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Water Balance Testing and Water-Saving Potential Analysis at Guangzhou Railway Polytechnic

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Abstract

This study examines the water-use efficiency and conservation potential of Guangzhou Railway Polytechnic (GRP) using an integrated methodology that combines water balance testing, functional-zone diagnostics, and behavioral surveys conducted between 2022 and 2024. Technical results show robust performance, with per capita consumption averaging 32.83 m^3/person·year—far below the provincial benchmark of 80 m^3—and a distribution-network leakage rate of 3.5%. Functional-zone analysis identifies dormitories (44.9%) and laboratory/practical buildings (20.9%) as the dominant water-use areas, underscoring the need for zone-specific strategies. Behavioral findings reveal that although students and faculty exhibit high awareness and positive conservation attitudes, students demonstrate weaker behavioral execution and limited familiarity with institutional policies (62.8%), contributing to elevated residential consumption. Drawing on the Theory of Planned Behavior and Triple-Loop Learning, the study concludes that while GRP has established a strong technical and governance foundation, further gains depend on digital monitoring, differentiated management, and targeted behavioral interventions. These findings provide actionable insights for developing data-driven and behavior-responsive water management systems in vocational institutions.

Keywords

Water Balance Test, Functional-Zone Analysis, Water-Use Efficiency, Behavioral Participation, Digital Monitoring

1. Introduction

China faces severe challenges in water resource management due to its large population and uneven spatial and temporal distribution of water resources [1]. Water conservation has always been a key component of the nation's water governance strategy. The Opinions on Strengthening the Protection and Management of Rivers and Lakes, recently issued by the General Office of the CPC Central Committee and the State Council, emphasize that by 2035, the efficiency of water resource utilization should be significantly improved [2]. As key public institutions, it is pointed out that universities play a vital role in demonstrating and promoting sustainable water use [3].

In recent years, water conservation in higher education institutions has emerged as a central component of the Chinese green campus agenda. Nevertheless, existing scholarship has predominantly examined comprehensive or undergraduate universities, with research largely concentrated on technological approaches [4]. Prior studies have documented the use of smart metering systems, optimization of sub-metering and pressure management, leakage detection and control, as well as rainwater harvesting and reclaimed-water reuse [5]. International literature similarly underscores the importance of monitoring platforms and data-driven management—such as real-time leakage detection in the U.S. [6]. Universities and stormwater utilization systems that enhance irrigation efficiency on Australian campuses [7]. In parallel, a growing body of work addresses institutional arrangements, including quota-based management, regulatory frameworks, and educational initiatives, highlighting the significance of governance mechanisms in advancing water-use performance.

Despite these contributions, both technological and managerial studies largely remain confined to a "facility enhancement-policy optimization" paradigm and provide limited insight into the behavioral dimensions of campus water use. To address this gap, the present study incorporates Ajzen's Theory of Planned Behavior (TPB) to explain the persistent discrepancies between users' stated intentions and their actual water-use behaviors [8]. TPB provides a structured lens through which attitudes, subjective norms, and perceived behavioral control jointly shape water-related actions. In addition, the study draws on Argyris and Schön's Triple-Loop Learning theory [9], which conceptualizes organizational learning as a progression from technical adjustments (single-loop learning), to institutional refinement (double-loop learning), and ultimately to cultural and value-oriented transformation (triple-loop learning).

Guangzhou Railway Polytechnic (GRP) was certified as a "Water-Saving University" in Guangdong Province in 2025, achieving 100% coverage of water-saving fixtures and maintaining a distribution-network leakage rate far below national and industry benchmarks. Despite this solid foundation, several challenges remain: the absence of a real-time digital monitoring platform, insufficiently structured behavioral intervention mechanisms, and limited empirical analysis of consumption variations across different functional zones. These issues underscore the need for a comprehensive and theoretically informed assessment of GRP's water-use structure, conservation potential, and systemic constraints.

Against this backdrop, the present study adopts GRP as a case institution and integrates technical indicators, spatial consumption patterns, and user behavioral factors into a unified analytical framework supported by TPB and Triple-Loop Learning. Through a multi-dimensional evaluation of technical performance, governance capacity, and behavioral engagement, the study aims to generate empirically grounded and theoretically informed insights that can guide vocational institutions in developing digital, behavior-driven, and institutionally resilient water conservation systems.

2. Statement of the Problem

Although Guangzhou Railway Polytechnic (GRP) has made remarkable achievements in constructing a water-saving campus—such as realizing a 100% installation rate of water-saving devices and effectively controlling pipeline leakage—its overall water resource management still faces several key limitations. These limitations hinder the establishment of a sustainable and data-driven water conservation system.

In general, the problem lies in the absence of an integrated mechanism for evaluating, monitoring, and optimizing water use efficiency. While technical measures have been implemented, the lack of systematic data analysis and behavioral evaluation makes it difficult to achieve precise and sustainable management.

Specifically, three main problems can be identified. First, the school does not yet have a comprehensive digital water monitoring platform that can provide real-time data collection, leakage detection, and multi-zone water consumption analysis. This limits the ability to make evidence-based management decisions. Second, water-saving awareness and behavioral participation among students and staff remain uneven, and there is no continuous feedback system to evaluate the effectiveness of educational campaigns or behavioral interventions. Third, the quantitative analysis of the water balance and conservation potential across functional zones—such as dormitories, laboratories, and teaching areas—is still insufficient, leading to generalized rather than targeted management and technical measures.

Addressing these issues requires a systematic analysis of the school's water balance to identify inefficiencies, propose management and technological innovations, and promote behavioral change among campus users. Through this study, a practical and replicable model for water-saving university construction in vocational colleges can be developed, contributing to the broader goal of sustainable water resource management in higher education institutions.

3. Methodology

This study employed a quantitative–descriptive design supplemented by qualitative analysis to examine the water-use structure and conservation potential of GRP. The methodological procedure consisted of four integrated stages: data acquisition, water balance computation, efficiency assessment, and validation through institutional and behavioral evidence. All analytical steps adhered to the Technical

Guidelines for Water Balance Testing in Water-Using Units (GB/T 12452-2021) [10].

Water-use data were collected from the campus water supply system covering 2022 to 2024, including meter records, supply logs, maintenance reports, and leakage repair documentation. Monitoring points were distributed across major functional zones—teaching buildings, laboratories, dormitories, and canteens—to ensure comprehensive spatial coverage. Secondary sources, such as administrative reports and technical documents from the school's water-saving initiative, were used to corroborate the operational data.

The water balance was calculated following standardized parameters, including total inflow, metered consumption, system losses, and reuse-water output. Core indicators were derived using formula-based computations. For example, the pipe network leakage rate was calculated as:

$$L = \frac{Q_{in} - Q_{metered}}{Q_{in}} \times 100\% \tag{1}$$

where denotes total water inflow and represents metered consumption. Water-use efficiency was assessed using the ratio:

$$E = \frac{Q_{effecive}}{Q_{in}} \tag{2}$$

and per capita consumption was computed by:

$$C_{pc} = \frac{Q_{annual}}{N_{standardized}} \tag{3}$$

These formulas provided a consistent basis for evaluating performance against national and provincial benchmarks.

To examine user behavior and awareness, structured questionnaires were administered to 300 students and 50 faculty and staff members. The questionnaire was developed following established survey design principles and consisted of three sections: water-saving awareness, daily water-use habits, and attitudes toward conservation. Most items used a five-point Likert scale (1 = strongly disagree to 5 = strongly agree) to enable standardized comparison. To ensure content validity, the questionnaire items were adapted from previously validated instruments in environmental behavior research, including studies informed by Ajzen's Theory of Planned Behavior. Three experts in water resource management reviewed the instrument for clarity and relevance, and a pilot test with 30 students and 5 staff members was conducted to evaluate item comprehension. Minor wording adjustments were made based on pilot feedback. Internal consistency reliability was assessed using Cronbach's alpha, yielding coefficients of 0.82 for awareness, 0.79 for behavior, and 0.85 for attitude items, indicating acceptable reliability. (**Table 1**, **Table 2**)

All respondents participated voluntarily under informed consent, and the study received approval from the Ethics Review Board of Guangzhou Railway Polytechnic. Quantitative survey responses were analyzed through descriptive statistics and correlation tests to explore associations between awareness levels and self-reported practices. The survey will be distributed with the tool of Questionnaire Star.

Table 1. Participants of the study.

Participants		Frequency	Percentage (%)
Teachers		50	14
Students	Road engineering technology	80	23
	Railway engineering technology	95	27
	Civil and Architectural Engineering	85	24
	Foreign Languages and Business	40	12
	Total	350	100

Table 2. Structure of the water-saving behavior questionnaire.

Dimension	Item Description
I. Water-Saving Awareness	A1. I am aware that the university is promoting the construction of a water-saving campus. A2. I know the major water-use sectors on campus. A3. I believe water conservation is necessary for campus sustainability. A4. I am familiar with common water-saving practices in daily life.
II. Daily Water-Use Behavior	B1. I reduce unnecessary water use during washing or personal hygiene. B2. I check whether taps are fully closed before leaving the dormitory or laboratory. B3. I consciously shorten shower or cleaning time. B4. I report leaks or faulty fixtures to campus management when detected. B5. I remind peers to conserve water.
III. Attitudes and Behavioral	C1. I am willing to participate in school water-intention saving activities. C2. I believe my personal water-saving behavior has an impact on campus water conservation. C3. I am willing to adjust my behavior if the school provides feedback or reminders. C4. I intend to maintain water-saving habits in the future.

All items were rated on a five-point Likert scale (1 = strongly disagree, 5 = strongly agree).

Quantitative data processing was performed using IBM SPSS Statistics 26.0, which supported descriptive statistics, cross-sectional comparisons, and trend analyses. Microsoft Excel was used for visualization and time-series data plotting to identify changes before and after key interventions, such as fixture replacement and pipeline rehabilitation.

To complement the numerical findings, qualitative document analysis was conducted on institutional records, including management policies, committee reports, meeting minutes, and educational activity logs. Using a thematic coding framework, these documents were examined to identify recurring patterns related to governance mechanisms, maintenance procedures, and engagement strategies. Triangulation was applied by comparing qualitative themes with quantitative indicators, enabling validation of technical and behavioral interpretations.

Through the integration of measurement-based water balance computations, statistical analysis, and qualitative evidence, this methodological framework provided a rigorous and replicable approach for assessing campus water-use efficiency and identifying opportunities for enhanced water conservation.

4. Data Analysis

The analysis of water-use data at GRP drew upon institutional records from 2022 to 2024, the 2024 Water Balance Test Report, and functional-zone monitoring datasets. All quantitative data were cleaned, validated, and standardized prior to analysis. Descriptive statistics were then generated to examine overall consumption patterns, efficiency indicators, and spatial variations across campus facilities. The subsequent analytical procedures, supported by statistical and documentary evidence, provide a multi-dimensional interpretation of the institution's water-use dynamics.

Annual and semi-annual consumption data are presented in **Table 3**. Total water consumption exhibited a gradual decline over the three-year period, decreasing from 365,210 m^3 in 2022 to 351,980 m^3 in 2023. In the second half of 2024, total consumption reached 182,423 m^3, corresponding to an annualized per capita use of 32.83 m^3/person·year based on a standardized population of 11,112 persons. This value remains far below the provincial benchmark of 80 m^3/person·year, indicating sustained efficiency in campus water use.

Table 3. Total water consumption and per capita use, 2022-2024.

Year	Total Consumption (m^3)	Standardized Population	Per Capita Use (m^3/person·year)
2022	365,210	10,850	33.67
2023	351,980	11,000	31.91
2024* (Half Year)	182,423	11,112	32.83 (Annualized)

Spatial analysis of functional zones revealed distinct patterns in water-use intensity in **Table 4**. Dormitories accounted for the largest proportion (44.9%), followed by laboratory buildings (20.9%), canteens (15.0%), and teaching buildings (11.6%). The relatively high share of laboratory consumption suggests that experimental and practical teaching activities constitute an important driver of institutional water demand and represent a key area for efficiency enhancement.

The campus distribution network demonstrated strong operational performance, as summarized in **Table 5**. The measured leakage rate was 3.5%, substantially lower than the national benchmark of 10%. Metering coverage reached 100%, and meter accuracy was verified at 98.7%. The water-balance deviation across campus zones remained within ±1.2%, well within the allowable engineering tolerance. These indicators collectively reflect a stable and well-maintained supply system.

Table 4. Water use by functional zone, second half of 2023.

Zone	Consumption (m^3)	Share (%)
Dormitories	81,950	44.9
Canteens	27,430	15.0
Teaching Buildings	21,210	11.6
Laboratory/Practical Buildings	38,060	20.9
Administrative & Public Areas	13,773	7.6

Table 5. Water distribution system performance indicators (2023, half year).

Indicator	Recorded Value	Technical Requirement	Interpretation
Leakage Rate	3.5%	≤10%	Exceeds efficiency standards
Metering Coverage	100%	≥95%	Full coverage
Meter Accuracy	98.7%	≥95%	Meets technical criteria

Non-conventional water use, including rainwater harvesting and reclaimed-water systems, also contributed to campus water efficiency in Table 6. In 2023, the combined utilization of rainwater and reclaimed water reached 30,530 m^3, accounting for 8.6% of total consumption, higher than the typical 5% observed in comparable institutions. These resources were primarily used for landscape irrigation, road cleaning, toilet flushing, and other non-potable applications.

Table 6. Utilization of non-conventional water resources (2023).

Resource Type	Volume (m^3)	Share of Total Use (%)	Primary Applications
Rainwater	12,480	3.5	Irrigation, cleaning
Reclaimed Water	18,050	5.1	Flushing, landscape replenishment
Total	30,530	8.6	-

Survey data from 300 students, 50 faculty and staff members were analyzed to contextualize water-use patterns. As shown in Table 7, both groups reported high water-saving awareness and positive conservation attitudes, but clear differences appeared in daily behaviors. Faculty and staff demonstrated stronger behavioral compliance—such as turning off taps and reporting leaks—whereas students showed weaker follow-through despite positive attitudes. Notably, only 62.8% of students were familiar with campus water-saving policies, which may help explain higher water consumption in residential dormitory areas.

Table 7. Summary of behavioral survey findings by dimension.

Indicator	Students (n = 300)	Faculty/Staff (n = 50)
Water-Saving Awareness	High overall awareness; however, only 62.8% familiar with institutional water-saving policies.	Very high awareness and strong understanding of campus water-saving policies (88.0%).
Daily Water-Use Behavior	Moderate compliance; less consistent in reporting leaks or reminding peers; 81.2% habitually turn off taps.	Moderate compliance; less consistent in reporting leaks or reminding peers; 81.2% habitually turn off taps.
Attitudes & Intentions	Generally positive attitudes; willingness to participate in activities (76.3%) but weaker follow-through in practice.	Strong conservation attitudes and higher readiness to adjust behaviors in response to institutional feedback.

Taken together, the empirical evidence points to a highly efficient and well-governed water-use system. Declining consumption trends, exceptionally low leakage rates, and substantial non-conventional water utilization demonstrate the technical effectiveness of GRP's conservation measures. At the same time, functional-zone disparities and gaps in student policy awareness highlight opportunities for targeted interventions. The combined quantitative and qualitative findings form the evidential foundation for the subsequent Results and Discussion section.

5. Results and Discussion

The findings of this study provide a comprehensive assessment of water-use performance at GRP and directly address the institutional and operational challenges identified in the Statement of the Problem. Through the integration of water balance computations, functional-zone diagnostics, and behavioral analysis, the results reveal both the strengths of GRP's existing conservation system and the areas where targeted improvements remain necessary.

The quantitative results show that the institution has consistently maintained relatively low water consumption compared with provincial benchmarks. The annualized per capita consumption of 32.83 m^3/person·year remains well below the recommended threshold of 80 m^3/person·year for higher education institutions. As illustrated in Figure 1, total water consumption demonstrates a clear downward trend from 2022 to 2024. Despite a gradual increase in the standardized campus population, overall consumption declined steadily during this period, suggesting that the conservation benefits derived from water-saving fixtures, pipe rehabilitation, and standardized management practices have been both cumulative and sustained. The smooth slope of the trend line indicates that these improvements were the result of long-term structural enhancements rather than short-term administrative interventions.

The spatial distribution of water use provides further insight into the structural characteristics of campus demand. As shown in Figure 2, water use is heavily concentrated in dormitories (44.9%) and laboratory/practical buildings (20.9%), followed by canteens (15.0%) and teaching buildings (11.6%). These patterns confirm that earlier water-saving measures were applied primarily on a facility-wide basis and did not sufficiently account for functional differentiation. The results highlight the need for targeted strategies: dormitory areas require behavior-oriented interventions—such as strengthened awareness communication, feedback displays, and optimized fixture flow rates—while laboratory zones would benefit more from technical optimization, including closed-loop cooling systems, fixed-volume valves, and scheduled equipment operation.

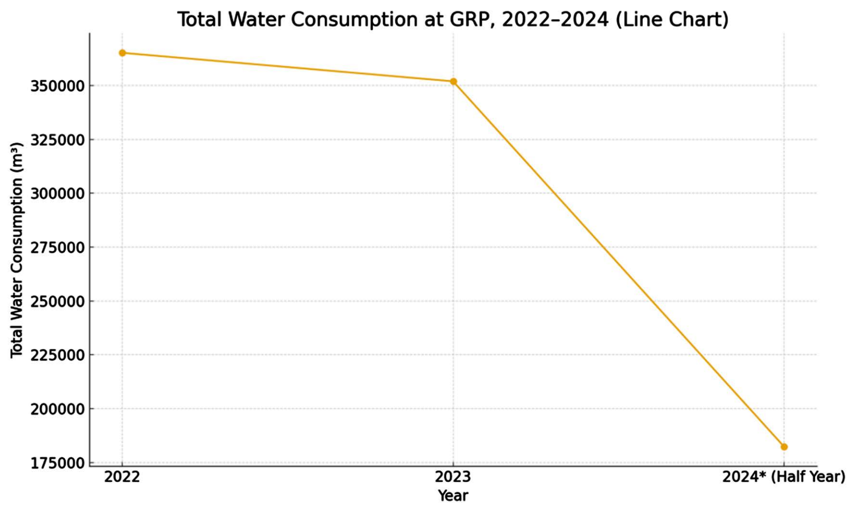

Figure 1. Total water consumption at Guangzhou Railway Polytechnic from 2022 to 2024 (2024 represents half-year consumption).

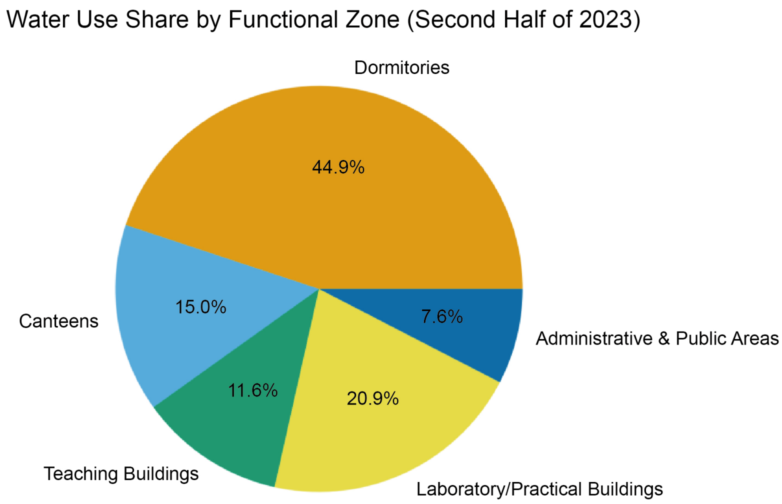

Figure 2. Water use share by functional zone at Guangzhou Railway Polytechnic in the second half of 2023.

Operationally, the water distribution network exhibited high stability throughout the testing period. A leakage rate of 3.5%, full metering coverage (100%), and zone-level balance deviations within ±1.2% collectively demonstrate robust infrastructure performance. These results indicate that routine manual inspections and scheduled maintenance activities have effectively ensured stable system operations even in the absence of a real-time digital monitoring platform. Nonetheless, this stability also reinforces the need for enhanced monitoring technologies—one of the core issues identified in the Statement of the Problem—as the current system lacks the ability to perform predictive diagnostics, automated anomaly detection, or real-time decision support.

Behavioral findings provide important insight into the second major problem previously identified: uneven awareness and insufficient behavioral participation. Survey data from 300 students and 50 faculty/staff showed high levels of water-saving awareness and generally positive conservation attitudes across both groups. However, clear differences emerged in daily behavioral execution. Faculty and staff demonstrated stronger behavioral compliance—such as consistently turning off taps, reporting leaks, and reducing unnecessary water use—whereas students showed weaker follow-through despite positive attitudes.

A particularly notable finding is that only 62.8% of students reported understanding the institution's water-saving policies, compared with 88.0% of faculty and staff. Students were also less likely to report leaks or remind peers to conserve water. These discrepancies between awareness, attitudes, and actual behaviors align with Ajzen's Theory of Planned Behavior, which posits that attitudes alone are insufficient for sustained action unless supported by perceived behavioral control and reinforcing social norms. The dominance of dormitory water consumption shown in **Figure 2** further underscores the need to strengthen student-centered educational interventions and develop behavior-guiding feedback systems.

Supporting qualitative evidence indicates that GRP's existing governance mechanisms have played a significant role in sustaining its current level of performance. The establishment of a Water-Saving Working Committee, the adoption of quota-based allocation methods, the implementation of standardized maintenance protocols, and the use of incentives reflect a maturing institutional framework. These developments are consistent with Argyris and Schön's Triple-Loop Learning Framework: the institution has progressed from technical adjustments (single-loop learning) to policy reinforcement and system refinement (double-loop learning), and is gradually moving toward embedding conservation values into campus culture (triple-loop learning).

6. Conclusions

This study combined water balance testing, functional-zone diagnostics, and behavioral survey data to evaluate water-use performance at Guangzhou Railway Polytechnic. The findings indicate that GRP has achieved strong technical efficiency—characterized by low leakage rates, complete metering coverage, and per capita consumption well below provincial benchmarks—demonstrating the sustained impact of infrastructure upgrades and standardized maintenance practices.

Despite these achievements, substantial variation across functional zones persists, with dormitories and laboratory buildings exhibiting disproportionately high demand. This pattern suggests that earlier conservation efforts, while effective at the system level, were not sufficiently tailored to the operational characteristics of high-use areas. Simultaneously, behavioral results reveal that although students and faculty hold positive conservation attitudes, students exhibit weaker behavioral execution and limited familiarity with institutional policies. These gaps align with the Theory of Planned Behavior and help explain the elevated consumption observed in residential settings.

Overall, the results highlight the need for GRP to integrate technical, managerial, and behavioral strategies more tightly. Priority areas include developing digital monitoring capabilities, implementing zone-specific water-saving interventions, and strengthening student-focused behavioral programs. These conclusions offer evidence-based guidance for vocational institutions seeking to establish data-driven, behavior-responsive, and resilient campus water management systems.

Limitations

Although this study provides a comprehensive analysis of water-use performance at a vocational institution, several limitations warrant consideration. First, the research is based on a single-institution case study, which may limit the generalizability of the findings. GRP's campus structure, management practices, and user population may differ from those of other vocational colleges, suggesting the need for multi-campus comparative studies to enhance external validity.

Second, the data set covers the period from 2022 to 2024, a relatively short time span that may not fully capture long-term variability arising from climatic factors, institutional changes, or demographic fluctuations. Extending the temporal scope of future research would support more robust trend analysis and modeling.

Third, the behavioral findings rely on self-reported questionnaire data, which may be subject to social desirability bias or recall bias. Future studies could complement survey data with observational measures, smart-meter-based behavioral tracking, or controlled intervention experiments to strengthen the reliability of behavioral insights.

Finally, although the study integrates technical, managerial, and behavioral perspectives, it does not examine broader economic, cultural, or psychological drivers of water use that may further refine the understanding of user decision-making. Incorporating these dimensions into more complex behavioral models would deepen theoretical explanations of water-use patterns in campus settings.

Recognizing these limitations helps situate the study within its appropriate scope and highlights promising avenues for advancing research on water conservation in vocational education institutions.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] Xie, R. (2025) China's Water Resources Middle School Politics, History, and Geography. *Applicable to Middle School*, **9**, 44-48.

[2] General Office of the Communist Party of China Central Committee and General Office of the State Council (2025) Opinions on Comprehensive Promotion of River Protection and Governance. State Council Information Office of the People's Republic of China. http://www.scio.gov.cn/zdgz/jj/202506/t20250627_919015_m.html

[3] Zu, L.M. (2025) Overall Approach and Countermeasures for the "15th Five-Year Plan" Water Security Guarantee in the Yellow River Basin. *China Water Resources*, **20**, 1-6.

[4] Xie, F., Hao, Z.R., Wang, G.T., *et al.* (2022) Analysis of Water Use Patterns and Water Saving Technologies in Universities System Construction. *Construction Technology*, **1**, 4-7.

[5] Liu, X.G., Zhang, D.S., Yan, Q.H. and Gan, H.X. (2025) The Enlightenment of American Water Conservation Certification Practice on Water Conservation Management in China. *Research on Water Conservancy Development*, **7**, 29-35+59.

[6] Huang, N. (2021) Introduction to Australia's Green Building Policy Measures and Comparison with China Building. *Energy Efficiency*, **49**, 52-58.

[7] Zhang, D. (2025) Research on the Construction of Water Saving Universities in Guangxi. *Economist*, **6**, 157-158+165.

[8] Ajzen, I. (1991) The Theory of Planned Behavior. *Organizational Behavior and Human Decision Processes*, **50**, 179-211. https://doi.org/10.1016/0749-5978(91)90020-t

[9] Argyris, C. and Schön, D. (1978) Organizational Learning: A Theory of Action Perspective. Addison Wesley.

[10] National Standard Information Public Service Platform (2022) Opinions on Comprehensive Promotion of River Protection and Governance. China National Institute of Standardization.
https://std.samr.gov.cn/gb/search/gbDetailed?id=E3C42FB7ACFF2086E05397BE0A0A19F0