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Impacts of management and modernization on water savings in large irrigation systems

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Abstract

This study was conducted to assess and optimize the conveyance performance of major irrigation systems in the case of the NIA-Magat River Integrated Irrigation System in the Philippines. Options Analysis in Irrigation System (OASIS) was used to evaluate and optimize the conveyance efficiency of the system. Management and modernization scenarios were undertaken in the irrigation system assuming that the rehabilitation projects exerted efforts on improving efficiencies and reduced losses in the conveyance and distribution systems. Based on the results, the actual condition of the irrigation system as the reference of improvement will have 1,365,759 million cubic meters diversion supply from MARIIS and Baligatan diversion dams. Having been improved from 76% of conveyance efficiency to 95% assumed result of the improvement measures, approximately 84,303 million cubic meters or 6% increase from the actual diversion requirement can be realized. With every 1% increase in conveyance efficiency, there will be approximately 33,831 cubic meters savings in irrigation diversion requirements. This could be achieved through canal repairs of damaged structures, the lining of earth canals, and modernization of control structures. The OASIS program has shown its ability to assess the effects of irrigation management and modernization in a large irrigation system that can serve as a science-based planning and decision-making support program. It may also be used to study the management and optimization of irrigation in other irrigation systems in the country and elsewhere in the world.

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Introduction

Degradation of canal systems due to age, siltation, and extreme weather events caused water distribution to substantially decrease in irrigation systems. Land-use change has caused the dwindling of water available as well as the service areas in national irrigation systems (Tabios and De Leon, 2020). Unreliable water supply from rivers and creeks is also a problem in communal irrigation systems due to lack of water resources data and assessments (Luyun and Elazegui, 2020). These have adverse impacts on crop production as irrigation supply is consequently reduced. This can cause reduce food availability and thus food security is at stake. Smallhold farmers who depend on irrigation supply are the ones directly hit especially during dry seasons. Climate change could also aggravate this as it may bring prolonged dry spells and substantial reductions in seasonal rainfall. Projections show that climate change is inevitable and that it will bring drier dry seasons and wetter wet seasons (Philippine Atmospheric Geophysical and Astronomical Services Administration, 2018). It was also projected that climate change would shrink potential irrigable areas significantly from 50% tp 97% (Alejo and Ella, 2019) and that it would reduce corn and aerobic rice production in rainfed and upland areas substantially (Alejo, 2020; Balderama *et al.*, 2016). Water is now seen as one of the main sustainable development ingredients (Mkhandi, 2003; Pienaar and van der Schyff, 2007). Water management that is a primary tool in agricultural development is a continuous process in the pursuit of the National Irrigation Administration's objective of improving water use efficiency as well as increasing rice production. Its importance also plays a key role in the development of the nation, especially in the operation and maintenance of existing irrigation systems all over the country. Irrigation development has been one of the key strategies for inclusive growth and the competitive global economy of the Philippines by 2040 (National Economic and Development Authority, 2017). Funding for irrigation projects has been increasingly observed in the country since 2008 (Inocencio and Briones, 2020). This highlights the importance of assessing the irrigation projects' before implementation or as part of proposals to ensure the worthiness of investments.

In 1969 the NIA developed eight Pilot Projects on Water Management through the Asian Development Bank's technical assistance. Such eight pilot projects were strategically positioned on the country's premier irrigation systems. The development and execution of the NIA-ADB Pilot Projects on Water Management produced positive results and ended with the proposal to undertake a comprehensive and system-wide reconstruction and enhancement of the NIA irrigation system in the country with the Angat and Magat River Integrated Irrigation System as the focus representing the country's two largest systems. The Angat-Magat Integrated Agricultural Development Project was then pushed through to achieve food self-sufficiency by improving the water management irrigation system and subsequent expansion of the irrigated area and the adoption of improved crop cultural practices. A result of the benchmarking study on the NIA-MARIIS showed that there was a significant increase in the irrigated area based on the past 5 years of analysis (Bareng *et al.*, 2015). However, the irrigation diversion requirement being used by this national irrigation system was developed many years ago and has not been updated. Consequently, downstream farmers are deprived of enough irrigation supply. Moreover, the system's overall irrigation efficiency is generally low at 48 to 50% due to various losses incurred in the system. Minimizing these losses, therefore, is an important step to optimize the system's irrigation performance. Therefore, the challenge for the years to come will be the capacity to increase food production with less water, especially in areas with scarce water and land resources. As a result of the GIS-based investigation, 43 per cent or 13 million hectares in the Philippines will be under drought conditions due to climate change (Dar and Obien, 2008). Isabela, which is the service area of MARIIS, is on the top of the list registering 432,916 hectares.

Maintenance of canal systems in large irrigation systems could be costly but could help decrease losses along the distribution lines. However, there is a need for improved irrigation system conveyance and distribution. The creation of these strategies is very complicated as water is used for different purposes and objectives. In general, the management of water resources has become a science where computer-aided analytical techniques are anticipated to support the dynamic decision-making process involving many stakeholders with different interests and different socio-economic goals of developing natural resource and management strategies (Bazzani, 2005; Hippel *et al.*, 2008; Prasad *et al.*, 2005). Tools to support decision-making would help to promote the plan and execution of water management approaches (Haasbroek *et al.*, 2003; Juana *et al.*, 2008; Prasad *et al.*, 2005). Models play an important part in the creation of reliable interventions to improve irrigation efficiency. Achieving improved water efficiency will be a primary challenge and will require the use of technologies and practices that provide a more dependable water source for rice production. Options Analysis in Irrigation Systems (OASIS) is a planning platform for medium to large-scale irrigation systems. It was designed to capture the impacts of a range of structural (hardware) and managerial (software) interventions on water use, depletion, and productivity in irrigated agriculture. Options analysis through simulation modeling of the whole system will introduce interventions that will present the best efficiency and productivity to support decisions of higher-ups before providing efforts, time, and money in repair and rehabilitation. This way financial losses and wasted efforts are avoided. Only few papers utilizing the OASIS model were found published. These studies are focused on water recycling through irrigation return flows from ponds (Roost, 2006; Roost *et al.*, 2008b, 2008a). Ponds have been found useful as a means for groundwater recharge for irrigation. To date, the OASIS model has not been used to focus on quantifying water savings in a large canal distribution network of national irrigation systems. Also, this is important as the basis and justification of irrigation investments in the country. The study aims to evaluate and optimize the conveyance efficiency of large irrigation systems in the case of NIA-MARIIS.

Materials and methods

Site selection and characterization

The NIA-MARIIS is the largest irrigation system being used for agricultural purposes in the Cagayan Valley. It is located in the central part of the region and geographically located at 16°49.363' N and 121°27.435' E. The Magat dam is its reservoir, which has storage capacity level of 1.25 billion cubic meters at the full supply level. It serves 84,795 hectares of the service area.

Data collection

This study utilized available data on conveyance losses, inflow capacity, water releases, and irrigation diversion requirements. These data were gathered from the offices of NIA-MARIIS. The weather data used as input to the model was taken from the ISU-DOST-PAGASA. Percolation data used were taken from the lysimeter test conducted at the four (4) divisions of the NIA-MARIIS.

OASIS model overview

OASIS was developed to fix key deficiencies in other irrigation models (Roost *et al.*, 2008b). It is based on an integrated modeling paradigm consisting of a theoretical representation of the key components of the irrigation system-including groundwater and drainage systems-and their relations.

The innovation lies in its ability to capture all major water balance components within the irrigation system, including unprocessed degradation of fallow and non-crop vegetation. It can also catch and allow recycling irrigation return flows, thus facilitating the use of connective canals, groundwater, and drainage water. Based on these, it can accurately measure the performance, competitiveness, and equity of water usage under real or hypothetical conditions.

OASIS simulates the operation of a medium to large irrigation scheme over a season or year, taking into account real or assumed land use, facilities and water management activities, climate, and resource availability conditions. It can assess metrics such as water use efficiency, productivity, and equity that allow comparative valuation of alternatives and provide appropriate support for strategic decision-making in a basin-wide context for water management. The OASIS modeling hierarchically simulates from the field, sector, and systems levels.

Fields are composed of the particular soil and land cover where the soil-crip-water relations are modeled. OASIS considers the irrigation system as the main canal's command area, which diverts irrigation water from a sole source that could be from a river, reservoir, pumping station, or other irrigation canals. It accounts for large spatial variability in an irrigation system by modeling units as divisions and sectors. The delineated reach of the main irrigation network is referred to as the division.

A sector is a part of a division on one side of the main canal that has its specific distribution, drainage, and groundwater systems. A sector's groundwater system is simulated as a horizontal reservoir. The drainage system is defined as two-channel levels, with a horizontal surface water level. A linear flux-head relationship governs the connection between the surface and underground 'reservoirs.' Smaller variability within irrigation systems is considered by associating each sector with a set of fields. Fields are simulated as point entities to represent soil and land cover differences in sectors. More detailed information on the modeling framework of OASIS is found in Roost *et al.* (2008b). The OASIS program is available free and can be requested via email. Information on how to obtain the program is available in https://www.iwmi.cgiar.org/resources/data-and-tools/models-software

OASIS Scenarios

Scenarios were simulated base on improved efficiencies brought about by intervention on canal structures in the system i.e. lining of canal, rehabilitation of canal & others.

Table 1 shows the conveyance efficiency which depends primarily on the length of the channels, the type of soil or permeability of the channel banks and the condition of the channels.

Results and discussion

The NIA-Magat River Integrated Irrigation System

The simulation modeling study considered the entire system for improved efficiencies impact scenarios. The MARIIS is composed of four divisions I, II, III, and IV.

The layout of the irrigation system

Main canal reach

The system has four (4) main irrigation canals where volumes of releases at each headgate are known. These were the South High Canal, Oscariz main canal, North Diversion Canal, and MARIIS Main canal (Fig. 1). Each main canal was defined according to its conveyance efficiency, inflow, and outflow capacities. Data on conveyance efficiency was taken from the recent studies conducted in the system and inflow and outflow capacities from actual data gathered from the NIA office.

Fig. 1. Map showing the four (4) Divisions and four (4) Main canals of NIA-MARIIS.

Irrigation units, IU

These are the rice cropped areas that are being irrigated. Each irrigation units was defined base on area irrigated. There were seventeen (17) irrigation units identified in the system.

Main water sources

There were two (2) diversion dams in the system namely the Baligatan and MARIIS reservoirs. These two (2) diversion dams catch water from the Magat reservoir. MARIIS has two (2) main canals, the MARIIS Main canal with a design capacity of 121.5cms and the North Diversion canal with a design capacity of 36cms. The Baligatan diversion dam also has two (2) main canals, the South High canal with a design capacity of 26.04cms and the Oscariz Main canal with a design capacity of 7.66cms.

Flow links

The Magat reservoir is the main source of water supply in the NIA-MARIIS service area. Water is diverted to the irrigation units from the main canals and laterals (Fig. 2). The following links were considered in the model:

1. Segment-segment. This is the flow connections among segments or main canals
2. Reservoir-segment. This is the flow connections between reservoirs and segments.
3. Supply. Definition of supply links (between segments and Irrigation Units)
4. Seepage. Definition of seepage links (segment seepage into IUs; reservoir seepage into IUs or segments)
5. Drainage. Definition of drainage links (Irrigation Units drainage into segments or other IUs)

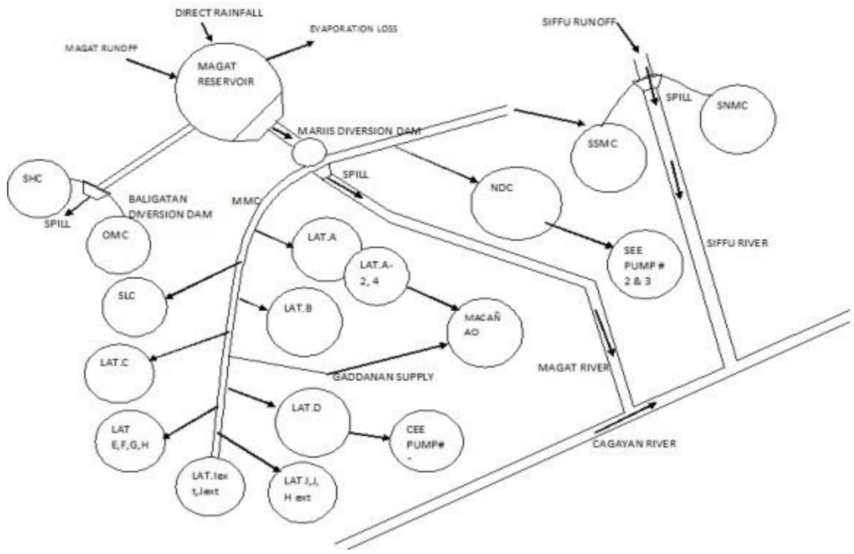

Fig. 2. Schematic layout of the NIA-MARIIS for simulation.

Environment

The input data necessary for capturing the environment condition were the agrometeorological and hydrological data in the NIA-MARIIS.

1. AgroMeteorology. The agrometeorological data considered in the area were taken from the ISU-DOST-PAGASA Agromet station that is located in the NIA MARIIS service area. Analysis of average historical weather data of 25 years from 1988 to 2013 showed that the average temperature is 27°C, average humidity is 86%, average wind speed is 5m/s and average radiation is 16 MJ m^{-2} day^{-1}.

The annual rainfall amounts to 1768mm which is highest in October and lowest in February. Evapotranspiration is high in April with 142mm and lowest in December with 69mm. Evapotranspiration is higher than rainfall in January to April (Fig. 3). These months are critical to crops. Irrigation in addition to rainfall should be available to ensure the productivity of lowland rice crops.

Inflow hydrograph.

An inflow resource availability constraint from the Magat dam was taken into account and defined as the inflow hydrograph of main canals namely the South High Canal (SHC), Oscariz Main Canal (OMC), North

Diversion Canal (NDC) and MARIIS Main Canal (MMC). The SHC and OMC supplying the Division 1, NDC for Division 3 andmmC for the Division 2 and 4. Additional water resources from other sources were not considered due to a lack of inflow hydrograph data. Insufficient data on groundwater and drainage use was also limited.

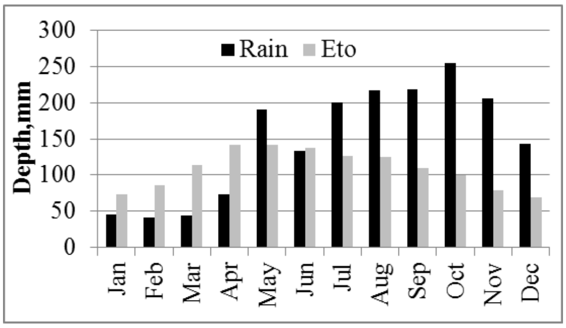

Fig. 3. Monthly rainfall and potential evapotranspiration (mm) in the area.

Water Management

Based on the benchmarking study conducted, MARIIS is considered a relatively low performing irrigation system. There is, therefore, a fraction of the water supply that is lost as seepage or deep percolation as reflected in the conveyance and distribution efficiency. The irrigation requirement for the whole service area is being reported as the irrigation diversion requirement for each main canals and laterals. Water delivery and its volume are being requested by the division offices. The method of irrigation in the NIA-MARIIS is purely basin irrigation. The area being served by the Magat dam is purely for rice production.

Impacts of management and modernization

Since rehabilitation projects often exert efforts on improving efficiencies and reduce losses in the conveyance and distribution systems, improvement scenarios assuming that traditional intervention measures such as canal lining and precision land leveling would result in 95% efficiency as reported by FAO. Field efficiency mainly depends on the irrigation method and the level of farmer discipline. Simulations were conducted base on long canal length, which was 60%, 70%, 80%, 90%, and 95%.

As a result of the improvement scenario from the actual, approximately 84,303 million cubic meters or a 6% increase from the actual diversion requirement can be realized (Fig. 4). Besides, results showed that diversion requirement decreased as conveyance efficiency increased (Fig. 5). With every 10% increase in conveyance efficiency, there will be approximately 33,831 million cubic meters savings in irrigation diversion requirements. The diversion water requirement needs to compensate for all the water losses in the irrigation system which includes the losses in the conveyance system. With improved conveyance efficiency, the diversion water requirement is decreased. To optimize the performance of the system, there is a need to increase its efficiency in terms of conveyance, which is oftentimes the focus of rehabilitation projects. This area is usually managed through canal repairs of damaged structures and lining of earth canals. On the other hand, there is an opportunity at the farm level, to save water provided the farmers will adopt water-saving technologies. Only, this will take time especially that it is not as easy as implementing rehabilitation projects in the canal systems. Farmers are usually hesitant in limiting water supply to their farms.

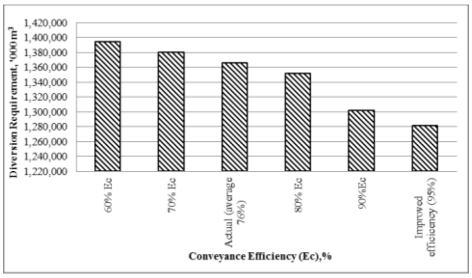

Fig. 4. Diversion requirement and conveyance efficiency. Note: Ec is the conveyance efficiency.

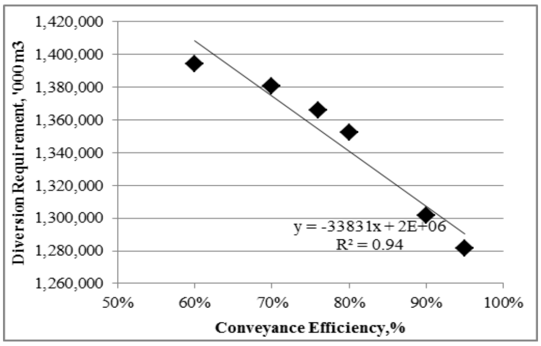

Fig. 5. Relationship of diversion requirement and conveyance efficiency.

Conclusions

This study was conducted to evaluate and optimize the conveyance efficiency of large irrigation systems in the case of the NIA-Magat River Integrated Irrigation System. The simulation period considered was the dry season of the year 2011. Management and modernization scenarios were undertaken in the irrigation system assuming that the rehabilitation projects exerted efforts on improving efficiencies and reduced losses in the conveyance and distribution systems. The study showed that substantial water savings could be realized with improved conveyance efficiencies. To optimize the performance of a large irrigation system, there is a need to increase its efficiency in terms of conveyance, which is oftentimes the focus of rehabilitation projects. This area is usually managed through canal repairs of damaged structures and lining of earth canals. On the other hand, there is an opportunity at the farm level, to save water provided the farmers will adopt water-saving technologies. Only, this will take time especially that it is not as easy as implementing rehabilitation projects in the canal systems. Farmers are usually hesitant in limiting water supply to their farms. The OASIS program demonstrated its capability in assessing the impacts of irrigation management and modernization in a large irrigation system, which may serve as a science-based support to planning and decision-making. It could also be used to assess irrigation management and optimization in other irrigation systems in the country and other parts of the world.

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Conflicts of interest

The authors declare no conflicts of interest.

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