DIAGNOSTIC ASSESSMENT APPROACH FOR FORMULATING A CLIMATE-PROACTIVE MODERNIZATION STRATEGY FOR SMALL-SCALE NATIONAL IRRIGATION SYSTEMS IN THE PHILIPPINES

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ABSTRACT

The publicly funded national irrigation systems (NIS) in the Philippines could only irrigate an average of 67 - 75% of their service area despite considerable rehabilitation and improvement efforts. The assertions coming from different stakeholders on the reasons for this relatively low performance included technical, managerial, institutional, policy and, in recent years, climate change. While the stakeholders would easily agree that each of the problems raised contributes to mediocre performance, a consensus on what is the right approach to address these constraints is hardly reached. Diagnostic assessment is a performance evaluation method specifically aimed at identifying the bottlenecks of irrigation system performance and, hence, appropriate approaches and solutions to address them. Diagnostic approaches for irrigation performance assessment have been carried out in a number of studies. It is considered a crucial prelude in the modernization process. Unfortunately, system diagnosis is not a part of the planning and formulation process for system improvement projects of the National Irrigation Administration (NIA); hence it is rarely carried out. This study explored the utility of a logic design framework and the diagnostic tools of the mapping system and services for canal operation techniques (MASSCOTE) in two small-scale NIS to contribute to the development of an improved and systematic approach to identify the root causes and solutions.

The applicability of the water-related, external indicators of the rapid appraisal procedure (RAP) and the structures sensitivity assessment as diagnostic tools were limited by the lack of flow data and the infeasibility of field experiments due to tight rotational irrigation schedules and laissez-faire direct offtakes. A pragmatic approach using discharge-head relations, hydraulic flexibility concept and the findings from walkthroughs and interviews was adopted as an alternative. The results of the study show that inconsistency in the system designs and lack of, or poorly performing flow control structures, drought-vulnerable main water diversion structures and tropical cyclone-related damages were the main contributing factors to mediocre irrigation service and overall system performance. The present logic design framework, RAP internal indicators and capacity assessment focus on canal structures and operation. Inclusion of headwork aspects will make these techniques more relevant to adaptation actions to climate change. The utility of the proposed diagnostic assessment framework that examines logical coherence among the system objectives, physical components, system operation and water supply was demonstrated. This diagnostic approach has a system modernization orientation and, in particular, will be suitable for mostly ungauged, run-off-the-river type NIS.

Keywords: irrigation system; diagnostic assessment; rapid appraisal; irrigation modernisation; climate change; Philippines.

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1 INTRODUCTION

Provision of irrigation facilities has been a key strategy of the Philippine Government to achieve its goals of rice self-sufficiency and alleviation of rural poverty. Rehabilitation and improvement of irrigation systems were carried out to arrest deterioration of irrigation facilities, maintain the irrigation service areas, close the gap between the actual area irrigated and the design service area and improve water delivery service. Despite considerable national irrigation system (NIS) rehabilitation and improvement efforts during the period 1980-2012, an average of about 30% of their aggregate service areas was not irrigated (Delos Reyes *et al.*, 2015). The NIS service area lost to irrigation during the same period was about 97,000 ha. The dismal performance of rehabilitation and improvement efforts was attributed to problems on irrigation technology, management, institutional, policy and, in recent years, to climate change. While there was agreement among concerned government policy- and decision-makers, irrigation professionals, academicians, system operators and water users on the identified causes, there was no consensus on the appropriate approach to address them. The difficulty in formulating a collective action plan of intervention measures is due to a less-than holistic view of the multi-faceted and multi-tiered nature of planning and implementation of irrigation development programmes and projects. Most NIS have undergone a mix of technical, management, policy and institutional changes whose interplay and effects had not been well understood. From solely government managed, NIS are now in different stages of irrigation management transfer contracts with water users' associations. Project identification and planning, especially in rehabilitation and system improvements, now involve the water users. The physical components of NIS were modified and replaced as necessitated by clamours for improved water delivery, changes in water demand and allocation, shift in irrigation development thrusts and policy directions of the Government, and requirements of financing institutions. Initiatives on irrigation system modernization have been articulated at the national agency level. Meanwhile, the drier dry season and stronger monsoons attributed to climate change have contributed to low cropping intensity and poor irrigation service. They highlighted the inadequacy in the planning and design of irrigation systems and exacerbated the adverse effects of such shortcomings.

A diagnostic analysis of the functioning and performance of NIS under the present circumstances is imperative for a systematic identification of the bottlenecks of NIS performance and formulation of appropriate solutions. At present, the planning and formulation of NIS improvement or modernization projects lacks the benefit of system diagnosis (Delos Reyes *et al.*, 2015).

Most diagnostic techniques usually examine one or a combination of the following: mechanism and process of water delivery; system capacities, canal operations, problem tree and system input-output ratios. They typically require extensive water-related data, which are not readily available. This paper presents a diagnostic assessment framework that links NIS performance to logical coherence among the scheme objectives, physical structures, management and water supply. The utility of this diagnostic technique is demonstrated by applying it in two small-scale NIS, the Balanac RIS and Sta. Maria RIS. Each system irrigates about 1,000 ha of rice fields in Region IV-A of the country.

2 METHODS

A combination of the logic design configuration illustrated by Ankum (2001) and the diagnostic tools used in the mapping system and services for canal operation techniques (MASSCOTE) was used in developing the diagnostic assessment framework for small-scale NIS. The logic design framework examines the coherence of the design philosophy, overall system objectives, objectives of system operation, design configuration of physical structures and flow control methods (Figure 1). A similar logic design concept was synthesized by Horst (1998).

Parameters	Choices for design philosophy/system objectives				
Irrigation target	Protective			Productive	
Cropping system	Rice mono cropping			Diversified cropping	
Design irrigation season	Wet season			Dry season	
Irrigation during other season	Dry season: all area - fallow small area - protective	Dry season: all area - protective small area - productive		Wet season: supplementary	
Irrigation supply in the system	Equitable supply to farmers	Equitable supply to hectares		Flexible supply based on water need and availability	Flexible supply based on water demand
	Choices for operational objectives of main system				
Decision-making on water allocation to tertiary unit (TU)	Imposed allocation			Semi-demand allocation	On-demand allocation
Method of water allocation to TU	Splitted flow	Intermittent flow	Adjustable flow	Intermittent flow or Adjustable flow	Intermittent flow or Adjustable flow
Method of water distribution through the main system	Splitted flow	Rotational flow	Adjustable flow	Adjustable flow	Adjustable flow
Flow control method	Proportional control	Upstream control or simultaneous control		Upstream control or predictive control	Downstream control or volume control

Logical design choices for: protective irrigation (gray); productive irrigation (green); both (blue)
Logical design combinations of parameters of operational objectives are grouped in stacks.

Figure 1. Logic choices for overall system objectives, parameters of operational objectives and flow control methods (adopted from Ankum, 2001).

The diagnostic tools of MASSCOTE, which include the rapid appraisal procedure (RAP) and assessments of physical capacity and hydraulic behaviour (sensitivity and perturbations) of irrigation systems, focuses on canal operations and specifically developed for medium- to large-scale irrigation systems (Renault *et al.*, 2007). RAP examines the water balance, internal processes and mechanisms (hardware, operational procedures, management and institutions) of water delivery at different canal levels, irrigated area and crop production. A combination of the logic design and MASSCOTE diagnostic tools would clearly distinguish between design and management constraints, including their respective root causes. Thus, an appropriate and priority engineering and/or management solutions or adaptation strategy to climate change would be evident.

To keep the system diagnosis and performance expectation in perspective, a review on the general design considerations and guidelines for NIS and history of scheme development, rehabilitation, improvements, management changes and system performance was carried out. The lack of flow records and reliable data on water balance parameters and the infeasibility of flow measurements due to tight irrigation scheduling and laissez-faire direct offtakes precluded the use of water-related external indicators of RAP and flow-based sensitivity assessments. The general discharge-head relations $Q = c\,H^{\alpha}$ and the diversion sensitivity or hydraulic flexibility values of commonly used design configurations as conceptualized in Horst (1998) and Ankum (2001) were adopted as pragmatic alternatives. Based on generalized equations, an overshot offtake (α = 1.5) is more sensitive than an undershoot offtake (α = 0.5) for a given water level variation. An overshot cross regulator is less sensitive to discharge variation than an undershot cross regulator. A hydraulic flexibility or a ratio of discharge variation in the offtaking canal to discharge variation in the parent canal equal to unity (F = 1) is conceived to proportionally distribute flow fluctuations through the canal downstream. Thus, diversion structures that yield F = 1 are viewed appropriate for systems under upstream control (Horst, 1998; Ankum, 2001). In upstream control, it is approximated by either both overflow or both underflow offtakes and cross regulators (Ankum, 2001). The diagnostic assessment framework used for the case study is shown in Figure 2. It underscores the precedence of coherent system design and the system operations adherence to it.

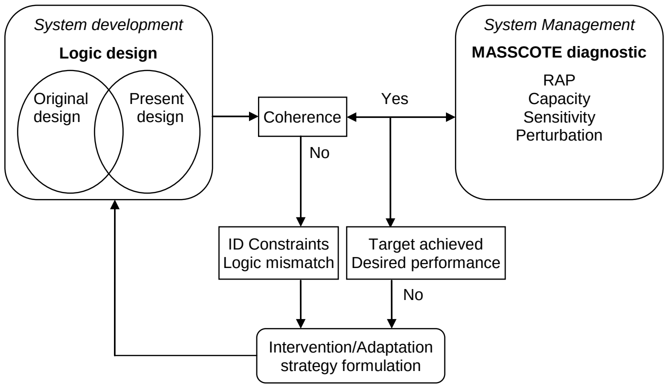

Figure 1. The proposed design-operation diagnostic assessment framework for NIS.

3 RESULTS AND DISCUSSION

3.1 Logic design

The original Balanac RIS was designed for 'productive irrigation' during the dry season based on 'equitable supply per hectare'. The operational objective was 'imposed allocation' to tertiary units or irrigation service delivery points by 'adjustable flow' and with 'adjustable flow' through the major conveyance canals. Based on the permitted diversion rate of 3.9 m^3s^{-1}, design service area of 1,200 ha and main canal capacity, the water duty for productive irrigation during the dry season could be very well met by Balanac RIS. The 'imposed allocation' was demonstrated by the fact that the NIA system officials decided on water allocation to offtakes downstream of which the farmers managed the water. The 'adjustable flow' as method of water allocation and water distribution was manifested by the adjustable gates for offtakes and cross regulators at major bifurcation points. The use of cross regulators implied 'upstream control' as the intended method for regulating water flow levels.

From the perspective of the logic design framework, there was coherence among the design philosophy, objectives and flow control method in the original design of Balanac RIS. However, the shift to 'splitted' flow and 'proportional control' as manifested by duckbill weirs at major bifurcation points was not consistent with the unchanged overall system objectives.

The design philosophy and overall system objectives of the original Sta. Maria RIS were the same as those of the original Balanac RIS, except in the case of the design irrigation season. With the permitted diversion rate of 2.1 m^3 s^{-1} and design service area of 2,500 ha, its water duty was 0.8 l s^{-1} ha^{-1}, which is much lower than the 1.5 l s^{-1} ha^{-1} conventional design value used by the NIA. A plausible logic for such low water duty is that the wet season was the 'design irrigation season.' In other words, the system was designed to supplement rainfall and was not intended to irrigate the whole service area during the dry season. Sta. Maria RIS had the same design operational objective as that of the original Balanac RIS as suggested by the similar flow control structures and water allocation decision process. Its original system design was logically coherent from the standpoint of logic design framework.

The reduction in service area to 974 ha and the shift to the dry season as the main irrigation season had maintained the coherence among the objectives of Sta. Maria RIS. However, the addition of open direct turnouts along the main canals compromised this coherence.

It was noted that the headwork aspect was not given as much emphasis as the canal network in the logic design framework. A productive irrigation objective means providing water for optimum crop growth and is usually selected when there is abundant supply of water (Ankum, 2001). The run-off-the-river (ROR) dams of the two systems would not support well the 'productive irrigation' objective because they were not equipped to store water, hence more vulnerable to prolonged droughts associated with climate change. This issue is of particular importance to the irrigation sector since ROR systems account for about 90% (215) of all NIS. An impounding or reservoir-type headwork is a more logical match to productive irrigation and cases of prolonged droughts.

3.2 RAP internal indicators

In general, the values of the primary internal indicators of RAP for the two systems were low (0 and 4 indicating least and most desirable, respectively) (Table 1). The low values of indicators for control and operation of canal structures implied insufficiency of the existing flow control structures and operational procedures for quality water delivery service. The social order and system management were likewise in poor state. It was noted during the walkthrough in Balanac RIS that the original offtakes and cross regulators at the junctions of the main canal and secondary canals still existed along side with the proportional weirs but without their gates. Such seemingly confused configuration upset the proportional flow and orderly water distribution goals. It did not sit well with water users as evidenced by unauthorized demolitions of proportional weirs segments by them.

3.3 System Capacity

The headwork diversion and storage functions were added to the system capacity assessment. The two systems had either decreased capacity or inherently limited capacity to perform the various system functions and to satisfy present demands (Tables 2 and 3). Aside from the inherent limited storage capacities of the dams, the most telling capacity issues were the diversion capacity of the dams in both systems and in the division capacity of canal system of Balanac RIS.

Table 1. Indicators for water delivery service, control and operation and management for Balanac RIS and Sta. Maria RIS

	Balanac RIS			Sta. Maria RIS		
Water delivery service		Actual	Stated		Actual	Stated
Service to individual ownership (i.e., field, farm)		1.1	2.0		1.1	2.6
Service to field channels (operated by paid employee)		0.9	1.9		0.9	2.6
Service by the main canal to the second level canals		0.4	1.8		1.2	3.0
Control and operation	Main	Second-level	Third-level	Main	Second-level	Third-level
Cross-regulator hardware in the canal	1.6	1.1	1.1	3.1	1.9	--
Travel time of a flow rate change throughout the canal	4.0	--	--	4.0	--	--
Turnouts from the canal	0.7	1.3	1.3	2.4	1.7	--
Regulating reservoirs in the canal	0.0	0.0	0.0	0.0	0.0	--
Communications for the canal	1.0	1.3	1.3	1.5	1.3	--
Existence and frequency of remote monitoring at key spill points, including the end of canal	0.0	0.0	0.0	0.0	0.0	--
General conditions of the canal	1.4	1.2	1.2	1.4	1.8	--
Operation of the canal	1.3	1.3	0.8	1.9	1.9	--
Clarity and correctness of instructions to operators	1.3	1.3	1.3	1.3	1.3	--
Social order and system management						
Social order in the canals operated by paid employees			0.5			1.5
WUA strength			0.3			2.2
Budgets			1.2			2.4
Employees			1.9			1.9

Table 2. Physical capacities of Balanac RIS

Functions	Capacity aspect	Actual vs. design	Design vs. requirement
1. Division	Dysfunctional duckbill weirs, ungated direct offtakes	<	<
2. Storage (canal)	No online mini reservoirs; canal wall seepage; big canals	~	<
3. Conveyance	Cracks on canal linings; siltation; direct, ungated offtakes and drainage inlets; rubbish dumps	<	<
4. Sediment control	Dysfunctional dam sluice gates; silt entry over canal berms	<	<
5. Discharge transfer	Within the day	~	~
6. Water level control	Dysfunctional long-crested weirs	<	<
7. Flow measurement	Not done; missing staff gauge	<	<
8. Safety	With freeboard; no spill points except end checks	~	<
9. Communication	Mobile phones	>	<
10. Water reuse	2 check gates	~	<
11. Transport/access	20%	<	<
12. Diversion (dam)	Minimal head	<	<
13. Storage (dam)	no storage; heavily silted	<	<

Table 3. Physical capacities of Sta. Maria RIS

Functions	Capacity aspect	Actual vs. design	Design vs. requirement
1. Diversion (canal)	Some dysfunctional offtakes and cross regulators	<	~
2. Storage (canal)	No online mini reservoirs; big canals	~	<
3. Conveyance	Silt deposits; direct ungated offtakes and drainage inlets	<	~
4. Sediment control	Dysfunctional sluice gates; silt entry over canal berms	<	<
5. Discharge transfer	Within the day	~	~
6. Water level control	Some modular stoplogs and damaged cross regulators	<	~
7. Flow measurement	Silted flume approach; missing staff gauge	<	<
8. Safety	With freeboard; no spill points	~	<
9. Communication	Mobile phones	>	<
10. Water reuse	9 check gates	~	<
11. Transport/access	92%	~	~
12. Diversion (dam)	Minimal head; intake gate spindles askew	<	<
13. Storage (dam)	Silted dam	<	<

3.4 Sensitivity

The two systems were designed for gate proportional diversion (hydraulic flexibility F = 1) as indicated by the combinations of both overflow (Balanac RIS) and both underflow (Sta. Maria RIS) offtake and cross regulator (Table 4). The proportional flow distribution objective was altered by missing or heavily damaged diversion structures. With highly variable water supply, a combination of both underflow offtake and cross regulator in Sta. Maria RIS would require frequent adjustments of the cross regulators to maintain gate proportional diversion. Such required adjustment is too cumbersome and impractical. Consequently, offtaking canals would usually have a higher discharge variation than the continuing canal.

3.5 Performance, agronomic constraints and interventions

The irrigated areas in both systems remained less than their respective firmed-up service areas (FUSA). The non-irrigated FUSA were unserviceable due to lack of operational irrigation facilities and unreliable water supply during the dry season. The programmed areas remained less than the FUSA for the same reasons. There were noticeable gaps between irrigated and benefitted areas, especially during the wet seasons. Benefitted areas were irrigated areas with yield of more than 2 ton ha^{-1}. The lower yields in "irrigated-but-not-benefitted" areas were mainly due to monsoon-related causes such as crop submergence and typhoon-lodging (Figure 3). During the dry season, they were caused by water shortages and pests and diseases. While it is a common knowledge that Balanac RIS had more water supply than Sta. Maria RIS, low yields due to water shortage were reported in the former. Balanac RIS practiced laissez-faire cropping and continuous irrigation. In contrast, augmentation of water supply by tapping nearby small streams and recapturing drainage water from upstream farms together with segmental relay planting and rotational irrigation to circumvent the limited water supply were practiced in Sta. Maria RIS. However, the relay-planting practice provided continuous presence of host plants to pests and diseases.

Table 4. Indicative sensitivity at branching points of Balanac and Sta. Maria

Main branching points	Offtake/Turnout	Cross regulator	Hydraulic Flexibility F
Balanac RIS			
MC - Lat. Buboy	Overshot Undershot	*Overshot*[1]	F > 1 F < 1
MC - Lat. A	Overshot Undershot	Overshot	F = 1 F < 1
Lat. A - Lat. A1	Undershot	None	F < 1
Lat. A1 - Lat. A1A	Open	None	F > 1
Sta. Maria RIS			
SMMC - Lat. A	*Undershot*	Undershot	F ≥ 1
SMMC - Lat. B	Undershot	Undershot	F ≥ 1
SMMC - Lat. C	Undershot	Undershot	F ≥ 1
SMMC - Lat. D	Undershot	Undershot	F ≥ 1
MMC - Lat. E	Undershot	Undershot	F ≥ 1
MMC - Lat. F	Undershot	Undershot	F ≥ 1

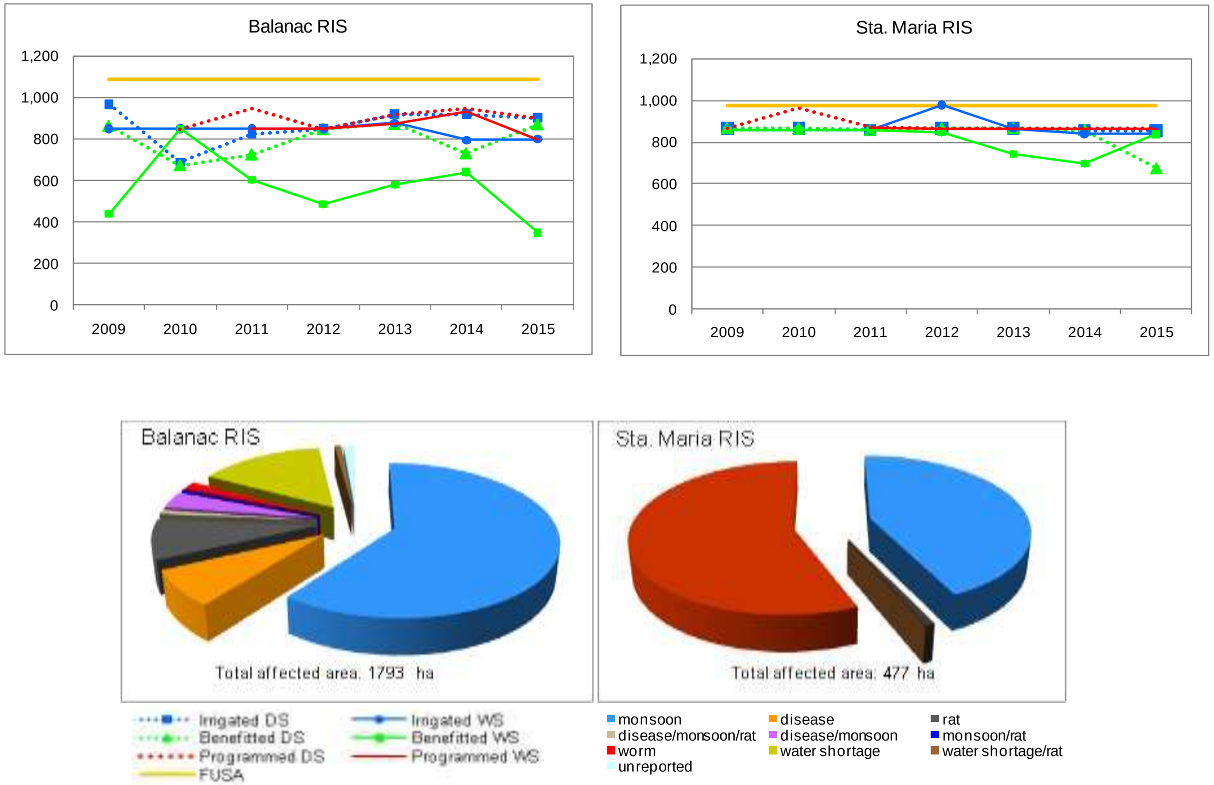

Figure 2. Performance in terms of areas and yield constraints in Balanac RIS and Sta. Maria RIS.

The findings of Delos Reyes *et al*. (2015) on the nature of improvement works carried out for the two systems included the following: lining with concrete had the most investment; Balanac dam has become prone to flood damages and necessitated urgent major constructions, which made it the second most invested work; service road in Sta. Maria had more investment than dams and flow control structures. In both systems, investment on canal structures, including those for water reuse was at most 5% of the total.

4 CONCLUSIONS

The proposed diagnostic framework used in this study would result in a more comprehensive system diagnosis. The logic design analysis provided a clear-cut framework for identifying inherent constraints in the design of the systems while the MASSCOTE diagnostic tools provided a systematic approach to assess the integrity and soundness of physical structures and ensuing irrigation service. In the case of Balanac RIS, the hypothesis of unwieldy water distribution deduced from logic design mismatch between the productive irrigation objective and the shift to splitted flow and proportional flow control method was supported by the low ratings of RAP internal indicators and the unauthorized demolition of proportional weirs segments by farmers. The logical coherence of Sta. Maria RIS was compromised by the added open direct turnouts along the main canal. Damages, dysfunctions, missing components and poor maintenance reduced the capacity of the physical structures to perform their functions. The incoherence in system design and the reduced or inherent limited capacities of the physical structures led to poor water delivery service. The proposed diagnostic framework emphasized the link between system design and management and provided continuity of analysis and feedbacks channels for necessary adjustment or modifications of intervention strategy.

Inclusion of the headwork component in each of these diagnostic tools will put the water supply issues arising from climate change in clear perspective. With prolonged, drier dry season, systems designed with productive irrigation objective but without storage-type dam are facing high chances of failure. The ROR feature of the case study systems constrained the irrigation coverage of their FUSA. It was less amenable to the strategic shifting of planting season initiated in Sta. Maria RIS to circumvent the droughts and more adverse monsoon season associated with climate change. While it is not easy to imagine the foremost importance of securing water supply to avert the adverse impact of climate change, making the headwork aspect part of diagnostic technique will make it hard to overlook. Adaptation strategy to climate change must address the storage capacity issues of ROR systems. Potentials for augmenting the water supply from other sources need to be pursued.

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