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ASSESSMENT OF THE ENGINEERING ASPECTS OF THE IFUGAO RICE TERRACES

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ABSTRACT

The Ifugao Rice Terraces was included among the living cultural landscapes in the UNESCO World Heritage List in 1995. However, in 2001, it was reclassified under the World Heritage In Danger List. Climate change has started to impinge on the 2,000-year-old landscape, causing reduced water availability and increased occurrences of water shocks. This study assessed various water resources engineering aspects of the IRT in an effort to ensure its resilience.

A water balance model was developed to characterize water use at the paddy level. The model can estimate irrigation requirement, or the quantity of water that must be supplied to satisfy the consumptive use of crops. It can also determine the miscellaneous water requirements not provided by precipitation and water stored in the soil. The model can calculate IR for different stages of crop growth in dry, normal, and wet years. Simulations showed that irrigation requirement was highest from March to April and lowest from August to September. Excess in precipitation may occur during wet years or extreme rainfall events. This emphasizes the importance of proper control of drainage canals and spillways to minimize runoff in the dry season and prevent oversupply in the wet season.

1. RATIONALE AND SIGNIFICANCE

Warming of the climate system is unequivocal. This is evident from observations of increased global average of air and ocean temperatures, widespread melting of snow and ice, and the rising global sea level average (IPCC 2007). Climate change in the Philippines has also triggered a rise in temperature. It increased the uncertainty, variability, and patterns of rainfall and super typhoon events as well (DA 2011). Among the most highly vulnerable are fragile ecosystems such as the Ifugao Rice Terraces.

This study is part of the project entitled, “Ecosystem-based Adaptation Strategies for Enhancing Resilience of Rice Terrace Farming Systems to Climate Change.” It was organized by the Southwest Forestry University (SWFU) and the United Nations University Institute for Sustainability and Peace (UNU-ISP), with the support of the Asia-Pacific Network for Global Change Research (APN). The project aims to develop ecosystem-based adaptation strategies and provide a generic method to strengthen climate change resilience of traditional terrace farming systems in the Hani Rice Terraces of China and the Ifugao Rice Terraces of the Philippines. At the same time, it aims to demonstrate stable yield by improving water management and maintaining the current water cycle under future climate change conditions (UNU-ISP/ SWFU 2011).

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Prior to the development of these adaptation strategies, the study defined the baseline conditions in the area. It is the researchers' desire that the results enable further and more in-depth studies on evaluating and strengthening the resilience of the Ifugao Rice Terraces to climate change.

2. OBJECTIVES

The general objective of this study is to characterize and evaluate the various water resources engineering aspects of the Ifugao Rice Terraces. It specifically aims to assess the hydrologic properties of the IRT, and develop a water balance model to characterize the water usage of the rice terraces at the paddy level. The model will then be used to calculate the irrigation requirement of a single paddy.

3. PROBLEM STATEMENT AND DESCRIPTION

Water balance studies in paddy field levels have been carried out for years. These include experimental studies (e.g. Watanabe 1992, Chen and Liu 2002), numerical modeling (e.g. Walker and Rushton 1984), and empirical and semi-empirical modeling (e.g. Tsubo et al. 2007, Wopereis et al. 1994). The studies often focus on quantifying water availability and the corresponding growth and yield response of rice. The results are then used to identify best management practices and water-saving technologies for increased irrigation efficiency.

Furthermore, a water balance can be considered a model of the complete hydrologic process being studied. It can be used to predict the effects of changes on the components of the system or subsystem (ILRI 1983). It is, thus, a useful tool for assessing the impacts of climate change on a certain system or area. This is so because climate warming observed over the past decades has been consistently linked with changes in a number of components of the hydrological cycle and hydrological systems. Such components include changing precipitation patterns, intensity and extremes; widespread melting of snow and ice; increasing atmospheric water vapor; increasing evaporation; and changes in soil moisture and runoff (Bates et al. 2008).

For a single paddy, the water balance equation may be represented as (Fig.1)

$$I + P = ET + RO + DP \pm \Delta SF \tag{1}$$

where I is the irrigation water supplied, P is precipitation or rainfall, ET is crop evapotranspiration, RO is surface runoff, DP is deep percolation to the water table, ΔSF is horizontal subsurface flow into or out of the root zone (i.e. $\Delta SF = SF_{in} - SF_{out}$). Capillary rise was neglected considering the plow layer to be at a higher moisture potential than the capillary fringe at lower depths. Equation (1) was developed for steady-state conditions, such that changes in soil-water content are negligible compared with the changes in the other fluxes, considering long term average conditions. To characterize water use at the paddy and to estimate the irrigation requirement using Equation (1), the other terms of the water balance must be correctly quantified.

4. METHODOLOGY

To correctly quantify the different components of the water balance, meteorological and soil data were gathered.

Precipitation records from the PAGASA station in Halong (16°52'27.120" N, 121°2'60.000" E, 1101 masl) were subjected to cumulative frequency analysis to determine dependable rainfall values for wet (20% probability of exceedance), normal (50% POE) and dry (80% POE) years. Effective rainfall, the portion of precipitation which actually contributes to the water balance of the paddy, was then computed from these values using four widely used methods. Included are the FAO/AGLW Method, the USBR Method, the USDA SCS Method, and the Fixed Percentage Method, defined here as 80% for rainfall < 100mm, 60% for > 200 mm, and 70% otherwise.

Evapotranspiration (ET) was computed using the crop coefficient approach, with the reference crop evapotranspiration as given by the FAO Penman-Monteith equation. Meteorological data from the Baguio City PAGASA station (16°25'00" N, 120°36'00" E, 1500 masl) were used. Crop coefficients were determined based on the methodology by Allen et al (1998). Calculations were done for the *tinawon* rice variety and farming practices based on the agricultural calendar presented by Conklin (1980), reflecting traditional planting, harvesting, and fallow periods.

A 2D steady-state finite element model was used to solve the highly nonlinear governing equations of subsurface flow to account for seepage and percolation. Due to the absence of field data, soil type was obtained from a provincial soil map from BSWM. Hydraulic parameters, on the other hand, were based on van Genuchten approximations with values published in the literature.

Runoff was treated as a broad crested weir problem, assuming that the velocity of the water upstream of the spillway was negligible.

The calculated values were then plugged into a simple spreadsheet to determine the irrigation requirement for different scenarios (wet, normal, or dry year), different stages of crop growth, and various model geometries.

5. RESULTS AND RECOMMENDATION

Figures (2) to (7) and Table (1) show the results of the methods discussed earlier. Figure (2) shows the comparison of the four methods of computing effective rain. The fixed percentage method gave values which approached the average of those given by the four methods. Hence, values from this method were chosen for the water balance analysis. The total monthly values of effective rainfall are shown in Figure (3). Precipitation is generally highest in September.

Figure (4) shows that ET is greatest in April, corresponding to the height of the crop’s growth cycle. Figure (5), on the other hand, shows the basis for the subsurface flow domain. It was conceptualized with the idealization shown in Figure 6, where L represents the paddy surface, WH is the wall height, α is the slope of the mountain, and β is the slope of the wall. The model is composed of six distinct regions corresponding to the layers of Figure (5).

The results of the simulation reveal that there is a complex interrelationship between subsurface losses and geometry of the flow domain, as reflected in Table 1. Flow is observed to be predominantly downward, with most of the outflow occurring through the toe of the terrace. This is due to the free flow of water from regions of high hydraulic potential energy to regions of low energy. Lastly, Figure (7) shows the results of computations for runoff carried out for various spillway widths and paddy surface areas. As expected from the broad crested weir formulation, runoff is a linear function of the width of the spillway sill.

Results of a trial run for computing irrigation requirement are shown in Figures (8) and (9). The highest irrigation requirement occurs from March to April, while the lowest from August to September. Figure (10) shows results of a run where runoff is set to zero. This reveals that irrigation requirement is negative from August to October for a wet year. This indicates excess of precipitation rather than deficit. The excess rainfall may cause unwanted over-saturation of the paddy and lead to slope failure. This reflects the importance of proper control of the drainage canals and spillways to minimize runoff during the dry season and to prevent oversupply during the wet season or in extreme rainfall events.

Proper management of the local water resources should be practiced to ensure sustainability and resilience for the Ifugao Rice Terraces. One way to achieve this is through adequate supply of irrigation water to the terraced paddies. The model developed in this study can hopefully help attain this goal.

Figures

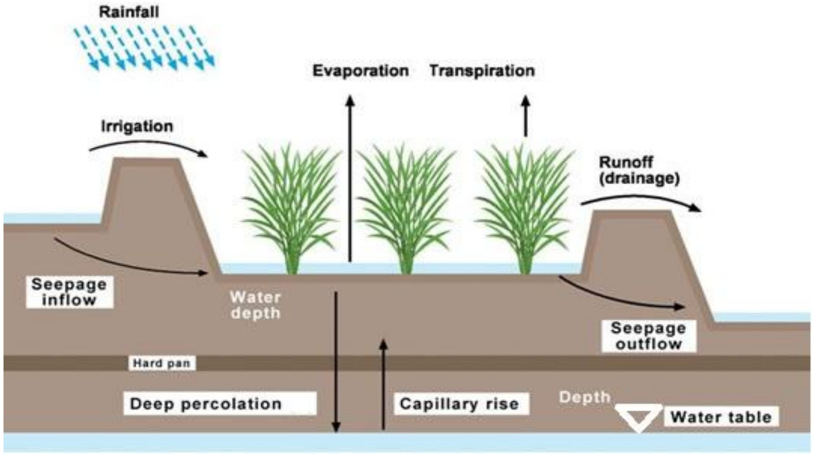

Figure 1. Components of the Water Balance

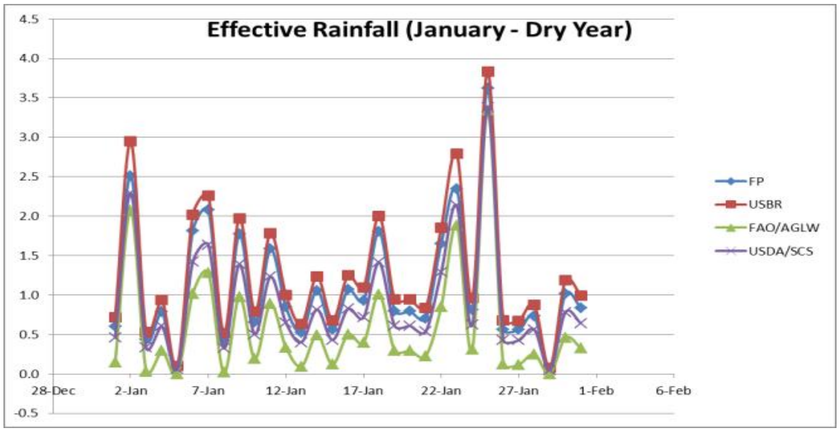

Figure 2. Comparison of the 4 methods for effective rainfall (January - Dry Year)

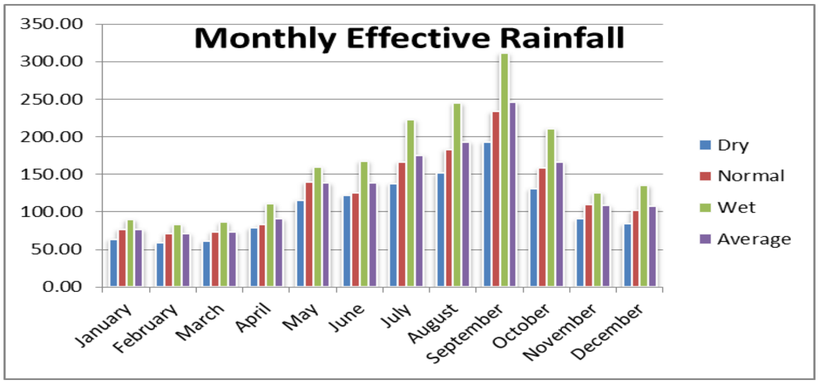

Figure 3. Total monthly effective rainfall (mm/month)

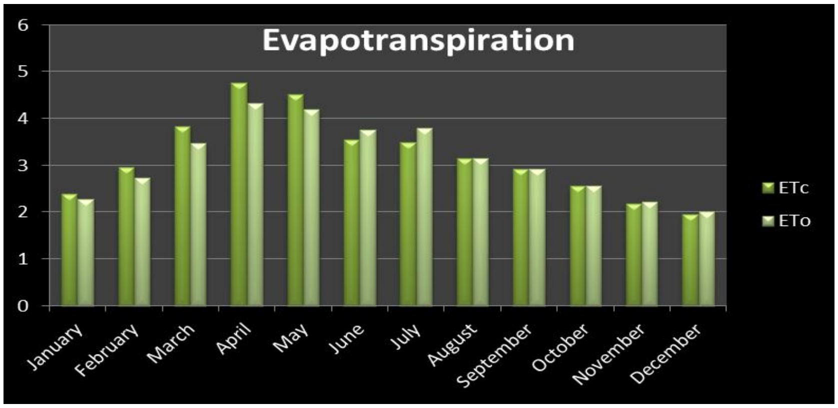

Figure 4. Average monthly evapotranspiration (mm/day)

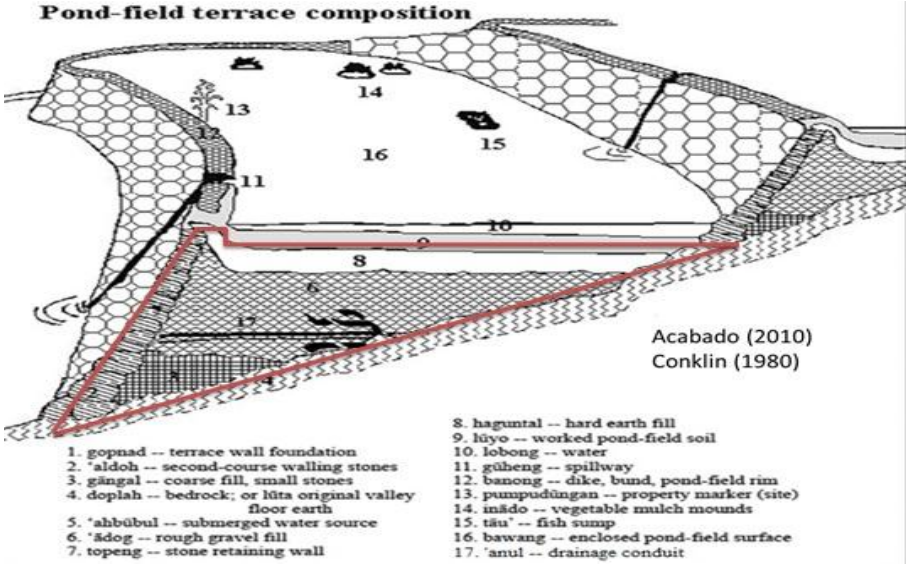

Figure 5. Cross Section of an Ifugao Pond Field. (Modified from Conklin 1980 & Acabado 2010)

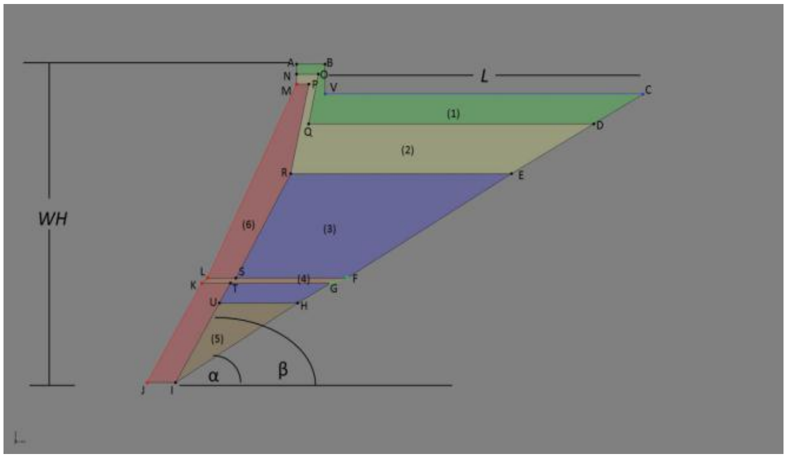

Figure 6. Model domain used for simulation of seepage and percolation losses.

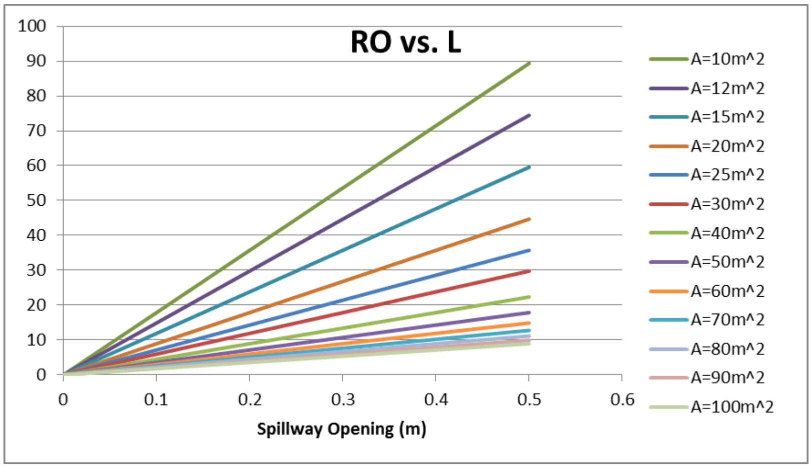

Figure 7. Surface Runoff (mm/day) vs. Spillway Opening

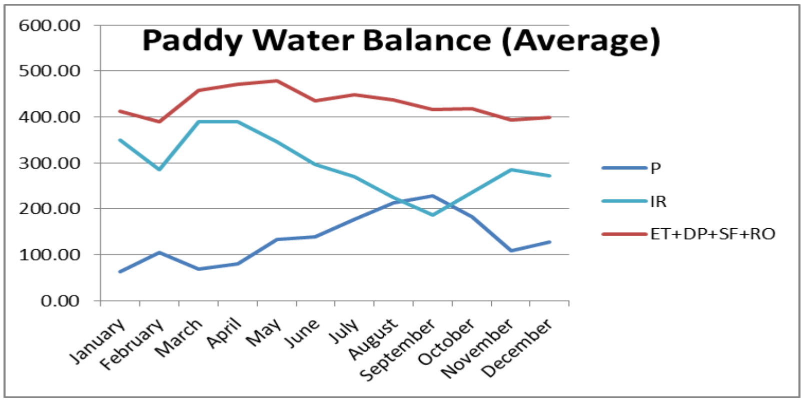

Figure 8. Average monthly water balance results

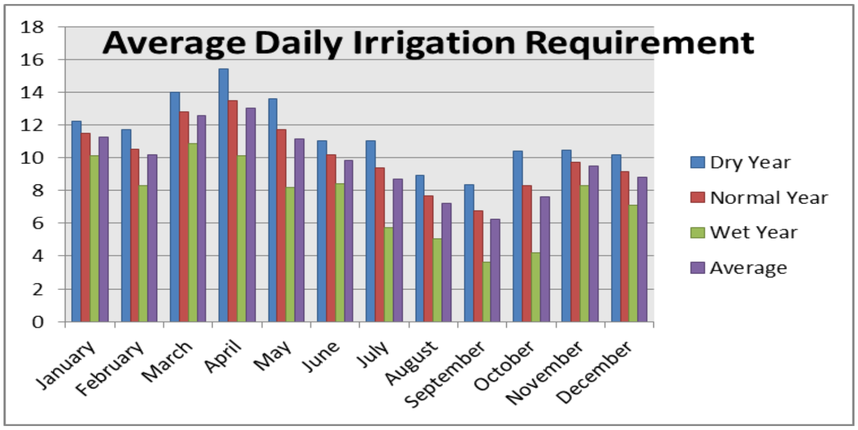

Figure 9. Average Daily Irrigation Requirement

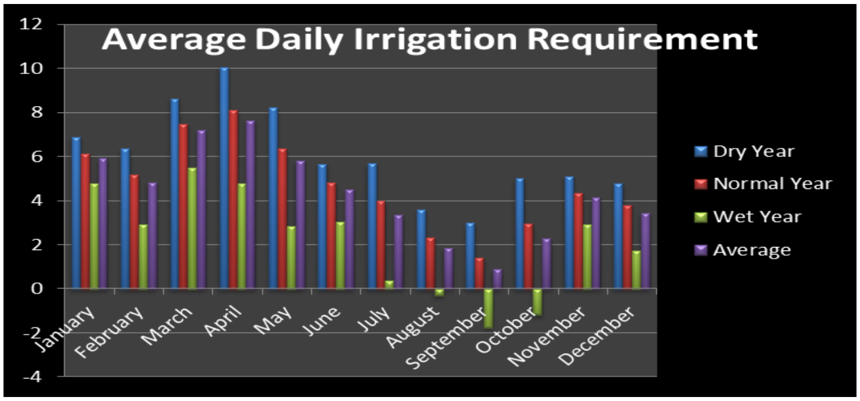

Figure 10. Average Daily Irrigation Requirement (mm/day) (RO=0)

Tables

Table 1. Summary of finite element analysis results for seepage and percolation

	α=30°						α=32.37°	
	β=90°		β=60°		β=60°		β=60°	
internal source q (cm^3/d)	0	0.0005	0	0.0005	0	0.0005	0	0.0005
WH (cm)	300	300	300	300	435	435	500	500
L (cm)	500	500	335	335	500	500	500	500
S + P (mm)	5.58	6.26	4.55	6.36	4.76	6.08	4.93	5.78
	α=45°						α=18°	
	β=90°		β=60°		β=60°		β=90°	
internal source q (cm^3/d)	0	0.0005	0	0.0005	0	0.0005	0	0.0005
WH (cm)	500	500	500	500	1185	1185	200	200
L (cm)	500	500	210	210	500	500	615	615
S + P (mm)	5.59	7.08	5.45	6.97	3.84	32.55	4.35	5.11

Photos

Photo 1. The Banaue Rice Terraces

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