 1).

At each site, soil moisture monitoring points are installed in typical fields to track root-zone soil moisture dynamics. Multiple water table observation wells are set perpendicular to representative drainage ditches at gradient distances up to 500 m, capturing lateral groundwater recession and recharge–

discharge processes. All sites have at least 2 years of continuous observations; the Wudaogou Hydrological and Water Resources Experimental Station has maintained records since 1963, providing core long-term data.

The Wudaogou Runoff Experimental Field exemplifies the drainage experiment layout. It includes two drainage zones: Zone I (0.4 km²) with ditch depths of 0.5 m and 1.0 m, spacing of 100 m, and length of 1,000 m; Zone II (0.8 km²) with ditch depths of 1.0 m and 1.5 m, spacing of 200 m, and length of 1,000 m. Nineteen water table wells and seven soil moisture points form a comprehensive surface–soil water–groundwater monitoring system (Figure 2).

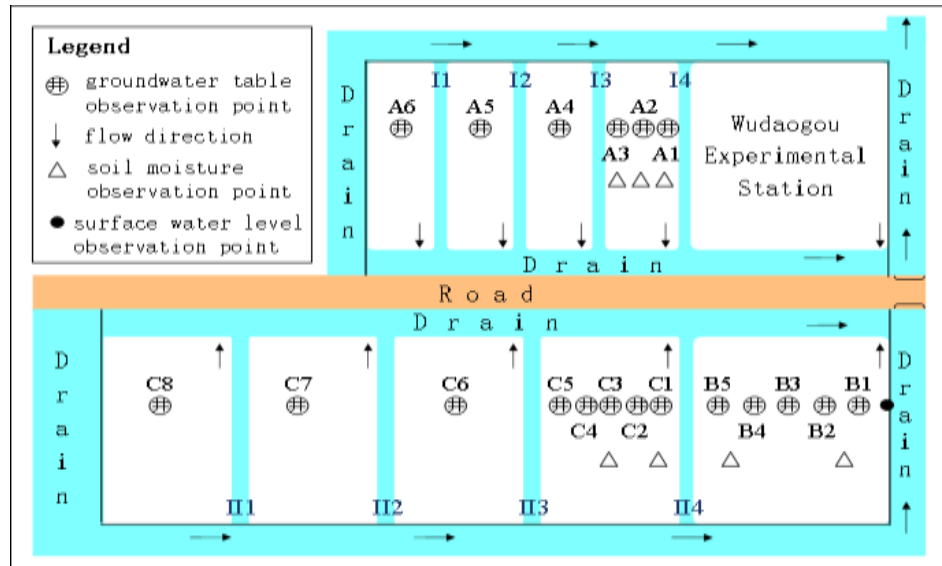


Figure 2. Layout of Monitoring Points in the Wudaogou Runoff Experimental Area

2.3 Methods

1. Groundwater Hydraulic Gradient Analysis: Hydraulic gradient curves are plotted using water table elevations at varying distances from drainage ditches to analyze lateral attenuation laws and define unilateral influence ranges and intensities.
2. Waterlogging Discrimination: Compliance with drainage standards is evaluated based on the water table receding to 0.5 m below the land surface within a specified period after rainfall for storms of different return periods.
3. Drainage Standard Comparison: Three-day maximum storm scenarios for 5-, 10-, and 20-year return periods are selected to compare post-rain groundwater and soil moisture recession durations, assessing the carrying capacity of the existing drainage system.

3 Results

3.1 Groundwater Influence Range of Farmland Drainage

Drainage ditches drive lateral groundwater discharge via water level differences, altering regional groundwater dynamics (Sang et al., 2023). Comparative analyses are conducted for representative southern (Guzhen) and northern (Mengcheng) sites. At the Guzhen site, according to the records of groundwater level at observation well C7 in Figure 2, the groundwater level of farmland ranged from 17.8 m to 20.0 m during 1981–1985, while the surface water level in the drainage ditches varied between 15.1 m and 18.3 m over the same period. The surface water level in the drainage ditches was 1.7–2.8 m lower than the groundwater level in the surrounding farmland. This indicates that the construction of

drainage ditches inevitably led to a decline in the groundwater level on both sides during the corresponding period. Since the surface water level was consistently lower than the groundwater level of the adjacent areas, this drainage experimental site was only applicable to the unidirectional investigation of groundwater discharge to surface water.

As shown in Figure 2, five groundwater observation wells (coded B1–B5) were installed at the drainage experimental site in Guzhen County. Figure 3 presents the interannual variations of water levels in the five observation wells in July from 1981 to 1985. The hydraulic gradient was steep within 150 m of the drainage ditch and gradually gentle beyond this distance, suggesting that the unilateral influence range of the drainage ditch on groundwater level extended to more than 250 m.

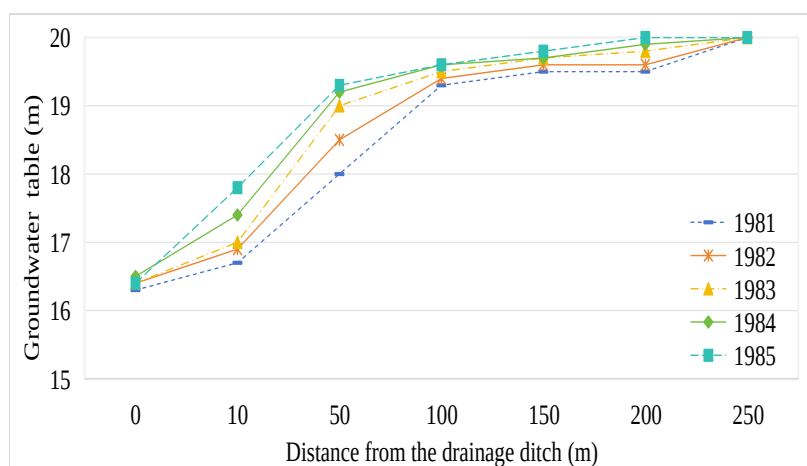


Figure 3. Groundwater Discharge Hydraulic Gradient Line in a Typical Month at the Guzhen Site

At the Mengcheng site, a total of eight observation wells were arranged perpendicular to the Qian River (used as a drainage channel), and another twenty-five observation wells were installed perpendicular to the main drainage ditch of Luzhuang. The field experiment was conducted from May 2012 to October 2014. Figures 4 and 5 show the averaged groundwater table under sunny and rainy conditions.

As shown in Figure 4, the water table tended to stabilize beyond 250 m, with a water level difference of 1 m. According to Figure 5, the river exerted a negligible influence on the water table at a distance of 500 m from the river channel, where the hydraulic head difference between groundwater and river water reached 2 m. All monitoring data from the Mengcheng site indicate that groundwater discharges toward the river channels, and the water table gradually rises with increasing distance from the drainage ditches.

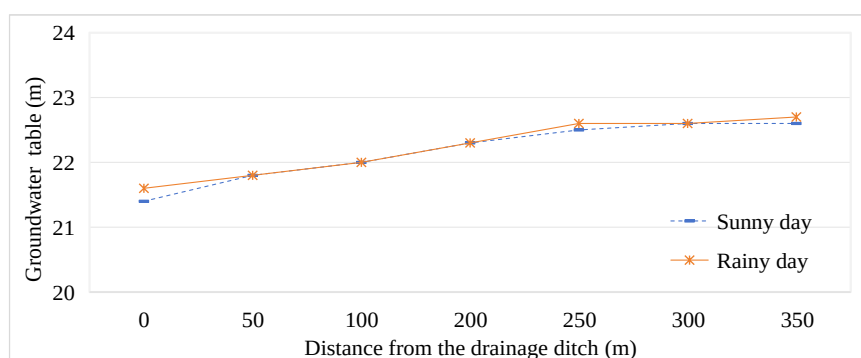


Figure 4. Groundwater discharge hydraulic gradient line perpendicular to Luzhuang Ditch under typical weather at the Mengcheng Site

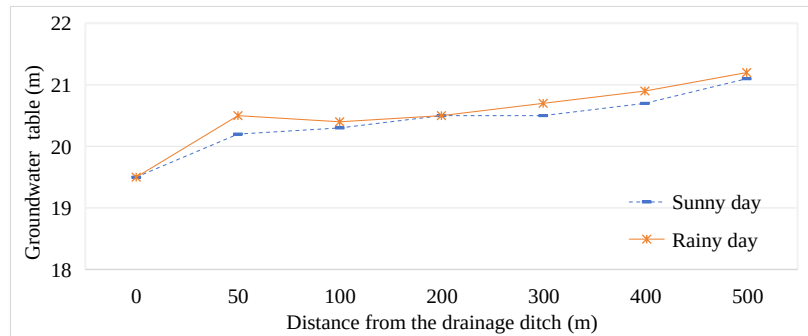


Figure 5. Groundwater Discharge Hydraulic Gradient Line Perpendicular to the Qian River Under Typical Weather Conditions at the Mengcheng Site

Across all sites, 250 m is the critical threshold: significant hydraulic gradient changes occur within 250 m, while regulation effects weaken substantially beyond this distance.

3.2 Hydrological Effects Under Different Drainage Standards

Surface drainage is the primary waterlogging control measure in the Huaibei Plain. The local standard requires the water table to drop to 0.5 m below the land surface within 4–5 days for a 5-year return period three-day storm. Southern (Guzhen) and northern (Xiaoxian) sites are compared.

At the Guzhen site (Table 1), the system meets 5-year return period requirements. However, under 10-year+ storms, performance depends on pre-rain water table depth: compliance is achieved at depths >3.0 m, but failure occurs at shallow depths, posing significant waterlogging risk.

Table 1. Soil Water and Groundwater Recession Events Under Different Drainage Standards at the Guzhen Site

Rainfall Period	Maximum 3-day Rainfall (mm)	Drainage Standard	Pre-rain Water Table Depth (m)	Time for Water Table to Drop to 0.3 m (d)	Time for Water Table to Drop to 0.5 m (d)
1987.7.3–7.5	160	>5-year return period	1.352	2	5
1997.7.4–7.6	175	>5-year return period	0.59	1	5
1996.7.3–7.5	183	>5-year return period	0.52	1	4
1991.7.5–7.7	203	>5-year return period	0.998	2	3
2007.7.2–7.4	225	>10-year return period	0.74	7	19
2018.6.27–6.29	230	>10-year return period	3.025	1	5

At the Xiaoxian site (Table 2), the recession characteristics of soil water and groundwater after rainfall under different drainage standards are presented in Table 2. The farmland groundwater table drops rapidly after rainfall under different return periods, complying with the required drainage standards. Notably, the existing drainage facilities still meet the design criteria even when the maximum three-day rainfall exceeds the 20-year return period. The local groundwater table is relatively deep, so farmland generally faces no obvious risks of waterlogging and subsurface waterlogging.

Table 2. Soil Water and Groundwater Recession Events Under Different Drainage Standards at the Xiaoxian Site

Rainfall Period	Maximum 3-day Rainfall (mm)	Drainage Standard	Pre-rain Water Table Depth (m)	Time for Water Table to Drop to 0.3 m (d)	Time for Water Table to Drop to 0.5 m (d)
2000.7.12–7.14	205	>5-year return period	5.77	1	1
2018.7.28–7.30	191	>5-year return period	2.52	1	1
2012.7.16–7.18	177	>5-year return period	1.72	1	1
2018.8.17–8.20	390	>10-year return period	0.93	1	1
1982.7.25–7.27	242	>10-year return period	0.73	1	1

Post-rain water table recession curves (Figure 6) show faster recession at Guzhen than Xiaoxian within one week. Guzhen meets the 5-year standard but fails for 10-year+ storms, while Xiaoxian consistently complies. Central-southern areas are identified as critical waterlogging control zones with limited extreme storm adaptability; northern areas perform well under high return period events.

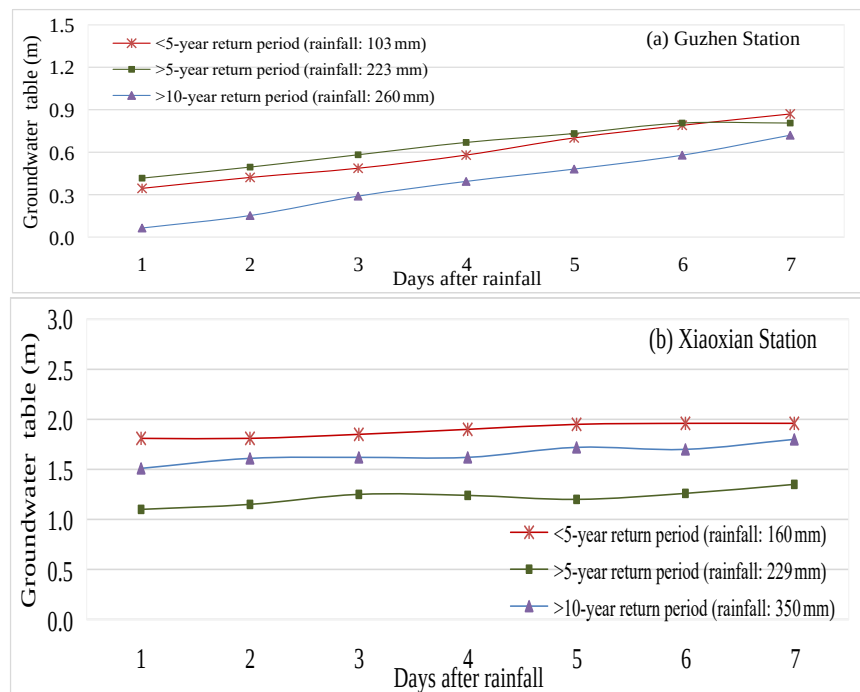


Figure 6. Post-Rain Groundwater Recession Within One Week for Different Return Periods at the Guzhen and Xiaoxian Site

3.3 Drainage Layout Patterns and Specifications

After 61 years of practice, three typical patterns have emerged, integrating main/secondary/tertiary ditches (waterlogging control) and field/deep moisture-conserving furrows (subsurface control): Deep-sparse type: The main ditches are approximately 5 meters deep and fitted with gated structures for

drainage and irrigation. The earthwork volume reaches 100,000 m³/km². This pattern features high costs and poor subsurface water control capacity.

Shallow-dense type: It adopts a compact layout with three main ditches and two field ditches. Its earthwork volume is 60,000 m³/km². This scheme is cost-effective and delivers superior performance in waterlogging and subsurface water regulation. Deep moisture-conserving furrow composite type: This design integrates all ditch categories. With an earthwork volume of 55,000 m³/km², it achieves the best overall efficiency and is applicable to large-scale implementation.

The overall layout of farmland drainage systems in the Huaibei Plain shall be determined in accordance with local conditions by comprehensively considering the alignment of main drains, the hierarchy of fixed drainage networks, channel connection modes, as well as topographic features and watershed areas. In light of the general terrain of the region, most main drains run north-south, while some local sections extend east-west. The hierarchy of drainage networks is determined by the drainage area of main drains, and the connection pattern between drainage channels at all levels is adapted to local landforms. As illustrated in Figure 7, the comb-type layout is generally adopted for gentle-slope terrain, whereas the grate-type layout is applied for undulating terrain.

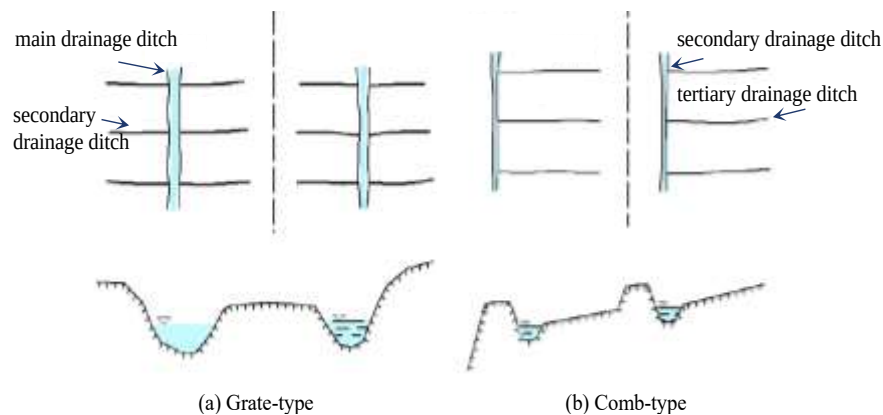


Figure 7. Connection Patterns of Ditch Networks in Farmland Drainage Systems

As shown in Figure 7, the field drainage networks in this area are generally arranged in two patterns: three flood drains with two subsurface drains (3-waterlogging-1-subsurface) and three flood drains with one subsurface drain (3-waterlogging-2-subsurface). In general, the 3-waterlogging-1-subsurface pattern is widely applied in the south-central Huaibei Plain, while the 3-waterlogging-2-subsurface pattern is commonly adopted in the northern Huaibei Plain.

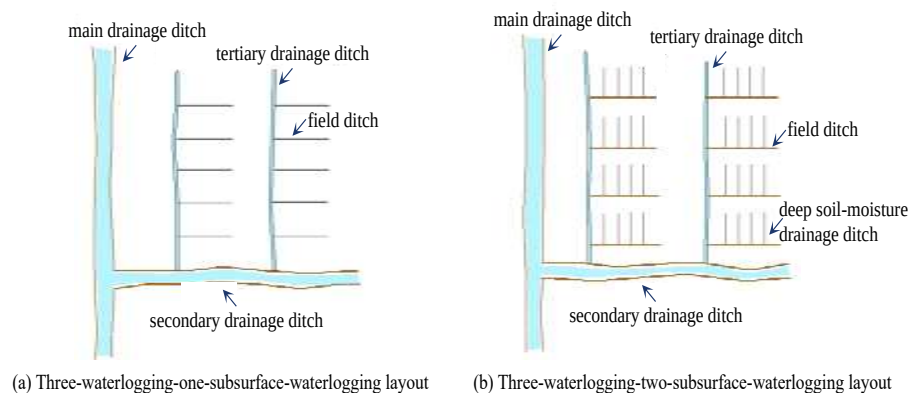


Figure 8. Layout Patterns of Field Ditch Networks in Farmland Drainage Systems

4 Conclusions and Discussion

4.1 Conclusions

- (1) Drainage ditches significantly reshape groundwater recharge and discharge as well as hydrological cycles, with a unilateral effective influence range greater than 250 m. The 250 m threshold serves as a key reference for ditch spacing planning.
- (2) The existing system meets the standards for the 5-year return period but cannot cope with storms of 10-year return period and above in central-southern areas; northern areas consistently comply due to the deep groundwater table.
- (3) The three layout patterns differ markedly: deep-sparse type (100,000 m³/km², large capacity and high cost), shallow-dense type (60,000 m³/km², high efficiency), and deep furrow composite with moisture retention (55,000 m³/km², optimal overall performance).
- (4) Differentiated layouts are recommended: comb/grate-type for main networks; the 3-waterlogging-1-subsurface pattern for the south-central Huaibei Plain, while the 3-waterlogging-2-subsurface pattern for the northern Huaibei Plain.

4.2 Discussion

This study quantifies drainage ditch influence ranges using long-term multi-site data, addressing limitations of short-term single-scale research and providing parameters for Huang-Huai-Hai Plain ditch optimization. However, irrigation and human water management impacts are not considered; future work will integrate irrigation scenarios. Standardized ditch depth/spacing formulas for varying slopes and soils are not developed, requiring further modeling to establish design parameters.

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