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Assessment of the Water Use Efficiencies of Selected Laterals and Paddy Fields at the Upper Pampanga River Integrated Irrigation System (UPRIIS), Philippines

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ABSTRACT

Large gravity irrigation systems have been performing inefficiently implying that irrigation efficiency needs to be properly addressed if sustainable irrigation development is to be achieved. The conveyance and application efficiencies of selected laterals, farm ditches, and paddy fields at the Upper Pampanga River Integrated Irrigation System (UPRIIS) were assessed in terms of conveyance, application, and storage losses. The inflow-outflow method was used to determine the conveyance losses in selected laterals while water balance computation using ponding and tank methods was used to determine farm ditch and application losses in selected paddy fields. Results showed that conveyance losses from these canals ranged from 0.175 to 1.65 m^3/s while conveyance efficiency ranges from 41.3% to 81.0%, which has no significant difference with FAO values for adequately maintained canals. Percolation losses ranged from 1.98 to 10.12 mm/d which were significantly different with paddy fields and soil types and generally higher than NIA design percolation losses for each soil type. The measured farm ditch losses range from 0.09 to 23.87 lps/km with considerable variations attributed to the condition and maintenance of the ditches. Using both secondary data and measured losses, the average storage, conveyance, and on-farm efficiencies were computed as 93%, 60%, and 76.8% (dry), and 36.4% (wet), respectively. The system efficiency for UPRIIS using these representative values was found to be 32%, which is about the same as that of many large systems based on FAO studies. While a statistically significant assessment of the UPRIIS was not attained due to its size, quantifying and analyzing the causes of these water losses is necessary to provide measures to increase water use efficiency and help improve water management. Reduction of losses in irrigation systems improves water use efficiency thereby increasing the irrigated area and crop production.

Keywords: *conveyance efficiency, irrigation, irrigation system, on-farm efficiencies, percolation rate, storage efficiency, system efficiency, Upper Pampanga River Integrated Irrigation System, UPRIIS*

INTRODUCTION

Irrigation plays a very important role in Philippine agricultural development as it increases crop yield and cropping intensity. The unit area productivity in irrigated rice-based cropping systems is 1.5 to 2.8 times larger than that in rainfed areas (David, 2003). For the 10-year period 2010-2019, the average yield for irrigated rice is 4.27 metric tons (MT) per hectare (ha), which is 1.41 times larger than the 3.02 MT/ha in rainfed areas (PSA, 2015-2020). Cropping intensity in rice farms in Central Luzon increased from 120% before UPRIIS to 182% after the Casecnan extension became fully operational in 2012 (Moya, et al., 2015). Providing irrigation to under-irrigated and rainfed areas can address the problems of poverty and food insecurity in the country.

The National Irrigation Administration (NIA) is responsible for the construction of new irrigation projects and the rehabilitation of irrigation systems in the Philippines. As of December 2019, about 1.972 million hectares (ha), or 63.02% of the total irrigable area in the Philippines have been developed for irrigation. Of these, 914,319.37 ha or 46.4% are irrigated by national irrigation systems (NIS), 709,083.30 ha or 36.0% are under farmer-managed communal irrigation systems (CIS), 177,733.14 ha or 9.0% are irrigated by privately owned systems (PIS), and 170,610.28 ha or 8.6% are irrigated through assistance by other government agencies (e.g., Bureau of Soils and Water Management) (NIA, 2020). Large gravity irrigation systems have historically and continuously been performing inefficiently and below expectations. The water use efficiency of the rice-based cropping systems served by these systems is less than 30% (David, 2003). A rapid appraisal process conducted by FAO in 14 selected irrigation systems in seven countries in Asia showed that the command area irrigation efficiency of rice-based systems is about 45% on average, and lower in the wet than in the dry season (Facon, 2010).

Irrigation development has been the single biggest expense item in Philippine agriculture accounting for about a third of the total since the 1960s, and at close to half of the total in the 1970s, early 1980s, and in recent years when world rice prices rose to unprecedented levels (Inocencio et al., 2016). Despite these efforts, the irrigated area in the country is still low, thus jeopardizing food security. Ella (2016) stated that most of the conveyance systems of NIS and CIS are unlined, causing excessive seepage and percolation losses, and greatly reducing the conveyance efficiency of irrigation. Consequently, the downstream portions of irrigation systems are either under irrigated or left unirrigated, resulting in low cropping intensity. Application efficiency of flooded rice paddies is also low inferring that irrigation efficiency needs to be properly addressed if sustainable irrigation development is to be achieved.

The Upper Pampanga River Integrated Irrigation System (UPRIIS), constructed in 1974, supplies irrigation water to the province of Nueva Ecija (89.6% of its total service area), Tarlac (1.2%), Pampanga (3.9%), and Bulacan (5.3%). This system was initially designed to provide irrigation water to about 77,000 ha of aggregated agricultural land in the region but an additional service area of 37,200 ha was added after the completion of the Casecnan Irrigation and Power Project in 2009. The system has a potential irrigable area of 130,811 ha with a current firmed-up service area (FUSA) of 116,914 ha during the wet and dry season that benefits 82,428 farmers (members of 388 irrigator's associations). UPRIIS is divided into five divisions. Nine rivers supply water, which is collected, stored, and regulated in several reservoirs: the Pantabangan reservoir as the main storage dam, Masiway dam as a regulation dam, 2 auxiliary reservoirs in Aurora (Canili and Diayo), 5 diversion and subsidiary storage dams (Rizal, Aulo, Tayabo, Atate, and Peñaranda) and 13 re-use dams (Vaca, Murcon, etc.). The system also comprises 75.84 km of diversion canals, 197.36 km of main canals, 1,455.728 km of secondary and tertiary canals, and 4,550 turnouts. Canals, including main, secondary, and tertiary mostly have mixed physical construction. Some parts are lined and some are lined. A total of 467.14 km are lined and the remaining 523.845 km, mostly secondary and tertiary canals, are earthen or unlined (NIA-UPRIIS, 2013).

The movement of water through an irrigation system can be regarded as three separate operations: conveyance (scheme or system level), distribution (farm level), and field application (field level) (Bos and Nugteren, 1990). Conveyance is the movement of water from its source through the main and secondary canals (laterals) up to tertiary offtakes. Distribution is the movement of water through the tertiary (distributary) and farm ditches up to the farm inlet. Field application is the movement of water from the field inlet to the crops. Only part of the irrigation water taken from a source reaches the root zone of the plants. Part of it is lost during transport through the canals (conveyance losses) and during application in the field (application losses). Water losses are due to (a) evaporation from the water surface, (b) deep percolation to soil layers underneath, (c) seepage through the bunds or paddies, (d) runoff in the drain, (e) overtopping the bunds or paddies, and (f) breaks or holes in the bunds or paddies (Brouwer, 1989).

Seepage (S) is the rate of lateral movement of subsurface water between fields while percolation (P) is the vertical movement of water beyond the root zone to the water table. Studies by Bhuiyan (1982), Tuong et al. (1994), and Kukal & Aggarwal (2002) reported that combined S&P are site-specific and depend on soil texture and structure, bulk density, ponding water depth, puddling intensity, water table depth, hydraulic conductivity of the hardpan, and proximity to drainage outlet and farmer's field water management status. Bouman and Tuong (2001) reported that typical values of S&P vary from 1-5 mm/d (in heavy clays) to 25-30 mm/d (in sandy and sandy loam soils). Bouman et al. (2007) reported that their values range from 0.3 to 32.8 mm/d based on several studies in the Philippines (particularly in Central Luzon) and China from 2002 to 2004. Another study by David et al. (2012) in selected irrigation systems in Ilocos Norte showed that the average P loss rate ranges from 4.0 to 41.5 mm/d. All these field values are relatively higher compared to the P loss rate of 1-2 mm/d used in the design of those systems.

The study aimed to estimate the conveyance and application losses of selected laterals, farm ditches, and paddy fields within the UPRIIS. An attempt was also made to quantify the system efficiency of UPRIIS assuming the limited estimates represent the system conditions. The overall water use efficiency is the product of storage filling, conveyance, and on-farm application efficiency (Figure 1). Storage filling efficiency was computed using secondary data from Pantabangan dam's storage data. Conveyance efficiency was estimated from the actual measurement of conveyance losses on selected canals per division in UPRIIS. On-farm application efficiency was computed from measured actual farm ditch losses, and seepage and percolation losses on selected paddy fields. Advanced technologies in water use efficiency measurement like isotopic techniques and eddy covariance (International Atomic Energy Agency, 2017; Hatfield and Dold, 2019; Marshall et. al., 2021) are already available but they require sophisticated instruments and measurement

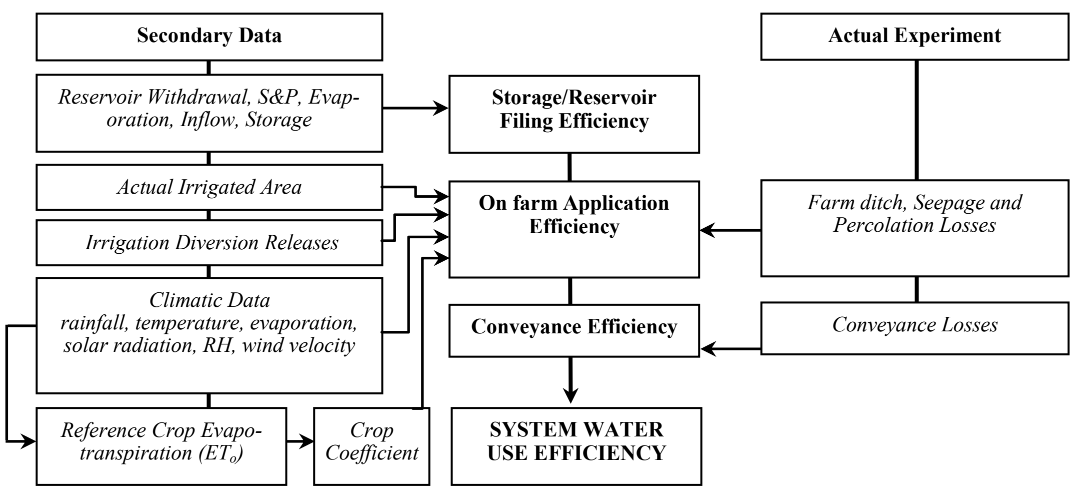

Figure 1. Schematic diagram of the computed efficiencies and the primary and secondary data gathered.

techniques that would become prohibitive for the scale of the study. Moreover, these methods are applied mostly on crop water use efficiencies and while the measurement of stable isotopes of oxygen (^{18}O) can be used to indirectly measure conveyance and application efficiencies, they still need calibration and validation using direct measurements.

MATERIALS AND METHODS

To determine overall water use efficiency, significant conveyance and application water losses were quantified. The specific losses in each component of the irrigation scheme were determined through experiments and field evaluations. Because of the immense size of UPRIIS with numerous and extensive canal networks, using a statistically significant representative sample size would entail considerable time, effort, and funds, which the study did not have. The conveyance and application losses were measured at the upstream, middle, and tail-end portions using only representative canals, farm ditches, and paddy fields. The methods of measurement adopted the procedures conducted by David et al. (2012). Overall system assessment required the use of a 10-year record of Pantabangan Reservoir's withdrawal, seepage and percolations, surface evaporation, releases, and daily storage level. Field experiments were conducted on representative laterals and paddy fields in each division of UPRIIS from July 2013 to April 2016 covering a total of six cropping seasons.

Conveyance losses

Measurements of conveyance losses were carried out in four representative laterals of UPRIIS (Lateral F1A of Division I; Lateral C1 of Division II; Lateral C1 of Division IV; Lateral E1 of Division V). These were selected based on the following criteria: (a) canals should be relatively straight, (b) in good and functional condition, (c) with at least medium flow of water, and (d) there are no control structures, turnouts, or illegal taps between the points of inflow and outflow measurements. Flow measurement from end to end of each lateral was considered impractical due to the presence of control structures and numerous legal and illegal turnouts, hence, the selected lateral was divided into several reaches. Conveyance loss in each reach was obtained using the inflow-outflow method and computed as the difference between the inflow and outflow rates of water in that reach. The inflow and outflow discharges per reach were determined as the product of flow velocity and cross-sectional area of the canal perpendicular to the flow. The flow velocities were measured using a digital Price current meter (Figure 2). In canal sections with water less than 1-m depth, velocity was measured at about 0.6 of the depth as measured from the water surface. For water depths greater than 1-m, however, velocities at 0.2 and 0.8 of the depth were measured and then averaged. Canal dimensions such as top width, bottom width, side slope, and depth were measured to determine the cross-sectional area. Relatively wide (>1-m) canals were divided into several sections and the area multiplied with the velocity in that section was added to determine the total flow rate passing through the canal.

On-farm Application losses

On-farm application losses include seepage and percolation losses in both farm ditches and paddy fields. Farm ditch losses were measured using ponding methods (Figure 3) and were performed at 15 selected sites representing the three most common soil types in all divisions. Initially, 5 random sites per division were designed for the

Figure 2. Flow measurement on a canal using digital current meter.

experiment. Sites were selected from the upstream, middle, and tail-end portion of the division's main service canal. But since the field experiments usually take between 2 to 4 weeks from equipment installation to data monitoring and the experiment may interfere or affect farming activities, the willingness of the farmers was considered. Moreover, trial runs showed that a maximum of only 3 sites could be accommodated for a set of daily monitoring due to the long distance between each sampling site. Due to time and budgetary constraints, only 3 sites per division were evaluated within the project duration. Farm ditches were selected based on the following criteria: (a) relatively straight with at least 10-m length, (b) relatively uniform cross-section, (c) near a water source, and (d) accessible. Each farm ditch was cleared of grasses, weeds, and other debris or obstructions. Earthen dikes were constructed across the canal to create a pond with a minimum length of 10-m. For a deep canal, the minimum length should be 60 times the canal depth. The dikes were sealed with plastic or metal sheets and a buffer zone of about 1.5 m at both ends of the pond was also constructed. These were done to ensure that any seepage losses would only come from the sides and bottom of the farm ditch. The actual condition and compaction of the canal bottom were preserved during pond construction. The water level in the pond was maintained to approximate the maximum supply level of the ditch under normal irrigation operation. A stilling basin was placed in the middle of the pond with its rim leveled with the water surface and submerged in the water leaving 2 cm above the water surface.

The actual length and average top width of the pond were measured. A hook gauge was used to measure the changes in the water level in the stilling well (Figure 3). Measurements were done every 15 min for the first hour, and every 30 min for the succeeding hours. In setups with a very slow decrease in water level, measurements were done every hour or two. Measurements were carried out continuously until readings became stable, that is when the change in depth became constant. Water was added into the pond when the water level reached 5 cm below the original water level.

To measure on-farm application losses, 11 paddy fields serviced by the chosen farm ditches were selected based on the following criteria: (a) with unimpeded water supply from the farm ditch for ease of water control; (b) accessibility for ease of equipment installation and continuous data gathering; (c) free from interference (e.g., farming activities, farm animals, etc.). Similar to the farm ditches, the farmer's willingness was also considered since the experiment may affect farming activities.

The water balance method using different tanks (Figure 4) was used in quantifying the on-farm application losses following the study of David et al. (2012). This includes evaporation (*E*), percolation (*P*), and seepage (*S*) tanks. The evaporation tank

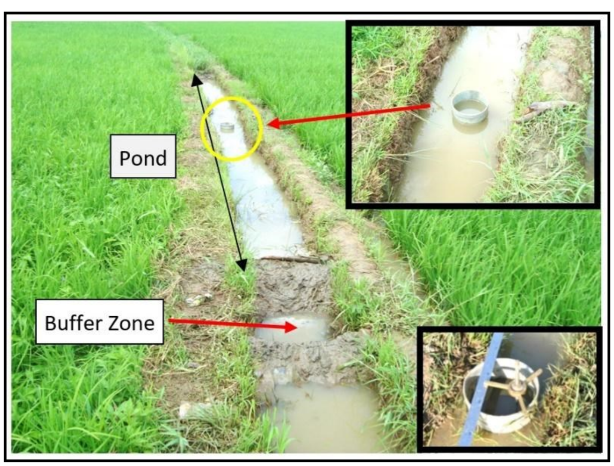

Figure 3. Farm ditch losses measurement setup.

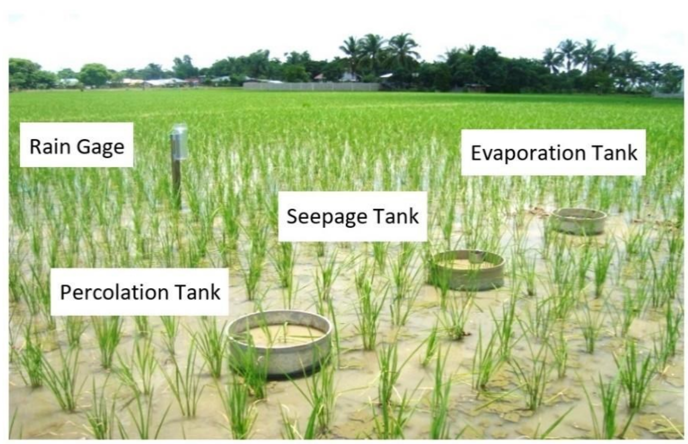

Figure 4. Set up for measurement of application losses on paddy fields.

measures the water losses due to evaporation and crop transpiration (evapotranspiration) while the seepage and percolation tanks measure the water losses due to evaporation, crop transpiration, seepage, and percolation. The tanks were placed at least 1-m from the bunds for ease of measurements and to minimize errors due to possible shading and wind obstruction. The *P* tank was first installed into the soil with its bottom set down to the hardpan and the rim or unsubmerged part is level. The other tanks were then installed with their rims at the same level as that of the *P* tank. A clearance of 5 cm between the rim of the tank and the water surface of the paddy was sustained to minimize thermal mismatch error due to exposure to sun and wind. The water surface in the tanks was maintained at approximately 2 cm higher than the water surface in the rice paddy field to correct this error. In any case, only the change in water level is more important in the measurement. A rain gauge was also installed in the paddy field to correct the measurements in the tanks for any additional water due to rainfall.

A micrometer hook gage was used to measure water level changes in the tanks. Measurements were done twice a day, one in the morning between 7:00 AM to 9:00 AM, and one in the afternoon between 3:00 PM to 5:30 PM. The actual time of measurement was recorded. Additional measurements were done during periods of heavy rainfall and to monitor possible water overflow in the tanks. For each trial, measurements were carried out continuously until readings became stable, that is when there are three comparable values for the evapotranspiration, percolation, and seepage losses.

Determination of Water Use Efficiency

The overall water use efficiency was determined using the equation suggested by the International Commission on Irrigation and Drainage (ICID) (Bos, 1985) and Central Water Commission of India (CWC, 2014):

$$W_P = W_R \, x \, W_C \, x \, W_F \, x \, W_D$$

where:

W_P is the overall system efficiency
W_R is the storage filling efficiency/diversion efficiency
W_C is the conveyance efficiency
W_F is the on-farm application efficiency
W_D is the drainage efficiency

The storage filling efficiency was computed using data obtained from UPRIIS Dam and Reservoir Division including the dam live storage, 10-yr daily record of dam inflows, power plant withdrawal, irrigation releases, spillway releases, evaporation, and seepage losses. It is computed using the equation:

$$W_R = \frac{\sum_1^n W_y}{n}$$

where:

Wy is the storage filling efficiency for a particular year (y = 1,2,3…n) and is computed as:

$$W_y = \frac{Annual\ Net\ Storage}{Designed\ Live\ storage}$$

where the Annual Net Storage was computed as:

$$Annual\ Net\ Storage = (S_i + I) - (R + S + E)$$

where:

S_i is the initial storage, million cubic meter (MCM)
I is the total inflow, MCM
R is the total releases or withdrawal, MCM
S is the total seepage loss, MC
E is the total evaporation loss, MCM

The conveyance efficiency was obtained using the equation:

$$e_c = \frac{V}{I} \, x \, 100$$

where:

e_c is the conveyance efficiency, %
V is the total volume delivered to the farm, m^3/s
I is the inflow discharge in the lateral, m^3/s

Since the laterals were divided into reaches, the difference between the measured inflow and outflow for a certain reach was considered as the conveyance loss of that reach. The sum of the losses in all reaches was used to determine the conveyance efficiency of that lateral. Hence, the conveyance efficiency of the lateral was computed using the equation:

$$e_l = \frac{I - \sum_1^n L_i}{I}$$

where:

e_t is the conveyance efficiency of the lateral, %
I is the inflow discharge in the lateral, cms
L_i is the loss in each reach, cms (i = 1, 2, 3…n)

The conveyance efficiency of each system was obtained by computing the average conveyance efficiency of the representative laterals.

The on-farm application efficiency (e_a was determined using the equation:

$$e_a = \frac{Farm\ Irrigation\ Requirement}{Actual\ Irrigation\ Supply}$$

The Actual Irrigation Supply is the total actual diversion releases and the Farm Irrigation Requirement (FIR) was computed as:

$$FIR = \frac{(E_T + P) - R_e}{e_c}$$

where:

E_T is the actual crop evapotranspiration planted in the area, m^3
P is the field percolation loss, m^3
R_e is the effective rainfall, m^3
e_c is the conveyance efficiency

The on-farm application efficiency of each division was obtained by computing the average efficiency using the 10-year data. The drainage efficiency was assumed to be equal to unity since all excess water in the canals and paddies drained either into the next paddy or into the reservoir for reuse. Furthermore, the percolation losses beyond the root zone were already accounted for in the on-farm application efficiency computation.

RESULTS AND DISCUSSIONS

Conveyance losses and efficiencies

Table 1 summarizes the results of the conveyance loss experiments. No lateral was selected on Division III because of logistics and other inadvertent problems that arose during the study period. The total conveyance losses from the four selected laterals of UPRIIS range from 0.278 m^3/s to 1.380 m^3/s. Conveyance efficiency for each canal stretch considered ranges from 57.0% to 98.2%, while the computed efficiency for the lateral ranges from 47.8% to 73.8%. The t-tests at 95% confidence interval showed that the computed conveyance efficiency per stretch has no significant difference with the corresponding FAO values both for adequately maintained short earthen canals, and long and medium laterals (>200 m) (Brouwer et. al, 1989) as outlined in Table 2.

Table 1. Conveyance losses measured on each selected canal in UPRIIS.

DIV	CANAL	STRETCH	LENGTH (m)	CONVEY-ANCE EFFICIENCY (%)	TOTAL LOSS (m^3/s)	COMPU-TED EFFI-CIENCY* (%)
I	Lateral F1-A	1	185.0	85.4	0.2783	73.8
		2	120.8	97.2		
		3	134.9	94.7		
		4	110.9	98.2		
		5	69.0	70.4		
II	Lateral C1	1	1000.1	78.8	1.3811	71.1
		2	552.0	89.8		
IV	Lateral C1	1	440	93.5	0.2962	47.8
		2	2406	57.0		
V	Lateral E1	1	247.1	69.3	0.4516	49.0
		2	110.0	97.4		
		3	111.0	76.6		
		4	80.0	98.1		

It should be noted that most parts of these laterals are unlined with only about 2-5% of their total length being lined. Considering the large volume of water flowing through these lateral canals, significant amounts of water are lost. While it appears that the longer the canal the lower is the stretch conveyance efficiency, the t-test showed that there is no significant difference. The low computed efficiencies on the selected canals in Divisions IV and V may be attributed to poor maintenance, siltation, presence of vegetation, and illegal taps. These losses severely reduce the amount of irrigation water conveyed and distributed to downstream or tail end fields.

While the number of lateral canals studied is insignificant compared to the total number and length of the canal networks in UPRIIS, we should consider that the laterals in UPRIIS are of the same soil type and physical characteristics, having been transported from the same source during construction. With the limited budget and duration of the study, and as an attempt to try to quantify the system efficiency of UPRIIS, we assume that the measured losses on the selected laterals to be representative of the total volume of water lost from the other laterals. Conveyance loss and efficiency are important parameters for the estimation of irrigation releases and other performance indicators of an irrigation system. They are also major components for determining overall water use efficiency.

On-farm application losses and efficiencies

Table 3 presents the measured farm ditch losses in lps/km of canal length and the application losses in the paddy fields served by the farm ditches. The measured farm ditch losses from the 15 sites range from 0.09 to 23.87 lps/km while the measured application losses range from 1.98 to 10.12 mm/d. The average particle sizes (microns) of the different soil types were determined and found to have no significant correlation with farm ditch losses (0.33) but have a positive correlation (0.70) to the application losses. Farm ditch losses can be significantly affected by numerous factors like physical condition, poor maintenance, holes, and leaks.

Table 4 summarizes the average percolation rates per soil type in comparison with design values. The average soil particle size has a positive correlation (0.93) to the average percolation rate, that is, coarse-grained soils have a higher percolation rate. The highest (23.87 lps/km) and lowest farm ditch losses (0.09 lps/km) were obtained from sandy loam soils which have the highest particle size. Moreover, a relatively high farm ditch loss of 10.36 lps/km were also observed from the smallest soil particle size. There were considerable variations in farm ditch losses reflecting not only the difference in soil type but the physical condition and maintenance of the

Table 2. Indicative values of the conveyance efficiency for adequately maintained canals.

CANAL LENGTH	EARTHEN CANALS			LINED CANALS
	SAND	LOAM	CLAY	
Long (> 2000 m)	60%	70%	80%	95%
Medium (200-2000m)	70%	75%	85%	95%
Short (< 200)	80%	85%	90%	95%

Source: FAO (Brouwer et al, 1989)

Table 3. Soil texture, farm ditch losses, and application losses in the paddies served by the farm ditches at 15 sites in UPRIIS.

SITE (DIVISION)	SOIL TEXTURE	FARM DITCH LOSSES LPS/KM	APPLI-CATION LOSSES MM/D
1 (DIV I)	Sandy Loam	0.53	7.00
2 (DIV I)	Sandy Loam	0.09	5.40
3 (DIV I)	Sandy Loam	0.53	2.00
4 (DIV I)	Loam	1.27	2.40
5 (DIV I)	Clay Loam	0.16	2.10
6 (DIV I)	Clay Loam	0.13	2.90
7 (DIV II)	Silt Loam	10.36	2.52
8 (DIV II)	Loam	19.01	3.93
9 (DIV II)	Sandy Loam	23.87	6.96
10 (DIV III)	Sandy Loam	20.11	6.83
11 (DIV III)	Loam	0.86	2.62
12 (DIV IV)	Sandy Loam	19.8	10.12
13 (DIV IV)	Clay	0.81	1.98
14 (DIV V)	Silty Clay Loam	0.68	2.45
15 (DIV V)	Loam	2.18	6.15

farm ditches as well. Most farm ditches were not well maintained during the setup of trial ponds. Numerous holes and leaks were also observed, most likely made by eels that were abundant in the area. The leaks were patched but in actual field conditions, outflows due to leaks and holes are part of farm ditch losses. Nevertheless, these results warrant the need for more sampling tests for different soil types across the whole UPRIIS.

Table 4. Average percolation losses per soil type compared with design values.

SOIL TEXTURE	AVERAGE PERCOLATION RATE (MM/D)	
	MEASURED	DESIGN (BSWM, 1997)
Sandy Loam	6.39	4.0
Loam	3.78	-
Clay Loam	2.50	1.75
Silt Loam/ Silty Clay Loam	2.49	1.65-1.75
Clay	1.98	-

Actual seepage loss on rice paddy fields is technically difficult to quantify since sideward leaks on bunds depend on many factors such as soil type, bund condition, grass cover, and the hydraulic gradient between adjacent paddies from all sides, among others. David et al. (2012) observed fluctuations in seepage losses and found it was not possible to monitor the seepage flow from paddy to paddy. To simplify, it was assumed that the volume of water seeping into the paddy is the same as the water seeping out of it.

Except in one site, the actual seepage and percolation losses were higher than the design values used by NIA (BSWM, 1997). There is no published value for the design percolation rate for loam and clay. Having actual percolation rates greater than design values lead to underestimation of the required water for irrigation and overly optimistic assumptions regarding water application efficiency (David et al., 2012). These results may explain the low ratios of actual area irrigated to design service areas in most irrigation systems. The use of erroneous estimates of percolation rates during the design stage will be subsequently carried over in the formulation of other design criteria such as crop water, farm water, and diversion water requirements.

Table 5. Weighted percolation rate of each division of UPRIIS.

SOIL TYPE	FIRMED-UP SERVICE AREA KM^2	PERCO-LATION RATE, MM/D	WEIGHTED PERCO-LATION	AVERAGE PERCO-LATION RATE, MM/D
Division I				
Clay Loam	37.31	2.50	93.275	2.50
Silt Loam	272.00	2.49	677.260	
Sandy Loam	0.203	7.26	1.476	
Division II				
Clay Loam	60.81	2.50	152.030	4.50
Silt Loam	154.79	2.49	385.432	
Sandy Loam	156.172	7.26	1133.809	
Division III				
Clay Loam	298.67	2.50	746.675	2.50
Silt Loam	217.61	2.49	541.849	
Sandy Loam	1.025	7.26	7.441	
Clay	10.136	1.98	20.069	
Division IV				
Clay Loam	271.68	2.50	679.200	2.54
Silt Loam	31.608	3.00	94.824	
Sandy Loam	48.41	2.49	120.541	
Division V				
Clay Loam	129.04	2.50	322.603	2.62
Silt Loam	153.63	2.49	382.539	
Sandy Loam	10.79	7.26	78.313	
Clay	21.41	1.98	42.390	

Farm management practices can affect soil percolation rates. Generally, greater soil compaction will result in a decrease in the percolation rate (Duiker, 2004). On the other hand, if the soil is tilled after compaction, the infiltration and percolation rate will be higher since its aggregates are coarser compared to that of previously compacted tilled soil. Puddling is also one important operation that alters and improves soil physical characteristics. The increased intensity of puddling significantly increased the depth of puddled layers and crack dimensions but reduced both seepage and percolation loss in the paddy (Kalita et al., 2020). Unfortunately, the degree of compaction and puddling intensity in the test sites were not determined.

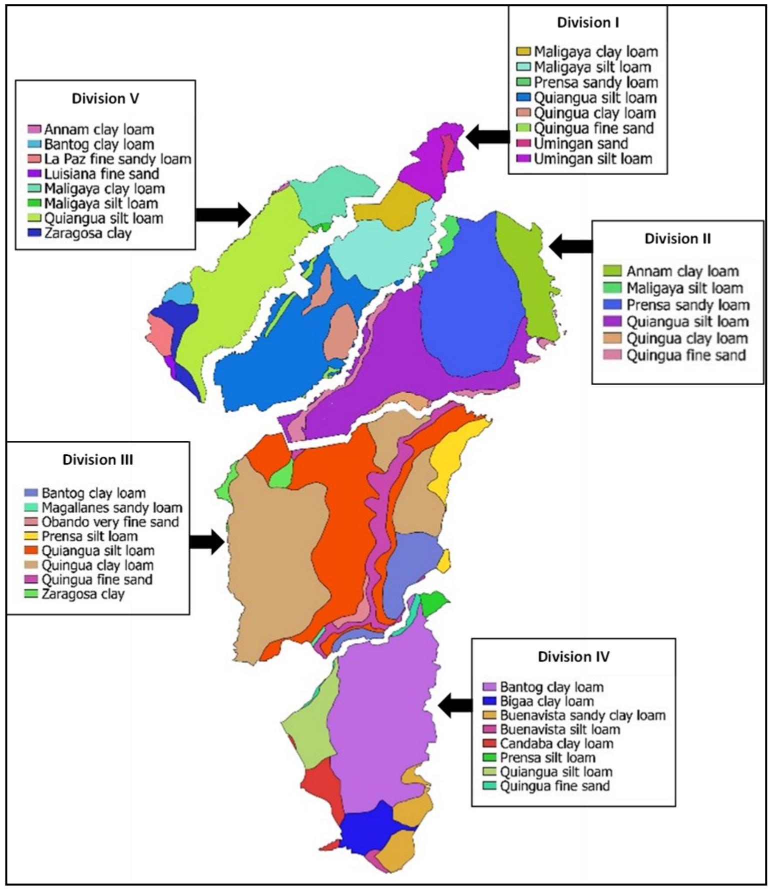

Figure 5. Soil map per Division in UPRIIS based on DA-BAR Philippines General Soil Classification Map.

Determination of water use efficiency of UPRIIS

The water use efficiency or the system efficiency of water utilization is computed based on the collective performance of each specific component of the irrigation scheme. As suggested by the ICID (Bos, 1985) and CWC – India (CWC, 2014), the overall water use efficiency is composed of conveyance efficiency, on-farm application efficiency, reservoir filling efficiency or diversion efficiency, and drainage efficiency. Each component of water use efficiency was determined using secondary data and field experimental data except for drainage efficiency which was assumed to be equal to unity as discussed in the methodology.

Conveyance efficiency is the indicator of water losses in the conveyance system and shows how well the system is designed and managed. It also reflects the percentage of flow relative to the supplied which is considered available and beneficial to the crop. Since UPRIIS is very large with approximately 1,500 km of laterals, it is difficult if not quite impossible to test even 10% of that length within the limited timeframe of the study. Based on the conveyance efficiency of four representative laterals, the average conveyance efficiency of UPRIIS was 60.4%. This value is within the practical achievable limit of 60% for unlined canals, which is understandable considering that the percent losses from its inflow were significantly higher compared to the design seepage losses (20% of canal flow) set by the USBR (1978) for unlined laterals.

On-farm application efficiency is an indicator of how much of the irrigation applied is stored and used by the crops (USDA SCS, 1993). It is primarily dependent on the losses including percolation, seepage, and tail runoff. It is also quite sensitive to application depths. Uneven or excessive depths that may be due to faulty or inflexible design and poor management significantly affect the distribution efficiency (CWC, 2014). The on-farm application efficiency of UPRIIS was computed using the actual percolation data collected from the field experiments and secondary hydrologic data such as irrigation diversion releases, climatic data, and irrigated areas of the different UPRIIS Divisions. For Divisions I and II, 9 years of records were used, while only 5 years were available for Divisions III, IV, and V.

Using the existing soil map per Division based on the DA-BAR Philippines General Soil Classification Map (Figure 5), the percolation loss for each Division was estimated using the average percolation loss per soil type (Table 4). As expected, low percolation losses (2 to 2.5 mm/d) were observed in clay to clay loam soils while a high value (7.3 mm/d) was observed in sandy loam soils. The average percolation per division ranges from 2.5 to 4.5 mm/d. Results of the analysis of variance showed no significant difference among the percolation values obtained from all divisions. Table 5 shows the percolation loss per division as weighted using the area covered by each soil type over the entire firmed-up service area. On the other hand, Table 6 summarizes the computed on-farm application efficiency per division. It should be noted that these values are just estimates based on the limited number of sampling sites, and should be checked or verified with actual measurements.

On-farm application efficiency was computed by getting the ratio of the sum of all the losses to the computed farm water requirement (David et al., 2012). Application efficiency per division ranges from 61% - 94% during the dry season and 19% - 46% during the wet season. Analysis of variance showed no significant difference among the application efficiencies in all divisions but significant differences were found between dry and wet season values. Efficiency during the dry season is relatively high, which is quite good since the limited irrigation water is utilized efficiently. Overall, the average application efficiency covering both dry and wet seasons is 56.6%, which is within practicable limits for predominantly rice-based cropping systems (Bos et al., 2005). But efficiency alone does not describe irrigation sufficiency because high efficiency sometimes results from limited irrigation water. As such, the annual irrigation water supply was compared with the irrigation water requirement for each division in both dry and wet seasons (Figure 6).

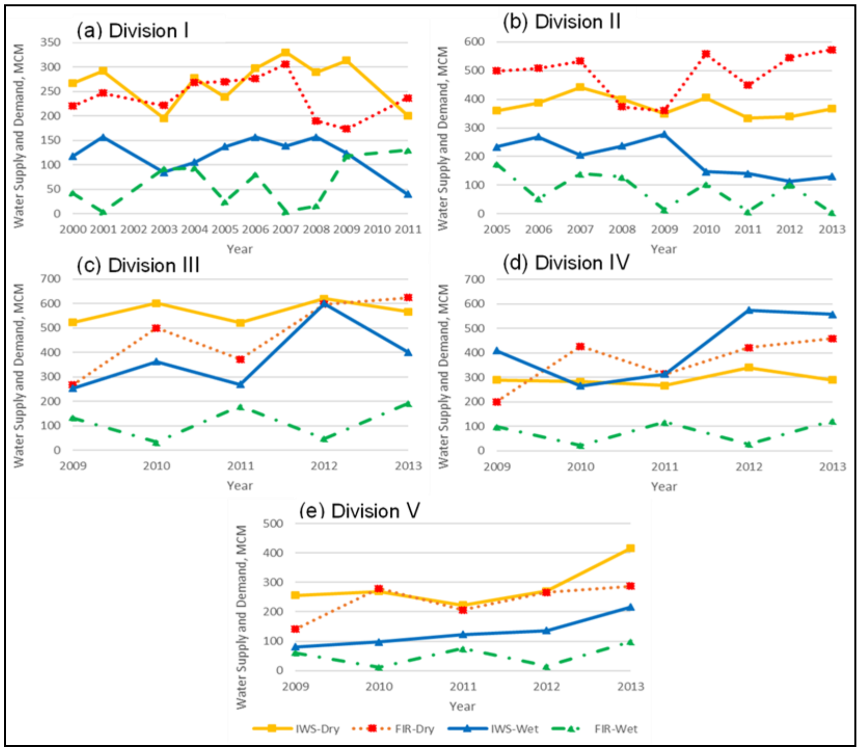

Figure 6. Comparison of the Dry and Wet Season Irrigation Water Supply (IWS) versus Farm Irrigation Requirement (FIR) for the 5 Divisions of UPRIIS.

Table 6. On-farm application efficiency of each division of UPRIIS.

DIVISION	CROPPING SEASON	APPLICATION EFFICIENCY, %
I	Dry	81
	Wet	46
II	Dry	94
	Wet	39
III	Dry	61
	Wet	37
IV	Dry	69
	Wet	19
V	Dry	79
	Wet	41
System Average	Dry	76.8
	Wet	36.4

Between 5 to 10 years of record were obtained with some missing years.

Results showed that there are some years with water deficits, especially during the dry season. This is expected due to the reduced rainfall and high evapotranspiration rate leading to high irrigation water requirement and low water inflow into storage. During the wet season, on the other hand, huge volumes of excess irrigation water can be observed. Continuous water releases, even during periods of low irrigation water requirements, can be attributed to hydroelectric power generation and flood control due to excess water in the storage areas of the different dams within UPRIIS. These explain the low application efficiency during the wet season. It is also possible that irrigation systems with high application efficiency have poor uniformity of water distribution in the field which results in less irrigation water in some areas. The uniformity of water distribution is not included in the scope of this study. The general approach of the study is to compute the water balance of the system, and the individual distribution on sub-service areas was not considered. Determination of uniformity of water distribution for large irrigation systems is too complex and could not be accomplished within the limited time frame of the project. Moreover, incomplete flow records per tertiary service area and the absence of flow measuring devices on service laterals make it difficult to estimate or quantify the volume of irrigation water per sub-service area.

Reservoir or storage filling efficiency is the ratio of the maximum live storage attained in the reservoir in a particular year to the designed live storage reservoir. It is important in evaluating the storage design efficiency based on hydrology, specifically in monitoring or describing the change in the hydrologic regime. The reservoir filling efficiency of the Pantabangan Dam was computed using the 7-year daily record of storage, inflows, withdrawals (based on the power plant and Masiway Dam irrigation tunnel spillway), evaporation, and seepage losses. Table 7 shows the computed annual storage filling efficiency and net storage of Pantabangan Dam based on the reservoir-designed live storage of 1,757 million cubic meters (MCM). Pantabangan Reservoir has an average storage efficiency of 93% which is near the reservoir efficiency practical achievable limits of 95% – 98%. The annual net storage exceeded the designed live storage only in 2011, hence the storage efficiency was greater than 100% (131.5%). The lowest storage efficiency can be observed in 2010, which pulled the average down. It should be noted that the Philippines experienced a moderate El Niño event in 2009-2010 which explains the very low inflow into the reservoir especially in 2010, and consequent higher water withdrawal, to save the crops in the drought-affected fields. The computed reservoir efficiency is for the Pantabangan dam only but the entire UPRIIS is supplied with water from 9 rivers, with several diversion, subsidiary storage, and re-use dams. A complete accounting of reservoir efficiencies of all these dams is very complicated and beyond the scope of this study.

The Overall Water Use Efficiency or System Efficiency is the product of the efficiencies of each of the identified irrigation components. The conveyance efficiency of 60.4%, on-farm application efficiency of 56.6%, and reservoir

Table 7. Annual storage efficiency of Pantabangan Dam.

YEAR	INITIAL STORAGE, MCM	INFLOW, MCM	WITHDRAWAL, MCM	LOSSES, MCM		NET STORAGE, MCM	STORAGE EFFICIENCY, %
				EVAPORATION	SEEPAGE		
2009	2140.60	1577.88	1,983.51	53.39	0.69	1,680.90	95.7
2010	1910.50	1510.38	2,151.51	43.90	0.22	1,225.25	69.7
2011	1223.71	2674.77	1,549.84	38.37	0.22	2,310.05	131.5
2012	2004.79	2228.14	2,476.14	45.87	0.33	1,710.59	97.4
2013	1638.44	1903.21	1,946.39	36.06	0.22	1,558.99	88.7
2014	1545.36	1572.15	1,784.19	36.46	0.13	1,296.74	73.8
2015	1287.81	1945.00	1,577.31	36.36	0.11	1,619.03	92.1

efficiency of 92.7% bring the UPRIIS system efficiency to 32%. Research studies using various sets of indicators have indicated that many irrigation projects perform far below their expectations. The overall efficiency of many systems may be as low as 30%, while well-managed systems show efficiencies of 50% or more (FAO, 2002).

SUMMARY AND CONCLUSIONS

An attempt was made to estimate the water use efficiency of UPRIIS in terms of conveyance, application, and storage losses. Due to the immense size of UPRIIS with its vast canal networks coupled with the limited funds and duration of the study, conveyance losses were measured in only four representative laterals, while farm ditch losses and on-farm application losses were measured in only 15 sites in UPRIIS. Using actual field data and obtained secondary data, conveyance losses, on-farm application losses, storage, and system efficiency were computed.

The inflow-outflow test results show that the conveyance losses from four selected laterals from UPRIIS range from 0.278 to 1.38 m^3/s. The conveyance efficiency ranges from 47.8% to 73.8% for an average of 60.4%. The conveyance losses indicate that significant amounts of water are lost since large volumes of water flow through these laterals. While some may argue that these waters are not completely lost but only leaked through the adjacent paddy fields, they severely affect the efficient and equitable distribution of water to the entire system and reduce the amount of irrigation water distributed to downstream or tail end fields. While the canals are considered adequately maintained with no significant difference with corresponding values set by FAO for adequately-maintained earthen short, medium, and long laterals, concrete lining of the canals would greatly increase conveyance efficiency.

The measured farm ditch losses using the ponding method range from 0.09 to 23.87 lps/km, with the highest generally coming from sandy loam soils. Some variations can be attributed to the physical condition and poor maintenance of the farm ditches such as the presence of numerous holes and leaks made by eels that were prevalent in the area. In actual field conditions, outflows due to leaks and holes are part of the farm ditch losses. If the losses seep into adjacent paddy fields and are used for the intended consumptive demand, no actual water loss would occur but equitable water distribution in the field is largely affected.

On-farm application losses in representative rice paddies were determined using a water balance method. Percolation losses ranged from 1.98 to 10.12 mm/d and were significantly different with paddy fields and soil types. The average percolation rates were 7.26 mm/d for sandy loam, 3.78 mm/d for loam, 2.50 mm/d for clay loam, silt loam, and silty clay loam, and 1.98 for clay. The measured values were higher than the design percolation losses used by NIA. Using these values for the different soil types based on the general soil classification map of UPRIIS, the weighted percolation losses for the different divisions of UPRIIS were similar (2.50, 2.50, 2.54 and 2.62 mm/d for Divisions I, III, IV, and V, respectively) except Division II (4.50 mm/d). This gives an average percolation loss of 2.93 mm/d for the whole UPRIIS. Actual percolation rates much greater than design values lead to underestimation of the irrigation water requirement and overly optimistic assumptions regarding water application efficiency. The use of erroneous estimates of percolation rates during the design stage will be carried over in the formulation of crop water, farm water, and diversion water requirements, which will subsequently result in less area being actually irrigated compared to the design area.

On-farm application efficiency per division ranges from 61% - 94% and 19% - 46% during dry and wet seasons, respectively. Overall, the annual application efficiency averaged at 56.6% which is within practical achievable limits for predominantly rice-based cropping systems. Efficiency during the dry season is relatively high, which is a good indication that the limited irrigation water is utilized efficiently. However, comparing total irrigation requirements with total irrigation supply, water deficits were observed for several years during the dry season. Low rainfall and high evapotranspiration rate lead to high irrigation water requirements and low water inflow into storage. On the other hand, there is a huge volume of excess irrigation water during the wet season. Continuous water releases for hydroelectric power generation and flood control, even with low irrigation water requirements explain the low application efficiency during the wet season.

The storage filling efficiency of the Pantabangan Dam was computed to be 92.7% which is close to practical achievable limits of 95% - 98%. It should be noted, however, that this value is for the Pantabangan dam only and does not include the different auxiliary, subsidiary storage, and re-use dams of UPRIIS. Assuming for the sake of quantification that the computed conveyance and application efficiencies from the selected canals and paddy filed were representative of the whole system, it was found that the overall system efficiency for UPRIIS was 32%. This value is about the same as the overall efficiency of many systems based on FAO studies. Well-managed systems, however, show efficiencies of 50% or more.

With the present conditions of most of the open and unlined canals, and structures in UPRIIS requiring minor maintenance and rehabilitation, water losses are unavoidable. Estimating conveyance and application losses and analyzing their causes is necessary to provide measures to increase system efficiency and help improve water management. Reduction of these irrigation system losses will subsequently improve water use efficiency thereby increasing the irrigated area and crop production.

RECOMMENDATIONS

The results presented here were based on the limited number of laterals and sampling sites and should be emphasized when using these values for the entire UPRIIS. Nevertheless, the test methods used are valid and the authors recommend that similar studies be duplicated to more canals, farm ditches and paddy fields in UPRIIS to improve the results of the current study. It is also recommended to revise the selection criteria for laterals to include the entire length of the canal including curved sections, control structures and turnouts (although the gates should be closed) to be able to identify problem areas and possibly quantify losses from illegal turnouts.

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