Re-use and Cyclic Use of Water Saving in Rice Cultivation in Gravity Irrigation System of Philippines

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EXTENDED ABSTRACT

This paper presents the situation analysis of a re-use system of return flow for irrigation in District 1 of the Upper Pumpanga River Integrated Irrigation System (UPRIIS), Philippines. While elaborating the situation analysis, emphasis is given to quantification of water re-use and its related economic benefits under gravity-fed irrigation systems. This irrigation system presents a distinct geophysical feature which provides opportunities for capturing irrigation outflows from rice fields of upstream areas through a network of natural creeks. These creeks feed into check dams which divert irrigation supplies for downstream areas. In UPRIIS area, the major sources of re-use system include groundwater pumping, lifting surface water from creeks and irrigation supplies from check dams.

Specifically, this study aimed to: a) quantify the current level of water re-use from creeks, groundwater and check dams; and b) to estimate the economic benefits of water re-use from pumping groundwater and creeks in District 1 of UPRIIS.

This study was conducted during the dry season of 2001, (19 November 2000 - 18 May 2001). During this period, the average rainfall was only 190mm (long term average of 170 mm). A comprehensive survey was carried out in District 1 with the help of the National Irrigation Administration (NIA). This survey focused on obtaining information regarding pumping technologies, sources of re-use water (groundwater or creek), existing cropping patterns and pumped water sharing practices. An additional 50 pump owners, from a total of 1154 pumps, were selected for detailed investigation and monitoring of total water with drawl from different sources of water.

The geographic information system (GIS) was developed to characterize the study area. To quantify the amount of water re-use, pumps were calibrated 7-9 times with a V-notch weir to determine the actual discharge for different sizes of pump. The total amount of water being pumped by each monitored farm was determined by multiplying the actual discharge with the total pumping times/hectare. Water and yield relations were determined by developing production functions, and economic benefits were determined by estimating the water productivity (economics) and calculating the marginal value of water.

In the study area, it was found that 22% of the farmers use pumps to draw water from shallow tube wells for supplementary irrigation. The pump density ranged from 0.13-0.2 pumps/ha, showing that the majority of the farmers depend on groundwater. The estimated total volume pumped per ha ranged from 0.39-6.93 m^3/ha during the dry season. Overall, this is equivalent to 30% of the water lost through seasonal actual evapotranspiration from the rice crop. There was no difference in pumping cost between the creek (0.012 $/$m^3$) and shallow pumps (0.012 $/$m^3$). Overall marginal value product (MVP) of water re-use was 0.0406 $/$m^3$. The MVP of water re-use from creek (0.0438 $/$m^3$) was slightly higher than the water re-use through the pumping ground water (0.0388 $/$m^3$).

The results showed that water re-use plays a dominant role in the growth of a rice crop during the dry season. The results clearly indicate that the quantification of volumes of water re-use is crucial for understanding and finding real water saving possibilities at the irrigation system level. The results also revealed that rice production systems are still profitable despite high pumping costs and other associated expenses in District 1. These findings would lead to an improvement in the water use efficiency and water productivity of irrigated rice systems.

1. Introduction

Rice is the staple food and also constitutes the major economic activity and a key source of employment and income for rural populations. Some 75% of the world's annual rice production is harvested from 79 million ha of irrigated lowland rice, mainly in Asia, where it accounts for 40- 46% of the net irrigated area of all crops (Dawe, 2005). Rice production consumes a high proportion of freshwater, and because of this water-use efficiency is low as compared to other crops (Hafeez et al., 2007). Improving water use efficiency and water productivity requires a complete understanding of water balances at various scales such as field, farm, and irrigation system level. Irrigation efficiency is the most commonly used term to describe how well water is being used within a system (Molden 1997). However, many scientists (Bos and Wolters, 1989; Keller et al., 1996) caution on the possible misconceptions of irrigation efficiency with regard to the broader spectrum of irrigated agricultural systems and river basins. For example, water lost from an individual farmer's field can be reused further downstream and is thus not lost to the whole irrigation system.

Principally, the water that flows out of a field into creeks, groundwater, or downstream areas can potentially be reused. This water can be reused by blocking creeks and diverting the water into new irrigation canals, by direct pumping from creeks and drains, or by pumping from (shallow) groundwater. In this way, one farmer's water loss may be another farmer's water gain (Seckler, 1996). In view of this possibility, water use efficiency at the system level is deemed higher than at the individual field level.

Irrigated rice receives at the field level 2-3 times more water than other cereals and is a major target for the development of water-saving irrigation technologies (Tuong et al., 2005). Water application varies from as little as 400 to more than 2000 mm depending on soil type and watertable depth. Between 25 and 85% of all water inputs to rice fields leave the field as percolation (Tuong et al., 2005). Though percolation flows are losses at the field level, they can be captured and reused downstream and do not necessarily lead to true water depletion at the irrigation system level. Reuse of water can be practiced at the farm level, irrigation system level, and regional level, provided the water is of good quality. However, the recapture and reuse of water that is "lost" upstream mostly involves additional investments and operation costs, such as pumping or the building of dams downstream (Guerra et al., 1998). Therefore, it is very important to carry out a complete cost-benefit analysis for water reuse at different spatial levels to assess feasibilities of recovery at the system level.

Reuse of water offers an effective way to increase the water-use efficiency and productivity of an irrigation system. Guerra et al. (1998) reported that recycling is being practiced in rice irrigation systems in many countries, while Zulu et al. (1996) reported that average drainage water reuse was about 14-15 % of the original irrigation water inflow in a rice irrigation system in Niigata Prefecture, Japan.

Water accounting concepts have been tested and methodologies developed to quantify the water use and water productivity in surface irrigation systems in India, Pakistan and Sri Lanka (Loeve et al., 2002). Other studies carried out at different spatial in the Zhanghua Irrigation System (ZIS) in China, show that secondary storage and reuse of water are of crucial importance in increasing the overall system-water productivity (Dong et al., 2001; Loeve et al., 2002). However, literature on the quantification of water reuses from different sources and its associated cost-benefits at different spatial levels in irrigation systems in Southeast Asia is limited (Hafeez, 2003). Few estimates exist that quantify and analyze the costs and benefits of water reuse at different spatial levels.

This study focuses on irrigated rice systems in the Philippines, where irrigated rice accounts for 61% of the 3.4 million ha of rice production area. This paper concentrates on the estimation of the total amount of water reused and its associated cost-benefit relation during the dry season of 2001, at five different spatial levels in the rice-based irrigation system of District 1 of the Upper Pampanga River Integrated Irrigation System (UPRIIS). Specifically, this study aimed to: a) quantify the current level of water re-use from creeks, groundwater and check dams; and b) to estimate the economic benefits of water re-use from pumping groundwater and creeks in District 1 of UPRIIS.

2. Method

2.1 Description of Study Area

UPRIIS lies in central Luzon, the Philippines, and covers an area of 102,000 ha which produces an average of 63 million tons of rice every year. Water is received from a combination of various river intakes and the large Pantabangan reservoir. UPRIIS is divided into four irrigation districts and this study was conducted in the area known as

District 1 (Figure 1). District 1 has a total area of 28,205 ha. It consists of the Talavera River Irrigation System-Lower (TRIS-L), and the Santo Domingo Area (SDA). TRIS-L receives its water directly from the Main Diversion Canal No. 1. Part of the water from the Main Diversion Canal No. 1 is diverted into the Sapang Kawayan creek, which also collects drainage water while it traverses TRIS-L. In TRIS-L, the De Babuyan check dam raises the water level in the Sapang Kawayan creek and the water is diverted into the Santo Domingo Main Canal that irrigates the SDA.

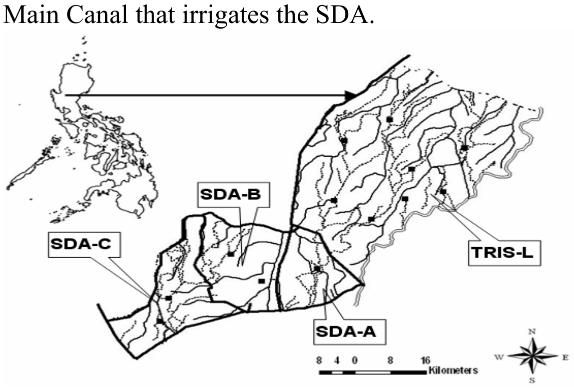

Figure 1: Location of four irrigation levels in District 1 of UPRIIS, Philippines where check dams (■), unit boundaries (▬), canals (—), creeks (······) and rivers (═)

This study was conducted in the dry season of 2001 (19 November 2000 - 18 May 2001). Rainfall for this season was approximately 190mm. Double cropping of rice is the most common land use in the area. Where water is scarce, upland crops such as onion, tomato, watermelon and maize are grown in the dry season. Use of small pumps is common among the upper and lower reaches of the lateral canals in District 1 (Moya et al., 2002).

District 1 was subdivided into four spatial units (Figure 1): TRIS-L, SDA-A, SDA-B, and SDA-C. All boundaries consist of roads, which were selected in such a way that all surface water flowing in and out of the areas could be measured. One additional spatial unit was created by combining all four spatial units, so that a total of five units (ranging from 1,513 ha at SDA-A to 18,003 ha at District 1) were obtained. Detailed information about the irrigated area for the five spatial levels of District 1 is provided in Table 1.

Table 1: Main characteristics of District I

Description	SDA-A	SDA-B	SDA-C	TRIS-L	District 1
Total area (ha)	1,513	2,240	3,011	11,239	18,003
Rice area (ha)	1,177	1,709	1,972	8,713	13,571
Upland crop (ha)	86	242	415	886	1,629
Rest (ha)	250	289	624	1,640	2,803
FIA's (number)	5	6	7	48	66
Farmers (number)	751	901	1,051	7,207	9,910
Pumps (number)	109	107	419	519	1,154
Pump users (number)	91	146	694	655	1586
Check Dams (number)	1	2	1	11	15

3. Data Collection

A Geographic Information System (GIS) was developed for the study area. This contained all relevant data layers, including the road network, irrigation canals, drains, creeks, monitored pumps, and farmer's irrigator association (FIAs).

3.1 Water Accounting

The water accounting framework classifies the components of the water balance based on the type of outflows and the way water within the domain of study is used (Molden, 1997). The 3-dimensional boundaries of our study area were the horizontal outer boundaries of the 5 combined units, the top of the surface/vegetation, and the bottom of the rootzone. In our study, gross inflow is rainfall plus all surface water flowing into each spatial unit. We neglected any change in stored surface water and water stored in the root zone of agricultural crops so that net inflow is the same as gross inflow. All surface outflows are considered committed when they flow into a neighbouring spatial unit or further downstream in irrigated areas of District 1 that are not included in our analysis. Water flowing out of District 1 is considered uncommitted. Depletion flows are only evapotranspiration (ET) flows since no water percolates to irretrievably deep or saline groundwater. Since the purpose of UPRIIS is to irrigate rice, we classify rice ET as process depletion, and all non-rice ET as non-process depletion.

Surface in- and outflows were measured twice a day by tracking all flows through drains, creeks, channels, or culverts (a total of 158 points) underneath the roads that formed the boundaries of our spatial units. For most open waterways, we measured water depth with installed staff gauges and obtained flow volumes from rating curves established (R^2 of 0.95) using current meters and measured cross sections. Rainfall was measured from eight rain gauges installed throughout District I, and total volume of rainfall for each spatial unit was estimated by spatial extrapolation using Thiessen polygons. Seasonal actual evapotranspiration (ET_a) was estimated through the Surface Energy Balance Algorithm for Land (SEBAL; Bastiaanssen, 1995) approach using six TERRA/MODIS and three Landsat 7 ETM+ optical satellite images over the irrigation season with ground truth data. ET_a was divided over rice (process outflow) and other land covers (non-process outflow) based on a supervised land use classification using a Landsat image from March 31 for all our spatial units. Further details on the measurements are given by Hafeez (2003).

3.2 Estimation of Water Reuse

No reliable information exists about lateral groundwater inflow and outflow for each spatial unit in District 1. Water pumped from creeks and shallow groundwater could, therefore, either be water that percolated upstream within the system, or be a net gain to the system if the water comes from a larger regional aquifer. We calculated the volume of percolation for each spatial unit by multiplying the area with the average percolation rate (2.1 mm/day) within rice fields. Here, we compared pumped volumes with estimates of water that percolated upstream within the system. When the amount of pumped water was less than the amount of water that percolated upstream, we classified the pumped water as reused within the system. When the pumped water exceeded upstream percolation, we classified it as net input into the system. Generally, irrigation water that percolates deeply and recharges an aquifer adds to the water supply available to groundwater users. When this aquifer feeds a creek, it benefits users that pump water from this source.

Pumping from Groundwater/Creek/Canal

Farmers informally reuse water by pumping from shallow groundwater, creeks, and drains during the dry season, particularly in downstream areas. We carried out in depth survey of all farmers in the area on pump ownership and pump use and counted the number of pumps in each of our spatial units. 50 representative farmers were selected and their pump operations monitored during the growing season. The selection depended on location, pump size and source of water, and the total pump usage for all farming activities from land preparation to harvesting over the dry season of 2001 (Hafeez et al., 2007). Each pump was calibrated 7-9 times with a V-notch weir to determine the actual discharge for different sizes of pumps. The pumped water volumes from each source were obtained by multiplying calibrated flow rates by recorded durations of pumping for the dry season 2001. It was assumed that the remaining farmers had similar pumping trends. The total water pumped for each spatial unit was estimated by multiplying the average water being pumped for each pump size with the total number of pumps installed at that spatial unit. In addition, the total volume of water per ha was estimated using GIS analysis at each spatial level.

Check Dams UPRIIS was designed to formally reuse surface water by building check dams in creeks and drainage ways within the irrigated area. Farmers have informally contributed to water reuse by constructing some dams themselves that are now 'sanctioned' by the irrigation system management. There are a total of 15 formal check dams in District 1, which are operated and maintained by either NIA or by groups of farmers. These check dams have regular structures for releasing water to supply additional water to the downstream canals for irrigation purposes. We estimated water flows in inlets at 9 of the 15 check dams by installing staff gauges and obtaining flow volumes from rating curves established (R^2 of 0.95) using current meters.

3.3 Economic Value of Water Reuse

Valuing water is a difficult and unsatisfactory process, considering that the marginal value of water varies throughout the season, between seasons, by location, type of use, and by water source. We selected two main approaches to estimate the value of water reuse: marginal productivity of rice using a rice production function and water productivity (economics) (WP_e) of irrigation. In addition, we calculated the economic value of water reuse for a) groundwater pumping, b) pumping from creeks, and c) overall pumping during the dry season of 2001.

3.3.1 Marginal Productivity of Water Reuse

Economic production functions are often used to estimate expected returns for crop and livestock, to simulate input decisions, and to estimate the value of the production realized at the end of the growing season. We estimated the Cobb-Douglas rice production functions in order to estimate the marginal productivity of reused water. A production function that shows the rice output at various spatial levels with different sources of water reuse can be specified as:

$$Y_{ij}(W_i) = \beta_0 + \beta_1 W_i + \varepsilon_i$$

where Y_{ij} is rice output (kg) from the ith water reuse source and jth spatial level; W_i is the amount of water use in m^3 in the dry season of 2001 from the ith water reuse source; β_0 is a constant, β_1 is the marginal physical product (MPP) of reuse water and ε_i is an error term. The three reuse water sources considered are pumping water from creek, groundwater and combined use.

3.3.2 Water Productivity (Economics) of Water Reuse

Economic productivity is the gross or net present value of the product divided by the value of the water either diverted or consumed by the plant. The present value can be defined in terms of value or opportunity costs in the highest alternative use (Barker et al., 2002). Rice yield and water use were obtained from sample group of farmers during survey. Gross returns were calculated by multiplying the yield with farm gate price of rice.

3.3.3 Pumping Cost

Total pumping cost was estimated by taking into account both fixed and variable costs. Total pumping costs include the costs from the day when the farm initially irrigated for land preparation and up to harvesting. Fixed costs were converted into annual capital costs (ACC) by taking into consideration the useful life of pumps, engine and accessories, and interest rates. Additional details of cost estimates are given in Hafeez et al. (2007).

4. RESULTS AND DISCUSSION

4.1 Water Accounting

Results of the water balancing and water accounting are given for each spatial unit in Table 2. Because of limited rainfall during the season, irrigation comprised 88-97% of all surface water inflows. Irrigation water inflow and total water outflows generally increased with increasing spatial scale within the whole SDA, indicating that large amounts of surface water flowed overland through the system without being depleted. Out of all surface water outflows, only 49 x 10^6 m^3 was uncommitted as it flowed directly into the Talavera River from TRIS-L. All other outflows were committed and flowed either into another spatial unit or into the downstream irrigated area of District I. Units that had a relatively large irrigation water inflow also had a relatively large surface water outflow. The result is that the net surface inflow increased quite linearly with spatial scale up to the 11,000 ha of TRIS-L.

Table 2: Water accounting components for 5 spatial units in District I, UPRIIS

Description	SDA-A	SDA-B	SDA-C	TRIS-L	District 1
Water flows across boundaries (all in 10^6 m^3)					
Gross Inflow	113	134	120	388	408
Irrigation	109.7	129.2	111.5	354.9	358.4
Rainfall	3.3	4.8	8.8	33.2	50.0
Storage Change	0	0	0	0	0
Net Inflow	113	134	120	388	408
Total Surface Outflow	101.3	118	110.1	323.7	368.8
Committed outflow	95.4	109.3	98.4	230.8	249.7
Uncommitted Outflow	0	0	0	49.1	49.1
Total Depletion	9.9	14.8	19.6	68.3	112.6
Process - ET_{rice}	8	11.6	13.3	57.4	90.2
Non Process $ET_{non-rice}$	1.9	3.2	6.3	10.9	22.4
Available Water	17.6	24.7	21.9	157.3	158.7
Balance*	7.7	9.9	2.3	39.9	-3

* Calculated as net inflow – total surface outflow (committed and uncommitted) – total depletion (Rice ET and non-rice ET)

Hafeez et al. (2007) also reported that per unit rice area, total net applied surface water (all surface inflows minus surface outflows) decreased linearly with increasing scale within the SDA from 1,500 mm at 1,500 ha to 1,000 mm at 6,800 ha. Overall, applied surface water decreased by 30 mm for every 1,000 ha. Out of the applied amounts of surface water, only 213-295 mm was rainfall in the different spatial units. The volume of rice and non-rice ET increased linearly with spatial scale, indicating uniform evaporation conditions within District I. Per unit area, the average rice ET was 665 mm for the whole season and 3.7 mm d^{-1}. The non-rice ET was 503 mm for the whole season and 2.8 mm d^{-1}.

The water balance term (net surface inflows minus surface outflows and all ET) was relatively small, being 1-10% of total surface inflows at different scales. The term was positive for all spatial units except for the combination of all units, for which it was close to 0. These positive values suggest that water percolated down and recharged groundwater or flowed as subsurface water into neighbouring units.

4.2 Quantification of Water Reuse

The total amount of water used from check dams, pumping from groundwater and creeks and total volumes of percolation for the five spatial units during the study period is presented in Table 3. The amount of percolation varies from 5.9x 10^6 m^3 (500 mm) at SDA-A to 70.1x10^6 m^3 (516 mm) at District I. The total pumping volumes, including groundwater and creeks, range from 1.8x10^6 m^3 (153 mm) at SDSA-A level to 27.1 10^6 m^3 (199 mm) at District 1, which are only 28% and 38% of the total volumes of percolation for each respective level. As the percolation volume is greater than pumping volume, it can be said that groundwater pumping is actually the reuse of percolated water for a given spatial level.

Table 3: Volume of percolation, and water reuse from groundwater, creek and check dams for different spatial units of District I

Descriptions	SDA-A	SDA-B	SDA-C	TRIS-L	District I
Rice irrigated area by pumps (ha)	204	227	954	1,674	3,059
Groundwater pumping (10^6 m^3)	1.62	1.78	8.53	14	25.93
Pumping from creek (10^6 m^3)	0.22	0.18	0.04	0.71	1.15
Total pumping (10^6 m^3)	1.84	1.96	8.57	14.7	27.07
Water reuse from check dams (10^6 m^3)	0	6.99	28.8	53.9	89.69
Percolation (10^6 m^3)	5.89	8.72	11.72	43.74	70.06

The reuse of surface water through check dams was well distributed across the area and increased linearly with 4.6x10^6 m^3 per added 1,000 ha. At the District I level, the reuse of surface water was 22% of the applied surface water and 57% of the available water. Hafeez et al. (2007) also reported that the total reuse of water through pumping increased with 1.3x10^6 m^3 per added 1,000 ha. At the District I level, the water reuse by pumping was 7% of the applied surface water and 17% of the available water. It was found that groundwater utilization to fully irrigate or supplement canal system deliveries can significantly alleviate the farmer's water scarcity problem in the area. It is also clear from Table 2 and 3 that the total amount of reused water from pumping (28x10^6 m^3) is equivalent to 30% of the water consumed by rice evapotranspiration (90x10^6 m^3) during the dry season 2001. On average, 16% of the farmers (or 1,586 farmers) use pumps to draw water from shallow tube wells, or from drains and creeks, for supplementary irrigation at District level during the dry season.

The pump density analysis at five spatial levels (Figure 2) shows that pump density increases towards the downstream areas of SDA-B and SDA-C. The light grey colour shows the pump density ranging from 0-0.02 pumps/ha, implying that these farmers do not fully depend upon pumps, while the dark black colour indicates a high pump density, ranging from 0.13-0.2 pumps/ha, which means the majority of farmers depend on pumping. Similarly, the estimated total volume pumped per ha (m^3/ha) was ranging from 0.39-6.93 m^3/ha during the dry season.

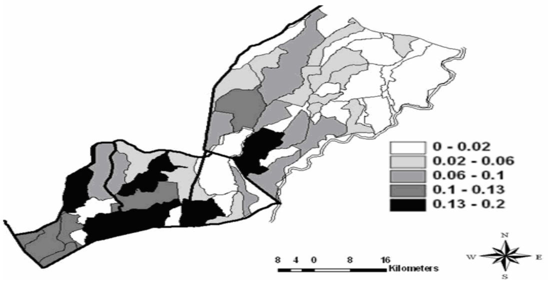

Figure 2: Pump density (pump/ha) at each FIA in District I.

4.3 Estimating Costs of Pumping

Hafeez et al. (2007) reported that the estimated pumping costs of 4-inch pump size were US\$0.009/m^3 which was more economical than the pumping costs associated with the 3-inch (US\$0.016/m^3) and 6-inch pumps (US\$0.013/m^3). Here, the pumping costs for creeks are higher (US\$0.56/hour) than for groundwater (US\$0.43/hour). This is due to high energy costs associated with limited water in creeks as compared to groundwater.

4.4 Estimating Economic Value of Water

To estimate the economic value of water reuse, regression analysis was performed between the actual crop production of rice at various levels and water reuse from different sources (Table 4).

Table 4: Regression estimates of marginal productivity of water reuse using rice production function in District 1

VARIABLE	Creek		Well		Overall	
	Coefficients	Std.Error	Coefficients	Std.Error	Coefficients	Std.Error
Regression Constant (β_o) (kg)	3279.52***	698.39	3402.62 ***	288.21	3405.98***	260.08
Marginal Physical Product (β_1) (kg/m^3)	0.21**	0.076	0.19***	0.03	0.19***	0.03
F Value		8.07***		46.85***		55.27***
R-square		0.45		0.69		0.63
Adjusted R-square		0.39		0.68		0.61
Number of observation		16		28		44

Source: survey data, 2000-2001
***, ** and * indicate the significance at 1, 5, and 10 percent probability levels, respectively

According to the results, estimated models were found significant with P<0.01, with reasonably high R^2 values. The overall marginal physical product (MPP) of water reuse was 0.19 kg/m^3. The MPP of reuse water from creeks was slightly higher at 0.21 kg/m^3 perhaps due to the amount of available water, which is in smaller amounts than available from groundwater. The MPP shows that with the extra application of one cubic meter of reused water, rice production will increase by 0.21 kg in case of creeks, and 0.19 kg in case of water from ground water.

The comparison of costs of irrigation, marginal values products (MVP) and water productivity in terms of economic return (WP (economics)) from different sources of water reuse is given in Table 5. The MVP was calculated by multiplying the MPP of reused water reuse, as obtained from regression models, with the farm gate prices of rice. Overall, the MVP of water reuse was US\$0.041/m^3. The MVP of water reuse from creeks (US\$0.044/m^3), was slightly higher than of groundwater (US\$0.039/m^3). The WP (economics) of pumping from the creeks (US\$0.044/m^3) was slightly better as compare to pumping from the well (US\$0.038/m^3). The results of WP (economics) were found consistent with MVP. The comparison of reuse water by using pumps and gravity system show that water reuse from the check dams using gravity system is economically more profitable as indicated in terms of low costs of irrigation (US\$0.0096/m^3) and higher WP (economics) (US\$0.52/m^3). This was mainly due to lower irrigation costs (18 US\$/ha) which farmers pay to NIA. There was no data available about the construction costs for the check dams in the study area. Therefore, it was not possible to get the costs of surface water reuse from the check dams. However, we think that such costs would need to be considered for the estimation of water reuse from the check dams.

Table 5: Comparison of Costs and Benefits of Water Reuse for different sources

Parameters	Pumping*			Gravity Irrigation**
	Creek	Well	Overall	Check Dams
Cost of Water Re-Use (\$/m^3)	0.0115	0.0117	0.0117	0.0096
Marginal Value of Water (\$/m^3)	0.0438	0.0388	0.0390	-
Water Productivity (Economics) of Re-use water (\$/m^3)	0.0440	0.0383	0.0406	0.052***

* Sample pumps

** Gross margin was taken from Moya et al., 2002

*** District I Level

Net benefits of water reuse from different sources (creek, groundwater, and both combined) at the five spatial levels in District 1 were also estimated. Total costs are estimated by multiplying the unit costs of each pump type with the total volume of respective pump usages, for a given spatial level. In a similar way, we estimated benefits by multiplying different marginal values of water with total volume of water usage. Finally, we estimated net benefits of pumping for different water reuses as summarized in Table 6.

Results show that the rice production system is still profitable despite high pumping costs and other associated expenses at all spatial levels in District 1. For example, the total net benefits of water reuse for growing rice ranges from approximately US$50,000 in SDA-A, to US$740,000 for the complete District 1. Not surprisingly, the 2,176 farmers using pumps to augment water supplies for growing rice District 1 do that for sound economic reasons.

Table 6: Net Benefits from different sources of water reuse at different spatial levels in District 1.

Description	Scales				
	TRIS-L	SDA-A	SDA-B	SDA-C	District I
Cost of Pumping ($)					
Groundwater pumping	163,333	18,900	20,767	99,517	302,517
Pumping from creek	8,170	2,532	2,051	468	13,221
Total pumping	171,500	21,467	22,867	99,983	315,817
Benefits of Pumping ($)					
Groundwater pumping	542,500	62,775	68,975	330,538	1,004,788
Pumping from creek	31,194	9,669	7,831	1,785	50,479
Total pumping	572,688	71,683	76,358	333,873	1,054,602
Net Benefits of Pumping ($)					
Groundwater pumping	379,167	43,875	48,208	231,021	702,271
Pumping from creek	23,024	7,136	5,780	1,318	37,258
Total pumping	401,188	50,217	53,492	233,890	738,785

4. CONCLUSION

This paper presents the situation analysis of the reuse system of return flow for irrigation in District 1 of UPRIIS, Philippines. While elaborating the situation analysis, emphasis is given to quantification of water reuse and its related economic benefits at five different spatial levels under gravity-fed irrigation systems. The pump density was established through GIS analysis which ranged from 0.02-0.2 pumps/ha; this shows that majority of farmers depend on the groundwater. Similarly, the volume of water reuse from all check dams was quantified through extensive measurements. Water and yield relations were determined by developing production functions, and economic benefits were determined by estimating the water productivity (economics) and calculating the marginal value of water. The MVP of water reuse from creek (0.044 US$/$m^3$) was slightly higher than the water reuse through the pumping ground water (0.039 US$/$m^3$).

The water reuse by pumping and check dams was 7% and 22% of the applied surface water at District 1 level. The reuse of surface water through check dams increased linearly in District 1. Similarly, the total amount of reused water from pumping is equivalent to 30% of the water lost through rice evapotranspiration during the dry season 2001. The reuse of water plays a vital role during the dry season which implies especially those farmers in downstream areas rely on reused water captured by 15 check dams and 1,154 pumps.

The cost-benefit analysis of water reuse shows that rice production systems are still profitable despite high pumping costs and other associated expenses at all spatial levels in District 1. Total net benefits of water reuse ranges from approximately US$50,000 (SDA-A) to US$740,000 (District 1). Therefore, it is concluded that small pumps owned by farmers play an important role in capturing the reused water, and serve to increase the water productivity of irrigation system as a whole. As a major rice producer of the country, the area would benefit greatly from improvement in water use efficiency.

5. REFERENCES

Bastiaanssen W.G.M. (1995), Regionalization of surface flux densities and moisture indicators in composite terrain, A remote sensing approach under clear skies in Mediterranean climates. Report 109, Agricultural Research Department, Wageningen, The Netherlands.

Barker R., Dawe D. and Inocencio A. (2003), Economics of water productivity in managing water for agriculture, *Water Productivity in Agriculture: Limits and Opportunities for Improvement*, CABI, Oxford, 19-36.

Bos M.G. and Wolters W. (1989), Project or overall irrigation efficiency. In *Irrigation theory and practice: Proceedings of Conference* held at the University of Southhampton, 12-15 September 1989. London, UK, 499-506.

Dawe D. (2005), Increasing water productivity in rice-based systems in Asia – past trends, current problems, and future prospects. *Plant Production Scie*nce 8, 221-230.

Dong B., Loeve R., Li Y.H., Chen C.D., Deng L. and Molden D. (2001), Water productivity in Zhanghe Irrigation System: Issues of scale, *Water-saving irrigation for rice: Proceedings of an International Workshop* held in Wuhan, China, 23-25 March 2001, IWMI, Sri Lanka, 97-115.

Guerra L.C., Bhuiyan S.I., Tuong T.P. and Barker R. (1998), *Producing more rice with less water from irrigated systems, SWIM Paper 5* IWMI-IRRI, Colombo, Sri Lanka.

Hafeez M.M. (2003), Water accounting and productivity at different scales in a rice irrigation system: a remote sensing approach. *Ecology and Development Series*, No. 8, 2003, University of Bonn, 155.

Hafeez M.M., Bouman B.A.M., Van De Giesen N., Mushtaq S., Vlek P. and Khan S. (2007), Water re-use and cost-benefit of pumping at different spatial levels in a rice irrigation system in UPRIIS, Philippines, Journal *of Physics and Chemistry of the Earth*.

Keller A., Keller J., and Seckler D. (1996), *Integrated water resources systems: Theory and policy implications. Research Report 3*, IWMI Colombo, Sri Lanka.

Loeve R., Dong B., and Molden D. (2002), Field level water savings in Zhanghe irrigation system and impact on system level, In *Water-Wise Rice Production*, IRRI, 300-315.

Moya P., Dawe D. and Valencia S. (2002), The effects of pumping on water use and profitability in dry-season rice: a case study in UPRIIS, Philippines, In *Water-Wise Rice Production*, IRRI, Los Baños, 333-346.

Molden D. (1997), *Accounting for water use and productivity, SWIM Paper 1*, IWMI, Colombo, Sri Lanka.

Seckler D. (1996), *The new era of water resources management: From "dry" to "wet" water savings, Research Report 1*, IWMI, Colombo, Sri Lanka.

Zulu G., Toyota M., and Misawa S. (1996), Characteristics of water reuse and its effects on paddy irrigation system water balance and the rice land ecosystem, *Agricultural Water Management* 31, 269-283.