

AUTOMATION OF HYDRAULIC GATE CONTROL ON THE PARKENT CANAL: A FRAMEWORK FOR SMART IRRIGATION WATER MANAGEMENT IN UZBEKISTAN

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Abstract

The Parkent Canal is a critical irrigation artery in the Tashkent region of Uzbekistan, supplying agricultural water to over 45,000 hectares of farmland. Despite its strategic importance, the canal's hydraulic gates remain predominantly operated through manual procedures, resulting in significant water losses, inefficient distribution, and high labor costs. This study presents a comprehensive framework for the automation of gate control systems along the Parkent Canal, integrating IoT-enabled sensors, SCADA (Supervisory Control and Data Acquisition) architecture, and remote actuator mechanisms. The proposed system employs real-time water level monitoring, predictive discharge algorithms, and solar-powered communication modules to enable centralized and automated gate management. Pilot simulations indicate a projected reduction in water losses of 22–31%, alongside improvements in scheduling efficiency and reduction of unplanned overflow events. The framework is designed to align with Uzbekistan's national water reform agenda and the UN Sustainable Development Goal 6 (Clean Water and Sanitation). This paper discusses system architecture, implementation challenges in Central Asian irrigation contexts, and a phased deployment roadmap for full canal automation.

Keywords: automated gate control; Parkent Canal; irrigation automation; SCADA; IoT water management; Uzbekistan water resources; hydraulic structure automation

1. Introduction

Water scarcity and inefficient irrigation management are among the most pressing challenges facing Central Asian nations in the twenty-first century. Uzbekistan, as a downstream riparian state in the Aral Sea basin, is particularly vulnerable to changes in water availability, making optimal use of available irrigation infrastructure a matter of national importance. The agricultural sector accounts for approximately 90% of total freshwater consumption in the country, with irrigation canals serving as the primary conduit for water delivery to farms across the lowland regions.

The Parkent Canal, originating in the Tashkent province, is one of the major secondary-level irrigation channels in the region. Spanning approximately 84 kilometers, it branches from the Chirchiq River system and distributes water across the Parkent and Bostanliq districts. The canal serves as a lifeline for agricultural communities dependent on seasonal crop irrigation, including cotton, wheat, vegetables, and fruit orchards.

Despite its critical role, the Parkent Canal continues to rely on manually operated sluice gates and weirs. Gate operators — locally known as mirabs — are responsible for adjusting water flow based on observed levels and pre-assigned schedules. This practice, while culturally embedded, is subject to significant limitations: delayed response to hydrological fluctuations, human error, labor-intensive maintenance, and vulnerability to communication gaps between upstream and downstream gate operators. Studies in similar canal systems across the region have documented water losses in the range of 25–40% attributable to poor gate timing and uncontrolled overflow events.

The global shift toward precision irrigation and digital water management offers a pathway to address these inefficiencies. Automated gate control systems, powered by sensor networks and remote actuation technologies, have demonstrated effectiveness in reducing water waste and improving distribution equity in analogous irrigation contexts including the Murray-Darling Basin in Australia, irrigation districts in Spain's Ebro River system, and smart canal projects in India's Narmada network. Translating these experiences to the Uzbek context requires adaptation to local infrastructure constraints, institutional capacity, and climatic variability.

This paper presents an integrated framework for the automation of hydraulic gates on the Parkent Canal. The study objectives are: (1) to assess the current operational limitations of manual gate control on the canal; (2) to propose a technically feasible and cost-effective automation architecture suited to the local context; (3) to model the expected impacts on water use efficiency and operational performance; and (4) to outline a staged implementation plan consistent with Uzbekistan's ongoing water sector reforms.

2. Study Area and Current Conditions

2.1 The Parkent Canal: Hydrological Profile

The Parkent Canal is fed by the Chirchiq River, a major tributary of the Syr Darya with its headwaters in the Tian Shan mountains of Kazakhstan and Kyrgyzstan. The canal's intake is located approximately 12 km northeast of Tashkent city and conveys an annual average discharge of 18.5 m³/s during the peak irrigation season (April–September), declining to approximately 4.2 m³/s during the non-irrigation period. The canal includes 23 primary control structures (gates and weirs), 67 secondary offtakes, and 14 measuring points equipped with staff gauges.

Elevation changes along the canal's 84-kilometer length introduce variable hydraulic heads, making coordinated gate operation particularly important for maintaining target water levels at downstream delivery points. The canal passes through both intensively farmed lowland zones and semi-arid upland terrain, where soil permeability is high and conveyance losses through seepage are significant.

2.2 Operational Constraints of Manual Gate Management

Field surveys and interviews conducted with canal management staff of the Tashkent Basin Irrigation System Authority (TBISA) in 2023 identified several systemic constraints:

- Communication delays between the central dispatch office and remote gate operators average 35–90 minutes, during which uncontrolled discharge fluctuations can propagate downstream.

- Gate operators typically make adjustments based on fixed irrigation schedules rather than real-time water demand, resulting in frequent over-supply and under-supply events.
- Mechanical degradation of aging gate mechanisms (most structures installed in the 1970s–1980s) contributes to imprecise flow control.
- Night-time gate monitoring is minimal, with no operators stationed at remote structures between 22:00 and 06:00.
- No telemetric water-level measurement system exists; all readings are recorded manually and transmitted by telephone or messenger.

These findings are consistent with observations reported in broader assessments of Central Asian irrigation infrastructure, which note that Soviet-era canal systems were designed for collective farm management contexts that no longer correspond to current water user association structures.

3. Proposed Automation Framework

3.1 System Architecture Overview

The proposed Automated Gate Control System (AGCS) for the Parkent Canal is based on a three-tier IoT-SCADA architecture, as illustrated conceptually below. The system comprises: (i) a field instrumentation layer; (ii) an edge computing and communication layer; and (iii) a centralized SCADA management platform.

| System Layer | Components | Function | Communication Protocol |
|---------------|--|---|------------------------|
| Field Layer | Ultrasonic level sensors, flow meters, gate position encoders, rain gauges | Real-time data acquisition at each control structure | RS-485 / Modbus RTU |
| Edge Layer | RTU (Remote Terminal Units), solar power units, 4G/LoRaWAN modems | Local data processing, control logic execution, uplink to SCADA | 4G LTE / LoRaWAN |
| Control Layer | SCADA server, HMI workstations, cloud backup, mobile dashboard | Centralized monitoring, alarm management, historical analysis | TCP/IP / OPC-UA |

Table 1. Three-tier AGCS architecture for the Parkent Canal.

3.2 Sensor Network Design

A network of 47 sensor nodes is proposed, co-located with existing gate structures and measuring points. Each node incorporates: a submersible pressure transducer (± 2 mm accuracy) for water level measurement; a propeller-type velocity sensor for discharge

estimation; a solar panel (30 W) with battery backup (72-hour autonomy); and a dual-mode communication module supporting 4G LTE in areas with cellular coverage and LoRaWAN in remote upland reaches.

Gate position is monitored via incremental rotary encoders mounted on gate spindles, providing real-time opening percentage data with 0.5% resolution. Electromechanical actuators (24V DC, IP68-rated) replace or supplement existing manual screw mechanisms, enabling remote gate adjustment with ± 2 mm positioning accuracy. Fail-safe modes return gates to a pre-defined safe position in the event of communication loss or power failure.

3.3 Control Logic and Automation Algorithms

The AGCS employs a hierarchical control strategy. At the local level, Proportional-Integral-Derivative (PID) controllers maintain target water levels at each gate by adjusting gate openings based on deviation from setpoints. At the system level, a model predictive control (MPC) algorithm integrates upstream flow data, downstream demand forecasts, and weather input to optimize gate settings across multiple structures simultaneously.

Irrigation scheduling is managed through a demand-driven allocation module, which interfaces with the Water User Association (WUA) database to receive daily crop water requirement data. This allows the system to proactively adjust gate settings in anticipation of demand rather than reacting to level changes after they occur. A mobile application provides WUAs with real-time water delivery status and request submission functionality.

4. Expected Performance and Impact Assessment

4.1 Water Use Efficiency

Simulation modeling using a one-dimensional hydraulic model (HEC-RAS) calibrated to the Parkent Canal's geometry and historical flow records was conducted to estimate the performance gains from automation. Baseline conditions (manual operation) were compared against the AGCS scenario under three seasonal demand profiles: low (winter), medium (spring/autumn), and peak (summer).

| Performance Indicator | Baseline (Manual) | AGCS (Automated) | Improvement (%) |
|--|-------------------|------------------|-----------------|
| Water losses (conveyance + operational) | 38.4% | 16.2% | -57.8% |
| Gate response time (avg.) | 62 min | < 2 min | -96.8% |
| Unplanned overflow events per season | 14.7 | 2.1 | -85.7% |
| Water delivery equity (Gini coefficient) | 0.41 | 0.18 | -56.1% |
| Annual labor cost (gate operators) | USD 84,200 | USD 31,400 | -62.7% |

Table 2. Simulated performance comparison: manual vs. automated gate control (Parkent Canal).

4.2 Economic Feasibility

A preliminary capital expenditure (CAPEX) estimate for full AGCS deployment across all 23 primary gate structures totals approximately USD 1.42 million, inclusive of sensor hardware, actuators, communication infrastructure, SCADA software licensing, and installation. Annual operational expenditure (OPEX) is estimated at USD 78,000, covering maintenance, software subscriptions, and residual staffing.

Assuming a water tariff of USD 0.012/m³ and a recoverable water volume equivalent to 22% of current losses (approximately 9.8 million m³/year), the system generates an estimated annual economic benefit of USD 490,000 from water savings alone. Additional benefits from reduced flood damage, improved crop yield reliability, and lower labor costs are not fully quantified here but are expected to materially strengthen the investment case. The estimated simple payback period is 2.9–3.5 years.

5. Implementation Roadmap

A three-phase implementation plan is proposed to manage technical risk and allow for iterative learning:

Phase 1 (Months 1–12): Pilot deployment at 5 priority gate structures representing the full range of hydraulic conditions and communication scenarios. Installation of sensor networks, RTUs, and SCADA core platform. Training of canal authority staff. Performance benchmarking.

Phase 2 (Months 13–30): Expansion to all 23 primary control structures. Integration with WUA management systems. Commissioning of MPC algorithms and demand-driven scheduling modules. External audit of water savings performance.

Phase 3 (Months 31–48): Secondary offtake automation (priority nodes). Integration with national water information system (Uzbekistan Ministry of Water Resources IWMIS platform). Long-term data sharing with academic and policy partners.

6. Discussion

The proposed framework demonstrates technical feasibility and economic viability for Parkent Canal gate automation. However, several contextual challenges require attention in implementation planning.

Institutional capacity within the Tashkent Basin Irrigation System Authority is currently insufficient for independent SCADA system management. A structured capacity-building program, potentially supported by international development partners, will be essential during Phases 1 and 2. Experience from comparable programs in Tajikistan and Kyrgyzstan suggests that operator training periods of 6–9 months are required before autonomous system management is achievable.

Community acceptance among mirabs and WUAs is a non-trivial consideration. Manual gate operation is not merely a technical practice but a socially embedded institutional role. Transition pathways that redeploy mirabs as system technicians or monitoring specialists, rather than simply eliminating their roles, are likely to generate greater stakeholder buy-in and reduce implementation resistance.

Connectivity infrastructure in the upper reaches of the Parkent Canal, particularly in the Bostanliq district, presents challenges for 4G-dependent communication. The dual-mode LoRaWAN fallback specified in Section 3.2 addresses this partially, though network planning should be validated with telecommunications providers prior to equipment procurement.

Climate change projections for the Chirchiq River basin suggest increased interannual variability in snowmelt-driven discharge over the coming decades. The MPC algorithms incorporated in the AGCS should incorporate ensemble climate scenarios to ensure robustness under a range of future hydrological conditions, not only the historical baseline used in this study's simulations.

7. Conclusion

This paper has presented a technically detailed and contextually grounded framework for automating hydraulic gate control on the Parkent Canal in Uzbekistan. The proposed AGCS integrates IoT-based sensing, remote actuation, and SCADA-driven control logic to replace manual gate operation with a responsive, data-driven management system.

Simulation results indicate substantial improvements across all key performance dimensions: water losses reduced by up to 57%, gate response times reduced from over one hour to under two minutes, and water delivery equity significantly improved. The economic analysis supports a strong investment case with a payback period under four years.

The study acknowledges that technical automation alone is insufficient — successful deployment requires concurrent institutional reform, operator training, and community engagement. The phased implementation roadmap proposed here provides a pragmatic pathway for canal authorities and national water management agencies to advance the automation agenda in alignment with Uzbekistan's water sector reform priorities and international sustainability commitments.

Future research should extend this analysis to secondary offtakes and inter-canal coordination scenarios, and should incorporate participatory monitoring methodologies to track socioeconomic impacts on water user communities alongside hydrological performance metrics.

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