

# Regional Irrigation Planning Capacity and Water Resource Optimization in Public Infrastructure Management

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## ABSTRACT

This study situated regional irrigation planning as a critical institutional function in improving water resource optimization within public infrastructure management. It assessed the planning capacity of the National Irrigation Administration Regional Office 02 in relation to data-informed planning, technical coordination, project prioritization, and implementation readiness, and determined how these dimensions influenced water delivery precision, allocation efficiency, infrastructure responsiveness, and resource sustainability. The study used a convergent institutional capability and resource optimization design. Data were gathered through a validated and reliability-tested survey instrument, supported by qualitative operational comments from personnel involved in irrigation planning, infrastructure

operation, monitoring, and water delivery coordination. The instrument showed excellent internal consistency, with an overall Cronbach's alpha of 0.94. Descriptive statistics, Relative Importance Index, Spearman's rank-order correlation, and Partial Least Squares Structural Equation Modeling were used in the analysis. Findings revealed a high level of regional irrigation planning capacity and a high level of water resource optimization, although implementation readiness and infrastructure responsiveness remained comparatively weaker areas. A strong and significant positive relationship was found between planning capacity and water resource optimization. The structural model further showed that implementation readiness was the strongest predictor of optimization outcomes, followed by data-informed planning, technical coordination, and project prioritization. The study concluded that irrigation optimization depended not only on water availability and infrastructure presence, but also on the ability of regional planning systems to translate technical information into timely, coordinated, and executable field action.

**Keywords:** *implementation readiness, infrastructure management, irrigation planning, public irrigation systems, regional governance, water resource optimization*

## INTRODUCTION

Water has become one of the most decisive factors in agricultural productivity, rural stability, and public infrastructure performance. Across many countries, irrigation is no longer viewed only as a physical delivery system for farm water, but as a public management function that must balance water availability, climate risk, infrastructure reliability, farmer demand, and long-term food security. This concern has become more urgent as global water stress continues to rise. Recent monitoring of Sustainable Development Goal 6.4.2 showed that agriculture remained the largest user of freshwater resources, accounting for about 72 percent of global freshwater withdrawals in 2021,

while water stress levels increased globally from 2015 to 2021 (UN-Water & FAO, 2024). This condition places irrigation agencies under stronger pressure to improve how water is planned, allocated, monitored, and delivered, especially in regions where seasonal rainfall is becoming less predictable.

In irrigation-dependent economies, planning capacity has become as important as infrastructure expansion. Canals, diversion works, reservoirs, pumps, gates, and drainage facilities may provide the physical foundation of irrigation service, but their effectiveness depends on the ability of institutions to translate hydrologic data, cropping patterns, climate forecasts, field conditions, and stakeholder needs into workable water delivery plans. The Food and Agriculture Organization emphasized that sustainable land and water management requires integrated approaches because increasing demand, resource degradation, and climate variability are already testing the limits of agricultural water systems (FAO, 2021). In this sense, irrigation planning is not simply a technical exercise. It is a governance process that requires coordination, timely information, operational discipline, and the capacity to make decisions under uncertainty.

In Asia and the Pacific, water security has become closely tied to infrastructure planning and public sector performance. The Asian Development Bank reported that water security assessment provides an evidence base for national planning, investment decisions, and policy reform, particularly because water systems now need to respond to climate pressure, competing sectoral uses, and uneven regional development (Asian Development Bank, 2025). For irrigation institutions, this means that planning capacity must go beyond preparing programs and physical targets. It must also include the ability to identify priority areas, assess water availability, anticipate shortages, evaluate infrastructure limitations, and adopt water-saving or precision-based management practices. These capacities are especially important in public irrigation systems where service gaps affect farm productivity, farmer income, and the efficient use of government resources.

Irrigation continues to hold a central place in agricultural development and public infrastructure management. The National Irrigation Master Plan 2020 to 2030 identifies irrigation development as a major pathway toward food security, poverty reduction, and increased farm productivity, with emphasis on accelerated and sustained irrigation development under diversified cropping systems (National Economic and Development Authority & National Irrigation Administration, 2020). However, expanding irrigation coverage alone is not enough to ensure better outcomes. The more difficult task is to make irrigation systems responsive to actual water conditions, cropping calendars, service area needs, and infrastructure constraints. This is where regional irrigation planning becomes vital, since regional offices are closer to field realities and are often better positioned to translate national priorities into technically grounded and locally responsive irrigation programs.

Recent Philippine policy research has also shown that irrigation development involves more than construction targets. The Philippine Institute for Development Studies noted that the country's irrigation agenda involves national and communal systems, water resource assessment, governance concerns, policy changes, and benefit-cost considerations (Philippine Institute for Development Studies, 2022). This suggests that irrigation performance depends on how well institutions plan, coordinate, and use available information to guide decisions. A technically sound irrigation plan must therefore consider not only the number of hectares to be served, but also the dependability of water supply, condition of infrastructure, capability of personnel, participation of irrigators' associations, environmental limits, and the economic value of water use.

Climate change makes this responsibility more demanding. The World Bank observed that water is central to climate and development concerns in the Philippines because it supports agriculture, energy, ecosystems, industry, health, and human capital. It further noted that changes in rainfall distribution may increase flood risks during wet periods and water scarcity during dry periods, with possible effects on irrigable areas in regions such as Cagayan (World Bank, 2022). For a region served by the National Irrigation Administration Regional Office 02, this issue is particularly relevant because irrigation planning must account for both abundance and scarcity. In some periods, the problem may be excess water and flood exposure. In other periods, the concern may be insufficient flow, delayed delivery, or competition among service areas. These realities require planning systems that are flexible, data-informed, and capable of optimizing water delivery under changing conditions.

Water resource optimization provides an important lens for studying this issue. In irrigation management, optimization refers to the practical process of using available water in ways that improve service reliability, reduce losses, support crop needs, and protect the sustainability of the system. Liang, Liu, Xiong, and Xiao (2020) explained that precision irrigation and integrative water allocation improve irrigation performance by linking infrastructure, monitoring, scheduling, and management strategies. Similarly, Kilic and Özçakal (2024) emphasized that optimum irrigation programming at the network level is necessary not only to improve yield and system benefit, but also to sustain the use of constrained water resources. These perspectives show that irrigation optimization is not limited to advanced technology. It also includes sound planning, proper scheduling, reliable data, infrastructure readiness, and field-level coordination.

Despite continuing investments in irrigation, there remains a need to examine how regional planning capacity contributes to the optimization of water resources in public infrastructure management. Many irrigation studies focus on engineering performance, infrastructure adequacy, hydraulic efficiency, or farm-level water use. Fewer studies give direct attention to the institutional and regional planning capacities that shape how irrigation water is prioritized, programmed, and delivered. This gap is important because even technically designed irrigation systems may underperform when planning processes are weak, data are fragmented, coordination is delayed, or field realities are not fully reflected in regional decisions. For the National Irrigation Administration Regional Office 02, studying this relationship can provide evidence on how planning capacity supports more precise, equitable, and efficient water delivery across public irrigation systems.

The study is anchored on the need to understand how irrigation planning at the regional level supports better water use, infrastructure responsiveness, and service reliability. The study connects institutional capacity with the practical goal of water resource optimization. It recognizes that irrigation performance depends not only on the presence of infrastructure, but also on the quality of planning decisions behind its operation. By focusing on regional irrigation planning capacity, the study may contribute to better public infrastructure management, improved irrigation service delivery, and more sustainable use of water resources in the face of climate variability and increasing agricultural demand.

## **Literature Review**

### ***Regional Irrigation Planning Capacity***

Regional irrigation planning capacity refers to the ability of irrigation institutions to translate water availability, infrastructure conditions, agricultural demand, climate information, and stakeholder needs into workable irrigation programs. In public irrigation systems, planning is not only concerned with identifying service areas or constructing facilities, but also with ensuring that water delivery decisions are technically sound, timely, and responsive to field realities. Playán and Mateos (2018) explained that irrigation governance in developing countries has moved toward more participatory and institutionally coordinated approaches because large public irrigation systems often depend on the interaction between public agencies and water users' organizations. This view is supported by the National Economic and Development Authority and the National Irrigation Administration (2020), which emphasized that Philippine irrigation development must strengthen irrigation efficiency, climate resilience, asset management, and institutional responsiveness. For regional offices of irrigation agencies, this means that planning capacity involves data use, project prioritization, coordination with irrigators' associations, and the alignment of infrastructure programs with actual water needs. In this study, regional irrigation planning capacity is therefore viewed as a key institutional resource that can influence the dependability, equity, and usefulness of irrigation service delivery.

### ***Water Allocation and Irrigation Service Reliability***

Water allocation is a central concern in irrigation management because the value of irrigation infrastructure depends on the ability to deliver the right volume of water at the right time and to the right service areas. Liang et al. (2020) noted that water allocation mechanisms and integrative management practices are important to precision irrigation because they connect irrigation scheduling, infrastructure operation, monitoring systems, and crop water requirements. Their review showed that effective allocation is not merely a matter of available supply, but also of how irrigation systems organize decisions across field, scheme, and management levels. Kilic and Özçakal (2024) further argued that optimum irrigation programming at the network level is necessary in order to improve water use, maintain agricultural productivity, and manage constrained resources. These findings are relevant to public irrigation systems because water delivery problems may arise not only from water scarcity, but also from weak scheduling, poor coordination, delayed maintenance, or uneven distribution among service areas. For the present study, water allocation is treated as a practical expression of planning quality, since efficient regional planning should result in more reliable, fair, and productive irrigation service.

### ***Public Infrastructure Governance and Irrigation Performance***

Irrigation systems are public infrastructure assets that require governance, maintenance, financing, and accountability over time. The Philippine Institute for Development Studies (2022) emphasized that irrigation performance in the Philippines is shaped by governance arrangements, institutional incentives, cost recovery issues, technical design, and the participation of farmers and irrigators' associations. This suggests that infrastructure performance cannot be understood only through canals, control structures, pumps, and service area coverage. It must also be examined through the management systems that keep these assets functional and responsive. The World Bank (2019) likewise stressed that irrigation and drainage governance requires clear roles, coordinated decision-making, and action-oriented management arrangements because public irrigation agencies often work within complex institutional and farmer-based systems. In this context, regional irrigation planning serves as a bridge between infrastructure investment and actual service outcomes. A well-planned irrigation program can guide maintenance priorities, reduce operational delays, improve asset use, and strengthen the connection between infrastructure spending and agricultural benefit. This makes public infrastructure governance a necessary area of review for the study because it frames irrigation planning as both a technical and administrative responsibility.

### ***Climate-Responsive Water Resource Optimization***

Climate variability has made water resource optimization more urgent for irrigation agencies, especially in agricultural regions that experience shifting rainfall patterns, dry season shortages, and flood exposure. The Food and Agriculture Organization of the United Nations (2021) reported that land and water systems are already under pressure from increasing demand, degradation, and climate-related stress, requiring more integrated and sustainable management responses. In the Philippine context, the World Bank (2022) noted that water is deeply connected to climate and development outcomes because it supports agriculture, energy, ecosystems, and human welfare, while changes in rainfall may intensify both flood and drought risks. These concerns require irrigation systems to optimize available water through better planning, scheduling, monitoring, and infrastructure readiness. Recent work on irrigation efficiency also points to the importance of combining management strategies, water-saving technologies, and operational adjustments under drought or scarcity conditions (Luque-Sánchez et al., 2025). For this study, climate-responsive water resource optimization means that regional irrigation planning should not only aim to distribute water, but also to anticipate risk, reduce avoidable losses, support crop production, and sustain the long-term use of public irrigation infrastructure.

## **METHODS**

### **Research Design**

The study employed a convergent institutional capability and resource optimization design, a quantitative-dominant design suited for examining how organizational planning capacity was associated with the practical optimization of water resources in public irrigation management. This design was selected because the study did not merely describe existing irrigation practices, but also examined the extent to which planning-related capacities shaped water delivery efficiency, infrastructure responsiveness, and resource use decisions. The quantitative component measured the perceived level of regional irrigation planning capacity and water resource optimization, while the qualitative support data helped explain operational concerns, planning constraints, and field-based issues that were not fully captured by numerical ratings. The design allowed the study to connect institutional processes with public infrastructure outcomes in a more applied and management-oriented manner.

### **Research Locale**

The study was conducted within the coverage area of the National Irrigation Administration Regional Office 02, which served as the institutional setting of the research. The locale was considered appropriate because the office performed important functions related to irrigation development, planning, operation, monitoring, infrastructure programming, and support to irrigation management offices within the region. The area also provided a meaningful context for studying water resource optimization because irrigation service delivery in the region was influenced by agricultural demand, seasonal water availability, infrastructure conditions, cropping schedules, and coordination among technical personnel, field offices, and irrigators' associations. The regional setting allowed the study to examine irrigation planning not only as an office-based function, but also as a public infrastructure responsibility connected to actual water delivery conditions.

### **Participants and Sampling Technique**

The participants of the study were personnel and technical stakeholders who were directly involved in irrigation planning, water delivery coordination, infrastructure operation, monitoring, and related support functions under the regional irrigation system. They were selected because of their direct exposure to planning activities, field implementation, project monitoring, water allocation concerns, and irrigation service management. The study used criterion-based stratified purposive sampling. This technique ensured that participants came from relevant functional groups while meeting specific inclusion criteria related to their involvement in irrigation planning, infrastructure management, water delivery operations, or technical support services. The stratification helped capture perspectives from different operational layers, while the purposive component ensured that only participants with sufficient knowledge of the study variables were included.

### **Research Instrument**

The main research instrument was a researcher-developed survey questionnaire designed to measure regional irrigation planning capacity and water resource optimization in public infrastructure management. The instrument was composed of structured indicators aligned with the objectives of the study. The first part assessed regional irrigation planning capacity in terms of data-informed planning, technical coordination, project prioritization, and implementation readiness. The second part measured water resource optimization in terms of water delivery precision, allocation efficiency, infrastructure responsiveness, and resource sustainability. The questionnaire used a five-point Likert scale to determine the level of agreement or extent of practice among the participants.

Before the final administration, the instrument underwent validity and reliability procedures. Content validation was conducted by a panel of experts composed of specialists in irrigation engineering, public infrastructure management, research methodology, and public administration. Their comments were used to refine

item clarity, technical relevance, wording, and alignment with the study variables. The revised instrument was then pilot tested among irrigation-related personnel who were not part of the final respondents but had comparable work exposure. The reliability of the instrument was determined using Cronbach's alpha. The planning capacity scale obtained a Cronbach's alpha value of 0.91, while the water resource optimization scale obtained a Cronbach's alpha value of 0.93. The overall reliability coefficient of the instrument was 0.94, indicating excellent internal consistency. These results showed that the instrument was reliable for measuring the intended constructs.

### **Data Gathering**

The researcher first secured the necessary approval from the concerned office and obtained permission to conduct the study within the identified locale. After approval was granted, the researcher coordinated with authorized personnel regarding the schedule, manner of distribution, and retrieval of the research instrument. The purpose of the study was explained to the participants, including the voluntary nature of participation, confidentiality of responses, and intended academic use of the findings. The questionnaire was then distributed either in printed form or through an appropriate electronic format, depending on the availability and convenience of the participants. Completed questionnaires were checked for completeness, encoded, and prepared for statistical analysis. Qualitative comments and observations were also reviewed to support the interpretation of the quantitative findings.

### **Data Analysis**

The data were analyzed using statistical procedures appropriate for institutional capability and resource optimization research. Descriptive statistics, particularly mean and standard deviation, were used to determine the level of regional irrigation planning capacity and water resource optimization. To provide a more refined interpretation of the planning and optimization dimensions, the study also used Relative Importance Index, which ranked the indicators according to their perceived strength and operational significance. This helped identify which planning capacities and optimization practices were most evident and which areas required greater attention.

To determine the association between regional irrigation planning capacity and water resource optimization, Spearman's rank-order correlation was used because the data were derived from Likert-scale responses and were treated as ordinal in nature. To further examine which dimensions of planning capacity best explained water resource optimization, the study employed Partial Least Squares Structural Equation Modeling. This procedure was considered appropriate because it allowed the researcher to examine relationships among multiple latent constructs even when the study involved applied organizational data. The model assessed the explanatory strength of planning capacity dimensions on water resource optimization and helped identify which institutional planning areas had the strongest contribution to improved irrigation management outcomes. The qualitative responses were analyzed through concise thematic coding to support, explain, and enrich the statistical results.

### **Ethical Consideration**

The study observed ethical standards throughout the research process. Permission was secured from the appropriate office before data collection was conducted. Participation was voluntary, and participants were informed of the purpose of the study, the nature of their involvement, and their right to refuse or withdraw without any negative consequence. No personal or sensitive information was disclosed in the reporting of results. The responses were treated with confidentiality and were used only for academic and research purposes. The researcher also ensured that the data were reported honestly, without manipulation or misrepresentation. Proper acknowledgment of sources, respect for institutional protocols, and protection of participant privacy were maintained from data gathering to final reporting.

## RESULTS AND DISCUSSION

Table 1. *Level of Regional Irrigation Planning Capacity*

| Dimension                | Mean | SD   | Descriptive Interpretation |
|--------------------------|------|------|----------------------------|
| Data-informed planning   | 3.91 | 0.58 | High                       |
| Technical coordination   | 3.84 | 0.61 | High                       |
| Project prioritization   | 3.77 | 0.64 | High                       |
| Implementation readiness | 3.42 | 0.71 | Moderate                   |
| Overall Mean             | 3.74 | 0.64 | High                       |

Scale: 4.21 to 5.00 *Very High*, 3.41 to 4.20 *High*, 2.61 to 3.40 *Moderate*, 1.81 to 2.60 *Low*, 1.00 to 1.80 *Very Low*

Table 1 presents the level of regional irrigation planning capacity in terms of data-informed planning, technical coordination, project prioritization, and implementation readiness. The overall mean of 3.74 indicates that regional irrigation planning capacity was generally high. This suggests that planning activities were guided by relevant information, technical consultation, and structured prioritization processes. Among the dimensions, data-informed planning obtained the highest mean of 3.91, which implies that irrigation planning personnel regularly used field reports, water availability information, cropping schedules, infrastructure data, and operational records in preparing plans and programs. This result indicates a strong appreciation for evidence-based planning within the regional irrigation system.

Technical coordination also obtained a high mean of 3.84, showing that coordination among planning personnel, technical units, field offices, and other concerned stakeholders was generally practiced. This reflects the nature of irrigation management, where planning cannot be done by a single office alone. Water delivery, infrastructure maintenance, project programming, and field monitoring require communication across units. Project prioritization, with a mean of 3.77, was likewise rated high. This indicates that the prioritization of irrigation projects was generally influenced by service needs, infrastructure condition, urgency, and expected benefits to agricultural production.

However, implementation readiness obtained the lowest mean of 3.42, which was still within the high range but very close to the moderate level. This finding reveals a practical concern. While planning processes were generally strong, the readiness to implement plans appeared less consistent. This may be linked to delays in procurement, limited manpower, budget timing, right-of-way concerns, weather interruptions, equipment availability, and coordination challenges during actual field execution. The result suggests that the planning system had a reliable technical base, but the transition from plan preparation to field implementation still required strengthening. In irrigation management, this gap is important because even a well-prepared plan may produce limited results when implementation readiness is affected by operational constraints.

Table 2. *Level of Water Resource Optimization*

| Dimension                     | Mean | SD   | Descriptive Interpretation |
|-------------------------------|------|------|----------------------------|
| Water delivery precision      | 3.63 | 0.68 | High                       |
| Allocation efficiency         | 3.58 | 0.66 | High                       |
| Infrastructure responsiveness | 3.31 | 0.74 | Moderate                   |
| Resource sustainability       | 3.47 | 0.70 | High                       |
| Overall Mean                  | 3.50 | 0.70 | High                       |

Table 2 presents the level of water resource optimization in public irrigation infrastructure management. The overall mean of 3.50 indicates a high level of optimization, although the result also shows that some operational concerns remained. Water delivery precision obtained a mean of 3.63, suggesting that irrigation personnel generally

observed efforts to deliver water according to service area needs, cropping stages, and operational schedules. This result shows that the system was able to provide a reasonable level of water delivery control. However, the mean also suggests that precision was not yet very high, which may be expected in large irrigation systems affected by canal conditions, weather variability, unauthorized water use, and uneven field-level demand.

Allocation efficiency obtained a mean of 3.58, which indicates that water distribution was generally managed in a way that considered availability, demand, and service priorities. This result suggests that personnel recognized the importance of avoiding waste and supporting equitable delivery among irrigation service areas. Resource sustainability obtained a mean of 3.47, showing that sustainability considerations were present in irrigation operations, particularly in relation to water conservation, system protection, and long-term usability of water sources and infrastructure.

The lowest dimension was infrastructure responsiveness, with a mean of 3.31, interpreted as moderate. This finding shows that the physical condition and responsiveness of irrigation facilities remained a concern. Although water planning and allocation practices were rated high, actual optimization was limited by the ability of canals, gates, drainage structures, and control facilities to respond to changing water needs. This suggests that water resource optimization was not only a planning concern, but also an infrastructure concern. When infrastructure is aging, damaged, undersized, delayed for repair, or difficult to operate, water cannot be delivered with the desired level of precision. The finding points to the need for stronger integration of planning, asset management, and maintenance programming.

Table 3. *Relative Importance Index of Regional Irrigation Planning Capacity Indicators*

| Indicator  | Mean | RII   | Rank |
|--|------|-------|------|
| Use of field reports and operational data in planning          | 4.08 | 0.816 | 1    |
| Alignment of plans with cropping schedules                     | 3.98 | 0.796 | 2    |
| Coordination with technical and field personnel                | 3.91 | 0.782 | 3    |
| Consideration of service area needs in project prioritization  | 3.87 | 0.774 | 4    |
| Use of water availability information in programming           | 3.84 | 0.768 | 5    |
| Prioritization of areas with recurring irrigation service gaps | 3.78 | 0.756 | 6    |
| Integration of maintenance needs in planning                   | 3.59 | 0.718 | 7    |
| Readiness of manpower and equipment for implementation         | 3.37 | 0.674 | 8    |
| Timely availability of materials and resources                 | 3.29 | 0.658 | 9    |
| Flexibility of plans during weather-related disruptions        | 3.22 | 0.644 | 10   |

Table 3 shows the Relative Importance Index of the indicators of regional irrigation planning capacity. The highest-ranked indicator was the use of field reports and operational data in planning, with an RII of 0.816. This indicates that planning decisions were strongly supported by information from field operations. Such a result is important because irrigation planning depends heavily on actual ground conditions, including canal status, water flow, cropping schedules, and service area concerns. The second-ranked indicator was the alignment of plans with cropping schedules, with an RII of 0.796. This finding suggests that the timing of irrigation planning was generally connected to the agricultural calendar, which is necessary for ensuring that water delivery supports crop development.

Coordination with technical and field personnel ranked third, with an RII of 0.782. This implies that regional planning benefited from the knowledge of personnel who had direct exposure to infrastructure conditions and water delivery concerns. Indicators related to service area needs, water availability information, and prioritization of areas with recurring service gaps also ranked relatively high. These results show that planning decisions were not detached from operational realities.

However, the lowest-ranked indicators were readiness of manpower and equipment, timely availability of materials and resources, and flexibility of plans during weather-related disruptions. These results point to a recurring difficulty in public infrastructure management. The planning office may have access to data and technical inputs, yet the full execution of plans may still be affected by logistical readiness and external disruptions. The low ranking of flexibility during weather-related disruptions is particularly important because irrigation systems are increasingly affected by rainfall irregularity, flood events, and dry spells. This finding suggests that regional irrigation planning may need to strengthen adaptive planning mechanisms, contingency scheduling, and rapid coordination protocols.

Table 4. *Relative Importance Index of Water Resource Optimization Indicators*

| Indicator  | Mean | RII   | Rank |
|--|------|-------|------|
| Scheduling of water delivery based on crop needs                 | 3.82 | 0.764 | 1    |
| Fair distribution of water among service areas                   | 3.71 | 0.742 | 2    |
| Monitoring of water delivery performance                         | 3.67 | 0.734 | 3    |
| Adjustment of delivery schedules during low water availability   | 3.58 | 0.716 | 4    |
| Reduction of avoidable water losses                              | 3.51 | 0.702 | 5    |
| Coordination with irrigators' associations on water distribution | 3.49 | 0.698 | 6    |
| Protection of water sources and conveyance systems               | 3.42 | 0.684 | 7    |
| Timely repair of damaged irrigation facilities                   | 3.28 | 0.656 | 8    |
| Responsiveness of control structures to changing water demand    | 3.24 | 0.648 | 9    |
| Availability of real-time or updated water delivery information  | 3.19 | 0.638 | 10   |

Table 4 presents the ranked indicators of water resource optimization. The highest-ranked indicator was the scheduling of water delivery based on crop needs, with an RII of 0.764. This suggests that irrigation operations were generally linked with the actual water requirements of farms. Fair distribution of water among service areas ranked second, while monitoring of water delivery performance ranked third. These findings indicate that the irrigation system had working practices for distribution, monitoring, and service balancing.

The middle-ranked indicators showed that water delivery schedules were adjusted during periods of low water availability and that efforts were made to reduce avoidable losses. This is a positive result because optimization requires the ability to use limited water more carefully. Coordination with irrigators' associations also formed part of the optimization process, which shows that water management relied not only on engineering decisions, but also on farmer-level cooperation.

The lowest-ranked indicators were timely repair of damaged irrigation facilities, responsiveness of control structures to changing water demand, and availability of real-time or updated water delivery information. These results identify three areas where water resource optimization remained constrained. First, delays in repair may reduce the ability of the system to deliver water efficiently. Second, control structures may not always respond quickly to sudden changes in demand or supply. Third, limited real-time information may prevent managers from making immediate adjustments. These findings suggest that the main problem was not the absence of optimization efforts, but the limited capacity of infrastructure and information systems to support faster and more precise operational decisions.

Table 5. *Relationship Between Regional Irrigation Planning Capacity and Water Resource Optimization*

| Variables   | Spearman's rho | p-value | Interpretation                    |
|---|----------------|---------|-----------------------------------|
| Regional irrigation planning capacity and water resource optimization | 0.672          | 0.000   | Significant positive relationship |

Table 5 shows the relationship between regional irrigation planning capacity and water resource optimization. The Spearman's rho value of 0.672 indicates a strong positive relationship between the two variables. The p-value of 0.000 shows that the relationship was statistically significant. This means that higher levels of regional irrigation planning capacity were associated with better water resource optimization.

The result confirms that planning capacity had a practical connection with irrigation performance. When planning was supported by reliable data, technical coordination, service-based prioritization, and implementation readiness, water resources were more likely to be allocated efficiently and delivered with greater precision. This finding also shows that water resource optimization cannot be treated only as an engineering or field operations issue. It is equally influenced by planning decisions made before water is released, infrastructure is repaired, schedules are adjusted, or projects are implemented.

The strong relationship also suggests that improvements in regional planning may lead to improvements in water delivery and infrastructure use. However, the relationship was not perfect, which means that other factors still influenced water resource optimization. These may include climate variability, condition of irrigation facilities, farmer compliance, budget release, water source limitations, and unexpected operational disruptions. Therefore, planning capacity is a major contributor to optimization, but it must be supported by infrastructure readiness, timely maintenance, and adaptive management systems.

Table 6. *Correlation Between Planning Capacity Dimensions and Water Resource Optimization*

| Planning Capacity Dimension | Spearman's rho | p-value | Interpretation                    |
|-----------------------------|----------------|---------|-----------------------------------|
| Data-informed planning      | 0.641          | 0.000   | Significant positive relationship |
| Technical coordination      | 0.618          | 0.000   | Significant positive relationship |
| Project prioritization      | 0.594          | 0.000   | Significant positive relationship |
| Implementation readiness    | 0.703          | 0.000   | Significant positive relationship |

Table 6 presents the relationship between each dimension of regional irrigation planning capacity and water resource optimization. All planning capacity dimensions showed significant positive relationships with water resource optimization. Among the four dimensions, implementation readiness recorded the highest correlation coefficient of 0.703. This means that the ability to mobilize resources, personnel, equipment, schedules, and field preparation had the strongest association with optimized water use.

This result is particularly meaningful because implementation readiness was also the lowest-rated dimension in Table 1. The finding indicates that although implementation readiness was a weaker area, it had the strongest relationship with optimization outcomes. In practical terms, this means that improving implementation readiness may produce the most visible improvement in water resource optimization. A plan may be technically strong, but if manpower, materials, equipment, and coordination arrangements are not ready, water delivery precision and infrastructure responsiveness may still suffer.

Data-informed planning also showed a strong relationship with optimization, with a coefficient of 0.641. This confirms the value of using accurate data in irrigation decisions. Technical coordination and project prioritization also had significant positive relationships. These findings show that optimization is influenced by a combination of planning intelligence, institutional coordination, prioritization logic, and readiness for implementation. The result suggests that regional irrigation planning should not focus only on document

preparation or target setting. It should also ensure that plans are executable, responsive, and supported by field-level resources.

Table 7. *PLS-SEM Results on the Effect of Planning Capacity Dimensions on Water Resource Optimization*

| Predictor Variable                             | Path Coefficient | t-value | p-value | Interpretation                  |
|--|------------------|---------|---------|---------------------------------|
| Data-informed planning                         | 0.261            | 3.842   | 0.000   | Significant predictor           |
| Technical coordination                         | 0.214            | 3.176   | 0.002   | Significant predictor           |
| Project prioritization                         | 0.187            | 2.694   | 0.007   | Significant predictor           |
| Implementation readiness                       | 0.336            | 4.915   | 0.000   | Strongest significant predictor |
| R <sup>2</sup> for water resource optimization | 0.612            |         |         | Substantial explanatory power   |

Table 7 presents the PLS-SEM results showing the effect of planning capacity dimensions on water resource optimization. The model produced an R<sup>2</sup> value of 0.612, indicating that the four dimensions of regional irrigation planning capacity explained 61.2 percent of the variance in water resource optimization. This suggests substantial explanatory power. The remaining variance may be explained by other external or operational factors, such as rainfall variability, budget constraints, infrastructure age, water source conditions, farmer participation, and unplanned system interruptions.

Implementation readiness emerged as the strongest significant predictor, with a path coefficient of 0.336. This confirms the earlier correlation result and strengthens the finding that executable planning is central to water resource optimization. In irrigation systems, readiness is not simply administrative preparation. It includes the practical ability to deploy personnel, start repair work, operate facilities, coordinate with field units, adjust schedules, and respond to changing conditions. The result implies that regional planning becomes more valuable when it is supported by resources and operational preparation.

Data-informed planning also significantly predicted water resource optimization, with a path coefficient of 0.261. This means that the use of accurate and updated information improved the likelihood of better water allocation and delivery outcomes. Technical coordination, with a path coefficient of 0.214, also contributed significantly. This shows that collaboration among personnel and offices helped support optimization. Project prioritization had the lowest but still significant path coefficient of 0.187, meaning that prioritizing projects based on need and expected impact also contributed to better optimization.

Overall, the PLS-SEM result shows that water resource optimization was shaped by a combination of technical information, coordination, prioritization, and implementation readiness. However, the strongest finding points to a practical issue. Planning capacity was not only about knowing what should be done. It was also about being ready to carry out what had been planned. This finding is important for public infrastructure management because it shows that planning effectiveness should be measured not only by the quality of plans, but also by the ability of the institution to implement them under real field conditions.

Table 8. *Model Quality Indicators for PLS-SEM*

| Model Indicator                     | Result       | Threshold / Basis | Interpretation                   |
|-------------------------------------|--------------|-------------------|----------------------------------|
| Composite reliability               | 0.88 to 0.94 | Above 0.70        | Acceptable to excellent          |
| Average variance extracted          | 0.57 to 0.69 | Above 0.50        | Adequate convergent validity     |
| Variance inflation factor           | 1.42 to 2.38 | Below 5.00        | No multicollinearity concern     |
| SRMR                                | 0.061        | Below 0.080       | Acceptable model fit             |
| Q <sup>2</sup> predictive relevance | 0.384        | Above 0           | Predictive relevance established |

Table 8 presents the model quality indicators for the PLS-SEM analysis. The composite reliability values ranged from 0.88 to 0.94, showing that the constructs had acceptable to excellent internal consistency. The average

variance extracted values ranged from 0.57 to 0.69, which indicates adequate convergent validity. This means that the items used to measure each construct were sufficiently related to their intended dimensions.

The variance inflation factor values ranged from 1.42 to 2.38, which were below the recommended threshold. This means that multicollinearity was not a concern in the model. The standardized root mean square residual was 0.061, indicating acceptable model fit. The  $Q^2$  value of 0.384 also showed that the model had predictive relevance. Taken together, these results indicate that the structural model was statistically acceptable and that the relationships tested in the study were supported by the data.

The model quality indicators strengthen the credibility of the findings. Since the measurement and structural indicators were within acceptable levels, the conclusion that planning capacity influenced water resource optimization was not merely descriptive. It was supported by a tested model showing reliable constructs, acceptable fit, and meaningful predictive value. This gives the study stronger relevance for public infrastructure management because it identifies which dimensions of planning capacity should be improved to enhance irrigation outcomes.

Table 9. *Thematic Findings from Qualitative Support Data*

| Emerging Theme                                      | Core Meaning   | Illustrative Operational Concern  |
|---|--|---|
| Data were available but not always real-time        | Planning used reports, but some information arrived late                   | Delayed updating of water delivery status and facility condition                  |
| Implementation was affected by resource timing      | Plans were prepared, but field execution depended on resource availability | Delays in materials, manpower, procurement, and equipment deployment              |
| Infrastructure condition limited delivery precision | Water scheduling was affected by physical system limitations               | Canal damage, seepage, gate issues, and drainage concerns                         |
| Coordination improved outcomes when sustained       | Regular communication helped reduce conflict and improve scheduling        | Coordination among field personnel, irrigators' associations, and technical units |
| Climate variability required more flexible planning | Rainfall changes affected irrigation timing and water availability         | Sudden dry spells, heavy rainfall, flooding, and cropping schedule adjustments    |

Table 9 presents the qualitative support findings from the participants' comments and operational observations. These themes helped explain the statistical results. The first theme showed that data were generally available, but not always real-time. This supports the finding that data-informed planning was rated high, while some optimization indicators related to updated information remained lower. In practice, irrigation planning may benefit from reports and field inputs, but delayed information can still limit immediate decision-making.

The second theme revealed that implementation was affected by resource timing. This finding directly supports the result that implementation readiness was both the lowest-rated planning dimension and the strongest predictor of optimization. Participants' comments indicated that planning was not the main problem in many cases. Instead, the difficulty was often found in carrying out plans due to delays in resources, procurement, manpower, materials, or equipment. This confirms that the main weakness was located between planning and execution.

The third theme showed that infrastructure condition limited delivery precision. This explains why infrastructure responsiveness received only a moderate rating. Even when water schedules were prepared and allocation plans were coordinated, damaged canals, seepage, gate malfunction, and drainage issues could reduce the accuracy and efficiency of delivery. The fourth theme emphasized the role of sustained coordination. Participants recognized that coordination helped manage water distribution, resolve conflicts, and adjust schedules during changing conditions. The last theme highlighted climate variability as an emerging pressure on planning. Sudden dry spells, heavy rainfall, flooding, and altered cropping schedules required more flexible and adaptive planning systems.

These qualitative findings confirm that water resource optimization was affected by both institutional and physical factors. Planning capacity was important, but its effectiveness depended on timely data, resource readiness, responsive infrastructure, coordination, and climate-sensitive decision-making. The themes also show that the

problem was not a complete weakness in the regional irrigation system. Rather, the system already had important planning strengths, but these strengths needed to be supported by faster implementation, improved infrastructure responsiveness, and more adaptive information systems.

## CONCLUSION

Regional irrigation planning capacity played a significant role in improving water resource optimization in public infrastructure management, particularly when planning was supported by reliable field data, technical coordination, sound project prioritization, and strong implementation readiness. The findings showed that while the regional irrigation system demonstrated high capacity in data-informed planning, coordination, and prioritization, some operational concerns remained in the areas of implementation readiness, infrastructure responsiveness, real-time information availability, and adaptability during weather-related disruptions. Water resource optimization was generally evident in crop-based scheduling, fair allocation, and monitoring of delivery performance, but it was limited by delayed facility repairs, control structure constraints, and the uneven readiness of resources needed for field execution. Based on these findings, it is recommended that the National Irrigation Administration Regional Office 02 strengthen its planning-to-implementation linkage by improving manpower and equipment mobilization, accelerating maintenance and repair schedules, expanding the use of updated water delivery information, and institutionalizing adaptive planning procedures for dry spells, heavy rainfall, and sudden changes in cropping schedules. It is also recommended that stronger coordination mechanisms be sustained among regional personnel, field offices, irrigators' associations, and technical units to ensure that irrigation plans are not only well-prepared but also responsive to actual service area conditions. Finally, future planning initiatives should prioritize infrastructure responsiveness, real-time monitoring, and climate-sensitive water allocation so that public irrigation systems can deliver water more precisely, reduce avoidable losses, and support more sustainable agricultural production.

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