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ENGINEERING PROTECTION SYSTEMS FOR POPULATED AREAS AGAINST FLOODS AND THEIR OPERATIONAL FEATURES

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Abstract

This article analyzes modern engineering methods for protecting populated areas from flood and flash flood events. The study examines various types of hydraulic structures, their functional mechanisms, and their efficiency in the context of climate change. A comparative analysis of passive and active protection systems is provided, highlighting the technical requirements for ensuring urban safety. The primary focus is placed on the implementation of combined drainage systems in complex, multi-layered hydrogeological conditions. The study details the operational synergy between horizontal drainage networks, which collect moisture from low-permeability upper soil layers, and vertical artesian wells that operate in a self-flowing (artesian) mode to reduce hydraulic pressure in high-permeability lower aquifers. The integration of these elements ensures a comprehensive reduction in groundwater levels, thereby protecting urban infrastructure, buildings, and public recreational zones from the detrimental effects of waterlogging. The findings highlight the efficiency of this integrated approach as a sustainable solution for urban flood mitigation and long-term structural safety.

Keywords

Flood control, engineering protection, levee, detention basin, hydraulic engineering, drainage systems, resilience, river discharge.

Introduction

With the increasing frequency of extreme hydrometeorological events due to global climate shifts, protecting residential areas from flooding has become a critical engineering challenge. Engineering protection for populated areas is a complex system of measures designed to regulate water flow, redirect excess discharge, and isolate vulnerable infrastructure [1-2]. Effective flood management is not merely about blocking water but managing the hydraulic energy of a basin to minimize socio-economic risks [3-5].

The regulation and removal of surface and wastewater from protected areas are carried out at the city-wide level, taking into account their integration into the irrigation and drainage (reclamation), water supply, sewerage, and stormwater drainage systems, as well as their subordination to the higher structures of adjacent urban areas. The objective of regulating and directing flooded areas is as much about reducing filtration losses from the aforementioned networks as it is about water management [6-8]. To achieve this, these networks are constructed to be waterproof or lined with anti-filtration materials . Additionally, bio-drainage is established within the water protection zones of these networks to further minimize losses [9-10]. The regulation of surface water networks—comprising irrigation, rainwater, and transit waters flowing through cities, as well as parks, ponds, lakes, and other water bodies-is aimed at preventing flooding and over-irrigation in public recreational areas [11-14].

Method. This study utilizes a systemic analysis of hydraulic engineering principles and comparative modeling of flood defense structures. The research evaluates the performance of structures based on the recurrence interval (T) and the probability of exceedance (P). Data from international flood management standards (including the Netherlands' Delta Works and East

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Asian flood diversion models) were synthesized to define the operational characteristics of modern systems.

Results and Discussion.

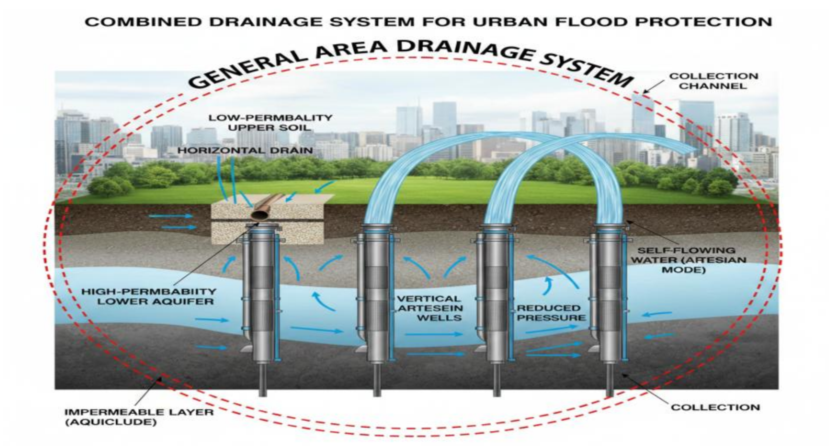
Groundwater drainage is the primary method for the engineering protection of cities against flooding. Technically, this method is implemented through the construction and operation of drainage systems and individual drains. Drainage systems and drains should be categorized by their types and varieties.

The type of drainage system determines the extent of coverage, whether it protects an entire area or is localized to specific buildings, structures, and their clusters. The classification of a drainage system is defined by the design of its water-collecting structures, which are categorized into horizontal, vertical, and combined (radiating) drainage. Sub-types of drainage are distinguished by their placement within aquifers or, more specifically, by the nature of how they intercept the aquifer. If a drain rests on an aquiclude (impermeable layer) or another sharp boundary, it is termed "perfect" (fully penetrating); if it is "suspended" within the aquifer, it is termed "imperfect" (partially penetrating).

Horizontal drainage exhibits the greatest diversity, with variations such as open or closed, deep or shallow, and is further defined by filling materials and structural elements. Vertical drainage types are also determined by their design features and construction materials. Combined drainage consists of both horizontal and vertical elements, designed to optimize water inflow under specific hydrogeological conditions. Horizontal drains are constructed in low-permeability soils where upper groundwater layers must be drained, especially when water seepage into the base or other types of surface entry is objectively inevitable or more costly to manage. Vertical drainage is primarily constructed in permeable soils where upper groundwater layers are hydraulically linked to lower layers, and where upward seepage is significant or comparable to surface water inflow.

Combined drainage is implemented in two-layered or multi-layered geological structures where layers differ significantly in their degree of water permeability. This type of drainage is highly effective when horizontal drains are placed in the upper, low-permeability soil layers, while vertical wells or boreholes are situated in the lower, high-permeability rock formations. In this configuration, the vertical wells operate in a self-flowing (artesian/gravity) mode, allowing for the reduction and management of pressures in the lower aquifers. The aforementioned drainage types and their networks are classified as general area drainage systems, meaning they are constructed to protect the entire territory of a city or its specific districts from the risks of flooding.

Figure 1. Combined drainage system for the engineering protection of cities against flooding.



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The operational mechanism of the drainage system is illustrated through the following stages and elements:

Two-layered hydrogeological structure:

1. Upper Layer: A soil layer with low water permeability. Horizontal drainage pipes are installed here to collect excess moisture.

2. Lower Layer: A highly permeable aquifer under hydrostatic pressure.

3. Vertical Wells and Self-flowing (Artesian) Mode: Vertical artesian wells are installed to reduce the high pressure (hydraulic head) in the lower layer. Water rises to the surface by its own pressure (self-flowing mode), which effectively lowers the overall groundwater level.

Integration of Horizontal and Vertical Elements: While horizontal drains collect water from the upper layer, vertical wells manage the pressure within the lower layers. This combination maximizes the system's overall efficiency. As seen in the background, urban buildings and structures are being protected from flooding (waterlogging) through this integrated system.

These structures act as physical boundaries between the water body and the populated area. Earth or concrete embankments constructed along riverbanks to prevent overtopping. Vertical barriers used in dense urban environments where space for wide embankments is unavailable. Their effectiveness depends on the crest height and the permeability of the core material to prevent internal erosion (piping).

These systems actively alter the hydrology of the flood event:

- These areas remain dry during normal conditions but store vast amounts of water during peak flow, releasing it gradually once the threat subsides.
- Artificial waterways that bypass the city center, redirecting the "peak" of the flood to less sensitive areas.

Table 1. comparative analysis of systems:

System Type	Primary Function	Advantage	Limitation
Levees	Containment	Cost-effective for long reaches	Risk of catastrophic breach
Detention Basins	Peak Shaving	Reduces downstream pressure	Requires significant land area
Bypass Channels	Rerouting	High reliability	High capital investment

The stability of these structures is calculated using the Factor of Safety ($F_s). For an embankment to be considered safe against sliding or overturning, the following condition must be met:

$$Fs=\frac{\sum \text{Resisting Forces}}{\sum \textit{Driving Forces}}\geq 1.5$$

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Furthermore, the discharge capacity (Q) of urban drainage systems must be designed to handle a 1-in-100-year flood event (Q_{100}), factoring in the Manning's roughness coefficient (n) to ensure the velocity does not cause structural scouring.

Conclusion. The engineering protection of urban areas against flooding is a complex task that requires an integrated approach to water management. The use of combined drainage systems-incorporating both horizontal and vertical elements-proves to be the most effective solution for complex hydrogeological conditions involving multi-layered soils. While horizontal drains efficiently manage surface and upper-layer moisture, vertical artesian wells alleviate deep-layer hydraulic pressure through self-flowing mechanisms. Implementing such systems not only prevents the waterlogging of buildings and infrastructure but also ensures the long-term stability and safety of the urban environment. Engineering protection of populated areas is transitioning from "fighting the water" to "living with water." While traditional levees and dams remain essential, they must be integrated with smart drainage systems and nature-based solutions (such as permeable pavements and urban wetlands). The future of flood engineering lies in the integration of real-time sensor data with physical hydraulic structures to create an adaptive and resilient urban environment.

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