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From Concept to Reality: The Practical Implementation of a Laboratory-Based Smart Water Campus Model

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Abstract: The emergence of smart campuses marks a pivotal advancement in educational pedagogy, environmental quality, resource allocation, and administrative services. This study presents the conceptualization and implementation of the Nanxun Campus of Zhejiang University of Water Resources and Electric Power (ZJWEU), which serves as an exemplary smart water initiative. Adhering to the philosophy of integrating educational facilities within the campus infrastructure, the campus incorporates several specialized zones: a key protection area, the water conservation area, the ecological stability area, the living water spirit area, and the teaching and practice area. This study clarifies the unique attributes, design philosophies, and operational mechanisms of these distinct zones. Central to the campus's identity is a water culture-centric strategy, with each building reflecting water-themed concepts and providing extensive real-world engineering teaching and practice environments. Since its opening in 2022, the campus has been admitting approximately 5000 students annually and has been a model of water culture campuses that integrate ecology, intelligence, humanism, and synergy. The insights and infrastructure provide a valuable reference and foundational support for the evolution of smart campuses, underscoring the potential to merge water culture with avant-garde educational practices.

Keywords: smart campus; water conservation; educational enhancement; ecological development; intelligent management

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1. Introduction

In the global pursuit of educational informatization and smart campus development, various policy documents have been issued [1–3]. The United States Department of Education outlined a comprehensive vision in the 2010 National Education Technology Plan (NETP), advocating for enhanced campus infrastructure with high-speed broadband networks, learning devices, digital learning environments, and supportive policies for effective learning [4]. The 2024 NETP emphasizes an innovative approach, empowering educators to become architects of interactive learning experiences and leveraging technology to engage and inspire students [5]. The Digital Education Action Plan (2021–2027) for Europe presents a shared vision for high-quality, inclusive, and accessible digital education, aiming to adapt educational systems to the digital era [6,7]. Smart campuses serve as dynamic hubs for the research, development, and implementation of intelligent technologies alongside their traditional academic roles [2,8,9]. According to statistics, the framework for the concept of a smart campus consists of seven categories, namely, smart building, smart environment, smart mobility, smart living, smart people, smart governance, and smart

data [10]. Smart campuses prioritize human interaction, learning experiences, intelligent technologies, spatial design, sustainability, and eco-friendliness [11–13]. Common smart technologies include cloud computing, the Internet of Things (IoT), augmented reality (AR), and artificial intelligence (AI), which significantly contribute to campus evolution [14]. The IoT is instrumental in environmental and water resource surveillance, facilitating the deployment of sensor networks for tracking water quality, pressure, and flow in real time [9,15]. Fifth-generation (5G) mobile communication enhances these efforts with its high-speed, low-latency capabilities, enabling efficient real-time data transmission for water management [1,16]. AI further augments water management by automating water flow monitoring, adjusting distribution, and detecting leaks, thereby bolstering the efficacy and dependability of water resource systems [5,17]. The Egypt-Japan University of Science and Technology offers a framework to guide universities in adopting innovative strategies to enhance educational performance and student life through the strategic use of the IoT [18]. The Federal University of Campina Grande in Brazil identifies living conditions, technology, and security as key elements of a smart campus, highlighting the importance of process optimization through information sharing via IoT and information and communication technology (ICT) [19]. Nanyang Technological University in Singapore incorporates smart learning spaces, eco-friendly practices, and smart devices to foster a smarter and more sustainable campus environment [20]. The Universitat Politècnica de València focuses on campus open spaces, offering multifunctional landscape services to enhance student experiences [21].

In China, the concept of the "intelligent campus" was first articulated in the "Twelfth Five-Year Plan" for informatization in 2010, advocating for a forward-looking approach to educational technology. This was further emphasized in 2012 with the "Ten-Year Development Plan for Educational Informatization (2011–2020)", which urged educational institutions to expedite the informatization process [22]. Subsequent strategic documents, including the "Outline of the National Informatization Development Strategy" and the "National Informatization Plan for the 13th Five-Year Plan" have underscored the imperative for higher education institutions to align with technological advancements and to pivot towards the construction of smart campuses, thereby facilitating an educational paradigm shift towards a more intelligent and integrated system.

The national standard "Overall Architecture of Smart Campus (GBT36342-2018)" [23] provides detailed guidelines on the deployment of a smart campus's overall architecture, the realization of a smart campus environment, the construction of smart teaching resources, the deployment of a smart teaching management system, and the development of smart teaching services. An increasing number of Chinese campuses have embraced innovative informatized teaching models, leveraging big data platforms, smart management services, and advanced informatization strategies [22,24,25]. Shanghai Jiao Tong University's Fahua Campus established a carbon-neutral smart services platform, where intelligent solutions for campus carbon neutrality can be integrated through carbon emission monitoring and carbon sink [26]. Notably, Zhejiang University introduced the concept of an "exciting" smart campus in 2010, focusing on pervasive network learning, integrated research innovation, transparent administration, diverse campus culture, and convenient campus living. The university's strategic timeline began with network infrastructure development in 2005, followed by targeted digital applications in 2007, the launch of smart campus initiatives in 2010, and the establishment of numerous smart applications by 2015. Beijing University of Posts and Telecommunications, capitalizing on the high bandwidth and extensive reach of 5G networks, has integrated blue box virtual broadcasting technology to create a "5G Virtual Live Classroom". This innovation facilitates teaching in an immersive 3D virtual environment, integrating teacher images and offering an informationized and

intelligent mode of instruction. Students can access this content across various platforms, promoting ubiquitous learning and enhancing the interactive dynamics between educators and learners [22].

Despite these advancements, challenges have emerged in the construction of smart campuses, including intelligent rainwater, water environment and water safety management [15], sustainable waste management [27], and buildings' energy savings [28,29]. Functionally, while the informatization development plans for teaching and management in Chinese universities are relatively advanced, there remains a gap in integrating informatization into scientific research and leveraging it to support research and innovation among faculty and students. Ecologically, there is a current bias towards infrastructure development at the expense of natural, ecological, and green considerations. Ecological shortcomings not only affect the environmental quality of the campus but may also have long-term impacts on the sustainable development of the campus. For instance, the wastage of rainwater resources, insufficient green coverage, reduction in biodiversity, inadequate recreational spaces for the community, and excessive hardscaping leading to significant urban heat island effects are all critical concerns that necessitate integrated ecological considerations in the planning and construction of smart campuses [30–32]. Therefore, the construction of smart campuses should be approached as a comprehensive endeavor. This study integrates the unique water conservancy characteristics of the school with the cultural features of the Nanxun region to construct a distinctive smart water conservancy project within the campus. This approach aims to achieve a multitude of effects, encompassing scientific research, education, humanities, environmental management, and administrative efficiency.

2. Materials and Methods

2.1. Background

The Nanxun Campus of Zhejiang Water Resources and Electric Power University (ZJWEU) is situated in Huzhou City, Zhejiang Province, China, within the Shenzhuangyang polder of the Hangjiahu district, Lake Taihu basin, at geographical coordinates of 120.44° E longitude and 30.84° N latitude, as seen in Figure 1. The polder, encompassing an area of 3.6 km^2, is demarcated by Shenzhuangyang to the east, Bochengqiaogang to the south, Yangantang to the west, and Nanchangxingtang to the north. The campus itself spans 98 hm^2 with a water body occupying 15 hm^2. The surrounding rivers exhibit water quality ranging from Class IV to Class III, characterized by high turbidity and suspended solids, exemplified by the Bochengqiaogang river with a suspended solids (SS) concentration of 71 $mg \cdot L^{-1}$.

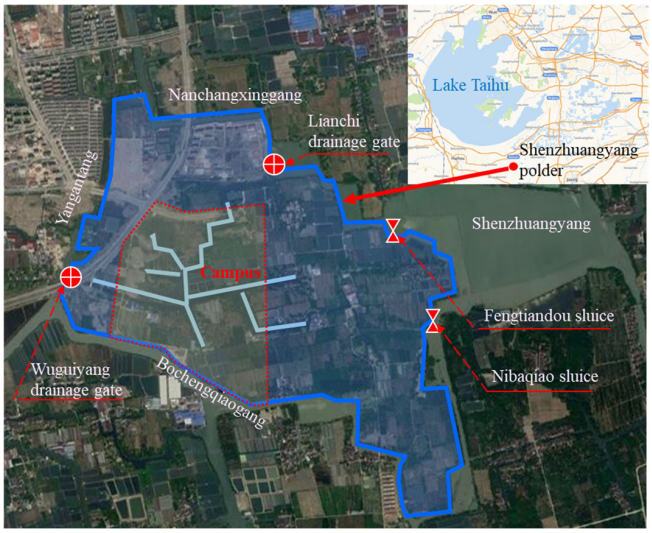


Figure 1. The location of Nanxun Campus of ZJWEU.

The flood protection and drainage standards for the Shenzhuangyang polder are designed to withstand a 20-year and a 10-year flood event, respectively. Peripheral flood control infrastructure includes river drainage gates, sluices, and a comprehensive dike system. Notable installations are the Lianchi drainage gate with a total discharge capacity of 4.50 $m^3 \cdot s^{-1}$ and Wuguiyang drainage gate with a total discharge capacity of 1.24 $m^3 \cdot s^{-1}$, along with the Fengtiandou sluice and Nibaqiao sluice. Under conditions of heavy rainfall, when the polder's water level exceeds that of the external river, sluice gates are opened to facilitate floodwater discharge. Conversely, when external water levels are higher, pump stations are activated to drain the polder, with sluice gates closed to prevent backflow. The normal water level and the 50-year flood level for external rivers are 1.20 m and 3.22 m, respectively, while for internal rivers, the initial drainage level, upper flood level, and lower flood level are set at 2.20 m, 2.50 m, and 2.00 m, respectively.

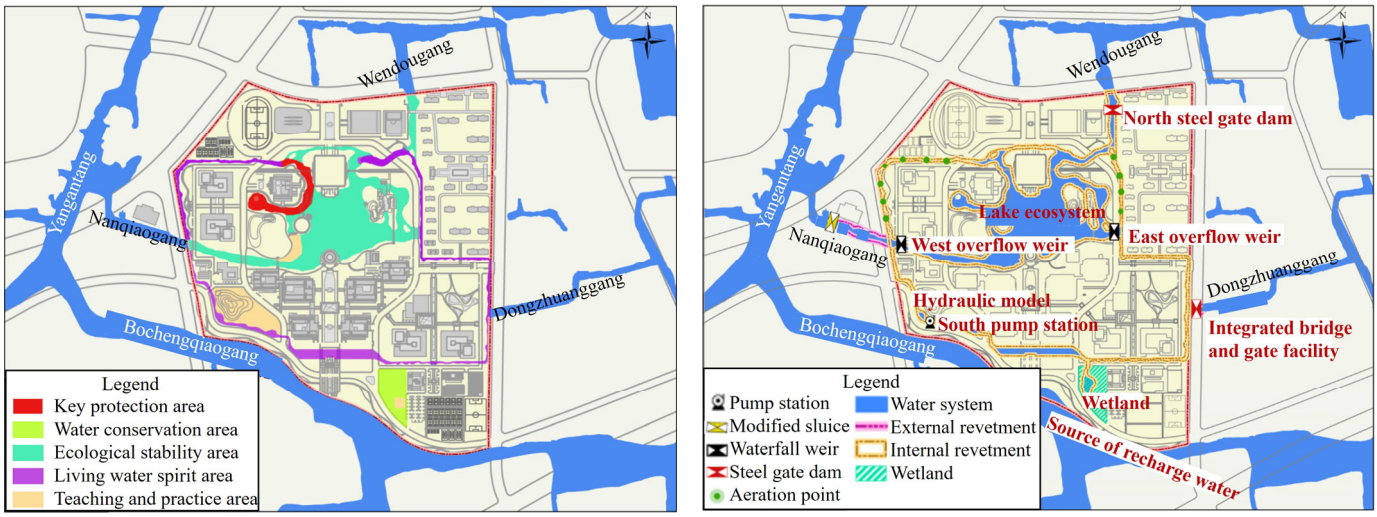
The calculation of the characteristic water level of the region is mainly based on the measured hydrological data, historical hydrological research results, topographic and river morphology data, meteorological data, urban flood control planning of Huzhou City (revised), and the regulation for hydrologic computation of water resources and hydropower projects (SL/T278-2020 [33]). The campus employs a ground elevation strategy for flood control, raising the ground level to 4.00 m, which exceeds the 50-year flood level of 3.22 m for external rivers, and elevating the riverbed to a range of 0.00 to 1.00 m. During heavy rainfall, the Wuguiyang sluice is closed to prevent floodwater backflow. The campus's drainage scheduling program is bifurcated into short-term and long-term plans. In the short term, the focus is on maximizing the benefits of large water surface areas, substantial storage capacity, and the operation of pump stations, including the Wuguiyang drainage gate and a proposed south pump station within the campus. For the long term, the plan includes the utilization of self-draining water through a proposed north steel gate dam. The targeted normal water level and controlled high water level for drainage are 2.50 m and 3.70 m, respectively.

2.2. Smart Water Campus Model Description

The Nanxun Campus of ZJWEU was conceived with innovative and visionary principles, aiming to establish an educational institution that doubles as a laboratory and a model for a smart water campus. Guided by the principles of site specificity, systematic approach, and integrated upgrading, the campus has implemented a suite of advanced technologies to enhance its water quality. As Figure 2 shows, these include source water purification, hydrodynamic regulation, water ecology construction, and the establishment of an intelligent small watershed system. Hydrodynamic regulation refers to the management of water flow in water systems, including flow direction, flow rate, velocity, water level, etc. Table 1 refers to drainage and hydrodynamic regulation projects.

Table 1. Drainage and hydrodynamic regulation projects.

Engineering Category	Design Parameters	Function
South pump station	2 $m^3 \cdot s^{-1}$	Campus drainage and internal self-circulating
North steel gate dam	Length: 70.56 m. Width: 16 m. Water retaining height: 3.22 m. Gate height: 3.5 m	Campus drainage, water retaining and overflowing
West overflow weir	Length: 18.0 m	Campus drainage and internal self-circulating
East overflow weir	Length: 14.3 m	Campus drainage and internal self-circulating
Wuguiyang revetment	Elevation of the top of the embankment: 3.50 m	Campus drainage



(**a**) (**b**)

Figure 2. (**a**) Functional zoning map of the campus (**b**) project layout diagram.

The campus is delineated into five primary functional zones: the key protection area, the water conservation area, the ecological stability area, the living water spirit area, and the teaching and practice area. The strategic objectives for the campus's development encompass achieving water quality standards that exceed Class III, ensuring water transparency exceeds 0.8 m, providing flood resistance for a 50-year event, ensuring drainage safety for a 20-year event, withstanding a once-a-century short-duration intense rainfall without flooding or damage, increasing the water environment's capacity, and realizing water movement. Additionally, the campus aims to achieve harmony between nature, ecology, and water, and to serve as a teaching demonstration site.

In the realm of teaching and demonstration construction, the campus features a pumped storage power station model, a model of the Oujiang River, a water–wind-light intelligent microgrid system, a water ecology teaching area, a wetland teaching area, and an intelligent system test area. These elements collectively contribute to the campus's role as a living laboratory for water resource management, ecological preservation, and educational innovation, showcasing the integration of smart technologies with environmental sustainability.

3. Results

3.1. Wetland for Water Resource Purification

The ecological conservation stability area of the Nanxun Campus of ZJWEU is designed to enhance ecological functions and water quality, ensuring a steady supply of high-quality water sources for the campus. The campus's water system operates independently, with water demand primarily consisting of evaporation from water surfaces, seepage water (including gate leakage and seepage from rivers and lakes), and water for greening and road flushing. Drawing from the "Huzhou Sponge City Construction Implementation Guidelines (Trial Version)", the average monthly daily evaporation rate in Huzhou City ranges from 1.04 to 3.79 mm·d^{-1}. Adopting the least favorable principle, the maximum daily evaporation of 3.79 mm·d^{-1}, which occurs in August, is used to calculate the evaporation from the planned water area of 15 hm^2 on campus. This results in an average daily evaporation from the water surface on campus of 571.91 m^3·d^{-1}. In accordance with the "Code for construction and acceptance of pumping station (GB/T51033-2014)" [34], the leakage is specified not to exceed 0.1 L·s^{-1} for every 1 m water stop rubber. Consequently, the maximum gate leakage is calculated to be 691.20 m^3·d^{-1}. The river and lake bottom on campus is predominantly silty clay with a permeability coefficient of approx-

imately 1.5 × 10^{-6} cm·s^{-1}. With a planned water area of about 15 hm^2, the calculated seepage from rivers and lakes is approximately 195.05 $m^3 \cdot d^{-1}$.

Referring to the "Comprehensive Planning of Water Resources in Zhejiang Province", the water quota for greening and road flushing is 0.28 $m^3 \cdot m^{-2} \cdot a^{-1}$. Therefore, the maximum daily water volume for these purposes is 640.69 $m^3 \cdot d^{-1}$, considering the non-water area of 83 hm^2. In aggregate, the total water demand for the campus is determined to be 2098.85 $m^3 \cdot d^{-1}$. Consequently, the daily capacity of the ecological conservation stability area is selected to be 3000 m^3. The wetland process design targets a water quality standard of Class III, aiming to upgrade water from the Bochengqiaogang River, which is currently at Standard III to IV, to Standard III. This is intended to achieve high clarity exceeding 2 m and to replenish the internal water system of the campus. As depicted in Figure 3, the ecological conservation stability area comprises a sand-settling regulating pond and a vertical flow artificial wetland. The final water outlet leads to a clear water pond and the campus system.

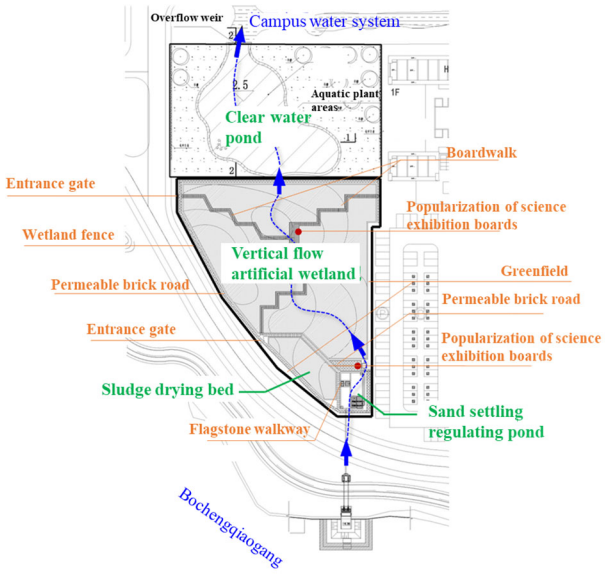


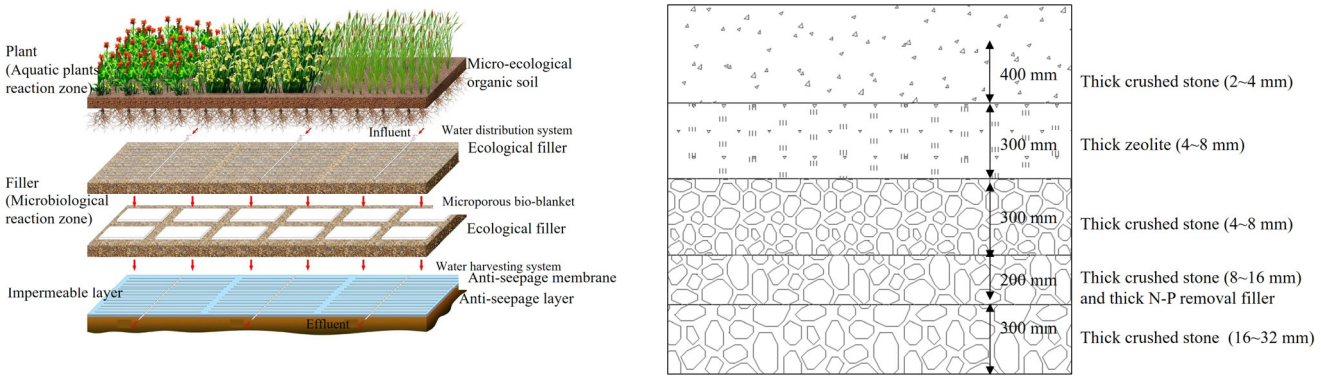
Figure 3. Diagram of the ecological conservation stability area. The arrows indicate the direction of the water flow.

In the vertical flow artificial wetland, key roles in water quality enhancement include filler filtration and adsorption, microbial decomposition, and plant absorption. The entire wetland area spans 6284 m^2, which includes a sand-settling regulating pond of 157 m^2, a sludge drying bed of 392 m^2, a vertical flow artificial wetland of 4745 m^2, and other areas for roads, landscaping, and facilities of 990 m^2. The clear water pond and other green areas encompass 3176 m^2, with the clear water pond covering 2146 m^2. The sand-settling regulating pond consists of a dissipating pond, a sand-settling pond, and a regulating pond. There are three pump stations for wetland recharge from Bochengqiaogang to the sand-settling regulating pond. The lifting pump is arranged on the river side with a design flow rate of 562.5 $m^3 \cdot h^{-1}$. The regulating pump is located in the regulating pond with a design flow rate of 562.5 $m^3 \cdot h^{-1}$. The sludge pump is positioned behind the sand-settling pond and regulating pond with a design flow rate of 32 $m^3 \cdot h^{-1}$. Due to the limited wetland area and high-water quality demands, the vertical flow artificial wetland utilizes intermittent water distribution. The key parameters are listed in Table 2. The selection of these design parameters was based on the Technical Specification for Constructed Wetlands in Wastewater Treatment Engineering (HJ 2005–2010 [35]), while also considering local climate, geological conditions, and the low concentration of pollutants in the influent.

This approach aims to optimize water purification processes while ensuring ecological protection, enhancing landscape quality, and facilitating educational opportunities in environmental science. As shown in Figure 4a, the vertical flow artificial wetland includes an aquatic plant's reaction zone, a microbiological reaction zone, and an impermeable layer. From Figure 4b, the surface crushed stone has a high removal rate for suspended solids, ammonia nitrogen, total phosphorus, and organic matter. The small particle size and large specific surface area are more conducive to microbial attachment, and the low material cost (the cost of a ton is about 50% of that of zeolite), making it the most predominantly used filler in vertical flow artificial wetlands.

Table 2. Parameters of the vertical flow artificial wetland.

Parameters	Values
Wetland type	Vertical flow artificial wetland
Surface load ($kg \cdot hm^{-2} \cdot d^{-1}$)	25.3 (COD)
Hydraulic load ($m^3 \cdot m^{-2} \cdot d^{-1}$)	0.63
Hydraulic retention time (d)	0.95
Wetland area (m^2)	4745
Filler	Zeolite, crushed stone
Depth of fill (m)	1.5
Filler porosity (%)	38~40
Water storage volume (m^3)	2847
Service life (y)	30



(**a**) (**b**)

Figure 4. (**a**) Schematic diagram of vertical flow artificial wetland structure layering, (**b**) filler arrangement.

Zeolite primarily has a selective adsorption effect on ammonia nitrogen, and after adsorption, it can form an adsorption–degradation equilibrium under the action of microorganisms, which can continuously maintain a higher rate of ammonia nitrogen removal and avoid the saturation of pollutant adsorption. Additionally, the thickness of 100 mm synchronous denitrification and phosphorus removal filler has been mixed filling with the bottom 8–16 mm particle size crushed stone, which is a composite filler containing iron, calcium, and inorganic carbonate minerals and is able to strengthen the removal effect of total nitrogen and phosphorus in this project. The mixed filler can play a role in anaerobic conditions and can avoid the slate. In the selection of aquatic plants, priority is given to plants with long root systems and high oxygen transfer capacity. On this basis, the purification function of plants on nitrogen and phosphorus, as well as the coordination between plants and the campus environment, should be considered. Iris, calamus, plantain, yellow-flowered iris, and pike grass were selected and planted using the seedling transplanting method. The ecological conservation stability area is designed to be a comprehensive and

sustainable solution for water management on campus, integrating various technologies and approaches to ensure water quality and ecological balance.

3.2. Water System Design and Hydrodynamic Regulation

To enhance the campus's hydraulic conditions and satisfy the demands for high-quality landscaping, key drainage engineering and hydraulic structures have been strategically implemented, as depicted in Figure 2b. These include the South pump station, North steel gate dam, West overflow weir, East overflow weir, and Wuguiyang revetment and drainage gate. The refinement of the hydrodynamic river network within the campus is executed through a four-step process. Step 1 Regulation Standard: utilizing river network hydrodynamic-water quality index regulation threshold determination technology to establish an optimization threshold of 0.05~0.15 $m \cdot s^{-1}$. Step 2 Optimization Scheme: developing a campus river-lake hydrodynamic-water quality-water ecology refinement model to devise a set of scheduling schemes targeted at the hydrodynamic optimization regulation threshold. Step 3 Regulation Means: implementing global and local node power optimization regulation strategies within the river network to precisely control overflow flow. Step 4 Precise Regulation: employing intelligent joint scheduling technology of gate–pump–weir groups to achieve precise and intelligent joint regulation of river-lake gate, pump, and weir engineering groups.

Specific implementations include the arrangement of the south pump station and drainage box culvert. The south pump station, with a capacity of 2 $m^3 \cdot s^{-1}$, is located on the campus side of the hydraulic model area to the south of the designed river. It operates underground and serves both flood control and navigation purposes. The internal water system circulates autonomously when upstream and downstream water levels are 2.40 m and 2.60 m, respectively. During drainage, the mode shifts to direct flow from the campus to Bochengqiaogang when upstream and downstream levels are 3.22 m and 3.42 m, respectively. The original Lianchi drainage gate, which had deteriorated due to long-term disrepair, has been replaced.

The north steel gate dam, newly constructed to the north of the campus, serves as a regular control mechanism for campus water levels and as a floodway during flood seasons. The steel dam gate measures 70.56 m in total length, with a gate opening width of 16.00 m, a water retaining height of 3.22 m, and a gate height of 3.50 m. The gate is elevated to 2.5 m to initiate overflow when campus and polder water levels are 2.50 m and 1.20 m, respectively. For recent water blocking conditions, the gate is elevated to 3.5 m under campus water level at 3.22 m and polder water level at 2.50 m. For forward overflow conditions, the gate is elevated to 2.5 m to drain flooded water under the campus water level at 3.16 m and the polder water level at 2.50 m.

The west and east overflow weirs are positioned at the west and east sides of the lake, separating the external circulating water system from the loop and extending the circulating water path. The west overflow weir's main structure is a three-hole box culvert with a net width of 6.0 m. A fixed weir is installed upstream of the side holes of the box culvert (on the inner lake side), with the weir top elevation aligned with the permanent water level of the inner lake and river at 2.50 m. The east overflow weir has a total length of 14.3 m, a height of 1.6 m, a top width of 0.6 m, side slopes of 1:0.5, and a bottom width of 2.40 m, with the weir top elevation set higher than the permanent water level of the inner lake and river at 2.60 m. These weirs typically function as water isolation structures, and during flood seasons, rainwater from the inner lake is discharged to the external water system through the overflow gate and the top of the weir. Considering the forward flood level of 3.17 m, the external revetment has been upgraded with the top height set at 3.50 m. Additionally, a wind-generated flow model is employed to evaluate lake patterns. The campus area,

located in a subtropical monsoon climate zone, is prone to typhoons during August and September, with a maximum wind speed of 20 $m \cdot s^{-1}$. The predominant wind direction is southeasterly, with 3~4 winds being the norm. For simulation purposes, a wind speed of 5 $m \cdot s^{-1}$ is assumed, with the wind direction primarily east-southeast. Two scenarios have been simulated: the pot bottom pattern and the center-underwater islanding pattern.

As illustrated in Figure 5, the pot bottom pattern exhibits minimal velocity, while the center-underwater islanding pattern generates good circulation, reaching 3 $cm \cdot s^{-1}$ around the center-underwater island. Therefore, the center-underwater islanding pattern is recommended, and the simulation results further support the lake topographic design.

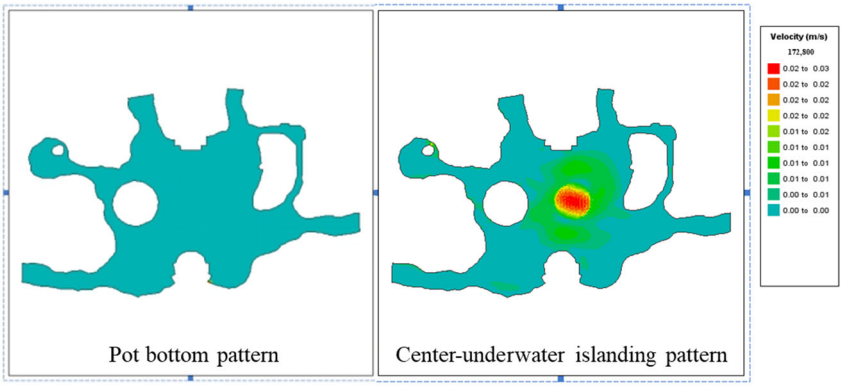


Figure 5. Wind-generated flow velocities in different lake patterns.

Considering that the area of this calculation area is small, the drainage water body is mainly a lake, and the water level changes along the river channel are small. The flat lake method is used to calculate the drainage water level process. According to the design bank slope, the water level and storage capacity curve is listed in in Table 3. The river discharge curve is also listed based on weir flow formula, where the inundation coefficient is 1.0, the side shrinkage coefficient is about 0.954, the flow coefficient is 0.32. The campus's flood control and drainage plans, designed for a 20-year flood, incorporate both short- and long-term strategies. Utilizing Huzhou "639" and storm atlas rain patterns, the runoff is determined through initial and post-loss method, along with the runoff coefficient method. As shown in Table 4, the maximum water levels for both short- and long-term drainage adhere to the controlled high-water levels of 3.70 m, satisfying drainage requirements.

Table 3. The water level and storage capacity curve of the lake and river discharge curve.

Lake		Rivers	
Water Level, m	**Capacity, 10^4 m^3**	**Water Level, m**	**Flow Rate, 10^4 m^3**
2.50	29.45	2.50	0.00
2.60	30.69	2.55	0.25
2.70	31.93	2.60	0.70
2.80	33.17	2.65	1.28
2.90	34.42	2.70	1.96
3.00	35.66	2.75	2.73
3.10	36.9	2.80	3.59
3.20	38.14	2.85	4.51
3.30	39.38	2.90	5.50
3.40	40.63	2.95	6.55
3.50	41.87	3.00	7.66
3.60	43.11	3.10	10.05
		3.20	12.63
		3.30	15.40

Table 4. Flood calculation result with a 20-year flood.

Category	Rain Pattern	Runoff Method	Highest Water Level, m	Maximum Flow Rate, $m^3 \cdot s^{-1}$
Short-term	Storm atlas	Initial and post-loss	3.22	3.24
		Runoff coefficient	2.87	3.24
	Huzhou "639"	Initial and post-loss	2.74	3.24
		Runoff coefficient	2.53	3.24
Long-term	Storm atlas	Initial and post-loss	3.16	11.5
		Runoff coefficient	2.97	6.99
	Huzhou "639"	Initial and post-loss	2.83	4.17
		Runoff coefficient	2.74	2.66

As shown in Figure 6, when the campus water level exceeds 2.50 m, the north steel gate dam and east overflow weir are utilized for overflow, maintaining the internal water level below 3.70 m. When the polder water level surpasses 2.50 m, the north steel gate dam and east overflow weir are lifted to prevent floodwater from entering the campus, with internal overflow weirs opened concurrently. The Wuguiyang drainage gate and south pump station are activated, with a combined volume of 3.24 $m^3 \cdot s^{-1}$. During internal self-circulation, a clockwise water cycle is established. The river depth averages 1.5~2.0 m, the lake's average depth is 3~4 m, and the main river flow rate exceeds 0.1 $m^3 \cdot s^{-1}$.

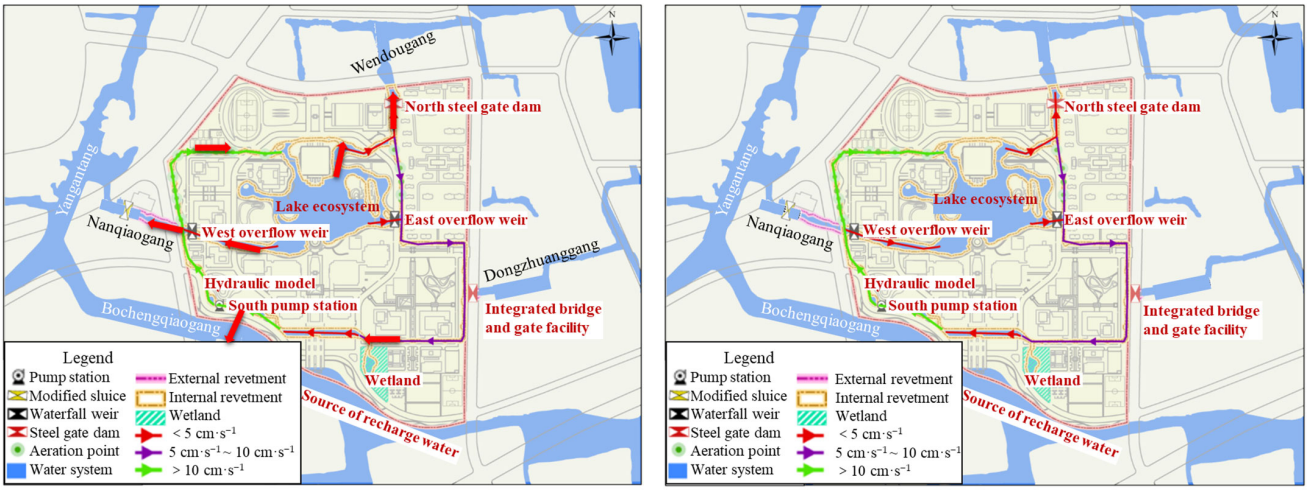


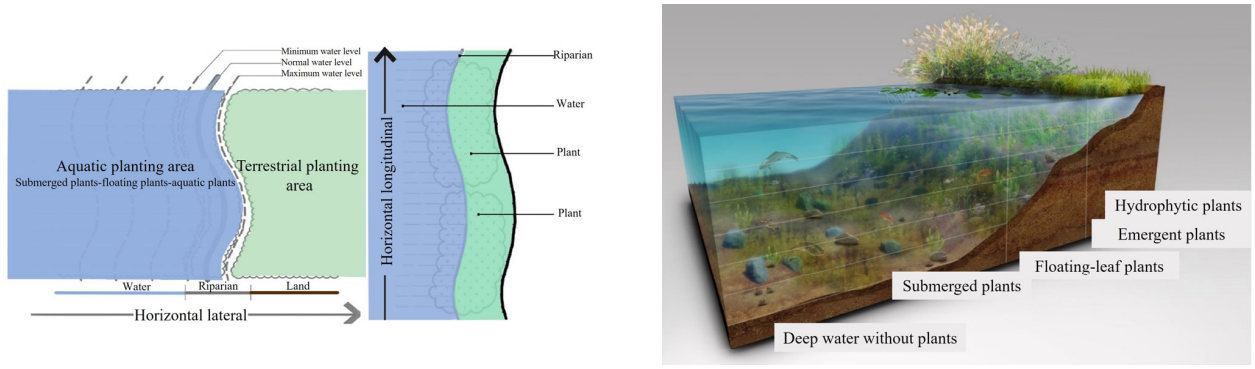
Figure 6. (**a**) Water flow of campus drainage, (**b**) internal self-circulating of campus water system.

To ensure the efficacy and safety of hydrodynamic control projects, a comprehensive approach to operation and maintenance is essential. This approach mandates rigorous monitoring of key hydrological parameters, backed by substantial operational budgets for maintenance, management, and pumping costs. Delineating management and protection scopes is crucial to prevent activities that could compromise the project's integrity. Infrastructure for management, transportation, communication, and observation is essential for agile engineering control. Customized observation items, such as deformation and uplift pressure, require specialized equipment. A well-staffed plan ensures daily maintenance and emergency readiness. Embracing market-oriented management, including the separation of management and maintenance, is key to enhancing the efficiency and competitiveness of water conservancy projects.

3.3. Water Ecosystem Restoration

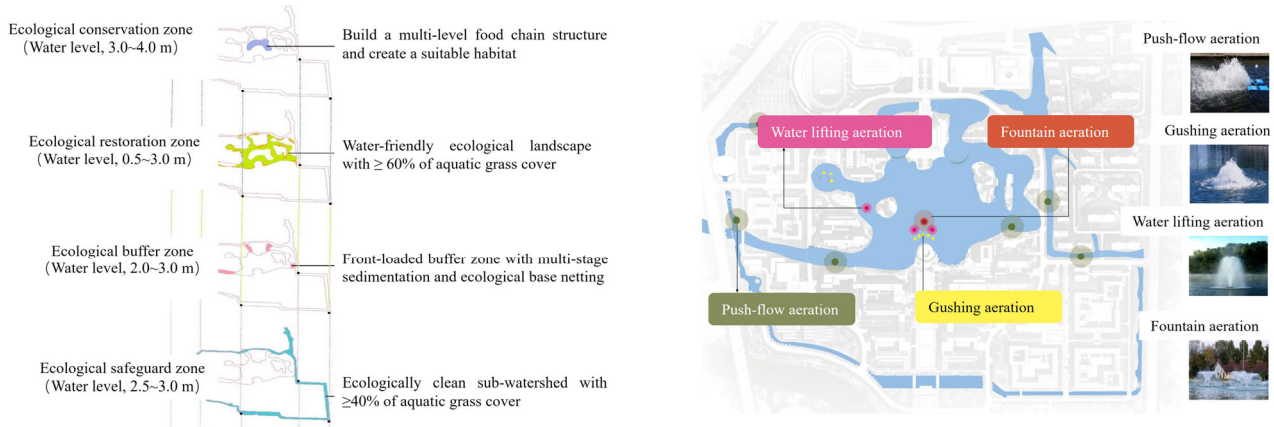
Based on the water quality status of the water system, the capacity of the water environment and the expected purification goal, the "clear water ecosystem" is artificially

constructed on the basis of submerged vegetation restoration, so that animals, plants and microorganisms can form a food chain structure with high purification efficiency, and the self-purification ability and stability of the water body can be improved. Figure 7 shows the aquatic ecosystem plant configuration principles from both the horizontal scale and vertical scale. It can emphasize the clear hierarchy on the landscape of the water body and the mutual influence and constraints of the food chain on the function, as well as understand the ecological niche hierarchy of the lake ecosystem in proximity. To ensure substantial supply of pristine water sources for the campus. The area is meticulously segmented into four key functional zones: the ecological safeguard zone, the ecological buffer zone, the ecological restoration zone, and the ecological conservation zone, see in Figure 8. The ecological safeguard zone, encompassing an area of 60,000 m^2 with dimensions of 10 m width and 2.5 to 3.0 m depth, is situated at the river's outer ring and the main lake inlet channel. It leverages the strip water system and shallow water depth habitat to initiate the strengthening process, which includes a submerged plant purification system, a waterfront plant purification system, and oxygenation and aeration treatments. This zone is instrumental in achieving the ecologically clean sub-watershed functions and in maintaining stable water quality within the main lake area. The ecological buffer zone, approximately 10,000 m^2 in size with a width of 20 m and a depth ranging from 2.0 to 3.0 m, facilitates water exchange between the outer ring of the river and the main lake, serving as an emergency backup water intake channel.



(**a**) (**b**)

Figure 7. Aquatic ecosystem plant configuration principles from (**a**) the horizontal scale and (**b**) vertical scale.



(**a**) (**b**)

Figure 8. (**a**) Water ecological functional zoning map and (**b**) aerations.

From the aspects of water ecological technology in Figure 9, terrain modification is strategically utilized for multi-stage sedimentation, effectively mitigating the influx of sediments into the lake. Additionally, ecological base netting is deployed to reduce the nutrient load entering the lake. The ecological restoration zone, encompassing an area of approximately 54,000 m^2, is characterized by water depths not exceeding 3.0 m. It capitalizes on the lakeshore zone and submerged topography conditions to construct a submerged plant purification system, a waterfront plant purification system, and aerations. The introduction of dwarf hardy bitter grass, prickly bitter grass, black algae, and goldfish algae enhances the biological diversity, presenting an "underwater forest" landscape. A point–line–surface layout in the waterfront plant purification system is aesthetically arranged, with exhibition plates detailing various plant species, thereby augmenting the ornamental value and educational outreach. Lastly, the ecological conservation zone, where the water level exceeds 3.0 m, constructs artificial fish nests underwater to foster aquatic animal habitats. Biomanipulation techniques usually contribute to the decline of phytoplankton biomass through a series of modulations of aquatic biota and their habitats to enhance some of these interactions. Carnivorous Siniperca chuatsi and benthic organisms such as mussels and clams are introduced to manage algal growth in this study. This systematic approach to ecological zoning and water management exemplifies the campus's commitment to creating a sustainable, self-purifying aquatic ecosystem that not only serves the academic and research needs of Nanxun Campus of ZJWEU but also contributes to the broader goals of ecological conservation and environmental education. In addition, the zoning strategy effectively utilizes natural characteristics such as water depth and flow patterns, which are fundamental elements of aquatic ecosystems. By prioritizing local climate data, hydrological conditions, and pollution sources, this method establishes a flexible framework suitable for diverse environments. The scalability of this approach depends on its ability to be tailored to the specific ecological and socio-economic contexts of different regions. With necessary modifications, it can serve as a comprehensive model for ecological restoration across various school campuses and communities. This adaptability underscores the importance of conducting localized ecological assessments and fostering community involvement in the planning and implementation processes, ensuring that the strategy aligns with the unique needs and conditions of each area.

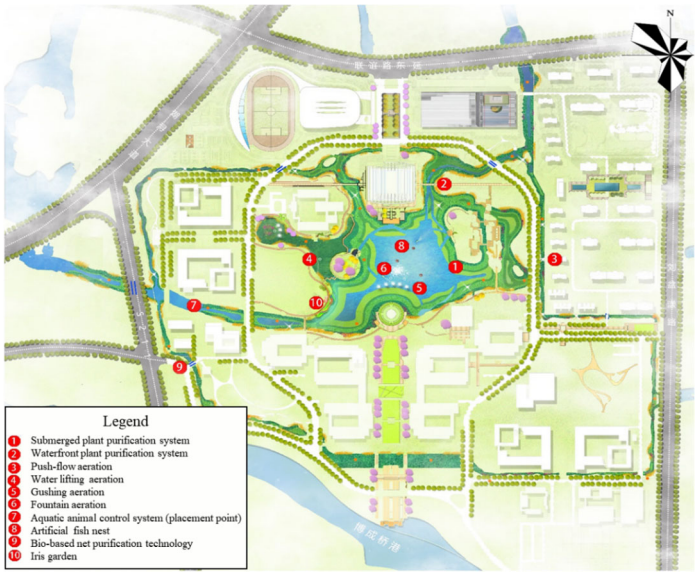


Figure 9. Water ecological technology.

In order to ensure the long-term stability of the water ecosystem, it is recommended to implement the following streamlined operation and maintenance measures. This strategy encompasses routine water quality assessments, transparency monitoring, and prompt removal of surface debris to maintain cleanliness. It also involves the rational introduction of aquatic species to preserve biodiversity and curb invasive species. Swift emergency responses to water quality declines or ecosystem imbalances are critical, employing measures such as isolation and regulation. Regular inspections of facilities like aeration systems are essential for equipment functionality. Enhancing personnel training and establishing a robust internal communication network are vital for swift responses to various scenarios. Scientific methods, including the deployment of algae-consuming zooplankton and flocculants, are employed to improve water quality and manage cyanobacterial blooms. Concurrently, pollution control measures address diverse sources of contamination, ensuring timely cleanup to protect water ecosystems.

3.4. Models and Buildings for Teaching and Practice

The teaching and practice area is situated on the southwest side of the campus, as seen in Figure 10. Miniature models of the Oujiang River, pumped storage power station, arch dam, gravity dam, and barrage power station have been constructed to create a high-quality research, teaching, and practice area. These model power stations are operational and can generate electricity, which can be integrated into the campus's smart microgrid system. At present, the high-speed water tank test section integrated within the facility, with observation points strategically embedded in the surrounding terrain, has been conducted for measurement-based teaching activities. The model control system, equipped with experimental modules, has been instrumental in organizing innovation challenges and fostering educational advancement and research development.

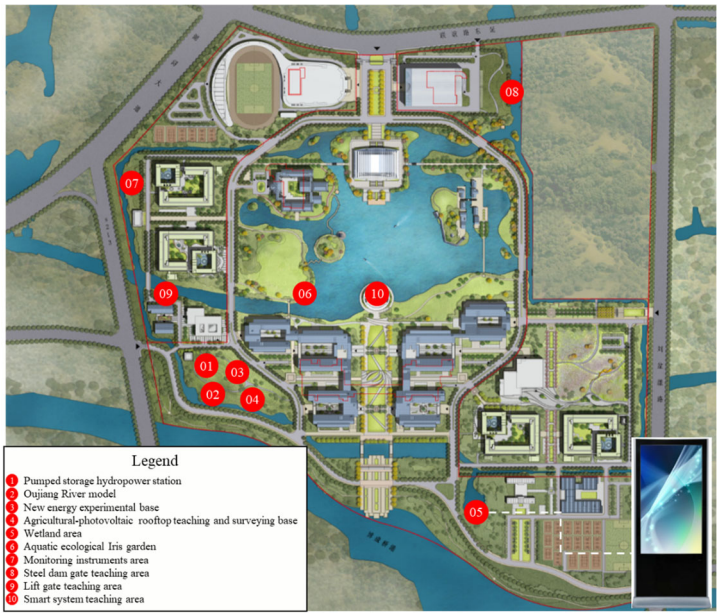


Figure 10. Diagram of the teaching and practice area.

As can be seen in Figure 11, the Panan pumped storage power station, representing the pinnacle of current pumped storage technology, serves as the prototype power station. The power station has a total installed capacity of 1.2 million kW, designed to house four reversible pump-turbine generator sets, each with a capacity of 300,000 kW. The key components of the power station's hub project include the upper reservoir, lower reservoir, water conveyance system, underground plant, and ground switching station. The

upper reservoir utilizes a panel rockfill dam, while the lower reservoir employs a crushed concrete dam. The experimental model of the pumped storage power station comprises an upstream reservoir, downstream reservoir, and experimental hall. Power similarity is a critical factor in the physical modeling of hydraulic structures, necessitating gravity and resistance similarity. To enhance the model's observational accuracy, a larger model geometric scale is selected. Based on the model site and water supply conditions, it is determined that this model test will directly employ a standard model. The total length of the model is 72.23 m, with a maximum water level drop of 9.5 m and a maximum water depth of 2 m for the reservoirs. The areas of the upstream reservoir, downstream reservoir, and experimental hall are 535.68 m^2, 535.68 m^2, and 536.25 m^2, respectively.



(**a**) (**b**)

Figure 11. (**a**) Panan pumped storage plant prototype (**b**) physical modeling of pumped storage power station. Specifically, the planar scale is 30, the vertical scale is 30, the roughness-specific scale is 1.76, the time-specific scale is 5.48, and the flow rate scale is 4929.5.

The Oujiang River spans 388 km with a drainage area of 18,000 km^2. The model study area encompasses the Kaitan, Wuliting, and Waixiong terrace power stations, extending upstream to the weak flood control area of the Oujiang River and downstream to the Waixiong hydropower station, see in Figure 12. The total length is approximately 52.5 km, with river widths ranging from 150 to 600 m, water depths of about 12 to 20 m, and an elevation difference of approximately 35 m between upstream and downstream. Based on the model area site, water supply conditions, and model functional orientation, it is determined that this Oujiang River model will use distorted models. The planar scale is 150, and the vertical scale is 50. Consequently, the total length is 350 m, the maximum water level drop is 0.7 m, and the river width and depth are 1–4 m and 0.3 m, respectively.

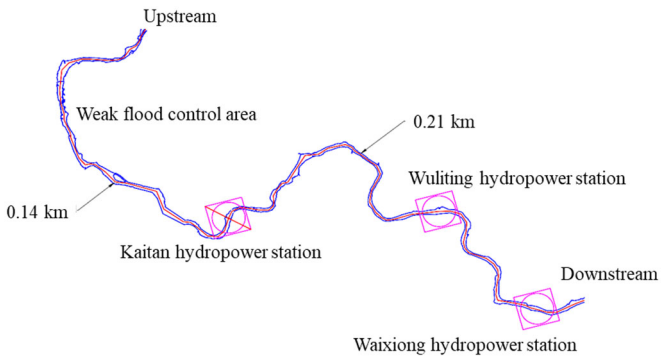


Figure 12. Oujiang River model.

The new energy experimental base and the agricultural-photovoltaic rooftop teaching and surveying base are located in the southwest area of the campus. These areas take

into account teaching, scientific research, innovation, and other applications, reserving interfaces for various types of energy equipment (photovoltaic, energy storage, charging equipment, electronic loads, etc.) and data communication interfaces to achieve flexible access. As depicted in Figure 11b, the experimental hall of the pumped storage power station is equipped with 24.3 kW photovoltaic modules. The energy storage system consists of a 100 kW/200 kWh lithium battery and a 60 kW/300 kWh lead-carbon battery. The main role of the energy storage system is to stabilize the load fluctuation of wind and photovoltaic energy, peak shaving, improve microgrid power quality conditions, and supply uninterrupted power to important loads.

3.5. Intelligent Small Watershed Management

The intelligent small watershed management platform at the Nanxun Campus of ZJWEU is a pioneering initiative that underscores innovation, demand orientation, and application-centric development. It integrates a suite of advanced technologies including 5G, drone surveillance, multi-source data fusion, three-dimensional scene construction, electronic sand table interaction, and mobile Internet of Things (IoT) to enhance the intelligence of water management and decision-making processes. This platform, as depicted in Figure 13, is structured around a foundational layer of monitoring facilities that provide real-time and reliable sensing data, which is essential for decision-making support. It encompasses a comprehensive coverage of water, rain, and project conditions with multi-indicator stations (water quality, water level, video), remote control, video, and flow-rate stations.

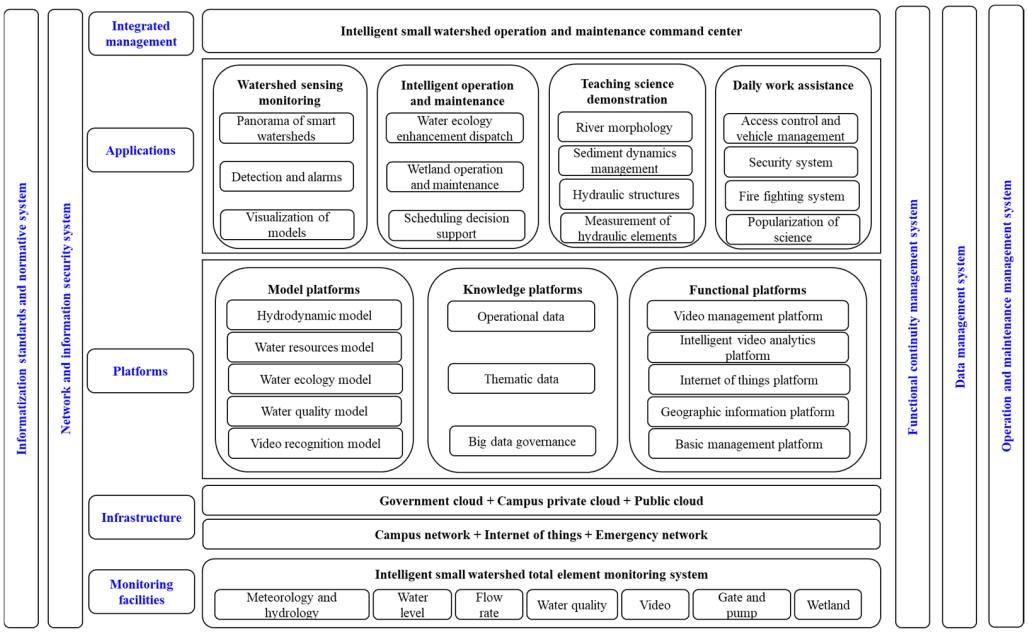


Figure 13. General architecture diagram of smart watershed platform.

As can be seen in Figure 14, the platform's architecture is composed of a model platform, a knowledge platform, and a functional platform, which include hydrological, hydraulic, and water quality models, as well as artificial intelligence (AI) recognition technology. Operationally, it features an integrated fusion display platform, an electronic sand table, a water culture display, and a virtual teaching pavilion, all designed to provide a holistic view of the water system. Furthermore, the intelligent operation and maintenance management system includes real-time monitoring and alarm management, inspection and maintenance management, and drone intelligent inspection management. This system is crucial for proactive incident response and increased employee productivity, ensuring optimal network performance and cost savings by promptly identifying and

resolving performance issues. The scheduling decision-making support system is another key component, which includes modules for flood control and drainage scheduling, water environment enhancement scheduling, wetland water replenishment scheduling, and scheduling decision-making programs, all controlled through a centralized system. This platform represents the first control system in China to focus on the dual objectives of "water safety and water environment" with an emphasis on intelligent teaching, setting a new standard for water resource management in educational and research institutions. It not only strengthens the campus's water safety but also serves as a valuable tool for educational outreach and scientific research in the field of water management.

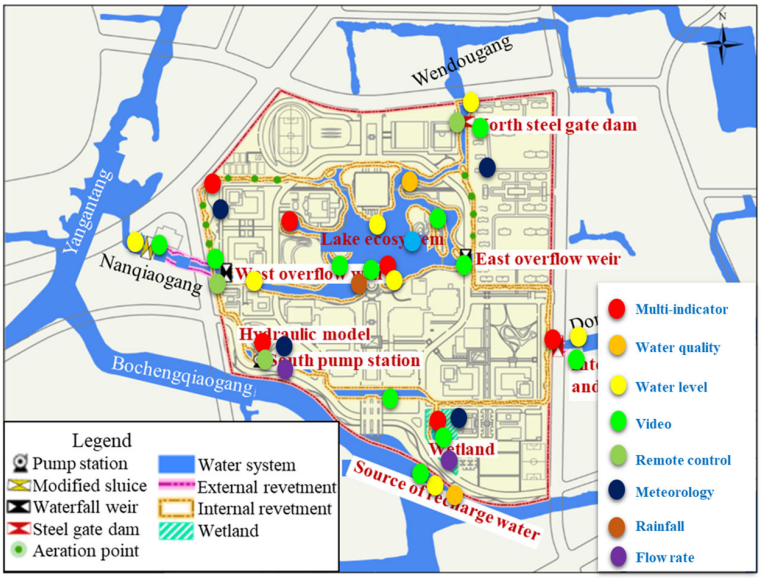


Figure 14. Monitoring facilities.

4. Discussion

Smart campuses are considered as the integration of computing in the cloud and the IoT, which helps in managing, teaching, research, and other activities of universities [36]. Most of the smart campus studies are conceptual, and only a few are prototypes or case studies. However, all of the ideas mentioned in this study have been applied to the creation of the campus. This study embodies the innovative concept and the ambitious vision of "establishing educational institutions atop laboratories to pioneer a model institution for intelligent water resource management". It is far from being merely a laboratory based on the IoT or AI [14] and is not an entity focused on green energy or environmental restoration objectives [37]. It is a system concept and is centered on the holistic objectives of "ensuring water security, enhancing water environments, developing water ecosystems, offering distinctive water education, promoting water culture, and implementing efficient water management". In an innovative approach, it seamlessly integrates the realms of water conservancy with hydroelectric power, mountainous rivers with plain river networks, traditional water conservancy with smart water management, and water conservancy education with research, thereby establishing a prestigious reputation for water conservancy and hydroelectric projects. The project's execution is grounded in the principles of source and systematic governance. Similar to the design of other cases of tanks, cisterns [38], and restored wetlands, the source wetland purification project is conducted, providing the campus with a daily allocation of 3000 m^3 of high-quality water. Generally speaking, sluice and pump hydraulic projects widely used in river networks are rarely used in simple water systems of schools. The water system in the Nanxun Campus of ZJWEU is representative and complex. The water dynamics regulation projects greatly enhance the circulation and

flow of campus river water, ensuring protection against flooding and waterlogging even during extreme rainfall events, such as a once-in-a-century storm. The water ecological construction project prioritizes the restoration of submerged vegetation, artificially creating a "clear water ecosystem" that enhances the water body's inherent self-purification capacity and stability. A study on the Duke University Campus also shows that obligate wetland species successfully colonized the pond and improved water quality services [39]. The water teaching and research hubs, conceived from educational, research, and experimental standpoints, utilize the campus river system to concentrate on hydrology-related disciplines and academic programs. Different from the network-based technologies via a virtual platform, these hubs establish a real network of over ten educational and research nodes across three principal domains: hydroscience, hydroculture, and hydroscapes [14]. The intelligent small watersheds management system, with the capabilities to make forecasts, issue early warnings, conduct simulations, and draft contingency plans, markedly diminishes the reliance on manual operation and maintenance, thereby reducing associated costs. The human-centered learning-oriented smart campus (HLSC) also emphasizes the interdisciplinary nature of the smart campus and the composition of the infrastructure layer, technology layer, and service layer [14]. Common features between HLSC and this study include the main technologies supporting the smart campus revolution, such as smart sensing devices, IoT, data-driven, forecast ability, AR, and AI.

In the actual implementation of the project, there are also many key points and difficulties, especially in the following two areas. These insights can serve as valuable references for other case studies. In the aspect of wetland and water ecological engineering, it is crucial to coordinate various construction processes to reduce redundancy. Planting should be strategically planned according to seasonal patterns to enhance plant survival rates. The trophic cascades within aquatic ecosystems must be carefully managed. Additionally, the emergency recovery capacity of campus water bodies following rainfall or sudden water pollution incidents needs to be ensured. Lastly, the long-term operation and maintenance of constructed water ecosystems should be guaranteed. Regarding water dynamics regulation, it is essential to ensure the reliable operation of pump stations during frequent use. Comprehensive safety measures must be in place for their utilization as educational and scientific outreach facilities. Overflow weirs must function effectively under various conditions, including flood prevention, normal overflow, and maintenance lifting. Furthermore, the precise construction of shallow lake islands should be guaranteed.

In the future, there are plans for more in-depth studies on the long-term operation and maintenance, as well as the widespread adoption of the system. By integrating a comprehensive design methodology and interdisciplinary expertise, the innovative potential and momentum of this work can be more effectively harnessed, thereby accelerating the transition to smart campuses within academic settings.

5. Conclusions

The design and construction of the Nanxun Campus of ZJWEU have been meticulously planned to maximize the comprehensive benefits of flood control, environmental protection, ecological environment enhancement, educational and research activities, and regional economic and educational development (Figure 15). The campus's flood control measures adhere to a 50-year standard, while its drainage system is designed for a 20-year standard. The water dynamics regulation projects ensure robust protection against water-related disasters and bolster the region's capacity for flood control and drainage, thereby safeguarding the water security of the institution. The campus boasts a water surface area of approximately 15 hm^2, with a central lake at its core, surrounded by an interconnected water system that exhibits a diverse array of water patterns. The source wetland

purification project and water ecological construction project improve water quality to the Class III surface water standards and contribute to the overall happiness and satisfaction with green campus life. Intelligent systems, model test areas, ecological pumps, and the construction of a new intelligent micro-grid have all contributed to the establishment of a novel scientific research base with unique research value. The disciplines involved in the smart water demonstration project are in line with the major fields of campus study, and effective water management has become a hallmark of the institution, showing its research, management, and educational achievements. The laboratory-based smart water campus model offers a compelling policy framework that integrates water management with educational, environmental, and infrastructural priorities. Serving as a dynamic experimental setting, it exemplifies a water-focused approach to urban planning and policy, ensuring strict adherence to flood control regulations. By integrating water-related education into its infrastructure, the model enhances students' understanding of sustainable development. This study establishes a pioneering paradigm of integrated water management in academic contexts, offering a scalable educational framework and smart campus design, which is crucial for the advancement of water resource management education.



Figure 15. Photography of the Nanxun Campus of ZJWEU.

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