Influence of underground engineering on surrounding water environment in sedimentary rock distribution area and its treatment principle

Maozhong Tian¹-²-³, Lihua Zhang¹-², Zheng Hu¹-² and Guo Guo¹-²

¹China Hydropower Consulting Group Guiyang Survey and Design Institute, Geotechnical Engineering Co., Ltd, Guizhou, 550081
²Guizhou Engineering Corporation, Guizhou, 550081
³Corresponding author’s e-mail: 1228941658@qq.com

Abstract. Sedimentary rocks are normally characterized by a stratification structure with high connectivity. According to the combinations of rock formations, they can be divided into permeable strata and impermeable strata. Due to the influence of post-stage tectonic events and the Karst phenomenon, the hydrogeological conditions are complicated. The groundwater level varies significantly in sedimentary rocks under the control of topographic variations. For underground engineering construction where the foundation is buried below groundwater level, changes may occur in the replenishment relationship between surface water bodies and groundwater runoff resulting from a large-scale excavation, which consequently makes an adverse effect on the water environment of the surrounding cities. This paper aims to highlight the impact of underground engineering projects on the water environment in Karst areas. Based on the study on characteristics of different types of sedimentary rocks in southern China, such as Karst development characteristics, water-rich characteristics of rock masses, groundwater environmental conditions in cities with a mountainous topography, and types of underground engineering, this paper analyzes the impact modes and treatment principles of projects distributed in spots, large expanse, and line under different geological conditions. The research results have been widely used in the construction of urban subways in a highly developed Karst stratum in southern China, which fully satisfies the requirements of projects.

1. Introduction

In recent years, with the rapid development of the national economy and urban construction, to improve the ground environment and make full use of land resources, large-scale urban underground projects have been continuously carried out in small and medium-sized cities across the country, consequently, the urban development has had a great impact on the surface water and groundwater environment around the projects areas, where various issues have been reported, such as surface water reserves reduction, water level decrease, or even disappear. In some cases, the decline of the groundwater level has changed the original groundwater environment, causing a series of engineering geological problems and social issues [1-3]. Thus, the risk assessment of construction projects has become a priority during the planning of new urban areas [4].

For soft rock and clastic sedimentary rocks, the rock mass itself is relatively impervious. Underground engineering construction in soft rock or clastic sedimentary rocks has little influence on the surrounding water environment. Whereas the impact is more serious in chemical sedimentary rocks,
Due to the development of internal bedding structure, the presence of faults and joints cutting, and the development of local karst pipelines and cavities, underground engineering construction may have a greater impact on the surrounding water environment, due to the relatively high permeability of such areas. In the practice of underground engineering construction in sedimentary rock areas, problems such as land subsidence, water logging in depression, anti-floating failure, groundwater pollution or water level decline, lake water level decline, and spring disappearance often occur in the surrounding area of underground engineering construction due to the change of surrounding water environment [5-7]. Yan Xuexin et al. [8] researched on ground subsidence caused by decompression and precipitation of foundation pits from the aspects of engineering hydrogeological characteristics, influencing factors, comprehensive zoning, and settlement estimation. Zhu Bangyan et al. [9] used InSAR and geological data to comprehensively analyze the evolution characteristics and causes of land subsidence in Hexi, Nanjing. Di Shengping [10] took Boxing County of Binzhou as the engineering background, based on the detailed hydrogeological and engineering geological data of the study area and the ground subsidence monitoring data over the years systematically analyzed the dynamic distribution of groundwater and the evolution characteristics of land subsidence in the area. Based on existing data and actual investigation and research, Su Guifen et al. [11] comparatively analyzed the changes in the cyclic evolution conditions of a karst water system in the middle section of Huaying Mountain under natural conditions and artificial activities.

At present, it is relatively rare to systematically study the impact of spotted, patchy, and linear projects underground engineering on the surrounding water environment in the sedimentary rock distribution areas, and the research on the mode and treatment principle. The change of groundwater environment may induce new engineering problems of the built or to be built projects. Zhang Yang et al. [12], Hou Guibao et al. [13], Gao Yong et al. [14] Based on the hydrogeological conditions of the linear engineering area, analyzed the main reasons for the change of groundwater aquifer structure and flow field caused by the impact of the project on the groundwater environment during the construction and operation period, and put forward the treatment measures; Zhuang Xufeng et al. [15], He Su et al. [16] analyzed the interaction between tunnel engineering and underground karst water system and the engineering problems caused by them with engineering examples.

The current research focuses mainly on understanding the impact the construction projects on groundwater dynamic in karst terrains, in order to determine practical treatment measures.

Based on summarizing the characteristics of underground engineering, geological structure, and hydrological characteristics, as well as the characteristics of water environment around the project in the sedimentary rock area, this paper analyzes the geological structure, groundwater level, runoff conditions and the relationship between the site and its surrounding areas, studies the influence degree and influence mode of the project construction on the surrounding water environment, and puts forward the treatment principles. It has a certain guiding significance to the sustainable development of the city and the safety of underground engineering construction.

2. Underground engineering characteristics
The underground projects are classified based on their characteristics; nature, scale and size, and the surrounding groundwater environment conditions; thus, the impact on underground environment varies according to the differences on the characteristics of different projects.

Under different water environment conditions, even the nature and scale of the project are the same, the impact of the construction on the surrounding water environment is also different. At present, domestic underground projects are classified according to their uses: underground traffic engineering, underground civil air defense engineering, underground national defense engineering, underground storage engineering, underground industrial engineering, underground commercial engineering, underground municipal pipeline engineering, etc. This article analyzes the relationship between underground engineering and the water environment, mainly classified and explained according to the scale of the project, the plane distribution, and the buried depth.
2.1. Project scale and plane distribution

According to the scale of the project and the plane distribution mode, it is classified as spotted project, patchy project and linear project.

Spotted underground projects: generally small in scale, mainly single underground buildings, mostly underground garages and underground air defenses.

Patchy underground projects: The scale of flaky underground engineering is relatively large, and it is mainly distributed in flaky underground buildings, such as underground garages in large residential areas, large underground shopping malls, and underground workshops. Linear underground engineering: Linear underground engineering is generally linear distribution with large extension length, mainly including urban subway engineering, urban tunnel engineering, urban comprehensive pipe gallery and underground municipal pipeline.

2.2. Buried depth of underground engineering

According to the characteristics of mountainous cities in Guizhou province, combined with the buried depth of underground engineering, underground engineering can be divided into three types: shallow underground engineering, middle underground engineering and deep underground engineering.

Shallow underground engineering generally refers to underground engineering buried depth less than 10m, mainly including underground garages, underground pedestrian passages, urban water, electricity, gas, communications, and other public facilities.

Middle underground engineering refers to the underground engineering buried depth between 10m and 30m, mainly including urban integrated pipe corridors, underground shopping malls, part of the subway, groundwater treatment plants, etc.

2. Geological structure and hydrological characteristics

As per definition, deep underground engineering mainly refers to underground projects with the foundation’s depth is greater than 30m, such as urban underground rail transit, municipal highway tunnels, and other important underground engineering facilities.

Underground engineering construction is closely related to the surrounding rock-soil combination characteristics and geological structural development. The degree and scale of karst development also have a greater impact on the engineering geological environment in the chemical sedimentary rock distribution area. Therefore, to analyze the impact of underground engineering on the surrounding water environment, firstly, the rock and soil texture characteristics and permeability performance in the engineering area should be analyzed and demonstrated.

3.1. Lithohydrological feature

In Guizhou province, the sedimentary rock strata can be roughly divided into three types, clastic sedimentary rocks, claystone, and chemical sedimentary rocks. According to the different lithological characteristics, the water yield property and water permeability performance of various rock mass combinations are described as follows:

3.1.1. Clastic sedimentary rocks. There are mainly sandstone, quartz sandstone, siltstone, argillaceous siltstone, sandy mudstone and other formations. It is more exposed in southern and northern Guizhou, with a distribution area of about 10%-20%. It is a thin-bedded, medium to thick-bedded, and thick-bedded structure, with developed internal bedding structure, argillaceous infilling, tight binding, and good connectivity. The rock mass is relatively impervious and weakly water yield property. Rock mass permeability is mainly controlled by the degree of weathering, interlayer structural planes, faults, and joint development. Generally, the highly weathered rock masses, faults zones, and highly fractured rock masses have high water permeability. The water permeability of the moderately weathered to slightly weathered rock mass is relatively low. In water resources and hydropower engineering, the relatively impervious stratum is often used as the bottom of an impervious curtain.
3.1.2. **Clay rocks.** Mainly claystone, shale, mudstone, calcareous mudstone, exposed everywhere in Guizhou, with a distribution area of about 5~10%. Extremely thin-bedded, thin-bedded, and medium-thick bedded structure, with well-developed bedding and layers, infilling with the gouge, and good interlayer cementation. Since the grain diameter of the rock texture is less than 0.005mm, the rock mass is considered impermeable. Even if there are faults and joints, most of them are infilling gouge and cemented, and there are no strong water permeability problem. It can be used as a better waterproof supporting stratum in engineering construction.

3.1.3. **Chemical sedimentary rocks.** There are mainly carbonate rock strata, which can be divided into limestone and dolomite. The limestone category includes limestone, biological limestone, siliceous limestone, flint limestone, micrite limestone, and carbonaceous limestone, dolomite limestone, etc. Dolomite categories include dolomite, lime dolomite, and micrite dolomite. The chemical sedimentary rocks have a large distribution in Guizhou, accounting for about 70-80% of the area of Guizhou Province. The rock structure is thin-bedded, medium-thick bedded, thick-bedded, and massive-bedded, with well-developed bedding, good connectivity, and poor interlayer bonding relative to clastic rocks and clay rocks. It has a certain water permeability. It is a water-bearing formation with relatively good water yield properties. The water permeability is mainly controlled by the development of bedding, faults, fractures, and karst. The seepage and water gushing phenomena in underground engineering construction mainly occur in such stratum, which is the main object of research on the impact of the water environment around the project.

3.2. **Tectonohydrogeological feature**

The geological structure of foundation rock mass mainly refers to the fault and the fracture structure produced in the process of crustal movement. The scale of the geological structure, the width of the fracture zone and fault affected zone, and characteristics of the filling cement have a greater impact on the groundwater environment. So it is one of the main objects of underground engineering construction research.

3.2.1. **Tectonohydrogeological feature of regional fracture.** Generally, the regional fracture refers to a large-scale fault structure with an extension length more than 10km, which has the characteristics of large extension length, large stratum fault distance, large fracture zone and large range of fault affected zone, and it is easy to become a collection and runoff channel of groundwater. According the mechanical properties of the fault, it can be further divided into compressive fracture and tensile fracture. Fractures formed under general compressive stress, the width of the fracture zone and affected zone is relatively small compared to the tensile fault, and most of them are filling cemented type, its water conductivity is relatively poor. The faults formed under the action of tensile stress have relatively large fracture zone and influence zone width, poor filling and cementation properties, and relatively good water storage and hydraulic conductivity.

3.2.2. **Tectonohydrogeological feature of associated (secondary) fault structures.** Mainly affected by regional faults, a series of small-scale secondary faults are formed around the main fault. The secondary fault generally extension length of 1~5.0km, and is distributed in cross and parallel with the main fault. The fault distance, fracture zone and affected zone are relatively small compared to regional faults. They are also the collection and runoff channels of groundwater, but their scale is limited.

3.2.3. **Hydrogeological characteristics of joints (fissures).** The water yield and conductivity property of the joints (cracks) in the rock mass are mainly controlled by joints density, aperture, and degree of rock weathering. Generally, highly weathered rock masses and rock masses near fracture zones have high joint (crack) density, poor filling and cementation, large aperture, and relatively good watery and conductivity. As the weathering degree of the rock mass decreases and further away from the faulted
structure, the joints (cracks) are less developed, and most of them are filled and closed, and the watery and hydraulic conductivity property is gradually weakened.

3.3. **Karst hydrogeological characteristics**
In the carbonate strata distribution area, due to the interaction of soluble rock and groundwater, inside the structurally developed rock masses, karst fissure crevices, caves, karst pipelines, and karst underground rivers of various sizes are often formed, which become groundwater collection, storage, and runoff channels. The types of karst water include fissure water, karst cave water, karst pipeline water, and karst underground river. They have the characteristics of dispersion, good permeability, and large variation of water volume. It is mainly distributed and exposed in linear flow, pulse flow, and streamflow.

4. **Characteristics of water environment around the project**
With the continuous development of urban construction in China, people's demand for material and cultural living standards of the city is increasing. Most of the living environments should be chosen in the beautiful areas with mountains and waters, and the corresponding municipal supporting projects and ancillary facilities will be built accordingly. Therefore, there are different surface water and groundwater environments around the projects. Its environmental characteristics are the key objects of underground engineering to research the surrounding water environment.

4.1. **Surface water environment characteristics**

4.1.1. **River system.** In generally large and medium-sized cities, most of them have one or more rivers and water systems, some passing through the city, and some passing around the city. In addition to the main rivers in mountainous cities, there are 1 to 2 or more tributary water systems distributed in a branch shape, as shown in Figure 1. Some constructions, urban roads, and subways are mainly distributed along both banks of the river, ranging from 50 to 200m away from the river bank. Some urban subways even cross the riverbed to connect the two banks. The river system has the characteristics of strong fluidity, large variation of water level, and water volume. The morphological characteristics, water surface width, river bed gradient, and the variation of river water level during dry seasons and flood seasons have a greater influence on the foundation depth, design schemes, and engineering treatment measures of the surrounding underground projects, and specific analysis and demonstration are required.

![Figure 1. Subway and river distribution in the main urban area.](image-url)
4.1.2. Lake landscape. In addition to the river system, there are also some lake landscapes in the city or suburban. According to the formation, the lakes can be divided into natural lakes and artificial lakes, with a distribution area ranging from 0.5 to 10.0 km², as shown in Figure 2. In general, natural lakes are relatively large while artificial lakes are small. Both of them have the characteristics of a certain surface water (or groundwater) recharge source, gentle water surface, and relatively stable water level. At present, in newly developed urban construction, artificial lakes are mostly used for landscape engineering. Around the lake, most of the urban infrastructures such as housing construction projects, urban road projects, underground rail transit, etc, which have been built or to be built, and the later underground engineering construction has a greater impact on the water environment.

Figure 2. Distribution of subway, lake and artificial lake in an urban area.

4.1.3. Ancient Wells and Springs. Ancient wells and spring groups are generally distributed in groundwater runoff, discharge datum nearby rivers, and lakes. They are exposed individually or in groups. General plains with shallow depth, hilly cities buried deep, for a long time, it has been one of the water sources for urban residents' domestic water, with a long history, and most of them as a focus on the protection of urban landscape. In recent years, due to the construction of large-scale urban buildings, deep foundation pits and a large number of pile foundation projects, it may change the environmental conditions of groundwater runoff and cause well springs to flow interruption. This is the work content that should be studied in the process of underground engineering construction.

4.1.4. Pumping Well Point. The pumping well point mainly refers to the location of the well hole where the groundwater source is collected. At present, most cities have canceled the groundwater supply method and switched to tap water supply. However, some factories and enterprises still use groundwater for cooling cycles, geothermal central air-conditioning, environmental greening, and other water use methods. Most of the wells are used to pump water, and the depths of the wells are mostly between 80 and 150m, mainly shallow groundwater. In urban planning and construction, especially the construction of linear underground works (such as subway), if the pumping well is close to the site, it may lead to the water level decline of the pumping well, or even the depletion of the pumping well, which should be investigated and studied.

4.2. Groundwater environment characteristics
In engineering construction, different groundwater environments have a greater impact on underground engineering construction, and there are many types and ways of impact. This paper mainly analyzes the free phreatic environment, confined water environment, karst underground river pipeline and structured
water system, which have a great influence on the construction and operation of underground engineering.

4.2.1. Free phreatic environment. Free phreatic environment mainly refers to the phreatic groundwater environment with the free water surface, relatively stable groundwater level, or relatively small hydraulic gradient in the water-bearing rock and soil body with certain permeability. Overall analysis, the groundwater with the characteristics of the free phreatic surface, as shown in Figure 3, its groundwater level and hydraulic gradient are mainly controlled by topography, rainfall, rock, and soil permeability. The water level is relatively stable in the sand and gravel layer, the permeable soil layer, and the weathered rock mass with a range of 3.0~5.0m and a hydraulic gradient of 1~3% in the dry flood season. In mountainous terrain and carbonate rock distribution area, the variation of groundwater level is relatively large, during the dry season and flood season, the variation of water level is 3.0~8.0m, and the hydraulic gradient is generally 3~7%, local area can reach 10~12%. Underground engineering construction is carried out in the free phreatic environment, the first thing to ascertain the groundwater confluence area, groundwater recharge, runoff path, water level, and permeability characteristics of rock mass and soil in the investigation and design stage.

4.2.2. Confined water environment. From the perspective of spatial analysis, the confined water environment is mainly distributed in the aquifer between the upper and lower aquiclude. The aquifer has a certain thickness, high at both ends, low in the middle, groundwater in a permeable body with certain pressure-bearing properties, free recharge and drainage areas at both ends, and a pressure-bearing area in the middle. Its artesian head is mainly controlled by the water level elevation of the free recharge and drainage area and the buried depth of the aquifer, the water volume is determined by the thickness of the aquifer and the water volume in the recharge area, as shown in Figure 3. The confined water environment is mainly distributed in the aquifer between the upper and lower water-resistant strata in the mountainous sedimentary rock distribution area, such groundwater environment is easily formed in the basin formed by synclinal structure. For the urban tunnel engineering, subway engineering, when passing through such groundwater environment, it is easy to appear water gushing, water permeation phenomenon, the treatment engineering is very difficult, so it should be avoided as far as possible.

4.2.3. Karst underground river, Karst pipeline and structural water environment. (1) Karst underground river and Karst pipeline

In the distribution area of soluble rock strata, due to the dissolution and erosion of groundwater, underground karst channels of various sizes are often formed in the soluble rock, and underground karst rivers are formed near the base level of groundwater drainage, with a length of several hundred to several thousand meters, the burial depth ranges from 10m to 100 m, and is a drainage channel for groundwater runoff. In underground tunnel engineering, foundation pit engineering, and bored pile foundation construction, the phenomenon of interception and blockage may occur, which will change groundwater runoff path and result in the reduction or disappearance of groundwater users and spring lake landscape downstream.

(2) Tectonic water environment
The tectonic water environment mainly refers to the groundwater system in the fracture zone. Most of the regional fault structures that formed under the action of tensile stress often become groundwater storage and runoff channels due to the relatively large length and width of the fracture zone. The main features of the tectonic water environment are the large confluence area, sufficient recharge, and abundant groundwater reserves. Large structural springs are often formed in the drainage area. Underground engineering should focus on its construction and ecological environmental impact during the planning and design stage.

5. The impact of underground engineering on the surrounding water environment

5.1. Impact on surface water

When the underground project is located near or below the surface water, the possible impacts during the construction process are mainly manifested in two aspects: one is the surface water backflow to pit; second, the water level of surface water decline and the water volume decreases. The details are as follows:

5.1.1. Surface water backflow. For urban deep foundation pit projects and subway line projects located near-surface water and below the water surface elevation, the buried depth of the foundations is mostly between 10 and 60m. Due to the loose structure of the subsurface soil and the influence of weathering, faults, fissures, and karst development on the underlying shallow rock mass, most of the rock mass within the depth of 0~40m has the characteristics of strong water permeability. In the process of foundation pit and tunnel excavation, surface water is easy to be irrigated backwards, resulting in water gushing and water permeation, which often happens in the process of engineering construction. For example, subway lines 1, 2, and 3 in a city of southwestern China all cross the Nanming River and tributary system when passing through the old city. Water and mud gushing occurred many times during the construction phase. A large amount of surface water backflow into the pit may cause the water level of the surface water to descend or dry up. At the same time, it has a great impact on the construction safety of surface landscape engineering and underground engineering. So it is necessary to carry out special waterproof curtains, anti-seepage treatment before underground engineering construction. Under normal circumstances, as long as the proper treatment measures are carried out during the construction period, the later period will have little impact on the surface water, landscape projects with small surface water bodies may cause lake water depletion.

5.1.2. Water level descend, water volume decreases. When the underground engineering and the rock and soil near the surface water are medium or weakly permeable, there may not be obvious surface water inversion during the construction process, but due to the impact of foundation pit and tunnel construction drainage, the hydraulic gradient increases and the seepage volume increases. When the local surface water supply is less than the seepage volume, the water storage capacity of surface lakes and artificial landscapes will decrease, and the water level will descend.

5.1.3. Wells and spring setting off. The influence of underground engineering on the ancient Wells, springs, and Wells (holes) will lead to water quantity reduction and water level descend, and even cause the phenomenon of well and spring setting off.

For example, in a county in western Guizhou, there are 108 springs, known as the "city of hundred springs" reputation. Among them, Hui long Pool is the first of the hundred springs, the "century-old lake". According to the survey, the daily normal water inflow is 20,000 to 30,000m³. After 2008, due to the basement excavation and pile foundation construction of the surrounding and upstream high-rise buildings, the water volume in 2009 gradually decreased. After 2011, the water flow was completely setting off, and the water volume of other springs water flow also reduced or setting off. After investigation, it is considered that it can not be recovered, which indicates that underground engineering has a great impact on the surrounding water environment.
5.2. Impact on the groundwater environment

In urban architecture, underground engineering and groundwater are an interactive community. The runoff conditions and type characteristics of groundwater are different from the scale and location of underground engineering, so there are great differences in the impact on groundwater environment, which need to be analyzed and studied one by one.

5.2.1. Impact of spotted engineering

Spotted engineering mainly refers to small-scale single-type underground structures, such as underground shopping malls, underground garages, underground civil air defense projects, etc, generally buried depth is 10-20m. From the perspective of the geological structure, most of them are located in the soil or shallow rock mass. According to the different characteristics of the groundwater environment, the influence methods are as follows:

1. **Impact on the phreatic environment**

   Underground and foundation pit excavations are carried out in permeable soils and weathered rock mass. Affected by the drainage of the foundation pit, there is a problem that the groundwater level of the surrounding foundation may descend during the construction process. For landscape projects that use groundwater runoff recharge sources, the recharge may be reduced or cut off during the construction period. However, due to the small scale of the project and the limited impact, most of them can be gradually restored after the completion of the construction, and the overall impact is not significant. As shown in Figure 4.

2. **Impact on the confined water environment**

   When the underground project debunks the upper water-impermeable formation into the confined water-bearing formation, it creates artificial gaps in the enclosed water environment. A large amount of water gushing may happen during the excavation of the foundation pit, and there will be a decrease in water volume or a cut-off phenomenon in the pressured drainage area, which will have a relatively large impact. If the anti-seepage project is handled properly during the construction period, the confined water environment may be recovered or partially recovered in the later period, but the treatment project is quite difficult, as shown in Figure 5.

---

**Figure 4.** Schematic diagram of influence relationship between underground engineering and groundwater.

---

**Figure 5.**
Impact on Karst pipeline water and structural zone water

In solvable strata areas, for shallow-buried water-passing karst pipelines and fractured structures near the water drainage datum, the water-passing sections are mostly small. Even in small-scale single projects, karst pipelines may be cut off and blocked during the construction of foundation pits and pile foundations. Due to the multi-directional characteristics of the karst pipeline, the cut-off karst pipeline water will have runoff diversion, resulting in changes in the karst pipeline water runoff conditions, which have a greater impact on the downstream landscape engineering that requires such groundwater recharge. Generally, it is difficult to recover, so it can only be effectively avoided by taking avoidance measures in the early stage or conducting special design treatment during the construction period, as shown in Figure 4.

5.2.2. The impact of patchy engineering. In large-scale construction sites and patchy underground projects such as large residential areas, underground shopping malls, and underground workshops where large-scale are excavated, when the buried depth of underground structures is below the groundwater level, large-scale excavation of foundation pits has a great impact on the surrounding water environment (as shown in Figure 6), which is mainly reflected in the changes of groundwater level and changes in groundwater runoff conditions. The degree of impact is analyzed as follows:

(1) Changes in groundwater level

In sedimentary rock areas, when the buried depth of the underground project is below the free water table, the large area of foundation pit excavation and drainage treatment may cause the surrounding groundwater level to descend in a large area, which has a greater impact.

After the completion of the project, the groundwater level on the upstream surface (or the waterfront surface) can be recovered to its original state or slightly increased, the groundwater level in some areas can rise to 2~3.0m, and the downstream surface cannot be restored basically, and there is a significant
For the confined groundwater environment, after the local project has debunked the relative aquifer, the water environment has been damaged or greatly changed, and the water level in the drainage area has generally descended, and the conditions for recovery are generally not available. For shallow-buried karst pipelines, it cannot be recovered after the water is cut off.

(2) Changing groundwater runoff conditions

Large-scale underground projects have greatly changed the underground environment. In addition to the large changes in the groundwater level, the runoff conditions of the groundwater will also change significantly. In sedimentary rock formations of the aquifer, for phreatic groundwater, karst pipeline water, and structural zone water will flow radially along both sides of the surface of the underground structure, while confined groundwater may change from subsurface to surface flow, it is discharged in the form of a rising spring on the construction site.

5.2.3. The impact of linear engineering

For linear projects such as urban subways and tunnels, due to their large extension length and good penetration, they may become groundwater collection and drainage channels during the construction and operation stages, which have a greater impact on the surrounding water environment of the project. This section mainly analyzes and explains the impact of changes in groundwater environmental conditions on the surrounding water environment through the relationship between groundwater runoff conditions and the location of underground projects.

(1) Influence of vertical runoff arrangement

When the extension direction of the underground line project is perpendicular or at a large angle to the direction of the groundwater runoff, and it is located on the upstream surface of the surface water, if the groundwater level is lower than the bottom elevation of the underground project, it will generally not affect the groundwater runoff conditions and make up for the surface water, it does not affect the drainage relationship of surface water and the groundwater flow.

For example, when the buried depth of the project is below the groundwater level or surface water level, the greater impact may be occurred, mainly in two aspects, temporary influence and permanent influence, as shown in Figures 7, 8 and 9.

Temporary impact mainly refers to the temporary change in the groundwater conditions during the construction period, the phenomenon of groundwater level decline, adjacent surface water intrusion, and draining, which occurred during the construction period, will gradually or partially recover during the operation period. It has little impact on the groundwater runoff conditions and the relationship between surface water recharge and drainage.

Permanent impact: Because the runoff channel is cut off, the recharge relationship of groundwater and surface water is changed. Even in the operation period after the completion of the project, the groundwater level is difficult to restore, which has a greater impact on the surface water landscape engineering that relies on the groundwater recharge source. From the time effect analysis, most of the impacts are permanent.
Figure 7. Groundwater runoff relationship map of subway Line 2 in a city.

Figure 8. Profile of groundwater runoff variation during subway construction.

Figure 9. Water gushing occurs during underground excavation of linear subway project.

(2) Impact of parallel runoff arrangement
When the linear underground project is arranged in the same direction as the underground runoff and located on both sides of the surface water or below the groundwater level, its impact is mainly in the construction and excavation stage. Underground line projects tend to become groundwater runoff drainage channels, causing the groundwater level around the project to descend, and surface water may appear the surface water flow backward. Generally, since the underground runoff conditions have not been changed, the groundwater level can be restored after the completion of the project, and the impact on the surface water is also small. However, it is important to pay attention to the consolidation and grouting of the surrounding rock of the tunnel during the construction phase. Otherwise, the loose surrounding rock may become an underground seepage channel, affecting the recovery of groundwater and surface water.

5.2.4. The impact of the Impervious grouting project. For the groundwater environment, seepage control is an engineering treatment method that artificially changes the conditions of groundwater runoff. The main purpose is to prevent the surface water from flow backward and groundwater leakage. The impervious curtain guides the discharge of groundwater in the planned direction to protect the safety of underground projects during the construction period and the impact of water seepage during the operation period. It is generally used in water conservancy and hydropower projects and some underground projects that require high waterproofing.

Although the installation of impervious curtain project effectively protects the seepage problem of underground projects, natural landscapes such as artificial lakes, ancient wells, and springs that need to be recharged by groundwater downstream may cause permanent cut-off and dry up, and have a greater social impact. Generally, the impervious curtain should be used with caution in urban scenic areas and groundwater environmental protection areas.

6. Principle of engineering treatment
In the natural water environment, surface water and groundwater are a dynamic balance of mutual circulation. The construction of underground projects will change this balance, which will adversely affect the supply and demand balance of the surrounding water environment, especially for urban water environment landscape projects. Some impacts are temporary, and some impacts may be permanent. How to reduce the adverse impact on the surrounding water environment during the construction of the project is a problem that the project builders have been discussing and thinking about. The first principle of project management is to protect the safety of the underground project during construction and operation. The second is to protect the surrounding water environment and landscape of the project from being greatly affected by the construction of the project. The above chapters have analyzed and demonstrated the geological structure, groundwater types, environmental characteristics, and impact relationships of the sedimentary area. This section mainly explains the principles of surface water and groundwater environmental treatment and protection.

6.1. Treatment of surface water flow backward
6.1.1. Treatment of adjacent surface water. (1) Underground linear project
Underground municipal road tunnels and subway projects are generally divided into left and right sections from the cross-section, with a distance ranging from 5.0 to 20 m. The diameter of a single tunnel is mostly between 5.0 and 12.0m, there are also a few slightly larger sections. When the line is located near the surface water and is below the normal water level, the surface water flow backward problem may occur during the tunnel construction process, and special engineering treatment measures need to be carried out.

a. Treatment principles
The principles of treatment are as follows: ① Prevent surface water (such as lakes, artificial water landscapes) from dry up due to a large amount of surface water flow backward to the underground tunnel;
② Protect the safety of underground engineering construction operations; ③ Does not affect the recharge and discharge of groundwater in the later period.

b. Treatment measure

① Set up impermeable curtain: The impermeable curtain is always set between the project and the surface water, within the range of 5.0~10m from the surface water boundary. According to the water permeability of the rock mass, 2~3 rows of curtain grouting holes can be arranged in the form of a plumflower pattern. The upper limit of the curtain is not higher than the construction surface water elevation. The lower limit can be determined according to the water permeability of the rock mass, generally, it is less than 3Lu or the permeability coefficient is less than $3 \times 10^{-5}$ cm/s, or 4.5~6.0m below the tunnel floor. The length range is limited to the possible influence boundary and can extend along the water boundary, as shown in Figure 10. For the tunnel facing the surface of the groundwater, the circular grouting method can be used to prevent seepage according to the seepage amount.

![Figure 10. Section of groundwater runoff variation during the subway construction process.](image)

② Tunnel anti-seepage consolidation grouting: This method is carried out in the tunnel. As the construction progresses gradually, it can be divided into two steps according to the strength of the rock mass permeability: (a) For the surrounding rock of tunnels of type IV and V with a permeability coefficient of $1.0 \sim 10$m/d, In the process of construction, 3~5 pilot water exploration holes of 30~40m depth can be arranged along the axis of the hole or on the side near-surface water at an Angle of 5~10°. Find out the possible water gushing problem in the forward direction. If the amount of water is large, advanced water plugging and consolidation grouting should be carried out. The consolidation grouting holes are arranged radially along the axis on the support surface and the hole depth is 35~40m. As shown in Figure 11, the grouting is segmented from the inside to the outside. If there is a large amount of water inflow, the karst pipeline can cut off by a mold bag or a cable bag and then grouting and consolidated. After the preliminary consolidation is completed, the water-stop grouting is visualized during the tunneling process. The size of the seepage volume determines further treatment measures. If the seepage volume is large, the surrounding rock of the annular section of the tunnel can be grouted twice every 10m. The depth is generally controlled in the range of 6~8m. The number of holes can be appropriately dense on the side close to the surface water. The grouting depth can be a large value. (b) For Type Ⅱ and Ⅲ surrounding rocks with permeability coefficient of 0.01~0.1m/d, if the seepage volume is small, the general equipment can be drained without treatment. For the class III and IV rock mass with slightly larger water seepage, annular consolidation grouting can be carried out for every 10m section of the vertical tunnel axis during the construction period, and the grouting holes can be properly encrypted in the part with large seepage. After the grouting treatment, the permeability coefficient of the consolidated body through the water pressure test is generally 0.02~0.05 m/d.
Figure 11. Schematic diagram of advanced anti-seepage grouting for whole tunnel section in strong permeable stratum.

(2) Deep foundation pit project

a. For deep foundation pit projects, the main consideration is the surface water flows backward during the construction period and the balance of groundwater recharge in the later period. Treatment measures can be comprehensively considered based on the surface water and groundwater runoff, recharge relationship, and the location of the foundation pit project. In general, appropriate treatment measures can be taken according to the upstream and downstream locations.

b. Engineering treatment measures

When the foundation pit project is located on the upstream side of the surface water recharge, the treatment principle should consider the problem of surface water flow backward and later period recharge sources. From the perspective of inversion treatment, it can be carried out according to the "anti-seepage curtain" scheme in the above-mentioned underground line engineering treatment. Considering that it will not affect the recharge of groundwater to the surface water in the later stage, blind ditch interception and drainage should be set up on the water surface and both sides of the foundation pit. The elevation of the bottom of the blind ditch is 1.0~2.0m below the base level of underground runoff, and the ditch is filled with permeable materials to lead the upstream groundwater to the surface water along the drainage ditch beside the foundation pit, without affecting the recharge and drainage relationship of groundwater and surface water. When the foundation pit project is located on the downstream side of the surface water, the impact of groundwater can be ignored. In terms of treatment measures, if the rock mass is broken and the water permeability is strong, and "anti-seepage curtain" can be set. If the permeability coefficient of the rock mass is less than 0.05m/d, anti-seepage treatment is not necessary, and the groundwater level will gradually recover after the construction and backfilling treatment, and it will not have a large impact on the surface water and landscape.

6.1.2. Treatment of projects cross the surface water. Generally, underground projects that cross the surface water are mainly linear highway tunnels, subways, and city pipe systems. This paper mainly in view of the mountain city subway, municipal tunnel crosses small lakes and rivers, commonly used open excavation and underground excavation method may be produced by surface water flow backward some have effectiveness stronger engineering treatment measures.

(1) Treatment of open-cut excavation method

For shallow-buried underground linear underground projects, the open-cut method is generally used when crossing the surface water. The advantage is that it can effectively avoid the collapse caused by the thin and poor integrity rock mass of the tunnel crown. However, it is necessary to solve the impact of surface water flow backward. In terms of engineering treatment measures, water-proof cofferdams can be installed in the range of 10-20m outside the excavation boundary of the project to divert surface water, and the waterproof cofferdam and the lower rock mass can be grouted together with anti-seepage.
In general, it can be set up 2~3 rows of grouting holes, the row spacing of grouting holes 1.5 m, the grouting curtain is 5~8m deep into the bottom of the tunnel, and the top is slightly higher than the water level of the surface water.

(2) Treatment of underground excavation method

For linear underground projects with a buried depth of more than 20m, the excavation quantity of open excavation is relatively large and uneconomical, and the underground excavation method is generally used for the construction. The treatment measures can be divided into two categories.

a. Ground sealing + consolidation grouting anti-seepage method: Cofferdams can be set on the surface of the tunnel excavation boundary within a range of 8~10m to clear alluvial and silt layers at the bottom of river beds or lakes, then grouting holes are arranged in a plum blossom pattern with a row spacing of 1.5m, and the bottom grouting is 5~6m below the bottom elevation of the tunnel. After the grouting curtain is completed, 0.5~1.0m thick C20 concrete is poured on the surface for sealing treatment. After all anti-seepage work is completed, tunnel construction can be carried out, as shown in Figure 12.

b. Tunnel consolidation grouting anti-seepage method: The specific measures are the same as the above-mentioned linear underground engineering near-surface water treatment measures, and will not be described in detail.

![Figure 12](image.png)

**Figure 12.** Schematic diagram of the treatment to prevent the river flow backward during the underground excavation tunnel cross the river.

6.2. Treatment of groundwater

Before the groundwater treatment is carried out, it is necessary to find out the groundwater's impact protection object, location and runoff recharge and discharge relationship according to the aforementioned requirements, and make a targeted engineering treatment plan.

6.2.1. Treatment of phreatic groundwater. (1) For linear underground projects:

When the local underground water depth is shallow and the project buried depth is large, the general situation is mainly to consider the treatment of tunnel water gushing during the construction period. The impact on the relationship of underground runoff recharge and drainage is mainly during the construction period. After the completion of the project, the original state can be restored. In principle, the treatment can be carried out in accordance with the tunnel anti-seepage consolidation grouting method. When the groundwater and the buried depth of the project are both shallow, the treatment method of water cut-off and draining should be considered. Set up blind drains on the upstream side of the water surface and within 5~10m away from the project boundary. The elevation of the bottom of the ditch is lower than 1.5~2.0m of underground water level in the dry season. Set up a collecting well every 10~20m, and each collecting well is arranged with a drainage pipe that spans the underground line project to divert and drain the groundwater to the downstream to facilitate the later recharge and recovery.
of the groundwater. As for the cut-off, it is mainly the anti-seepage treatment during the construction of the tunnel. The anti-seepage consolidation grouting method can be used, but the range is best controlled within 8.0m, which has little effect on the recovery of groundwater in the later period.

(2) Foundation pit projects whose basement is below the groundwater level:
   a. For pulsating, linear, and stream-type groundwater, according to the direction of underground runoff, blind drains should be set up under the groundwater level on the upstream side and on both sides to lead the groundwater to the rock mass on the downstream side. In order not to affect the underground runoff, during the excavation of the foundation pit, anti-seepage consolidation grouting should be avoided as far as possible on the surrounding rock mass. A water collection well can be set in the base to pump groundwater into the rock mass and soil mass on the downstream side.
   b. For the groundwater and karst pipeline water in the fault fracture zone, the water mainly flows along the fault and karst pipeline, and the water volume is relatively large. Drain and drainage pipes or inverted siphon pipes should be installed on the upstream side of the water outlet to guide the fault zone water and karst pipeline water along the periphery or bottom of the foundation pit to the downstream fault zone and karst pipeline. Other seepage and gushing water can be drained through a collection well, and after the completion of the project, the groundwater environment will not be greatly affected.

(3) Pile foundation engineering:
   In the water-conductive fault zone and strong karst development area, there are often holes passing through the water-conductive fault and underground karst pipelines during the construction of the pile foundation project. The water flow varies from 5.0 to 100L/s. Sometimes the water flow can be seen or heard at the top of the hole. Under normal circumstances, most of the construction parties use steel sleeves to protect the walls and then carry out underwater concrete pouring. After the construction of many bored piles, water diversion faults and underground karst pipeline water are cutoffs, leading to downstream wells and springs dry up. The correct method is that first conduct a connection test to find out the relationship between the flow direction of groundwater and wells and springs in the water source protection area. Pipe holes in karst areas should be backfilled with water-permeable blocks, and the upper part should be poured with C15 or C20 concrete. The pile foundation needs to be crossed or avoided, as shown in Figure 13. When the buried depth is relatively shallow, open trench excavation and burying of water diversion pipes can also be used. In short, the treatment measures are based on the principle of not cut off water channels and karst pipes.

![Figure 13. Schematic diagram of pile foundation karst pipeline treatment.](image)

6.2.2. Treatment of confined groundwater. The confined groundwater located between the two water-impermeable layers has the characteristics of a high water head and large water volume. When the underground project passes through or cuts through the upper impermeable stratum, a large number of water gushing may occur of the tunnels and foundation pit. Engineering treatment should be based on the principle of not cut off the confined water runoff path, effectively preventing water gushing, and ensuring safe construction.

(1) Linear underground engineering
When a tunnel project passes through a confined aquifer, the main engineering hazard is high-pressure water gushing. In the case of ascertaining the aquiclude and confined aquifer thickness, water head elevation, and rock permeability, high-pressure consolidation grouting can be used to prevent seepage treatment on the surrounding rock of the tunnel. According to the different locations of engineering treatment, it can be divided into ground consolidation grouting and tunnel consolidation grouting, which are described as follows:

a. Ground high-pressure anti-seepage consolidation grouting: According to the plane position of the linear underground project, high-pressure consolidation grouting is carried out in the tunnel and surrounding rocks mass along the axis of the tunnel and vertically downwards from the ground. In general, the range of grouting should be extended to 6~8m outside the boundary of the tunnel, and the grouting boreholes should be arranged in a row spacing of 1.5~2.0m in a plum blossom pattern on the plane. The grouting sequence can be divided into first stage hole and second stage hole interval construction grouting. As shown in Figure 10, the grouting pressure, water-cement mix ratio, admixture, etc. can be determined according to the grouting test. After the completion of grouting, the core pulling test and water pressure test should be carried out. If the grouting does not meet the requirements, reinforcement grouting should be carried out. Tunnel construction can be carried out after the completion of all anti-seepage work.

b. Tunnel anti-seepage consolidation grouting: The procedure of anti-seepage consolidation grouting the same as the above-mentioned grouting procedure of tunnels near-surface water, and will not be described in detail.

(2) Deep foundation pit project

During the excavation of the foundation pit, there may be a large amount of water gushing through the upper water-proof layer of the confined aquifer, which may even endanger the stability of the foundation pit slope. Therefore, anti-seepage treatment is a very important project. The focus is on the bottom of the foundation pit and the surrounding walls. In the case of ascertaining the thickness of the aquiclude, the confined aquifer, the elevation of the water head, and the water permeability of the rock mass, the high-pressure grouting method can be used to consolidate the aquifer around and at the bottom of the foundation pit. The anti-seepage curtain can be divided into ground consolidation grouting and foundation pit consolidation grouting according to different engineering treatment positions, which are described as follows:

a. Ground grouting treatment: Before the excavation of the foundation pit, grouting boreholes shall be arranged in a plum blossom pattern with a row spacing of 1.5~2.0m on the ground. The grouting shall be 4.0~6.0m away from the outer boundary of the foundation pit on the plane. The periphery of the foundation pit on the facade should be connected with the upper impermeable stratum and enter the impermeable layer 2.0~3.0m. The bottom of the foundation pit should be 5.0~6.0m deep below the foundation. As shown in Figure 14. To ensure the quality of grouting during the grouting construction process, the grouting holes should be divided into phase one and phase two to construct the grouting. The grouting sequence is from bottom to top. After the grouting work is completed, the drilling core-pulling inspection and water pressure test should be carried out, when the water permeability is less than 0.03m/d, foundation pit excavation can be carried out.
b. Grouting treatment in the foundation pit: When the local grouting is restricted by the construction conditions, the grouting method in the foundation pit can be used for treatment. In this method, it is advisable to keep 5m away from the pit boundary when the foundation pit is excavated at a depth of 2.0–4.0 m. The grouting boreholes are arranged radially downwards and the diagonal sidewalls, as shown in Figure 13. The scope of grouting is the same as the above-mentioned ground grouting method. The facade shape is shown in Figure 15. The grouting sequence can be carried out from bottom to top and from deep to shallow. After the grouting work is completed, drill core-pulling inspection and water pressure test should be carried out, foundation pit excavation can be carried out after meeting the requirement of water permeability less than 0.03 m/d.

**Figure 14.** Schematic diagram of ground grouting treatment for foundation pit in confined aquifer.

**Figure 15.** Schematic diagram of grouting treatment in confined aquifer foundation pit.

7. Conclusion
According to the analysis, in the southern sedimentary rock distribution area, especially where the Karst phenomenon was highly developed, impacts on the surrounding water environment caused by different types of projects are concluded. For projects distributed in spots, the impacts are relatively minor, which is much easier to be treated. While, the impacts caused by projects distributed in a large expanse is considerable, where the water environment conditions can generally be recovered by targeted treatment measures. In terms of projects distributed in line, the design and treatment measures for groundwater restoration should be determined first as groundwater runoff conditions have been changed. The current treatment methods generally affect the underground environment by 50 to 70%. Since underground
engineering has a sensitive impact on the urban water environment, with a further study on the improvement of treatment measures, the ultimate goal is probably to reach 70 to 90% of the original state of the water environment.

References
[1] Huang Q B, Peng J B, Wang F Y, et al 2019 Issues and challenges in the development of urban underground space in adverse geological environment[J]. Earth Science Frontiers, (3): 85-94.
[2] Huang Q B, Yan C C Zhang X N, et al 2020 The impact of urbanization on groundwater quantity, quality, hydrothermal changes and Its countermeasures[J]. Advances in Earth Science, 35(5): 497-512.
[3] Liu S Z, Tian C, Zhu Z Y, et al 2019 Mechanism research and prediction warning of land subsidence in typical sections of the Yellow River delta[J]. Acta Geologica Sinica, (S01): 251-260.
[4] Kang H Z, Chen L, Guo Q Z, et al 2019 An overview of quantification of groundwater recharge in sponge city construction[J]. Earth Science Frontiers, 26(6): 58-65.
[5] Gao X B, Wang W Z, Hou B J, et al. 2020 Analysis of karst groundwater pollution in northern China[J]. Carsologica Sinica, 39(3): 287-298.
[6] Huang J M, Deng X W, Hu R Q 2015 The relationship between groundwater and ground collapse and land subsidence in Jinshazhou, Guangzhou city[J]. Chinese Geology, 42(1): 300-307.
[7] Chen Z Q, Hu Z. 2018 Major geotechnical engineering problems of rail transit project in Guiyang city[J]. Water Power, 44(7): 20-24.
[8] Yan X X, Yang T L, Lin J X, et al 2019 Influence factors analysis and calculation of land subsidence caused by dewatering of ultra-deep foundation pit[J]. Journal of Nanjing University (Natural Science), 55(3): 401-408.
[9] Zhu B Y, Yao F Y, Sun J W, et al 2020 Attribution analysis on land subsidence feature in Hexi Area of Nanjing by InSAR and geological data[J]. Geomatics and Information Science of Wuhan University, (3): 442-450.
[10] Di S T, Jia C, Zhang S P, et al 2020 Regional characteristics and evolutionary trend prediction of land subsidence caused by groundwater over exploitation in North Shandong of the North China Plain[J]. Acta Geologica Sinica, 94(5): 1638-1654.
[11] Su G F, Xu M 2019 Analysis of cyclic evolution condition of a karst water system in central Huaying mountain[J]. Carsologica Sinica, 38(2): 193-201.
[12] Zhang Y, Li S T, Jin X L, et al 2012 An analysis of the impact of linear engineering construction on groundwater flow field[J]. Journal of Glaciology and Geocryology, 34(5): 1200-1205.
[13] Hou G B, Kang J W, Feng X, et al 2016 Aanalysis on the effect of the groundwater environment of “the Taiyuan metro line NO.2 project”[J]. Environmental Engineering, (S1): 1108-1110.
[14] Gao Y, Liang C, Che Z G 2020 The influence of typical subway project in Nanjing on underground flow dynamics[J]. Science Technology and Engineering, 20(28): 11711-11717.
[15] Zhuang X F, Sun D 2016 Influence of tunnel construction on karst water: Case analyses[J]. Carsologica Sinica, 35(6): 681-687
[16] He S, Jiang L W, Zhang G T 2019 Influence of drainage on karst groundwater at an existing tunnel in the east-spring mountains, Chongqing[J]. Carsologica Sinica, 38(4): 496-501.