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HydroCAD Analysis for Urban Stormwater Management: A Framework for Flood Mitigation

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Abstract

Rapid urbanization, characterized by the conversion of pervious natural surfaces into impervious areas, significantly disrupts the natural hydrologic cycle. This leads to increased surface runoff and elevated flood risks, particularly in cities with outdated or inadequate drainage infrastructure. This research paper presents a comprehensive framework for assessing urban stormwater management systems using the HydroCAD hydrological modeling software. Through a case study of a representative city, the study demonstrates the process of watershed delineation, data integration, and simulation of rainfall-runoff responses. The model was used to compute critical hydrological parameters, including peak flow rates, runoff volumes, and direct runoff hydrographs for selected sub-catchments. The analysis identifies key vulnerabilities within the existing drainage network and proposes targeted mitigation strategies, including infrastructure upgrades and the integration of green infrastructure. The findings demonstrate the critical role of hydrological modeling as a vital resource for urban planners and engineers in developing resilient, flood-resistant cities.

Keywords: Stormwater Management, HydroCAD, Hydrological Modeling, Urban Flooding, Runoff, Drainage Infrastructure, GIS.

1. Introduction

The global trend of urbanization is a primary driver of environmental change, particularly in hydrological systems. The replacement of natural, permeable landscapes with constructed, impermeable surfaces like roads, pavements, and rooftops fundamentally alters the land-water relationship. This transformation reduces infiltration, decreases groundwater recharge, and accelerates the volume and velocity of surface runoff.

The paper reviews studies linking increased ISC (Impervious Surface Coverage) to a decline in stream and river health [3]. The primary impacts include:

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- **Increased Flashiness:** Streams respond much faster and more dramatically to rainfall events, leading to **scouring** and **bank erosion**.
- **Decreased Baseflow:** Less infiltration means less groundwater recharge, which reduces the stable flow (baseflow) in streams during dry periods.
- **Habitat Degradation:** The combination of erosion and pollution destroys aquatic habitat, leading to a reduction in the diversity and health of Water Bugs and fish.

During intense precipitation events, this excess runoff often exceeds the capacity of conventional drainage systems, leading to urban flooding, property damage, and public safety hazards.

The challenge of urban stormwater management is especially acute in developing cities, where drainage infrastructure may be outdated, undersized, or poorly maintained. To address this, engineers and planners increasingly rely on sophisticated hydrological models to simulate and predict the behavior of watersheds under various rainfall conditions. These models provide a virtual laboratory to test scenarios and design effective interventions before their physical implementation. The evolution of personal computing has catalyzed the development of powerful hydrological and hydraulic modeling software. These tools have become indispensable for modern water resources management. Key software packages include the EPA Storm Water Management Model (SWMM), Bentley's SewerGEMS, HEC-HMS, and the HydroCAD system used in this study.

Zoppou's review is comprehensive, covering the mathematical descriptions of common modeling methods and summarizing the features of several prominent urban stormwater models [18]. **Abd-Elhamid, H. F.,** the study demonstrates and examines how urban growth affects the design of stormwater drainage systems. It highlights the urbanization is a major cause of flooding in urban area due to the creation of impervious surfaces [1]. **Askar, M.'s** study focuses on using GIS (Geographic Information Systems) and SCS-CN (the Soil Conservation Service Curve Number) approach to estimate the depth of runoff [5]. **Baumann, H.** describes the efficacy of 1D/2D hydrodynamic models for real-time urban stormwater applications, showing satisfactory accuracy when validated against real-world measurements [6].. **Bhatt B. V.** carried out their study through a comprehensive review of different smart techniques used in stormwater management systems and concluded that

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developing smart stormwater drainage concepts is vital because smart cities require well-designed infrastructure to ensure a more comfortable and high-quality living environment for residents. [9]. **Bhavsar, V.** T conducted an analysis using Dolarana Vasna (Gandhinagar District, Gujarat) as the study area, examining the associated environmental impacts and current wastewater management practices. [10]. **Pawar, A.** They conducted a study on the design of the sewer system for Vake village using SewerGEMS, focusing on developing an efficient sewer network for Vake in Malegaon Taluka, Nashik District, Maharashtra. [15]. **Sopariya, H.** showcased the utility of SewerGEMS software for The design and evaluation of sewer network systems, emphasizing its ability to handle complex urban layouts imported from CAD and GIS platforms [16]. Furthermore, **Klompmaker** provides critical spatial data for mapping urban characteristics and assessing changes over time [13]. The concept of "smart" stormwater management, reviewed by **Bhakra J.**'s analysis reveals that, at average seasonal rainfall levels, the study area is capable of generating a runoff volume exceeding the requirements for urban water management. [8]. **Cazanescu S.'s** studied literature highlights the significant impact that urbanization has on hydrological processes, but filling in these research gaps would enable comprehensive approaches to sustainable urban development and efficient water management measures [11]. **Patel, K. H.** carried out their study through a comprehensive review of different smart techniques used in stormwater management systems and came to the conclusion that it is important to gather ideas for a smart stormwater drainage system 14].

While these tools are widely used globally, their application in systematic stormwater studies for many rapidly urbanizing regions remains limited. This study contributes to filling that gap by demonstrating a standardized HydroCAD-based methodology that can be adapted to various urban contexts.

This paper details the application of the HydroCAD Storm Water Modeling System, a widely used tool based on the methodologies of USDA NRCS (Natural Resources Conservation Service), specifically TR-55 as well as TR-20. This study aims to:

1. Develop a hydrological model for an urban area using HydroCAD.
2. Simulate the catchment's response to design storm events.

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3. Analyze the resulting hydrographs to identify system bottlenecks and flood-prone zones.
4. Propose a set of engineering and planning recommendations to enhance stormwater resilience.

3. Study Area and Methodology

3.1. Study Area

The methodology is utilized for a representative urban region, which can be characterized as a rapidly developing city. For illustrative purposes, the study focuses on two specific sub-catchments:

- **Sub-catchment A (Residential-Commercial Mix):** A densely built-up area with a high percentage of impervious cover, representing the urban core.
- **Sub-catchment B (with Detention Pond):** A mixed-use area that drains into an existing natural depression/pond, which acts as a passive detention basin.

The city experiences seasonal heavy rainfall, and its existing drainage system comprises a network of pipes and open channels, parts of which are outdated.

3.2. Data Collection

The modeling process requires the integration of multiple data sources:

- **Topographic Data:** Contour maps and Digital Elevation Models (DEMs) were used for watershed delineation and slope calculations **(Fig. 1)**.
- **Land Use/Land Cover (LULC):** Satellite imagery was classified to determine pervious and impervious areas, which directly influence runoff coefficients.
- **Rainfall Data:** Historical rainfall data from the Indian Meteorological Department (IMD) was used, including intensity-duration-frequency (IDF) curves. A 24-hour, Type II NRCS rainfall distribution with a total depth of 3 inches was used as the design storm.
- **Soil Data:** Soil maps were consulted to classify soil types (e.g., Soil Group B, C) which determine infiltration rates.
- **Drainage Infrastructure:** Data on existing pipe sizes, lengths, slopes, and inlet locations were collected.

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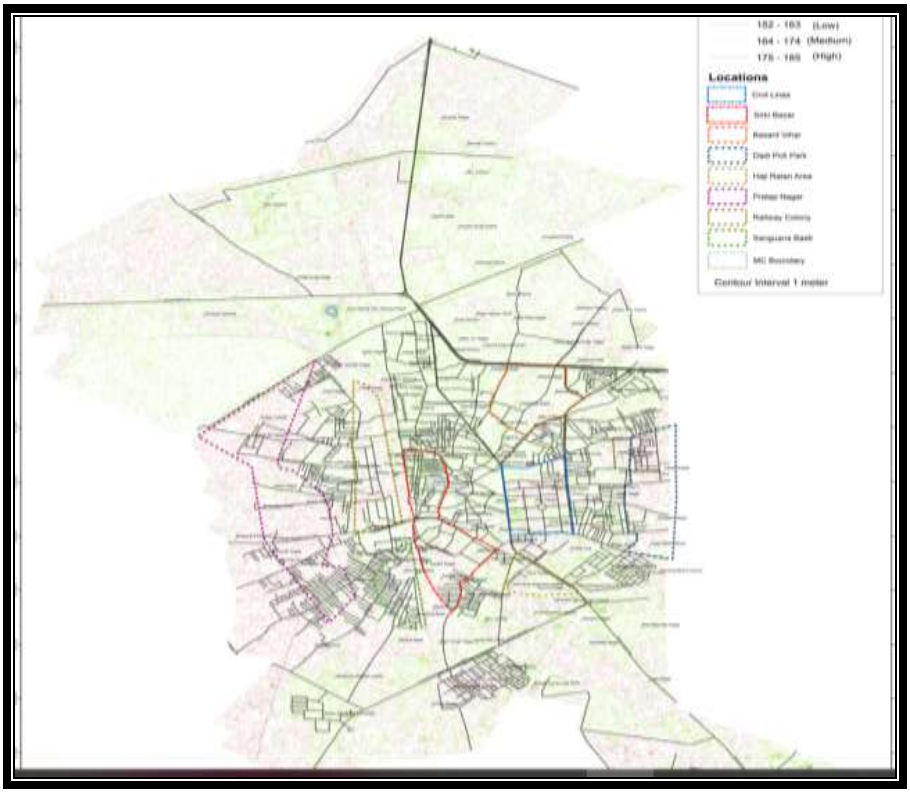

Fig. 1: Watershed Delineation and Contour Map of the Study Area

3.3. HydroCAD Modeling Framework

HydroCAD operates by simulating the flow of water through a user-defined network of sub-catchments and routing nodes (pipes, channels, ponds). The core steps are:

- **Project Setup and Schematic Creation:** A routing diagram was constructed representing the logical connection between sub-catchments and drainage elements **(Fig. 2)**.
- **Sub-catchment Parameterization:** Each sub-catchment was defined by its area, Tc (time of concentration), and a CN (Curve Number). The CN, a key parameter developed by the NRCS, is a dimensionless parameter indicating the potential for runoff based on type of soil, land use, and antecedent moisture level [2, 4, 7, 17]. Tc represents the time it takes for runoff to move from the farthest hydraulic point in the watershed to the outlet.

Routing Element Definition: Links (conduits, channels) and storage nodes (detention ponds) were defined with their respective geometric and hydraulic properties (e.g., Manning's roughness coefficient, dimensions, storage-elevation curves).

- **Simulation and Analysis:** The model was run for the design storm event. HydroCAD calculates runoff volumes, generates inflow and outflow hydrographs for each node, and routes flows through the entire system.

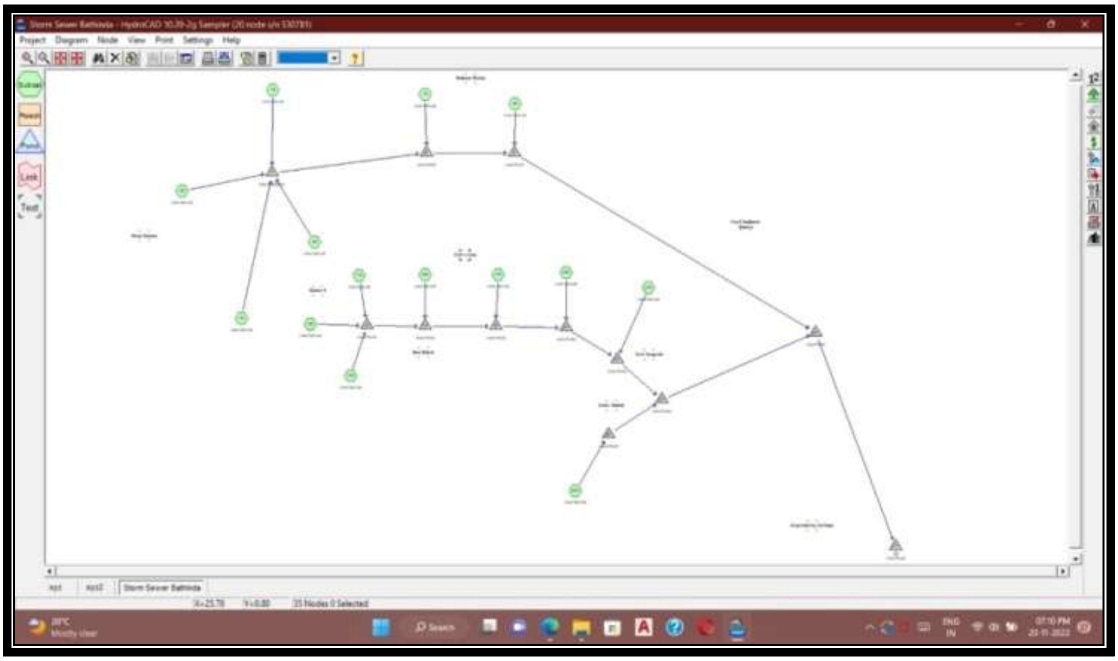

Fig. 2: HydroCAD Routing Schematic

4. Results and Discussion

The HydroCAD simulations provided quantitative insights into the performance of the stormwater system during the design storm.

4.1. Runoff Volume and Peak Discharge

The model calculated the total runoff volume and maximum discharge for each sub-catchment, as summarized in **Table 1**. The high CN value in Sub-catchment A confirms its high imperviousness, leading to a significantly larger runoff volume per unit area compared to Sub-catchment B.

Table 1: Sub-catchment Runoff Summary

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Sub-catchment	Area (acres)	Curve Number (CN)	Runoff Volume (acre-ft)	Peak Discharge (cfs)
A (Basant Vihar)	196.55	85	27.57	457.10
B (Chandsar Basti)	30.04	80	4.52	98.45

The peak discharge of **457.10 cubic feet per second (cfs)** from Sub-catchment A represents a substantial hydraulic load on the downstream drainage network. This value is critical for sizing pipes and channels to avoid overtopping.

4.2. Hydrograph Analysis

The hydrographs generated by HydroCAD illustrate the temporal pattern of runoff. **Fig. 3** shows the composite hydrograph for Sub-catchment A.

- **Rising Limb:** The steep rising limb indicates rapid runoff generation, characteristic of urbanized watersheds with efficient drainage inlets and little surface storage.
- **Peak Flow:** The sharp peak occurs at a relatively short time after the rainfall begins, reflecting a short time of concentration.
- **Recession Limb:** The gradual recession limb shows the slow drainage of water from the system after the storm peak. The extended duration (50-60 minutes in this case) indicates that the system remains under stress well after the peak rain has passed.

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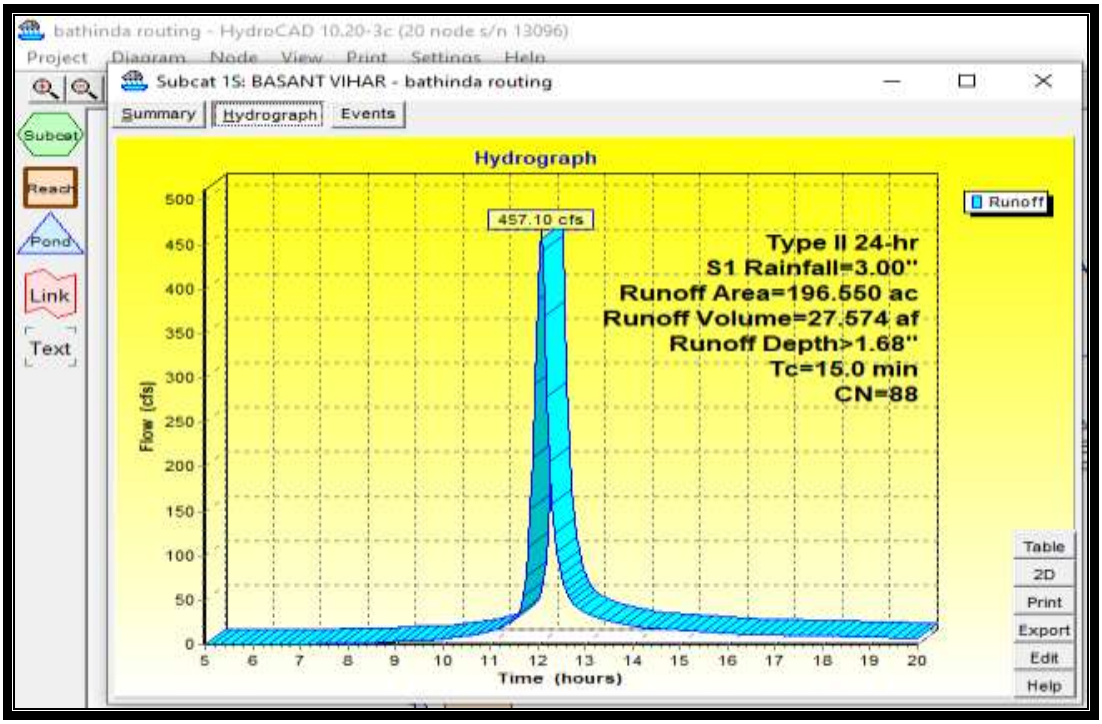

Fig. 3: Direct Runoff Hydrograph for Sub-catchment A

4.3. Evaluation of Existing Infrastructure

The simulation results were compared with the known capacity of the existing drainage infrastructure. The analysis revealed:

- **Conduit Surcharging:** Several pipes downstream of Sub-catchment A were shown to be operating under pressurized flow conditions, indicating they are undersized for the generated runoff.
- **Pond Performance:** The pond in Sub-catchment B was effective in attenuating the peak flow, reducing the outflow peak significantly compared to the inflow peak. However, the simulation showed that the pond reached its maximum storage capacity, suggesting that a larger volume or an improved outlet structure could enhance its performance.
- **Flood Risk Zones:** By tracking flow paths and identifying points of hydraulic overload, the model pinpointed specific intersections and low-lying areas at high risk of surface flooding.

5. Recommendations for Mitigation

Based on the model findings, the following integrated strategies are proposed to mitigate flood risk:

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1.Infrastructure Upgrades:

- **Pipe Enlargement:** Prioritize the replacement of critically undersized conduits identified in the model.
- **Constructed Detention Basins:** Strategically place new detention basins upstream of high-risk areas to temporarily store peak runoff and release it at a controlled, non-damaging rate. The model can be used to precisely size these facilities.
    - **2.Implementation of Green Infrastructure (GI):**
- **Permeable Pavements:** Replace conventional pavements in parking lots and low-traffic streets to promote infiltration.
- **Rain Gardens and Bioswales:** Implement these landscaped features to capture, treat, and infiltrate runoff from rooftops and driveways.
- **Green Roofs:** Encourage or mandate green roofs on new commercial buildings to reduce runoff volume at the source. GI solutions reduce the effective CN of the catchment, thereby lowering the overall runoff volume entering the conventional drainage system.

3.Improved Operational Practices:

- **Routine Maintenance:** Establish a strict schedule for cleaning drains and inlets before the monsoon season to ensure full hydraulic capacity. The CPHEEO Manual of Sewerage and Sewage Treatment Systems (2019 edition) is a comprehensive, multi-volume document published by CPHEEO (the Central Public Health and Environmental Engineering Organisation) under MoHUA (the Ministry of Housing and Urban Affairs), Government of India [12].

6. Conclusion

This study successfully demonstrates the application of HydroCAD software as a powerful decision-support tool for urban stormwater management. The model simulations provided a clear, quantitative assessment of the existing system's deficiencies under heavy rainfall, identifying specific sub-catchments with excessive runoff and pinpointing locations where the infrastructure fails.

The key takeaways are:

1. **Proactive Planning:** Hydrological modeling allows cities to move from reactive flood response to proactive, evidence-based planning.
2. **Cost-Effectiveness:** Simulating solutions virtually is far more cost-effective than trial-and-error construction. It ensures that investments in infrastructure are targeted and efficient.
3. **Integrated Approach:** A combination of traditional gray infrastructure (pipes, ponds) and modern green infrastructure offers the most sustainable and resilient path forward for managing urban stormwater.

By adopting the framework outlined in this paper, municipal authorities can develop a scientifically robust stormwater management plan, ultimately reducing flood damages, enhancing public safety, and creating more livable urban environments.

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