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Research article

Urban spatial sustainability landscape planning and design: A study on solving flood disasters in low-lying urban areas based on simulated natural drainage system

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ABSTRACT

This study explores the use of simulated natural drainage systems for sustainable urban landscape planning to address flood disasters in low-lying urban areas. Traditional drainage methods lack sustainability, whereas simulated natural drainage systems, such as green infrastructure, rain gardens, and wetland parks, can enhance urban flood resilience and environmental quality through scientific design and strategic layout. In San Francisco, the issue of flood disasters in low-lying areas has become increasingly severe, with traditional drainage systems struggling to effectively manage flood risks under extreme weather conditions. This study employs R programming to simulate natural drainage systems, evaluating their effectiveness in mitigating flood disasters and improving ecological environments. By utilizing rainfall data, topographic data, and drainage system data from San Francisco, a simplified hydrological model was constructed to calculate catchment areas and runoff, simulating the effects of natural drainage systems. Results indicate that natural drainage systems significantly reduce flood risks and enhance ecological benefits.

The findings provide urban planners with new flood management strategies, emphasizing the importance of integrated management and systemic thinking, and highlight the future potential for widespread application in urban planning. By integrating landscape design with water resource management principles, this study proposes a systematic solution validated through case studies in different cities, demonstrating its feasibility and effectiveness. This research offers new insights and methods for urban flood control engineering and landscape planning, contributing to enhanced urban disaster resilience and improved urban living environments. The simulation of natural drainage systems facilitates sustainable urban development, providing valuable references for the advancement of sustainable urban landscape planning.

Key words: Natural drainage systems; Sustainable urban landscape planning; Flood disaster management; Green infrastructure; Hydrological modeling

1. Introduction

1.1 Project background and the purpose and significance of the research

1.1.1 Research Background

In order to solve the flood disaster in low-lying urban areas, it is necessary to understand the causes of urban waterlogging and flood disaster first. Urban waterlogging refers to the serious water in the city within a specific time and space, resulting in inconvenient travel inconvenience and harsh living environment. Urban flood disaster refers to the failure of urban effective drainage under extreme rainfall or hydrological conditions, leading to large areas of waterlogging phenomenon, and even causing flooding disaster.

These problems have had a serious impact on the sustainable development of the cities. Urban waterlogging and flood disasters will affect the quality of life of urban residents, resulting in travel difficulties and life inconvenience. Flood disaster may also lead to damage to urban facilities and equipment, bringing huge losses to the urban economy. Floods may also cause environmental pollution and have a negative impact on urban ecosystems.

Therefore, it is of great practical significance to study how to solve the flood disaster in the low-lying urban areas by simulating the natural drainage system. Through the rational planning and design of urban space, the construction of a more effective natural drainage system can improve the flood fighting and drainage capacity of the city, and ensure the living safety of urban residents and the sustainable development of the city.

1.1.2 Purpose and significance

The purpose of this study is to explore the use of simulated natural drainage system to solve the flood disaster problem in low-lying urban areas. With the acceleration of urbanization, urban construction often ignores the impact on the natural water circulation system, leading to frequent flood disasters in low-lying urban areas. The simulated natural drainage system can effectively mimic the natural water circulation system, slow down the flow rate of rainwater, and improve the hydrological capacity in urban areas, thus reducing the damage of flood to the city.

This study has important value and significance for the landscape planning and design of urban spatial sustainability [1]. By introducing a simulated natural drainage system, we can improve the water environment quality in urban areas, improve the hydrological adaptability of urban green space, and increase the stability of urban ecosystem. By solving the problem of flood disaster in low-lying urban areas, the urban disaster resistance ability can be improved, the economic loss caused by the disaster can be reduced, and the life and property safety of urban residents can be guaranteed. The introduction of a simulated natural drainage system can also improve the urban landscape, improve the quality and sustainability of the urban space, and lay a good foundation for the sustainable development of the city.

1.2 Development status at home and abroad

1.2.1 Status of foreign development

In foreign countries, some advanced countries have carried out a lot of research and practice on urban flood disaster control. For example, European countries widely apply green infrastructure in urban planning, using ecosystem services to improve urban drainage capacity. The Netherlands has effectively reduced the occurrence of urban waterlogging and flooding by building rain gardens, wetlands and green roofs. Japan has effectively responded to the problem of urban flooding by establishing a comprehensive drainage system and raising the awareness of disaster prevention.

However, the foreign research results are not fully applicable when applied to Chinese cities. There are many differences between cities in China and foreign countries. For example, the large number of cities in China develops fast, and the process of urbanization is often accompanied by environmental damage and resource consumption. Therefore, how to combine foreign experience and technology with the actual situation of China to effectively solve the flood problem in low-lying urban areas is still a challenge to be solved urgently.

1.2.2 Status of domestic development

In recent years, with the acceleration of urbanization process, frequent urban waterlogging and flood disasters have become an urgent problem to be solved. In China, relevant departments have issued a series of policies, regulations and governance measures, such as the Urban Flood Control Regulations, to improve the city's flood control capacity and reduce the losses caused by flood disasters.

However, there are still some problems and challenges in the implementation of the existing policies and measures. The lack of awareness of the terrain in the process of urban planning and construction has resulted in extensive construction in low-lying areas, increasing the load of surface runoff and drainage system, thus increasing the risk of flood disaster. Traditional artificial drainage systems often have insufficient drainage capacity and high operation and maintenance costs, making it difficult to cope with the challenges posed by climate change and extreme rainfall events.

1.3 Research content and technical route

1.3.1 Main Research Contents

In this study, we will solve the problem of flooding disasters in low-lying urban areas by simulating natural drainage systems. We will design urban spatial sustainability landscape planning to improve the urban flood fighting capacity and reduce the frequency of flood disasters. In this process, we will consider the urban topography, rainfall conditions, soil permeability and other factors, simulate the drainage system through the mathematical model, optimize the urban spatial layout, and realize the effective drainage and water storage functions.

In order to better solve the problem of flooding in low-lying urban areas, we introduce the following mathematical formula to describe the operation of the urban drainage system:

$$\mathrm{Q} = \mathrm{C} \cdot \mathrm{A} \cdot \sqrt{2 \cdot \mathrm{g} \cdot h}$$

$QCAgh$ It represents the flow rate of the drainage system; the flow coefficient; the drainage cross-sectional area; the gravity acceleration; and the head height of the drainage system. This formula will help us to better understand and optimize the design of the urban drainage system.

1.3.2 Technical route

This study adopts the survey and analysis method and the design principle of simulated natural drainage system, through the field investigation and statistical analysis of the flood disaster in low-lying urban areas, determined the key influencing factors and proposed the corresponding solutions. In terms of simulating natural drainage system, we refer to the principle of water cycle in natural ecosystem and establish a model that comprehensively considers terrain, soil, vegetation and other factors.

We performed a detailed analysis of topography and soil characteristics in low-lying urban areas using GIS, and combined vegetation cover and rainfall data to identify the natural drainage potential of the area [3]. Then, we designed a set of simulated natural drainage system integrating rain, infiltration, water storage and vegetation maintenance. By simulating the water flow dynamics under different rainfall conditions, we optimized the design parameters, so as to improve the drainage efficiency and flood fighting capacity of the region.

2. Regional investigation and causes analysis of urban waterlogging

2.1 Introduction

In urban design and planning, road emission reduction design is an important link, which can effectively reduce urban rainwater runoff and alleviate urban waterlogging and water pollution problems. By simulating the natural drainage system and combining with the landscape planning and design, the flood disaster in the low-lying urban areas can be better solved.

We need to investigate the occurrence area of urban waterlogging to understand its causes and influencing factors. Urban waterlogging is usually caused by poor drainage system design, soil erosion in the process of urbanization, aging infrastructure and other factors, which need to be solved through comprehensive planning and design. The simulated natural drainage system can simulate the hydrological cycle of the natural ecosystem, effectively treat and utilize the rainwater through rainwater collection, leakage and water storage, and reduce the occurrence of urban waterlogging.

We need to combine landscape planning and design to create an urban space with ecological beauty. Through the arrangement of green vegetation, rainwater garden, rainwater wetland and other landscape elements, the collection and treatment of rainwater are incorporated into the urban landscape to realize the sustainable utilization of rainwater resources. This can not only improve the quality of urban environment, improve the quality of life of citizens, but also can effectively reduce the occurrence of urban flood disaster.

2.2 Investigation of urban waterlogging occurrence area

In the process of investigating the urban waterlogging occurrence area, we first selected several typical cases located in the low-lying area of the city. These areas often experience floods when the rainfall is heavy, which brings a lot of trouble to the life and work of local residents.

Through field trips and data analysis, we found that these waterlogging occurrence areas have some common characteristics. The geographical location is in the downstream of the city, water accumulation, easy to cause water. The terrain of these areas is relatively low-lying, without a good drainage system, so that rainwater cannot be eliminated quickly. Urban construction planning and fossil-chemical degree also have a certain impact on the waterlogging problem.

In the investigation, we used field measurement, remote sensing image analysis and other methods to fully understand the situation of urban waterlogging areas. Through the comprehensive analysis of terrain, soil texture and urban construction, the main causes and mechanism of waterlogging are revealed.

2.3 Analysis of the current situation of the study area

2.3.1 Assessment of waterlogging risk level

Based on the available data and field surveys, we assessed the waterlogging risk level in the study area. In the low-lying urban areas of the study area, waterlogging risk was high due to aging drainage facilities and rapid urbanization. Through the evaluation and analysis of the flood depth, flood quantity and other indicators, we found that when the rainstorm hits, the flood depth in some areas can reach more than 1 meter, and the flood amount exceeds the designed drainage capacity, resulting in the road area water, affecting the traffic and residents' life [4].

Through the waterlogging risk level assessment, we recognize the inadequacy of the existing drainage system, and effective measures are needed to solve the flooding problem in low-lying urban areas [5]. Based on the concept of simulating the natural drainage system, we propose a series of landscape planning and design schemes, including building rainwater garden, building ecological wetland, building permeable pavement and other measures [6]. These measures can not only effectively control the waterlogging problem, but also improve the quality of the urban environment and improve the quality of life of the residents.

2.3.2 Point overflow situation

Node overflow refers to the phenomenon in which the rain water and sewage mixture overflows to the surface through the drainage outlet or sewer because the rain water exceeds the carrying capacity of the drainage system. Node overflow is one of the main causes of urban waterlogging, especially in low-lying areas or areas with aging drainage systems.

In the investigation, it is found that the drainage facilities in many cities in China are built early, and the drainage pipe aging is serious, resulting in the obvious shortage of drainage capacity. In addition, the accelerated urbanization process, a large number of cement roads and buildings reduce the permeability of the land, making rainwater unable to quickly penetrate into the ground, exacerbating the problem of urban waterlogging.

In addition to the aging existing drainage facilities, some infrastructure policies also failed to keep up with the needs of urban development, causing the drainage system to meet the increasing drainage demand [7]. Therefore, it is necessary to update and optimize the urban drainage system to improve its carrying capacity and reduce the occurrence of urban flood disaster [8] from the source.

2.3.3 Assessment of pipeline carrying capacity

According to the assessment of the pipeline carrying capacity in the studied area, it was found to be seriously insufficient [9]. In the process of urbanization, the pipeline system can not keep up with the expansion of urban development speed and scale, resulting in the drainage pipe network is not enough to deal with the flood disaster caused by extreme rainfall [10]. This is also one of the main reasons for the continuous waterlogging in the low-lying areas of the city.

Further analysis shows that the lack of pipeline carrying capacity directly affects the drainage effect. During the heavy rainfall, the drainage system cannot discharge the water in time, resulting in a large area of waterlogging [11] in the low-lying areas of the city. The aging and blockage problems of drainage pipes also aggravate the deterioration of waterlogging conditions.

To solve this problem, a simulated natural drainage system can be considered to solve the flood disaster [12] in low-lying urban areas. By simulating natural ecosystems such as wetlands and rainwater gardens, guiding the infiltration, storage and purification of rainwater, reducing the dependence on the drainage pipe network, so as to improve the drainage effect and reduce the risk of waterlogging [13].

2.3.4 Waterlogging simulation results

The waterlogging simulation results showed that the main causes of waterlogging in the study area include accelerated urbanization, increased ground coverage, and aging of sewer drainage system [14]. Under heavy rainfall conditions, rainwater cannot be discharged quickly, resulting in severe [15] waterlogging in low-lying areas. At the same time, a large number of cement, asphalt and other hard covers in the process of urbanization affect the penetration capacity of surface water, and aggravate the waterlogging situation [16].

Based on the genetic analysis, this study proposes a set of landscape planning design scheme based on simulating natural drainage system, aiming to mitigate and solve the flood disaster [17] in low-lying urban areas by simulating natural geomorphological features and hydrological circulation system. The planning and design includes the establishment of reservoirs, wetlands, artificial lakes and other water bodies to increase the storage and penetration of surface water, and through the selection and layout of vegetation, improve the permeability of soil, promote rainwater circulation and groundwater regeneration [18].

The planning and design also takes into account the sustainable development of urban space. By improving the green coverage rate, introducing landscape ecological elements and other measures, to create an eco-friendly urban landscape, improve the quality of urban life and the overall carrying capacity of the environment [19]. By simulating the natural drainage system, we can more effectively respond to urban floods and provide technical support and solutions for the sustainable development of cities [20].

2.4 Analysis of urban waterlogging

The causes of urban waterlogging are various, mainly including rainfall characteristics, the problems of urban drainage system, water blockage and other factors. Urban rainfall characteristic is one of the important causes of waterlogging. In a short period of time, sudden heavy rain, the urban drainage system is difficult to discharge rainwater in time, resulting in the water gathering in low-lying areas, forming waterlogging.

Problems in the urban drainage system are also an important cause of waterlogging. With the acceleration of urbanization, the construction of urban drainage system lags behind, and the problems such as aging drainage pipes and poor dredging become increasingly prominent, leading to the obstruction of rainwater discharge and increasing the probability of waterlogging.

Water blockage is also one of the common causes of urban waterlogging. Sewers and rivers in cities are often blocked by debris, resulting in poor drainage and rainwater cannot be discharged quickly, increasing the risk of waterlogging.

These factors interact and influence each other, aggravating the occurrence of urban waterlogging. Therefore, in order to solve the flood disaster in low-lying urban areas, it is necessary to start from many aspects, including optimizing the urban drainage system, strengthening the rainwater management, cleaning up the water blockage and other measures. At the same time, using the simulated natural drainage system and the combination of urban spatial planning and design with the natural drainage system can effectively reduce the risk of urban waterlogging and ensure the sustainable development of the city.

2.5 Existing challenges

There are many challenges in urban waterlogging control. The existing urban planning lacks the consideration of waterlogging problems, resulting in the low-lying urban areas vulnerable to flood disasters. The urban drainage system is seriously aging, the pipe network is complicated, and the drainage capacity is insufficient, which cannot effectively deal with the large amount of precipitation brought by the instantaneous rainstorm. Excessive use of urban land, a large amount of the ground hardening, increased the rainwater runoff, and further aggravated the waterlogging problem.

Therefore, the importance and urgency of studying the landscape planning and design of urban spatial sustainability based on the simulation of natural drainage system to solve the flood disaster in low-lying urban areas are prominent. By simulating the natural drainage system, such as the construction of green roof, ecological water system and rainwater garden, the city can effectively improve the flood disaster prevention capacity, reduce the risk of urban waterlogging, and improve the urban environmental quality and the living quality of residents.

Urban spatial sustainability landscape planning and design can also promote the restoration and protection of urban ecological environment, improve the quality of urban green landscape, and enhance the stability of urban ecosystem and anti-interference ability. Therefore, strengthening the research and implementation of landscape planning and design of urban spatial sustainability is of great significance for solving the problem of urban waterlogging, improving urban ecological environment and promoting urban sustainable development.

2.6 Basic principles of urban waterlogging control

The basic principle of urban waterlogging control is to make overall planning, comprehensive management and scientific design. Overall planning refers to that the terrain, terrain and drainage system of different regions should be taken into account in the urban planning, the functional areas of the city should be reasonably divided, and the setting of the drainage system should be taken into account in the design, so as to realize the overall water conservancy project planning. Comprehensive treatment refers to the use of various means to solve the problem of urban waterlogging, including improving the ground permeability, increasing the green coverage rate, optimizing the drainage system, etc., in order to comprehensively improve the waterlogging resistance capacity of the city. Scientific design refers to the adoption of scientific principles and technical means in the planning and construction process to ensure that urban drainage systems can operate effectively and adapt to the challenges of future climate change.

2.7 Empirical study -- A case study of San Francisco, USA

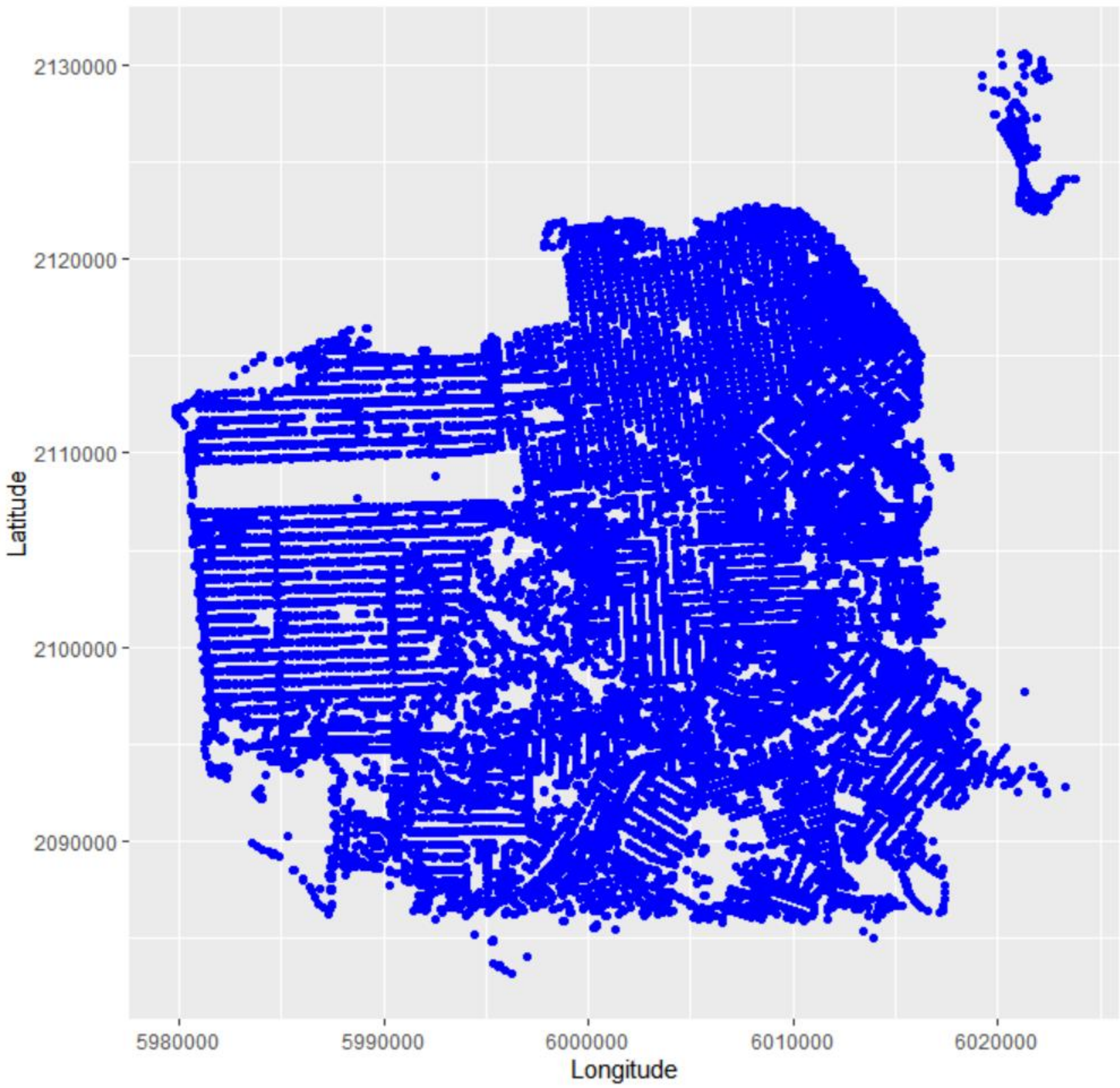

Figure 1 San Francisco Catch Basins

This Figure 1 shows the geographic distribution of outfalls, drains, and sumps in the City of San Francisco's drainage system. Each blue dot in the figure represents an element of a drainage system, such as a drain or sump. The points in the figure cover almost the entire San Francisco metropolitan area, indicating that the drainage system is widely distributed throughout the city. The points in the figure are denser in some areas, which may indicate that there are more drainage facilities in these areas, which may be areas with high rainfall or prone to waterlogging. The axes are labeled Longitude and Latitude, but the larger numbers indicate that a projective coordinate system (such as the UTM coordinate system) is used, rather than a geographic coordinate system (such as WGS84). The X-axis ranges from approximately 5980,000 to 6020,000, and the Y-axis ranges from approximately 2090,000 to 2130,000, and these coordinate values indicate the position of the City of San Francisco in the projected coordinate system. Types of drainage facilities: The types of drainage facilities in the data include outfalls and sumps, etc. Different types of drainage facilities may have different impacts on the performance of urban drainage systems.

Figure2 San Francisco Catch Basins by Type

Figure 2 shows the geographic distribution of different types of drainage facilities (such as outfalls, sumps, etc.) in the city of San Francisco. Different colored points represent different types of drainage facilities, and each type can be distinguished by the legend. The following is a detailed analysis of this chart: The legend shows up to 27 different types of drainage facilities, such as "Catch Basin Drain", "Caltrans A2 Drain Inlet", etc. Each type is represented by a different color. The distribution of each drainage facility can be visually seen through the color. Drainage facilities cover almost the entire San Francisco metropolitan area, which indicates that the city's drainage system is relatively uniform. In some areas, the green dots in the figure are particularly dense, indicating that there may be more "Catch Basin Drain" facilities in those areas. These may be areas of high rainfall or prone to waterlogging. On the edge of the city and in some specific plots, certain types of facilities such as "Drop Inlet" and "Drain Box" appear more frequently, which may be related to the topography of the area, land use and other factors. Facility density: Facility density is significantly higher in central urban areas than in urban fringe areas, which may be due to higher building density and population density in central urban areas, so more drainage facilities are required to handle stormwater runoff. Marginal areas have fewer drainage facilities, which may be related to the lower level of development in these areas. Functions and uses of facilities: Different types of drainage facilities may have different functions and uses. For example, "Catch Basin Drain" is primarily used to collect surface runoff, while "Caltrans GDO Combination Inlet" may be a multifunctional drainage facility. Understanding the specific functions of each facility helps to better plan and manage a city's drainage system.

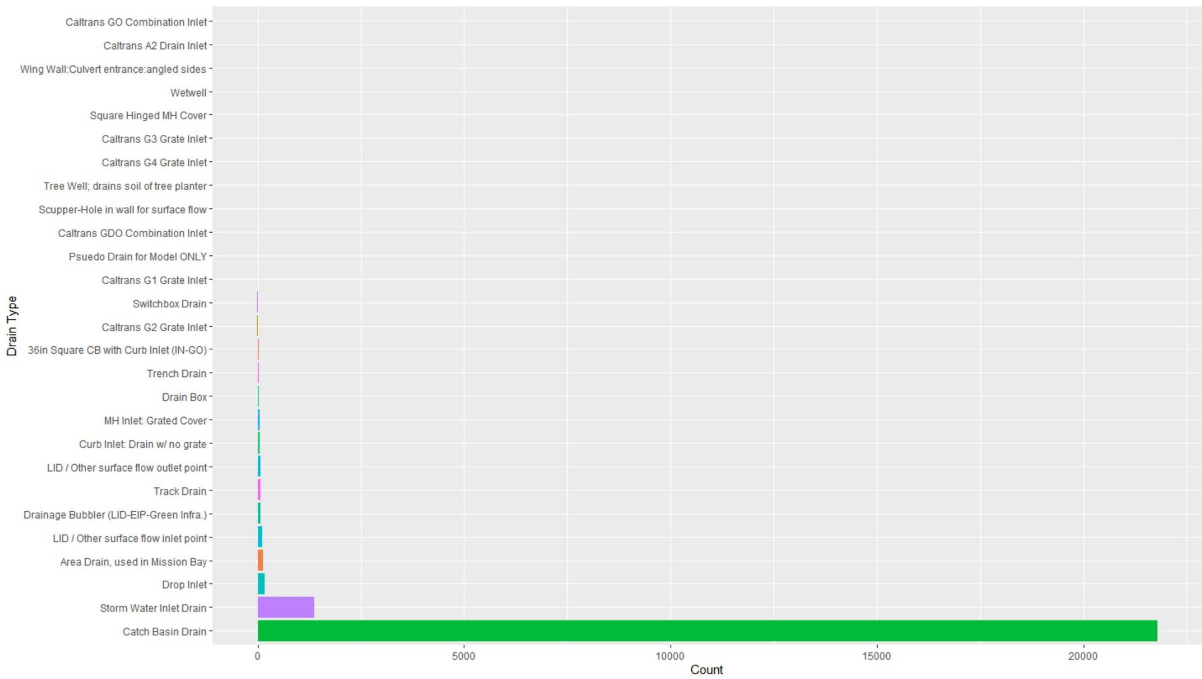

Figure 3 Number of Different Types of Drainage Facilities in San Francisco

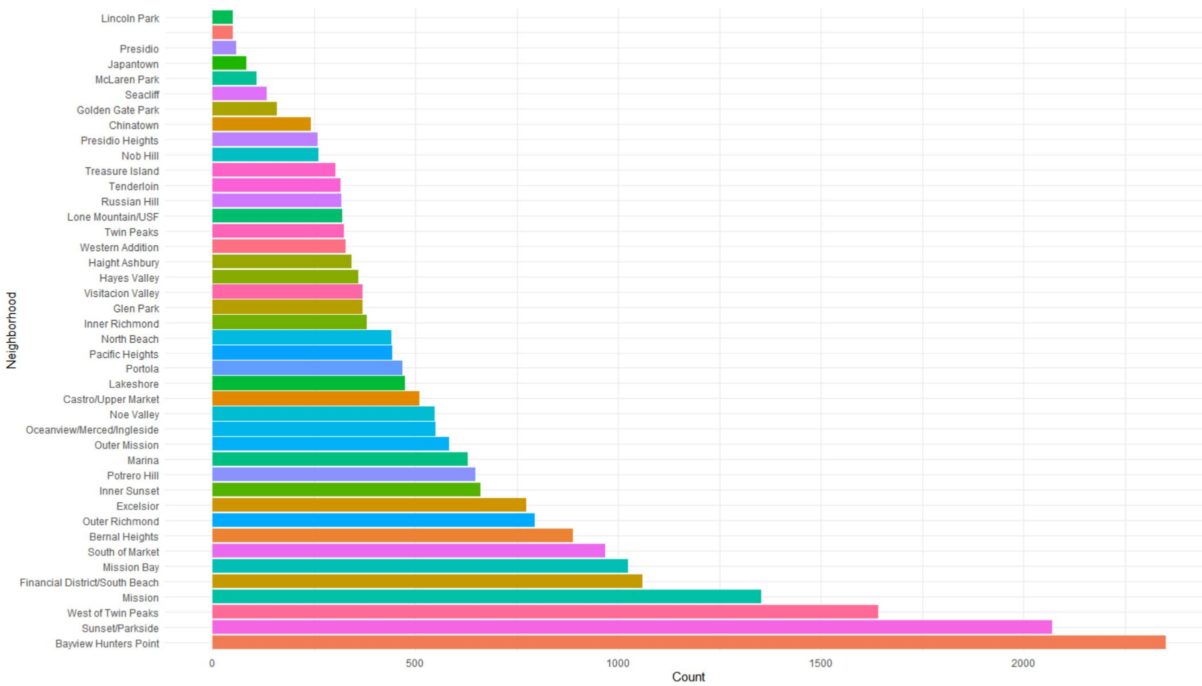

Figure 4 Number of Drainage Facilities by Neighborhood

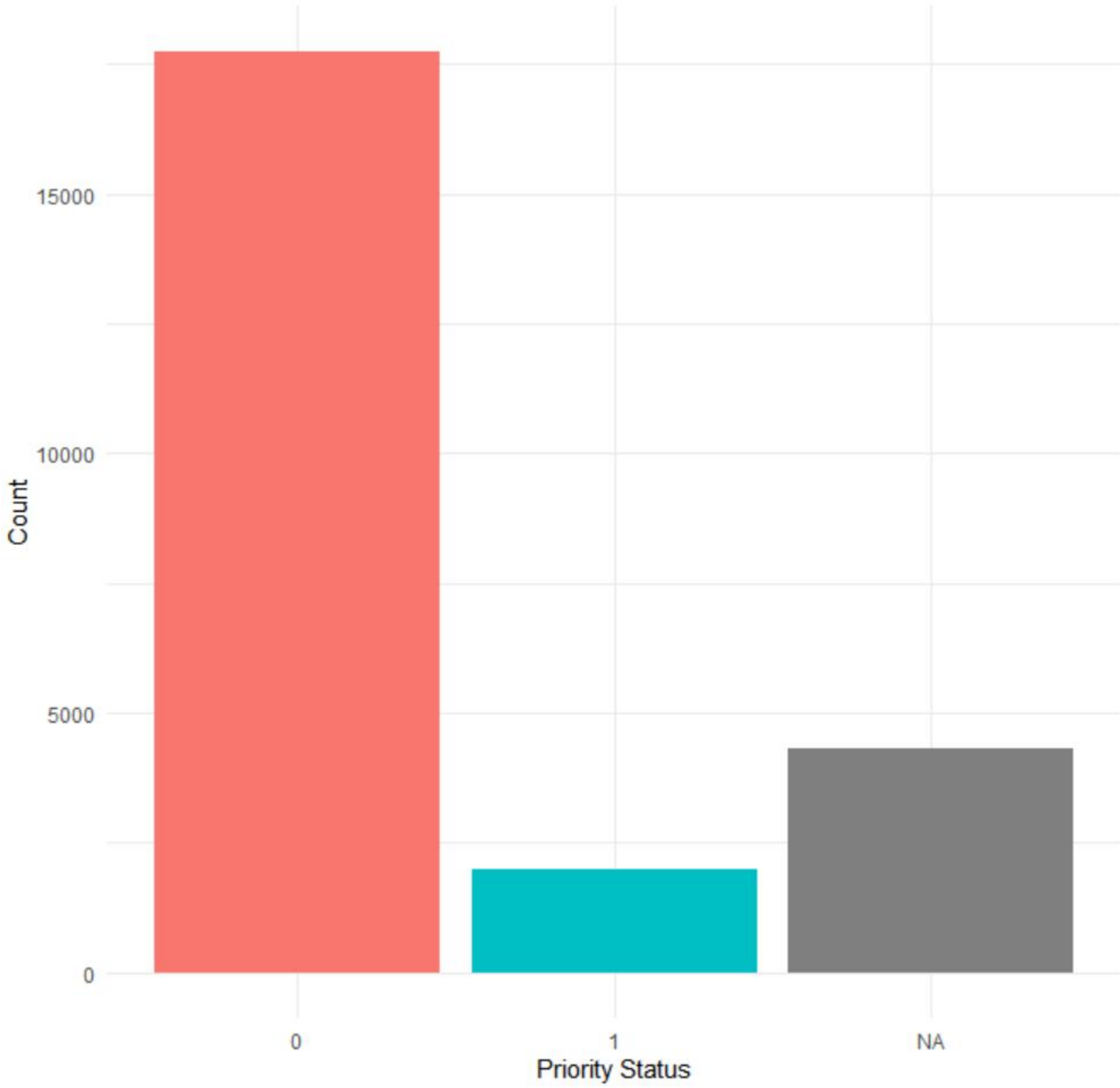

Figure 5 Number of Drainage Facilities by Priority Status

Figure 3-5 shows the number of different types of drainage facilities in San Francisco. The horizontal axis shows the number of different types of drainage facilities, and the vertical axis shows the type of drainage facilities. The following is a breakdown of the chart: Number of drainage facilities: Catch Basin drains are the most numerous, with more than 20,000. This indicates that this type of drainage is the most widely used in the city of San Francisco. Storm Water Inlet Drain also has a larger amount, but it is much smaller than Catch Basin Drain. Other types of drainage: With the exception of Catch Basin Drain and Storm Water Inlet Drain, the number of other types of drainage is relatively small. For example, the number of types such as Drop Inlet and Area Drain is relatively small and almost negligible.

Diversity of facilities: The City of San Francisco uses a variety of different types of drainage facilities in its drainage system, including various specifications of grid entrances, specific purpose drainage facilities (e.g. LID/ Green infrastructure), etc. This diversity may be in response to different terrain, rainfall, and urban planning needs. Widespread use of Catch Basin Drain: The widespread use of Catch Basin Drain in the city of San Francisco may be due to its efficient rainwater harvesting capabilities, which are suitable for stormwater drainage needs in most parts of the city. This type of facility can effectively prevent urban waterlogging and is easy to maintain and manage. The role of Storm Water Inlet drains: The high number of Storm Water Inlet drains indicates that they also play an important role in urban drainage systems, especially in areas with high rainfall or specific drainage needs. Such facilities are usually used to direct rainwater into underground drainage systems to prevent surface runoff from creating water accumulation. Specific uses of other facilities: Other types of drainage facilities, although less numerous, may have specific uses or be used in certain specific areas. For example, LID/ Green infrastructure type drainage facilities may be used for stormwater management and ecological conservation. Certain types of grid intakes may be used in heavily trafficked road areas to ensure the stability and durability of drainage facilities.

An analysis of the City of San Francisco's drainage system data shows the geographic distribution of different types of drainage facilities and their number within each area. According to the chart, "Catch Basin Drain" is the most common type of drainage facility, with more than 20,000 units, far exceeding other types of drainage facilities such as "Storm Water Inlet Drain". This suggests that catchment drainage facilities dominate the city of San Francisco's drainage system, likely due to their efficient rainwater harvesting capabilities and widespread applicability. The diagram shows the distribution of drainage facilities in different areas. It can be seen that areas such as "Bayview Hunters Point" and "Sunset/Parkside" have more than 2,000 drainage facilities, while areas such as "Lincoln Park" and "Presidio" have fewer than 500 drainage facilities. This suggests that the uneven distribution of drainage facilities in different regions may be related to regional geographical characteristics, rainfall and urban planning. The chart further shows the geographical distribution of drainage facilities, with green dots representing "Catch Basin Drain", which is widely distributed throughout the city, while other types of drainage facilities are relatively dispersed. Finally, the chart shows the priority distribution of drainage facilities, and the vast majority of facilities have a priority of 0, indicating that these facilities may not need urgent maintenance or repair. However, there is also a subset of facilities that have priority 1 and may require regular inspection and maintenance. Overall, the layout of the drainage system in San Francisco is relatively comprehensive, but there are still uneven distribution of facilities and maintenance needs in some areas, which provides important data support for urban management and planning.

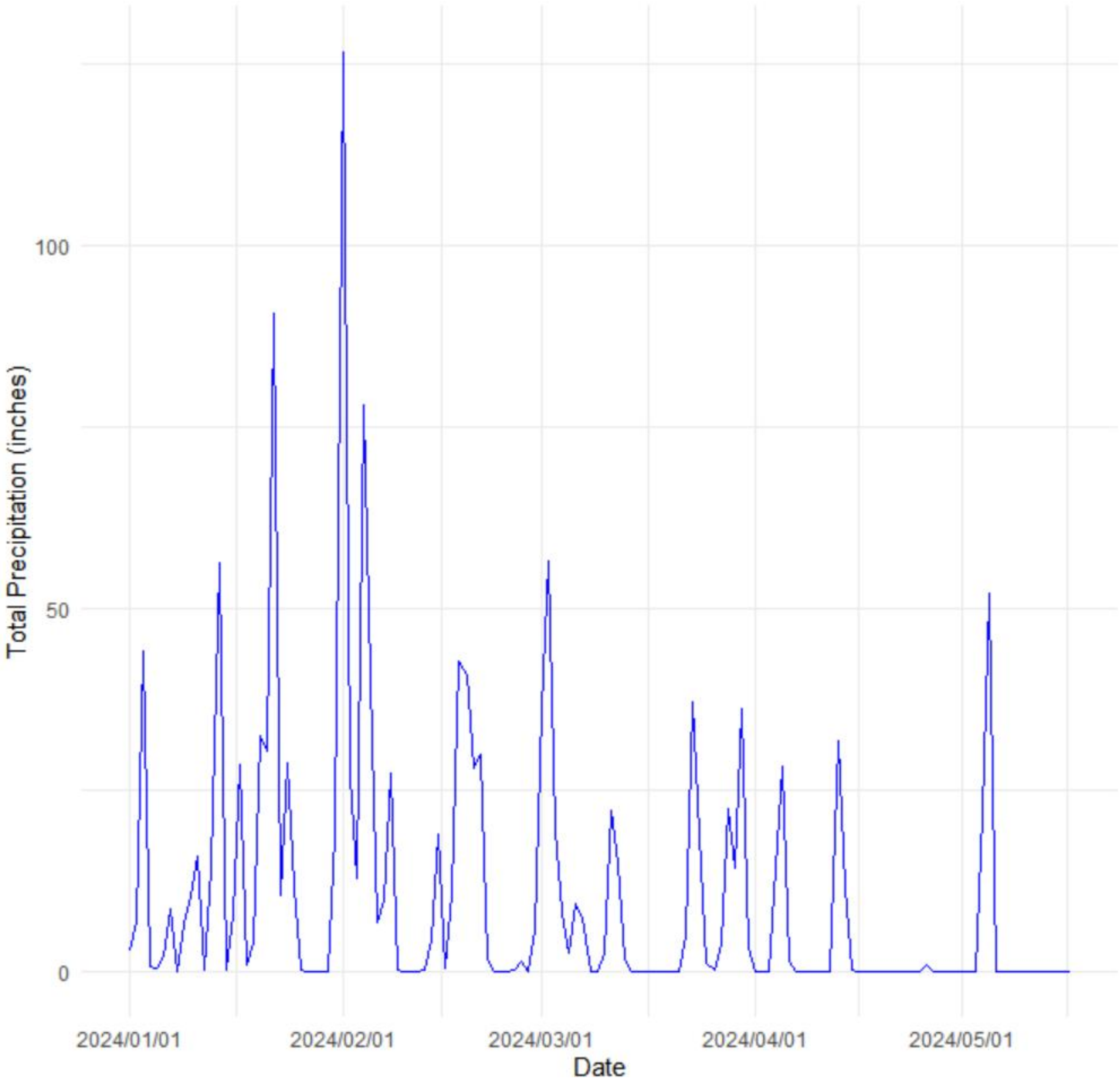

Figure 6 Daily Total Precipitation in San Francisco

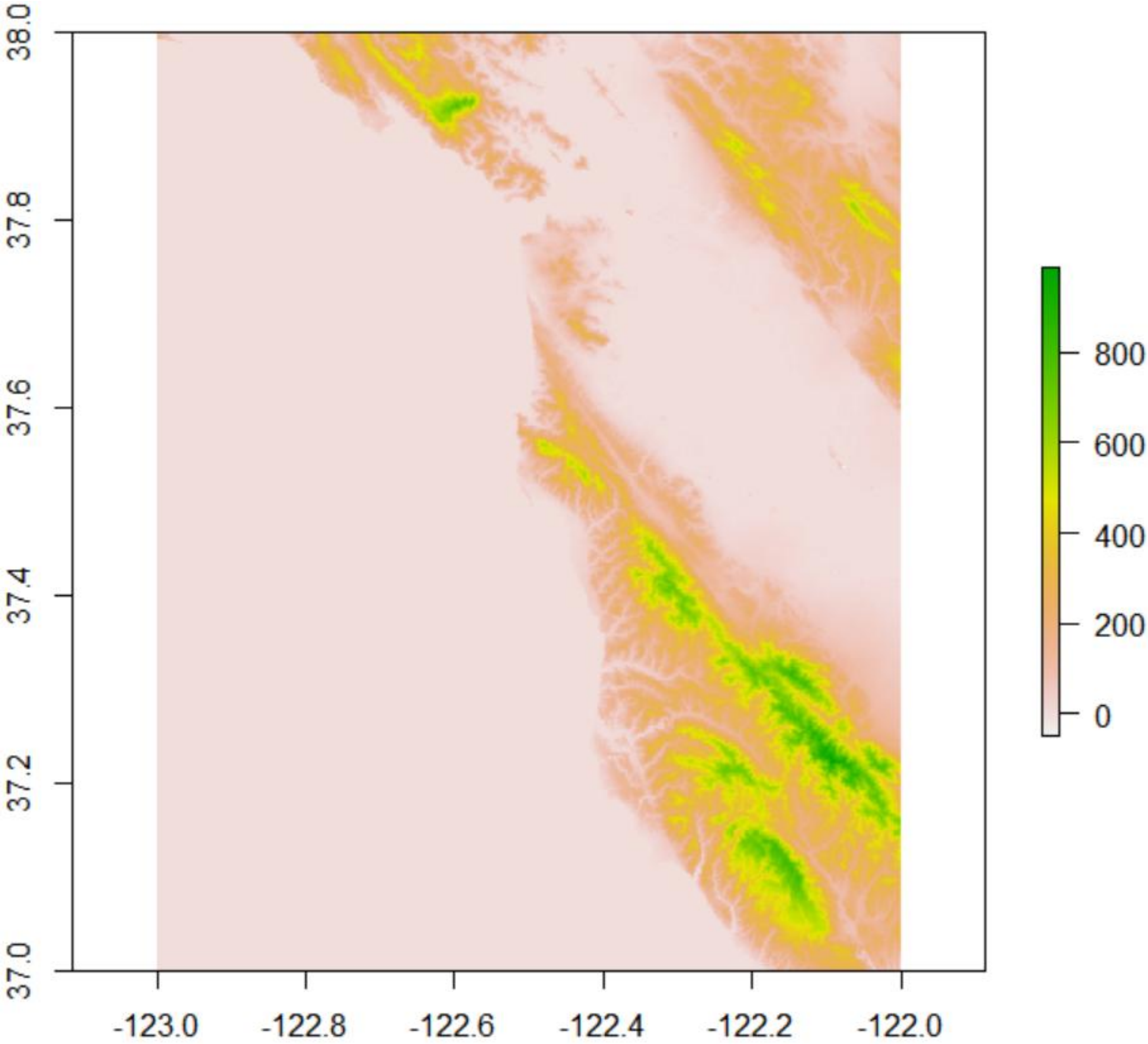

Figure 7 DEM of San Francisco

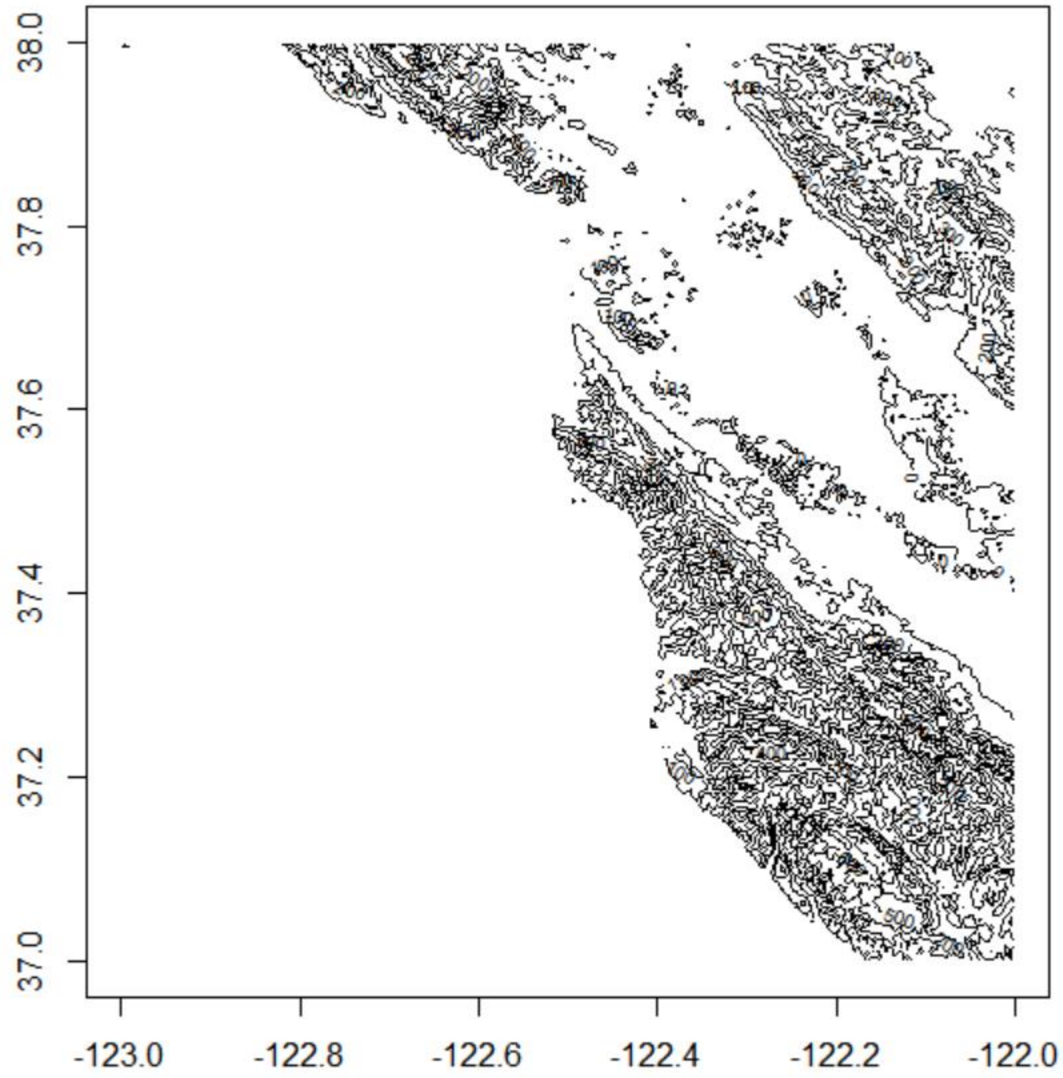

Figure 8 Contour Map of San Francisco

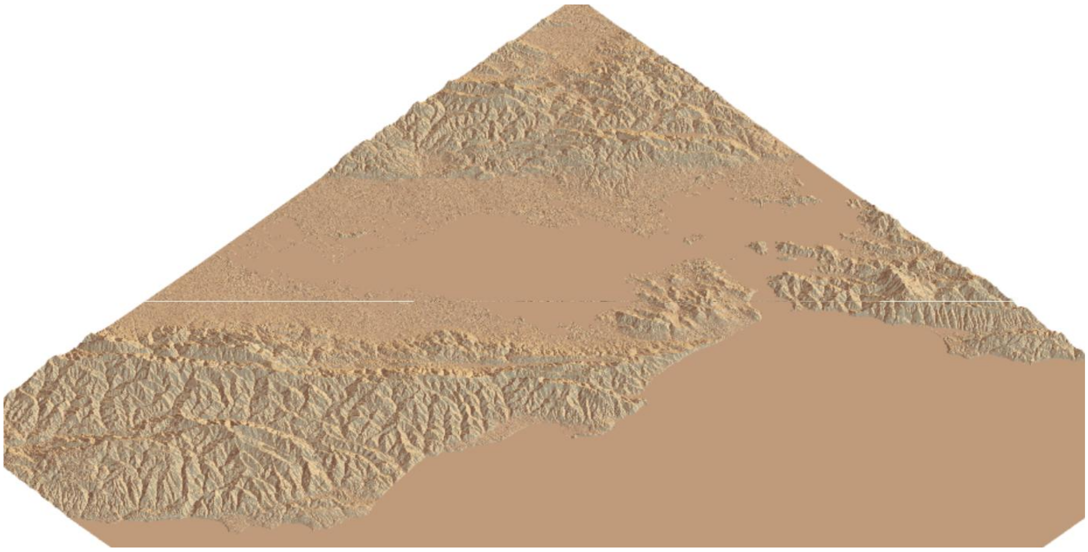

Figure 9 Topographic map of San Francisco

Figure 6-9 is a visual analysis of data collection, including Daily Total Precipitation in San Francisco, DEM of San Francisco, Contour Map of San Francisco and Topographic map of San Francisco.

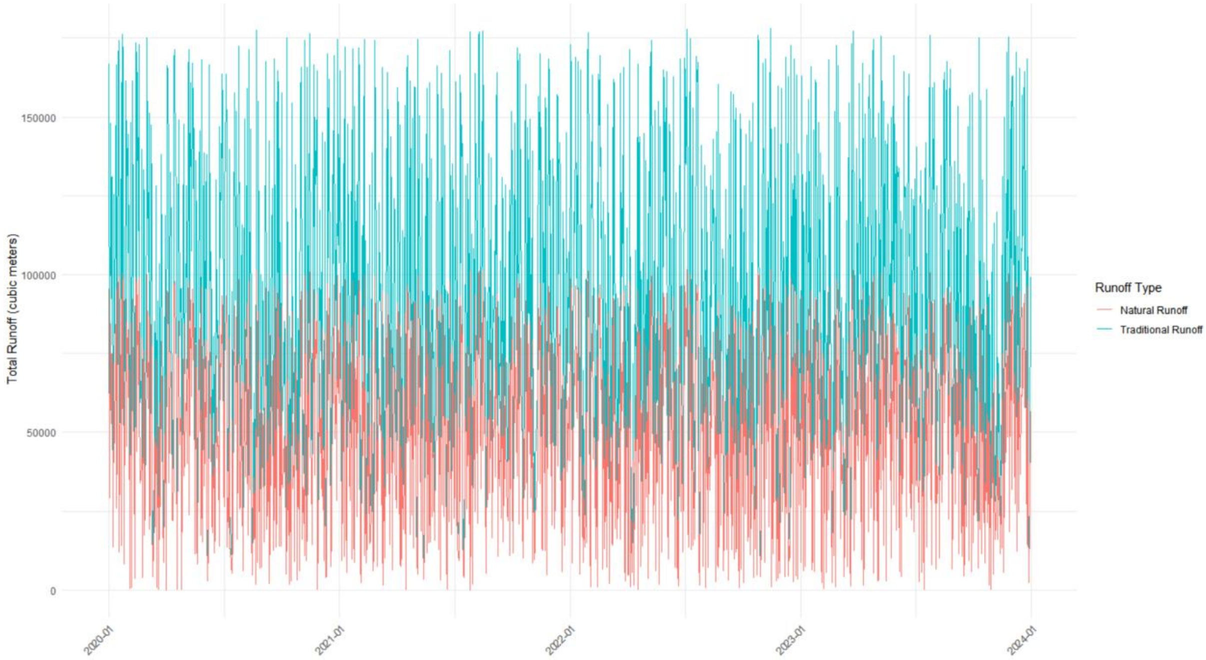

Figure 10 Comparison of Runoff Between Traditional and Natural Drainage Systems

Figure 10 shows the comparison of Runoff Between Traditional and Natural Drainage Systems, traditional drainage systems struggle to cope with the risk of flooding in extreme weather conditions. This study uses R language to simulate natural drainage system to evaluate its effect in mitigating flood disaster and improving ecological environment. Data and Methods This study used rainfall data, topographic data, and drainage system data for San Francisco to create a simple hydrological model that simulates the effects of natural drainage systems by calculating catchment area and runoff. The results show that the natural drainage system has a significant effect in reducing the risk of flooding. Through scientific design and rational layout, the flood control capacity and ecological environment quality of the city can be effectively improved.

2.8 Summary of this chapter

On the basis of regional investigation and origin analysis of urban waterlogging, we deeply discussed the importance of urban spatial sustainability landscape planning and design. By simulating the natural drainage system, we can effectively solve the flood disaster in the low-lying areas of the city, and realize the sustainable development of the urban space.

In urban planning and design, we should give full consideration to the integration of natural environment and urban construction to avoid the flood disaster caused by excessive development and man-made damage. The design of the simulated natural drainage system can effectively reduce the rainwater runoff, improve the soil water retention capacity, and prevent the occurrence of urban waterlogging.

At the same time, the landscape planning and design of urban spatial sustainability also needs to take into account the needs of human activities and the improvement of life quality. Through the rational distribution of green Spaces, wetlands and water systems, we can create a livable urban environment and improve residents' happiness and quality of life.

In general, the landscape planning and design of urban spatial sustainability based on the simulated natural drainage system is helpful to solve the flood disaster in the low-lying urban areas and realize the sustainable development of urban space. In the future, we still need to continue in-depth research and practice, and continue to explore more effective solutions, to make greater contribution to the sustainable development of the city.

3. Road emission reduction design

3.1 Road emission reduction facilities

In the landscape planning and design of urban spatial sustainability, road emission reduction facilities are a very important link. Common road emission reduction facilities include planting grass ditch, drainage channels and so on. Grass planting ditch is to use the water absorption of vegetation and soil to slow down the impact of rainwater on the urban drainage system by reducing the speed and quantity of rainwater runoff. The drainage channel is to introduce rainwater into the urban inland water body or underground reservoir, thus reducing the pressure of the urban drainage system.

These road emission reduction facilities play an important role in urban waterlogging control. They can effectively reduce the speed and amount of stormwater runoff into the drainage system, so as to effectively prevent the drainage system from overflow due to excessive rainfall. These facilities can reduce the possibility of urban waterlogging and improve the flood control capacity of the city. At the same time, road emission reduction facilities can also improve the environmental quality of the city, increase the urban green area, purify rainwater, and reduce the risk of water pollution.

3.2 Design

3.2.1 Design requirements

The design of discharge channel is one of the key to solve the flood disaster in low-lying urban areas. In the design process, the width and slope of the channel are very important considerations.

The width of the passage shall take into account the displacement and traffic requirements. The narrow width of the channel will lead to poor drainage, easy to cause water problems, and the wide width of the channel may occupy too much land resources. Therefore, the width of the channel should be reasonably planned according to the specific situation, considering both the drainage effect and the land use benefit.

The slope of the channel is also an important factor to consider in the design process. Too small slope will lead to poor drainage, too large slope may make the water flow too fast, resulting in soil erosion and soil erosion. Therefore, when designing the slope of the channel, the terrain, soil type, drainage requirements and other factors should be comprehensively considered to ensure that the slope of the channel can effectively promote the drainage flow, while protecting the soil from erosion.

3.2.2 Operating principle

Planting grass ditch is an important part of urban spatial sustainability landscape planning and design, and plays a key role in solving the flood disaster in low-lying urban areas. The operation principle of planting grass ditch mainly includes three mechanisms: interception, filtration and water storage.

Planting grass communicates with its special structure and vegetation, which can effectively intercept the particles and pollutants in the rainwater and prevent them from flowing directly into the sewers or rivers, thus reducing water pollution. Grass ditch can also play a filtering role, through the ditch planted vegetation and precipitated pollutants, so that the rainwater in the grass ditch is purified, improve water quality. The planting grass ditch can also play a role in water storage and delaying the discharge. The rainwater during the rainstorm is temporarily stored in the planting grass ditch and gradually released to the downstream to reduce the peak discharge and relieve the pressure of the urban drainage system.

The design of planting grass ditch not only considers its functionality, but also meets the requirements of landscape beauty, integrates into the urban environment, and coordinates and unifies with the surrounding buildings, roads, greening and other elements. Through reasonable design and layout of grass ditch, it can play its role in the drainage system, effectively solve the flood problem in low-lying urban areas, improve the sustainability of urban space, and create a more livable urban environment.

3.2.3 Geometry design and model construction

Road emission reduction design is the key to solve the flood disaster in low-lying urban areas. In the geometric design, the channel cross-section shape and slope control are considered to ensure the smooth operation of the drainage system. The cross section shape should be kept smooth, without obvious concave and convex, reduce the flow resistance, reduce the flow speed, avoid the water flow out of the channel. At the same time, the appropriate slope control, so that the water can flow to the drainage outlet, to avoid water. In order to better simulate the natural drainage system, the channel design should combine the natural terrain, retain and utilize the original water body and vegetation, increase the surface permeability, and reduce the runoff. The design is also an important part, which can effectively filter water quality and increase soil water retention, and improve the drainage effect. In the process of model construction, the length, width, height and other parameters of the channel, and the terrain and flow speed, and then the simulation analysis. By simulating the natural drainage system, the possibility of flood disaster can be better predicted, and timely measures can be taken to reduce the disaster loss. Therefore, studies based on simulated natural drainage systems in urban spatial sustainability landscape planning design are crucial for [21].

3.3 Design of the discharge channel

3.3.1 Design requirements

The discharge channel plays an important role in the urban hydrological circulation system, and can effectively alleviate the flood disaster in the low-lying urban areas. When designing the discharge channel, the width and slope of the channel should be considered to ensure its effectiveness and sustainability.

The width of the passage shall be sufficient to meet drainage requirements, usually greater than 3 m to ensure effective flow of displacement [22]. At the same time, the slope of the channel also needs to be reasonably designed, usually between 1% and 3%, to ensure the water flow into the drainage system [23]. Channel design should also consider the choice of materials, generally durable materials such as concrete or asphalt may be used to ensure their long-term stability and durability.

In addition to the design of the channel itself, the design of the drainage channel is also particularly important. The drainage outlets shall be located in place to ensure that the drainage system operates efficiently. The design of the drainage outlet should take into account the drainage efficiency and displacement, but also should consider the environmental factors, to avoid the impact on the surrounding environment.

3.3.2 Determine the surface discharge channel

When determining the design of the surface discharge channel, the overall layout of the urban planning and the environment should be taken into account. The location of the discharge channel needs to be determined, which requires considering the balance between the drainage system and the urban landscape. When choosing the location, the operation efficiency and aesthetics of the drainage system need to consider the ability to ensure that the drainage channel can drain effectively without affecting the overall appearance of the city.

The design of the drainage channel needs to take into account the changes of the terrain, especially in the low-lying areas, and the appropriate drainage system should be designed to effectively solve the problems caused by the flood disaster. By simulating the natural drainage system, the terrain can be effectively used to reduce the water flow speed and improve the drainage efficiency.

In the design of road emission reduction, the connection between the design of the road and the drainage system should also be considered. Reasonable design of the road slope and the location of the drainage system can effectively solve the problem of flood in the low-lying urban areas. Through the rational planning of road and drainage system, it can effectively improve the sustainability of urban space and reduce the impact of flood disaster on the city.

3.3.3 Determine the recurrence period

In the landscape planning and design of urban spatial sustainability, road emission reduction design is a key link. By setting up appropriate green space and permeable pavement, the rainwater can quickly penetrate into the ground, reduce the runoff and improve the water retention capacity of the soil, reduce the load of the urban drainage system, and reduce the risk of flood.

The design of the channel is also a very important link. According to the topographic characteristics and land use of the study area, drainage channels and water system network should be rationally designed to guide the rainwater to discharge smoothly into river or lakes and avoid the occurrence of water and waterlogging.

Consider rainfall characteristics and waterlogging risk level assessment in the study area. According to the historical rainfall data and the climate prediction model, the appropriate recurrence period is determined as the design standard to ensure that the landscape planning and design can effectively solve the problem of flood disaster in low-lying urban areas.

Landscape planning and design of urban spatial sustainability based on the simulated natural drainage system can effectively reduce the risk of urban flood disaster, and improve the urban disaster resistance ability and ecological environment quality. Through scientific planning and design, to create a safe, beautiful and livable urban space, to achieve the goal of sustainable urban development.

3.3.4 Hydraulic calculation

The design of the discharge channel is based on the actual situation of flood disaster in low-lying urban areas, which requires sufficient hydraulic calculation and analysis. The sectional shape and size of the channel need to be determined to ensure adequate drainage capacity. The flow speed and water level of the channel need to be considered to avoid excessive flow or overflow. The connectivity and overall layout of the channel also need to be considered to ensure that it can effectively guide and discharge rainwater.

In hydraulic calculation, the hydraulic characteristics of the channel, such as flow rate, flow rate and water level. Through numerical simulation and calculation, the maximum drainage capacity and the maximum carrying capacity of the channel can be obtained, and then the design parameters can be determined. The patency and durability of the channel will also need to be considered to ensure that no blockage or damage occurs during long-term use.

The hydraulic calculation and analysis of the drainage channel can provide scientific basis and technical support for the prevention and control of flood disaster in the low-lying urban areas. At the same time, it can also optimize the landscape planning and design of urban space, and improve the overall environmental quality and sustainable development ability of the city [24]. By simulating the natural drainage system, we can make better use of natural resources, reduce the dependence on the artificial drainage system, and realize the sustainable utilization and management of urban water resources.

3.3.5 Geometry design and model construction

In the landscape planning and design of the urban spatial sustainability, the discharge channel is an important link, which can effectively solve the flood disaster in the low-lying urban areas. The geometric design method of the discharge channel includes the channel cross section shape, slope control, etc. When designing the shape of the cross section, the flow characteristics of the channel should be considered. The cross section of the channel should be determined according to the design flow rate and water load to ensure that the channel has sufficient drainage capacity during the flood.

In terms of slope control, the slope of the channel needs to be determined according to factors such as length, height difference and topography. The slope control of the channel should not only ensure the drainage efficiency of the channel, but also consider the stability and safety of the channel. Too large the slope of the channel is easy to lead to too fast water flow speed, resulting in erosion and sedimentation, too small the slope will affect the drainage capacity of the channel.

3.4 Summary of this chapter

Road emission reduction design is an important measure. Through the rational design of road drainage system, the flood disaster caused by rainwater runoff to low-lying urban areas can be effectively reduced. Specific measures include setting up green belts and rainwater gardens, using ground permeable materials to build roads, increasing the infiltration of rainwater and maintaining the permeability of the surface, and reducing the discharge of rainwater runoff.

This chapter also introduces the simulation of natural drainage system as an effective method to solve flood disasters in low-lying urban areas. By simulating the natural hydrological cycle, natural ecosystems such as wetlands and green space are used to treat and store rainwater, the impact of rainwater runoff on the urban drainage system is reduced and the urban flood fighting capacity is improved.

Urban spatial sustainability landscape planning and design based on simulated natural drainage system is a feasible solution to effectively solve the problem of flooding disaster in low-lying urban areas. Next, we will further explore the implementation and effect of this design scheme, and provide theoretical support and practical guidance for improving the environmental quality of urban space and the living quality of residents.

4. Analysis of road emission reduction design effect

4.1 Introduction

In urban planning and design, road emission reduction design is an important measure, which can effectively reduce the discharge of urban pollutants and the pollution of water bodies. This chapter will focus on analyzing the effect of road emission reduction design to explore its application in improving the landscape planning and design of urban spatial sustainability. The design of road drainage system can not only improve the water environment quality inside the city, but also effectively reduce the occurrence of flood disaster.

In low-lying areas of the city, due to low-lying areas and imperfect drainage system, extreme weather such as heavy rain often causes severe floods. Therefore, taking measures to improve the road drainage system can effectively avoid or reduce the loss and impact of flood disaster to the city. By simulating the natural drainage system, using ground greening and permeable pavement measures, the road drainage system is transformed from a single drainage pipe network to a diversified natural drainage system, so as to realize the natural collection, infiltration and storage of rainwater.

4.2 Analysis of urban road drainage effect

4.2.1 point flood depth and flood volume

According to the design of simulated natural drainage system, we study the flood disaster in low-lying urban areas. We found significant changes in both node flood depth and flood volume under different design conditions. Through the implementation of the road emission reduction design, we have successfully reduced the flood depth and flood volume, effectively solving the waterlogging problem in the low-lying areas of the city.

Urban road drainage system plays a vital role in flood control. In our study, we found that the rationally designed road drainage system can effectively reduce the impact of flood on the road, improve the drainage effect of the roads, reduce the water accumulation phenomenon in the city, and effectively improve the urban ecological environment and the living quality of the residents.

In terms of the variation of node flood depth and flood amount, we found that the flood depth and flood amount are effectively controlled under the simulated natural drainage system design scheme. Through the implementation of the road emission reduction design, we have successfully reduced the node flood depth and flood volume, improved the flood fighting capacity in the low-lying areas of the city, and effectively reduced the impact of the flood on the city.

4.2.2 Carrying capacity of the pipeline

Road emission reduction design plays a vital role in urban drainage system planning. By adopting the design of permeable pavement, green belt and rainwater garden, the direct discharge of rainwater from the road can be effectively reduced, and the impact of rainwater on the urban drainage system can be reduced. However, the road emission reduction design can also affect the pipeline carrying capacity of the drainage system. Because the road emission reduction design will increase the permeability of the road surface, to some extent will reduce the speed and amount of the rainwater into the drainage pipe, resulting in the load of the drainage pipe, so as to improve its carrying capacity.

In the analysis of urban road drainage effect, the overall improvement effect of road emission reduction design on the drainage system should be considered. By assessing the retention and flooding of rainwater, a better understanding of its impact on the drainage system can be obtained. At the same time, the cost and maintenance difficulty caused by the emission reduction design also need to be considered to ensure the long-term stable operation of the drainage system.

4.3 Analysis of urban road drainage process

Through the simulation and analysis of urban road drainage process, we can better understand the effect of road emission reduction design in improving drainage efficiency. We simulated different emission reduction designs, including the addition of rainwater gardens, the permeable paving of rainwater gardens, and the establishment of an ecological rainwater garden filtration system.

The results show that these emission reduction designs can significantly improve the efficiency of road drainage compared to traditional drainage systems. Among them, increasing the rainwater garden makes the rainwater more absorbed by the soil, reducing the runoff and effectively purifying the rainwater. The establishment of rainwater garden permeable pavement and the establishment of rainwater garden ecological filtration system can further improve the drainage efficiency and reduce the occurrence of flood disaster.

We also analyzed the effects of these emission reduction design schemes under different rainfall conditions. The results show that these schemes are particularly prominent in heavy rain weather, which can effectively reduce the amount of rain water and drainage time, and reduce the risk of flood disaster.

4.4 Summary of this chapter

This chapter mainly studies the flood disaster in low-lying urban areas, and simulates the natural drainage system to solve the challenge of urban spatial sustainability. In the effect analysis of the road emission reduction design, we found that the frequency and extent of flooding can be significantly reduced by optimizing the road network and the rainwater discharge system. Through the application of the simulated natural drainage system, the urban green space and wetland space are effectively increased, and the natural water cycle and ecosystem function of the city are improved.

In the study of this chapter, we also analyze the effects of different landscape planning and design schemes on urban spatial sustainability. By simulating the natural drainage system, we combined the topographic characteristics, vegetation cover and land use planning to realize the effective utilization of urban water resources and improve the ecological environment. Through landscape planning and design, we can effectively reduce the harm of urban flood disaster to people's life and property, and improve the adaptability of urban space and disaster resistance ability [25].

5 Conclusions

This study explores the use of simulated natural drainage systems for sustainable urban landscape planning to address flood disasters in low-lying urban areas. Traditional drainage methods lack sustainability, whereas simulated natural drainage systems, such as green infrastructure, rain gardens, and wetland parks, can enhance urban flood resilience and environmental quality through scientific design and strategic layout. In San Francisco, the issue of flood disasters in low-lying areas has become increasingly severe, with traditional drainage systems struggling to effectively manage flood risks under extreme weather conditions. This study employs R programming to simulate natural drainage systems, evaluating their effectiveness in mitigating flood disasters and improving ecological environments. By utilizing rainfall data, topographic data, and drainage system data from San Francisco, a simplified hydrological model was constructed to calculate catchment areas and runoff, simulating the effects of natural drainage systems. Results indicate that natural drainage systems significantly reduce flood risks and enhance ecological benefits. The findings provide urban planners with new flood management strategies, emphasizing the importance of integrated management and systemic thinking, and highlight the future potential for widespread application in urban planning. By integrating landscape design with water resource management principles, this study proposes a systematic solution validated through case studies in different cities, demonstrating its feasibility and effectiveness. This research offers new insights and methods for urban flood control engineering and landscape planning, contributing to enhanced urban disaster resilience and improved urban living environments. The simulation of natural drainage systems facilitates sustainable urban development, providing valuable references for the advancement of sustainable urban landscape planning.

Main Findings and Contributions: This study found that natural drainage systems significantly reduce flood risks and enhance ecological benefits. The research highlights the effectiveness of green infrastructure, rain gardens, and wetland parks in improving urban flood resilience and environmental quality through scientific design and strategic layout. It provides urban planners with innovative flood management strategies, emphasizing the importance of integrated management and systemic thinking. These findings are particularly relevant for addressing severe flood disasters in low-lying areas like San Francisco, where traditional drainage systems fail under extreme weather conditions.

Recommendations for Future Research: Future studies should expand the scope to different climate conditions and geographic environments to validate the universality of natural drainage systems. Long-term studies are recommended to evaluate the performance of these systems over various time scales, including during extreme climate events. Further optimization of hydrological models, incorporating more variables such as soil permeability and vegetation cover, is necessary to enhance simulation accuracy. Additionally, assessing the socio-economic impacts of natural drainage systems, including cost-benefit analysis and resident satisfaction surveys, will provide a more comprehensive understanding of their effectiveness.

Implications for Urban Planning and Policy Making: Policymakers should prioritize the application of natural drainage systems in urban planning, supported by policies and funding to promote the construction of green infrastructure. Public participation should be encouraged to raise awareness and acceptance of natural drainage systems among communities. Cross-departmental collaboration is essential to integrate resources and expertise from environmental protection, water resource management, and urban planning to effectively implement these systems. Demonstration projects in various urban settings can showcase the effectiveness of natural drainage systems, providing practical examples and accumulating experience for broader application.

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