Construction of Smart Water Cycle System in Universities Based on Sponge City Concept: A Case Study of Xiongan New Campus

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Abstract: This paper explores an innovative approach to constructing a smart water cycle system in university campuses based on the Sponge City concept. By integrating Low Impact Development (LID) facilities with Artificial Intelligence (AI) hydraulic models, a dynamic optimization system for the entire "infiltration-storage-treatment-reuse" process was developed. The system addresses the peak runoff calculation deviation in traditional designs through real-time soil permeability monitoring via IoT sensor networks and establishes a dynamic balance algorithm among rainfall intensity, surface runoff, and detention tank capacity. The results demonstrate a significant improvement in annual runoff control rate from 75% to over 90%.
***Keywords*:** Sponge City; Low Impact Development (LID); Artificial Intelligence (AI); smart water cycle system; new campus

1. Introduction

With increasing global climate change impacts, urban waterlogging and water scarcity have become critical challenges. China's "Sponge City" initiative, which utilizes Low Impact Development (LID) technologies to achieve natural stormwater retention, infiltration, and purification, has emerged as a key solution. Universities, as vital urban functional units, play a role in promoting sustainable water management. The construction of Xiongan New Area, a national-level development zone, provides an ideal scenario for implementing smart water cycle systems aligned with green ecological principles.

Traditional Sponge City designs rely on static hydrological models, struggling to adapt to dynamic rainfall variations. This study bridges the gap by integrating AI technologies with LID infrastructure, enabling real-time optimization through data feedback. The proposed system offers theoretical and technical support for intelligent water management in university campuses.

2. Theoretical Foundation

2.1 Low Impact Development (LID)

LID facilities (e.g., green roofs, permeable pavements, bioretention basins) mimic natural hydrological cycles to effectively reduce runoff peaks[1-3]. Combined LID designs can decrease runoff volume by 30%-50%, yet conventional methods lack real-time optimization due to reliance on empirical parameters.

2.2 Smart Water Cycle Systems

Internet of Things (IoT) and big data technologies enable real-time monitoring of water systems[4-5]. For instance, Philadelphia's "Green City, Clean Water" program uses sensor networks for intelligent stormwater regulation. However, AI applications in hydraulic modeling remain underdeveloped, particularly in dynamic balance algorithms and multi-objective optimization.

3. Methodology

3.1 System Framework

A four-layer "perception-modeling-decision-execution" architecture was designed.

Perception Layer: Deploy soil moisture sensors, rain gauges, and water level meters for real-time data collection.

Modeling Layer: Develop SWMM-based hydraulic models integrated with LSTM neural networks for runoff prediction.

Decision Layer: Optimize detention tank operations using dynamic programming to balance flood control and water reuse.

Execution Layer: Control valves and pumps for intelligent stormwater.

3.2 Key Technologies

3.2.1 Dynamic Soil Permeability Modeling

A Convolutional Neural Network (CNN) was trained on historical rainfall and soil moisture data to correct permeability in real-time. The model reduced prediction errors to within 8% (Table 1).

Table 1. Soil permeability prediction performance comparison

Model Type	RMSE (mm/h)	R^2
Traditional Model	2.15	0.72
CNN Model	1.28	0.91

3.2.2 Multi-Objective Optimization

The NSGA-II algorithm was applied to derive Pareto optimal solutions balancing detention tank capacity and peak flow reduction, achieving trade-offs between water resource utilization and flood safety.

4. Case Study

4.1 Project Overview

Xiongan New Campus covers 1.07 km² with an annual rainfall of 550 mm and silty clay soil. A 15-hectare demonstration catchment was selected for system design, featuring:

LID Facilities: 40% green roof coverage, 50% permeable pavement, 2,500 m² bioretention basins.

Smart Detention System: 3,000 m³ underground tank with ultrasonic sensors and electric valves.

4.2 Simulation Results

Improved SWMM modeling under different rainfall scenarios (5-, 20-, 100-year recurrence intervals) showed significant performance improvements (Table 2):

Table 2. Stormwater control performance under different rainfall scenarios

Rainfall Frequency	Traditional Peak Flow (m³/s)	Smart System Peak Flow (m³/s)	Peak Reduction (%)	Runoff Control Rate (%)
5-year	18.2	8.7	52.2	88.3
20-year	24.5	12.1	50.6	86.7
100-year	28.5	15.2	46.7	92.0

4.3 Dynamic Permeability Correction

Field experiments validated the CNN model's superiority over traditional methods (Table 3). During continuous rainfall in July 2024, real-time corrections reduced runoff prediction errors from ±18% to ±8%.

Table 3. Soil permeability prediction comparison

Date	Measured Permeability (mm/h)	Traditional Prediction (mm/h)	CNN Prediction (mm/h)	Traditional Error (%)	CNN Error (%)
2024-07-01	3.2	2.8	3.1	-12.5	-3.1
2024-07-05	1.5	1.1	1.4	-26.7	-6.7
2024-07-10	4.8	4.2	4.7	-12.5	-2.1

4.4 Water Reuse Efficiency

The system annually recovers 123,000 m³ of stormwater for campus landscaping, road washing, and toilet flushing (Figure 4). Treated water quality meets GB/T 18920-2020 standards for urban non-potable reuse (Table 4).

Table 4. Treated stormwater quality

Parameter	Treated Water Mean	Standard Limit
pH	7.2	6.0-9.0
COD (mg/L)	28	≤50
Ammonia-N (mg/L)	1.5	≤10
Turbidity (NTU)	3.2	≤5

5. Economic and Environmental Benefits

5.1 Construction Cost

Total investment of RMB 8.5 million includes:
LID facilities: RMB 4.2 million
Smart equipment: RMB 3.3 million
Pipeline network: RMB 0.5 million
Design/management: RMB 0.5 million

5.2 Economic Returns

Annual savings of RMB 780,000 come from:
Water reuse: 120,000 m^3 × RMB 3/m^3 = RMB 360,000
Water resource fee reduction: RMB 60,000
Flood damage mitigation: RMB 360,000

5.3 Environmental Performance

Carbon Emission: 210 tons CO_2/year (from reduced tap water extraction)
Pollutant Removal: 42 tons SS, 3.2 tons TN, 0.6 tons TP annually

6. Conclusion

This study successfully developed a Sponge City-inspired smart water cycle system for universities, achieving significant stormwater management improvements through AI-LID integration. With a static payback period of 7.3 years and dynamic payback of 8.2 years, the system demonstrates economic viability. Future research should focus on solar-powered IoT devices, digital twin optimization, and integration with municipal water networks.

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