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Developing and Applying Climate Information for Supporting Adaptation in South East Asia

Philippine Case Study: Application of Climate Change Data to Estimate Irrigation Design Water Duty

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CONTEXT

The Asian Development Bank (ADB) has observed that use of climate services to support climate adaptation in Asia and the Pacific is constrained by limited availability of reliable climate information, insufficient capacity to interpret and use climate information, and limited technical and financial resources.

To address these challenges, the ADB supported a technical assistance (TA) project, TA-8359 REG: Regional Climate Projections Consortium and Data Facility for Asia and the Pacific. This project aims to, among others, provide users with advice on what climate information is available, where, and how to use it in support of adaptation decision-making.

About this Case Study

Purpose

The guideline developed in this TA outlines a 10-step approach to using climate data to develop climate information. The guideline is available on the RCCAP portal at www.rccap.org.

This case study complements the guideline by illustrating how climate change information can be developed and used in an impact and vulnerability assessment. It also shows how to transform the assessment results into knowledge products that are more digestible to the next- and/or end- users (e.g. planners, managers, policy makers, etc.).

Background

This case study was identified and planned at the TA project inception workshop in Chiang Mai (Thailand) in May 2015 and the first regional workshop attended by various stakeholders in Bali (Indonesia) in July 2015.

At the inception workshop, it was decided that case studies should be real cases if possible, and simple enough to complete within available resources, and be demonstrated through a one-week workshop.

Subsequently, a series of discussions with ADB were held, and the topic for the Philippine case study was finally decided and planned in April 2016.

Case study team

The team is comprised of TA-8359 Philippine specialists Rosa Perez (IAV Specialist), Gemma Narisma (Climate Change Specialist), and Lourdes Caballero (Knowledge Management Specialist); Thelma Cinco and Rosalina de Guzman of Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA); and hydrologist Rolando Maloles.

About this Document

Audience

This document is targeted at professionals who have some background knowledge of climate adaptation. Examples include researchers, university lecturers and students, consultants, sectoral planners, engineers, economists and personnel of meteorological and climatological departments whose mandates may include provision of climate information services.

Structure

This document has four main sections. This first section provides context for the case study and this report. The second presents the development of climate change information within this context, and is structured in line with the 10 steps outlined in the guideline. The third section describes how a detailed impact assessment is conducted, using the information developed in the second section. The final section provides a summary of the results and the production of a knowledge product based upon results of this case study that can be used by decision makers. References used are included in the reference list. Additional information on various technical calculations can also be found in separate training materials available at www.rccap.org.

CLIMATE CHANGE INFORMATION DEVELOPMENT

1 Define the Climate Change Information Requirements of the Assessment

Identifying the objective and scoping out the case study approach and requirements clarifies the information and resources required, and provides an operational framework to guide decisions along the way.

1.1 Assessment objectives

This case study uses climate information (both historical and projections) to estimatet the irrigation design water duty. The case is a continuation of previous work at the National Irrigation Administration.

1.2 Assessment scope

The domain of the study is for a proposed irrigation project located near Cabanatuan City, in the province of Nueva Ecija (see map, Figure 1). This location was chosen as it is in Central Luzon which is the main rice granary of the Philippines.

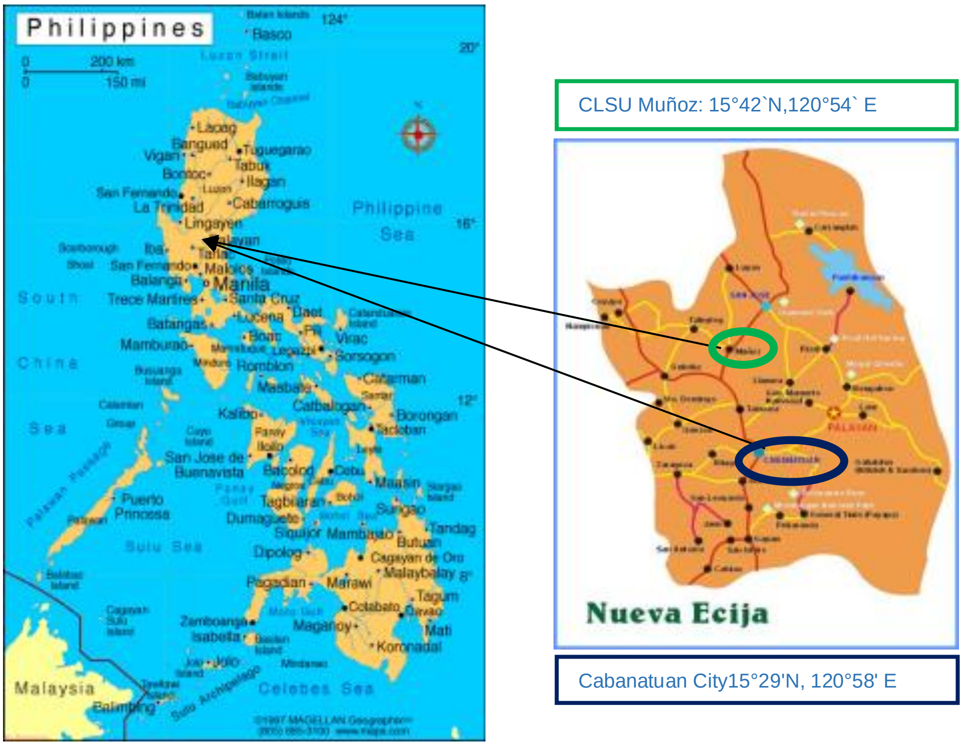

Figure 1. Maps of the Philippines and the case study sites

The assessment uses baseline (1971–2000) and future (2036–2065) climate data. The periods were chosen to be consistent with the PAGASA's previous report and due to the availability of climate simulation data. The design lifespan for irrigation infrastructure is on the order of 50 years, so the time period selected for future projections is 2036–2065 (30-year period centered around 2050).

The main climate variable needed in this case study is the rainfall data at a station, not a grid used in climate models. The crop model used in the impact assessment uses 10-day rainfall amounts. Temperature data is optional (Table 1).

Table 1. Main climate variables used in the case study

Daily rainfall data	Mean monthly temperature (optional)
• Observations – 1971 to 2000 • Projections – 2036 to 2065	• Observations – 1971 to 2000 • Projections – 2036 to 2065

While other factors, such as evapotranspiration, may also change into the future, this initial assessment only considers rainfall scenarios and focusses on the dry season. Future studies should evaluate potential impacts of changes in evapotranspiration.

1.3 Assessment context

1.3.1 Agriculture, water management and climate change

The agriculture sector is particularly sensitive to the potential impacts of climate change. One reason is that this sector has the largest consumptive water user. Reliable water supply is required to ensure that crops – whether staple or cash crops – will be sufficiently productive to ensure food security. In many parts of the world, irrigation is necessary to successfully grow crops used for food and other human and animal benefits.

In the Philippines, government efforts to adapt to climate change and to achieve rice self-sufficiency necessitate that policies and programs on agricultural water management address these needs (Labiano, 2012). Agricultural water management includes aspects of improving flood control, drainage, dam operations, planning database, capacity building, irrigation performance and related technologies. Increasingly, monitoring of hydrologic variables is a key element as well. Thus, irrigation infrastructure is required to be robust to meet these objectives.

Through the National Irrigation Administration (NIA), the target is to improve operational capability in designing or retrofitting irrigation systems, with the related aim to enhance water distribution mechanisms to reduce the effects of seasonal climate change and variability on water supply. The actions are two-fold: one is through physical intervention (e.g. expansion of irrigation area) and the other is through operational intervention (e.g. improved irrigation performance). The Philippine case study zeros in on this latter concern.

1.3.2. Irrigation projects and the use of climate information

To inform the design of irrigation projects resilient to potential climate change, two types of analysis are required: water resources study, and flood and drainage study (Maloles, 2013).

Water resources study

There are pathways on which water requirements for various purposes can be computed and used in the agriculture sector, providing the information needed to arrive at various decisions relating to water usage (Figure 2). For the purpose of demonstration and hands-on training, this document covers pathway 1 in Figure 2: the computation of design water duty. The design water duty refers to the irrigating capacity of a unit of water, reflecting the cropped area requiring irrigation and the quantity of irrigation water required during crop growth, as determined by the type of crop and agronomic characteristics (e.g. planting date, duration).

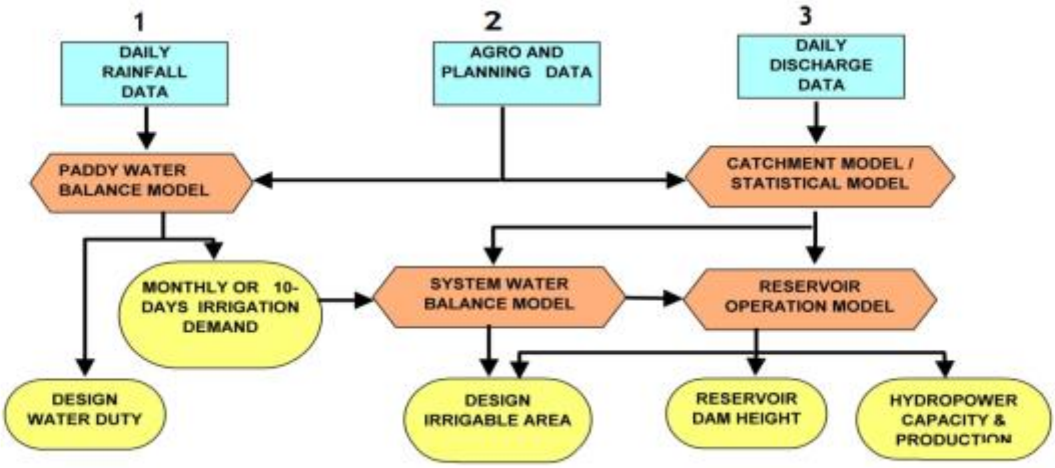

Figure 2. Process flowchart for the water resources study of an irrigation project

The principle of water duty is often applied in areas with a structural water scarcity, whereby the duty per hectare per season is only a fraction of the full irrigation need. Thus, farmers can either provide full irrigation to only part of their land or irrigate all of their crops but with a limited amount of water. Farmers may choose between crops with a high consumptive use (e.g. rice, sugarcane, most orchards) or a low consumptive use (e.g. cereals such as barley, millet, and sorghum).

Flood and drainage study

An overview of the process flow for the flood and drainage study, with the inputs needed, method of analysis and the expected output, is shown in Figure 3.

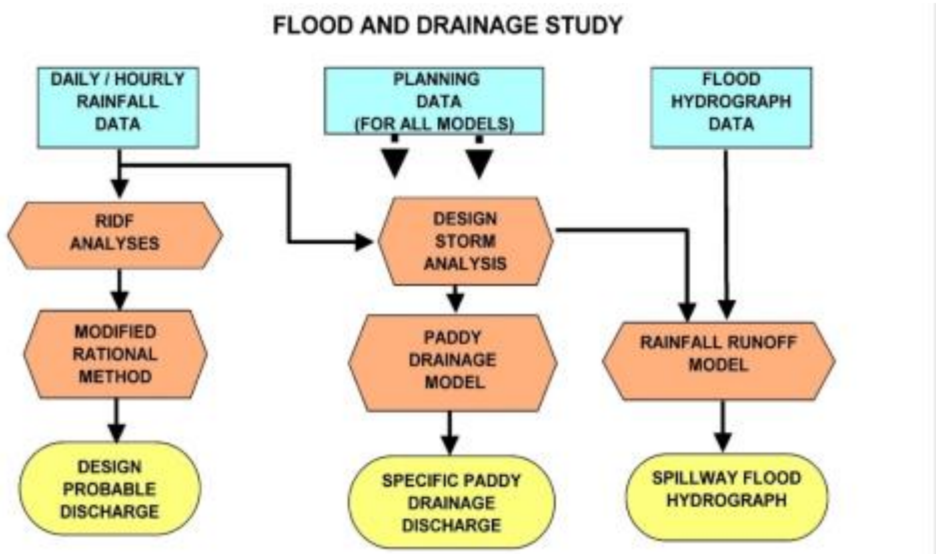

Figure 3. Process flowchart for the flood and drainage study for irrigation project

For both studies, hourly or daily rainfall data are the most important climatic parameter inputs. The design water duty uses a paddy water balance model, while the flood and drainage study uses the rainfall data to analyze the rainfall intensity-duration-frequency (RIDF) relationship.

Due to time and resources constraint, only the design of water duty was demonstrated for this case study.

2 Collect and Assess Observed Climate Data

Since the analysis will represent a sample paddy field, it is sufficient to adopt one location for the rainfall data to be used.

The closest observational station data to the study area is Cabanatuan City. This station has several years of missing data, so data from the nearby Central Luzon State University (CLSU) agro-meteorological station was used to fill in the data. However, this station only started in 1974. Alternative datasets, such as APHRODITE, could also be used. However, these gridded datasets are created using provided station data and are interpolated to a grid.

In order to make a continuous time series dataset, we filled in the missing data in Cabanatuan with data from CLSU Munoz. Any residual missing values were filled using APHRODITE extracted at (120.95 °E, 15.483 °N). The small number of days filled will not make significant impact on the results. The filling in of missing days was needed to complete the bias correction completed later.

This process of combining data from several stations needs to be completed with care. The stations must be located in similar topographic and geographic areas and climate zones. The CLSU station is located nearby, and in the same valley as, Cabanatuan City and has similar geography.

3 Select Representative Concentration Pathways

For this case study, both available forcing scenarios were chosen: RCP4.5 and RCP8.5. These scenarios will cover the range of likely greenhouse gas forcings and associated concentrations by mid-century, though the divergence of the scenarios by this time is relatively small.

4 Find Relevant Climate Model Data

All available and relevant global climate model (GCM) data at CSIRO (sourced from CMIP5 website) was used to extract data for the site location. In addition, downscaled climate data (approximately 25 km over the site location) was also extracted at CSIRO (data is available on the RCCAP portal at www.rccap.org).

5 Evaluate Climate Model Data

The initial evaluation was completed by comparing the annual rainfall and surface air temperature from the models with the observational data (see Figure 4). Similar plots for maximum and minimum air temperature are shown in Figure 5 and Figure 6.

Many models are within +/- 1 °C of the observations. Almost all models show a negative bias (too cold) relative to the observations (Only ACCESS1-3 is slightly warmer). The range of differences for simulated rainfall is wider, from less than 3 mm/day to more than 8 mm/day, as compared with the observations of around 5.3 mm/day.

Due to the relatively small size of the Philippine land mass, many GCMs do not have a land point near the station location. A range of options are available for selecting relevant climate information from the GCMs, ranging from nearest model grid point, nearest land point or interpolation of surrounding grid points. Due to the relative coarse resolution of the GCMs and the need in this case to have a value for a specific location, as opposed to a region, the nearest grid point was selected. Ideally, picking the nearest land point, or interpolation of surrounding grid values, would be preferable. However, since most of the GCMs did not have land point nearby, and interpolation may combine land and ocean values inappropriately, only the nearest grid point was used. This choice also makes the selection consistent across all the

GCMs. For those GCMs where the nearest grid point value was an ocean point, this might be part of the cause for the cool bias (air over oceans do not heat up as much as over land, while the minimum temperatures for small land masses being close to the ocean temperatures, leading to a cool bias averaged over the day). This is supported by comparing the observations with maximum and minimum temperatures (Figure 5 and Figure 6). The maximum temperatures have a much larger cool bias, while the minimum temperatures show a warm bias.

Outputs from six GCMs that were dynamically downscaled using CCAM had horizontal resolution of about 25 km, so could resolve the land much more realistically (for more information about these runs, see Katzfey et al. (2016)). The six regional climate model (RCM) results (dots) show very tight clustering for air temperature. This is the result of the bias correction used in these simulations which corrected the mean monthly ocean temperatures for the historical period to match the observed climatological ocean temperatures. With similar climatological ocean temperatures and using the same atmospheric model, the resulting rainfall amounts are also similar (though not as similar as temperatures).

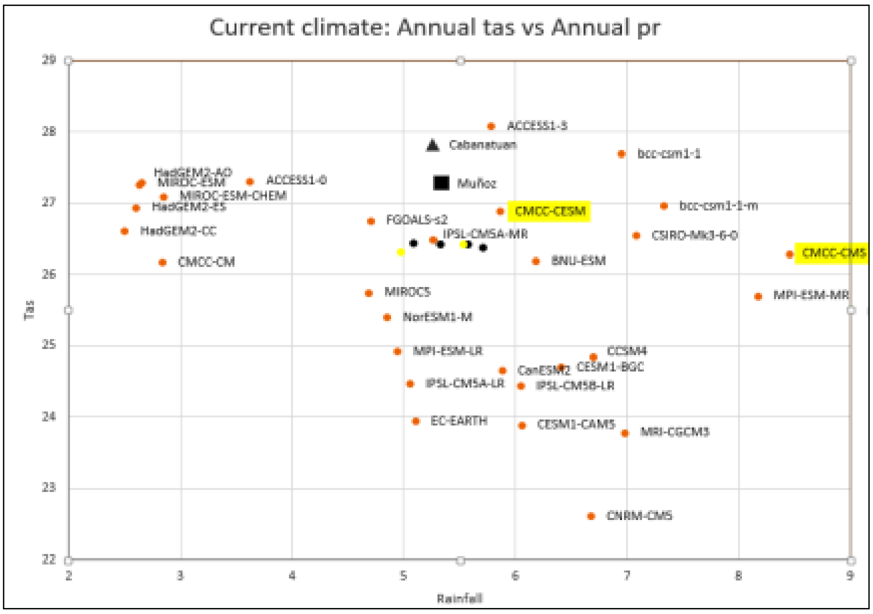

Figure 4. Plot of mean annual temperature (°C) and rainfall (mm/day) for the baseline period for global climate models (orange markers), regional climate model output (black and yellow dots) and observational data (black square and triangle). The models selected for the case study are indicated in yellow highlight for GCMs and yellow dot for RCMs.

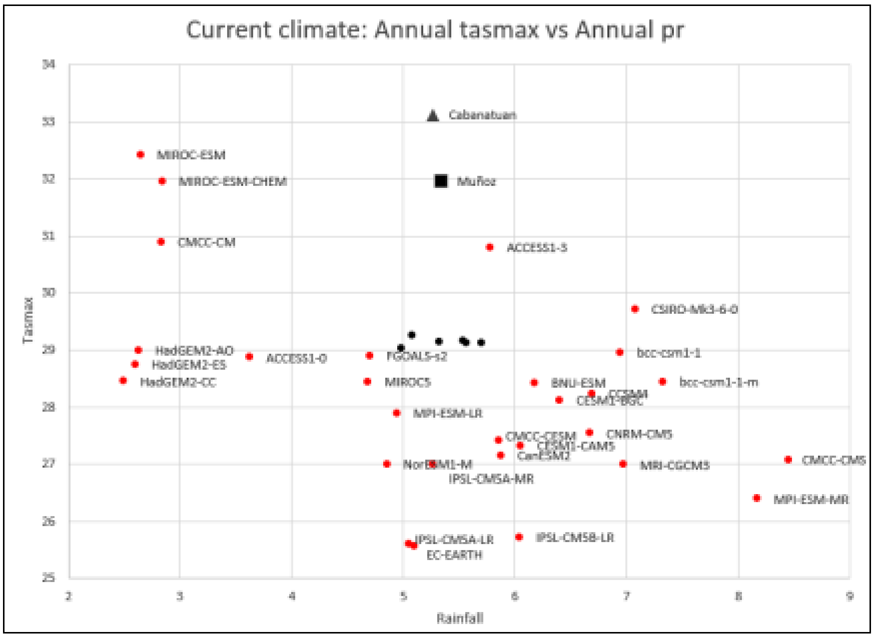

Figure 5. Plot of mean annual maximum temperature (°C) and rainfall (mm/day) for the baseline period for global climate models (red markers), regional climate model output (black dots) and observational data (black square and triangle).

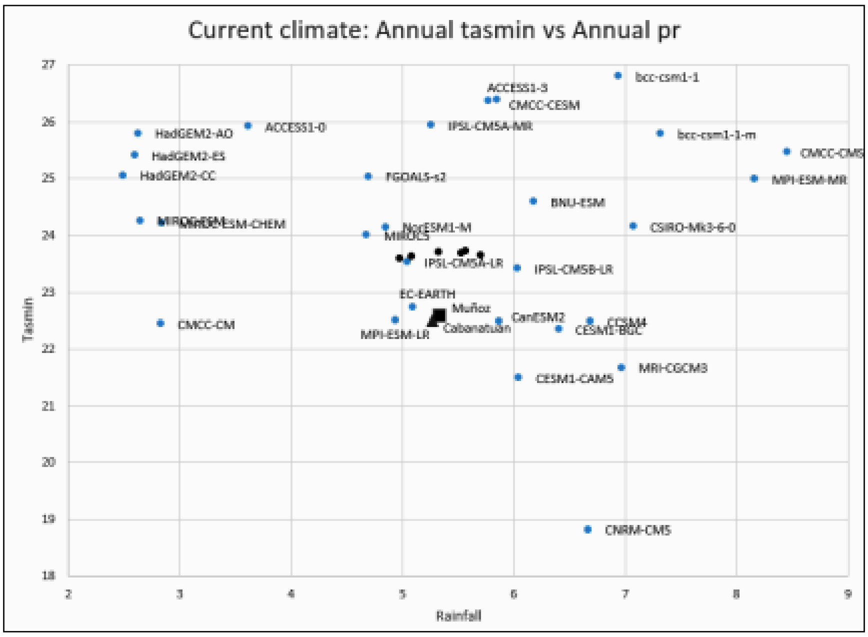

Figure 6. Plot of mean annual minimum temperature (°C) and rainfall (mm/day) for the baseline period for global climate models (blue markers), regional climate model output (black dots) and observational data (black square and triangle).

6 Select Model

While ideally all models could be used to assess the impact of climate change, it typically is not feasible and not necessary to use all models. We chose four models to capture the range of the projected futures. The rationale used is to pick a model with potentially the driest (here assumed largest decrease in rainfall) and wettest (largest increase in rainfall) case scenarios and the model which is closest to the majority of the projections in terms of rainfall changes. There is also a preference for higher resolution regional climate simulations as these should more realistically capture the regional climate and capture some of the potentially local affects (such as mountains) on the climate.

As highlighted in Figure 7, the models chosen are: CC10-CCSM which is the RCM showing the largest drying at this location, CC10-MPI-ESM-LR, which is in the middle of the projections as is representative of the most consensus and GCM results from CMCC-CESM and CMCC-CM5. The CMCC-CM5 results indicated the greatest increase in rainfall, but this model did not have results for the RCP4.5, so the results for CMCC-ESM were also selected.

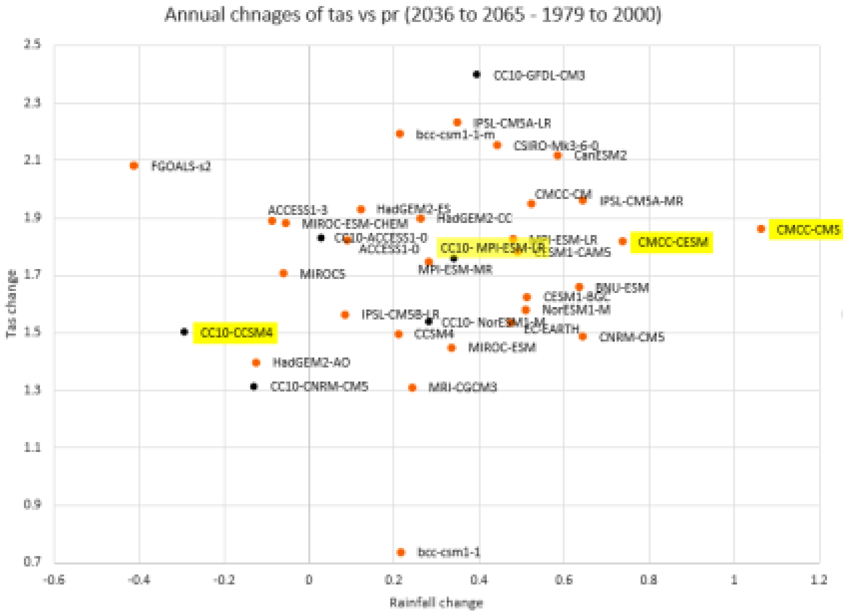

Figure 7. Plot of changes in annual rainfall (mm/day) and annual surface air temperature (°C) for the period 2036–2065 minus the period 1971–2000 for global climate models (orange markers), regional climate model output (black dots). The models selected for the case study are indicated in yellow highlight.

7 Construct Projections

Daily data at nearest grid point to station was selected from each model (GCM and RCM). Ten-day accumulation amounts for rainfall were then calculated, starting at the beginning of each year. The 1-in-5-year amounts were computed for each period: historical (1980–2000) and future (2035–2065).

8 Analyze Projections

While there was some spread in the changes of annual mean surface air temperature (see Figure 4), changes in rainfall will have the most significant impact on the results for the hydrological application of this case study. So, the spread of models chosen focused only on these changes. Note that the spread of temperature changes is relatively small (ranging from warming of 1.3 to 2.4 °C).

Changes in the annual cycle of rainfall could also be important, especially for the computation of the irrigation water requirement, since it is dependent on the cropping calendar. If the projected data indicates a shift in the start of the wet season, this will affect the preparation of the cropping calendar. It is noted that there is yet no indication that there will be a significant shift in the seasons in the climate projections (not shown).

Some assessment of the confidence and uncertainty of the projections used is necessary. This can be based partly on the evaluation (Step 5), number of models with similar projections (Step 7), but also considering other lines of evidence.

One line of evidence to build confidence in the projected changes is the number of models projecting similar values. As can be seen in Figure 4, most models project annual increases in rainfall of around 0.5 mm/day. This could be considered the more likely change scenario. However, from a risk perspective, the models which project large increases or some decreases, could present significant risk. While less likely (as indicated by the number of models indicating these changes) they are possible futures to be considered, though possibly with less confidence.

Based upon the ability of the models to simulate the current climate indicated in Step 5 can provide some confidence in the projections. As indicated, the RCM results were relatively close to the observed values. However, to capture the more extreme projected rainfall increases, one to two GCMs were selected which do have biases for the current climate. In the next step, the biases in rainfall are corrected, based upon their biases for the current climate, to help reduce the impact of these biases and thereby possibly reduce some of the uncertainty related to these biases.

9 Correct Possible Biases

Due to the errors noted in the evaluation for the current climate (Step 5), it was decided to test the impact of bias correction on the results. In this case, we chose the bias correction method using monthly quantile scaling.

There are six steps in the quantile scaling method (CSIRO and Bureau of Meteorology, 2015) for bias correction:

1. Rank the RCM data and define quantiles
2. Calculate RCM quantile-mean values for each month
3. Calculate observed quantile-mean values for each month
4. Calculate monthly correction ratios for each quantile
5. Modify RCM daily historical and future rainfall data
6. Correct any bias in monthly-mean rainfall change.

1 Rank the RCM data and define quantiles

For each month, daily rainfall is ranked in ascending order. This is done for 30-year periods centered 1985 (1971–2000, historical period), 2050 (2036–2065, future period), for two climate scenarios (RCP 4.5 and RCP8.5). Note that in rest of this section, we will use 1985 to denote 30-year period 1971–2000 and 2050 to denote period 2036–2065.

The sorted data are grouped into quantiles.

a) Ten deciles are defined. Decile 10 contains the highest 10% of values, decile 9 has the second-highest 10% of values, and so on, and decile 1 contains the lowest 10% of values. For example, 30-year January daily rainfall has 930 days, therefore each decile has 93 days.
b) To provide more detailed information about changes in extreme rainfall, decile 10 is split into 10 percentiles called 90, 91, 92, …, 98 and 99. For example, in January, the percentiles 90 to 99 each have about 9 days.

2 Calculate RCM quantile-mean values for each month

Calculate monthly-mean values for each decile and upper percentile (quantiles) for 1985 and 2050, for RCP 4.5 and RCP8.5.

3 Calculate observed quantile-mean values for each month

a) The time series for observed data is a combined time series from two sites: Cabanatuan (1971–1973) and Munoz (1974–2000). Any residual missing values were filled using APHRODITE data extracted at (120.95ºE, 15.483ºN).
b) Repeat steps 1 and 2 above for observed data obtained in (a).

4 Calculate monthly correction ratios for each quantile

For a given month, change ratios are calculated for each quantile.

The ratio $D_i = (X_i' - X_i)/X_i$, where *i* is the quantile number (deciles 1–9 and percentiles 90–99), X_i are monthly-mean values for the period centered on 1985, and X_i' are observed mean monthly values. For example, if the July mean value of X_8 is 5.7 mm and X_8' is 14.5 mm, then the ratio D_8 is 1.54. A site-specific example for the CCSM4 RCM is given in Table 2.

5 Modify RCM daily historical and future rainfall data.

The same procedure as used with the observed data is applied to the climate model data:

a) Using 30 years of RCM historical daily rainfall (1971–2000), sort the data into 10 deciles. For example, 30-year January daily rainfall has 930 days, therefore each decile has 93 days.
b) Split decile 10 into 10 percentiles, for example, in January, the percentiles 90 to 99 each have about 9 days.
c) Modify the RCM daily rainfall to get modified modelled data (RCMO) using the following formula:

$$RCMO_{(historical)} = RCM_{(historical)} + d_i{*}D_i$$

$$RCMO_{(future)} = RCM_{(future)} + d_i{*}D_i$$

[Note: The observed values are considered the 'truth', while the model values are to be corrected]

Where d_i is the RCM quantile mean and $*D_i$ is defined as $(X_i' - X_i)/X_i$,

The results for monthly historical rainfall quantile mean matches well with observed historical rainfall quantile mean (Figure 9).

6 Correct any bias in monthly-mean rainfall change

Step 5 modifies the shape of the RCM rainfall frequency distribution in a way that is broadly consistent with changes simulated by RCM climate model. However, it is important to ensure that the modified RCMO in monthly-mean rainfall is consistent with the RCM-simulated change in monthly-mean rainfall. This requires an assessment and correction of any biases.

Bias assessment and correction is performed as follows:

i. Compute the historical RCM monthly mean (RCM historical)
ii. Compute future RCM monthly mean (RCM future)

iii. Compute RCMO-*historical* monthly mean described in step 5 (RCMO historical)
iv. Compute RCMO-*future* monthly mean described in step 5 (RCMO future)
v. Ratio1 = RCMO future/RCMO historical
vi. Ratio2 = RCM future/RCM historical
vii. Bias factor = Ratio2 / Ratio1
viii. RCMO-corrected = RCMO * bias factor

For example, if the RCM July-mean change is 1.5 (a 50% increase) and the equivalent RCMO change is 1.3 (a 30% increase), then the bias factor is 1.15. This factor would then be applied to all daily RCMO data to correct the bias. The resulting RCMO-corrected data would have a distribution with a change in monthly mean and a change in shape consistent with the RCM (see Figures 8–10).

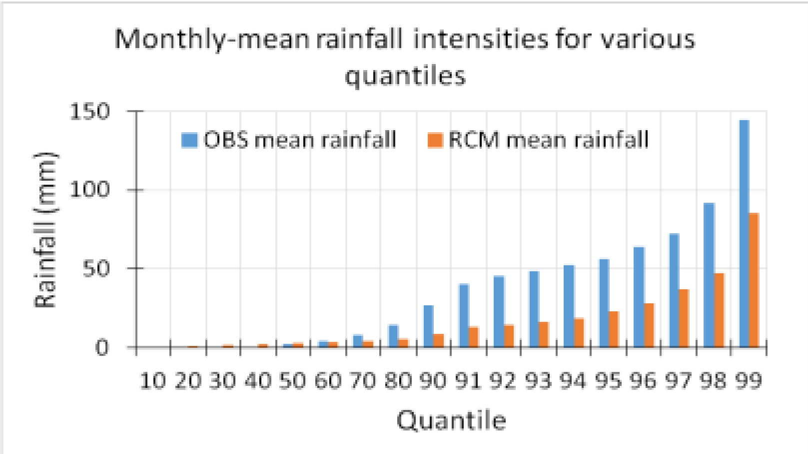

Figure 8. July mean intensity distribution for OBS historical (1985) daily rainfall (blue line), CCSM4 RCM daily rainfall (orange line) for each quantile at MUNOZ (120.95ºE, 15.483ºN)

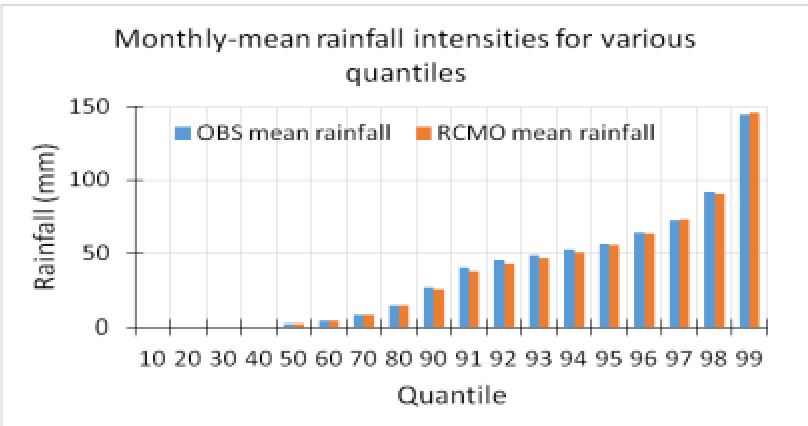

Figure 9. July mean intensity distribution for OBS historical (1985) daily rainfall (blue line), CCSM4 RCMO daily rainfall (orange line) for each quantile at MUNOZ (120.95ºE, 15.483ºN)

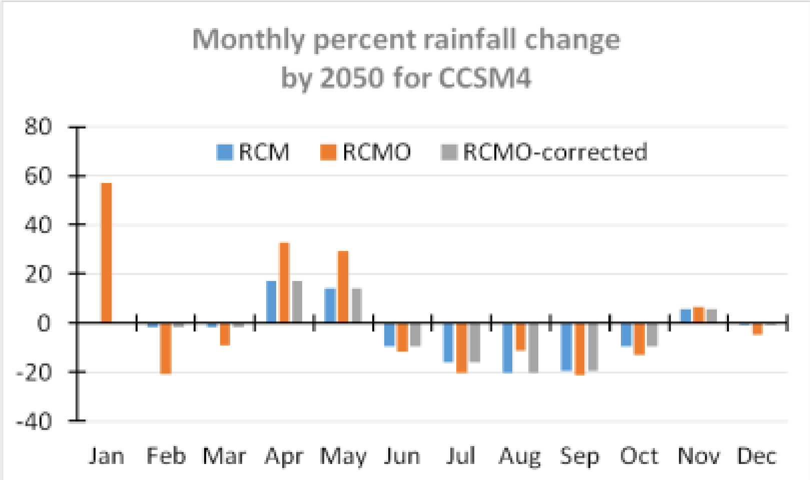

Figure 10. Monthly rainfall percent change by 2050 from raw RCM CCSM4, quantile scaled rainfall (RCMO) and monthly adjusted of quantile-scaled rainfall (RCMO-corrected)

Table 2. Sample corrections

Quantile	Correction ratio
Percentile 10	-1.0000
Percentile 20	-1.0000
Percentile 30	-1.0000
Percentile 40	-0.8051
Percentile 50	-0.2775
Percentile 60	0.2229
Percentile 70	0.8883
Percentile 80	1.5487
Percentile 90	1.9273
Percentile 92	1.9816
Percentile 93	2.0594
Percentile 94	2.0005
Percentile 95	1.7835
Percentile 96	1.4369
Percentile 97	1.2690
Percentile 98	0.9412
Percentile 99	0.9412
Percentile 100	0.7014

10 Communicate Information

Historical and projected daily rainfall data is used for the impact and vulnerability assessment. This is summarized in Table 3.

Table 3. Climate information requirements

Variable	Period	
	Baseline	Projected
Daily rainfall data	1971–2000	2036–2065

IMPACT MODELLING: IRRIGATION WATER REQUIREMENT COMPUTATION

Conceptual Framework

There are several parameters needed in the design of irrigation projects. These include: Size of Service Area, Design Water Duty, Drainage Specific Discharge, Diversion Design Flood Discharge, Construction Flood Discharge, Normal Operating Elevation, Minimum Reservoir Elevation, Maximum Reservoir Elevation, and Spillway Design Flood. Hydrologic design is a term used to describe the process of determining the design parameters required for an irrigation project by applying appropriate hydrologic analysis.

For the purposes of demonstration, this case study looks only at the design water duty. The water duty is computed separately for the wet season and the dry season. For the design of the diversion works and the main canal, the highest water duty for the wet season or dry season is adopted.

In this case study the computation is done on a 10-day basis, considering that the water stored in the paddy will be sufficient to supply the crop requirement for 10 days with zero rainfall. If no irrigation is provided after 10 days, the crop will be damaged or the yield will be significantly reduced.

Application of Climate Change Data for Impact Modelling

The application of the climate change data to the impact models will be demonstrated through the determination of the design water duty, which is one of the hydrologic parameters needed in the design of an irrigation system. The hydrologic design parameters that will be needed will depend on the proposed scheme of development, and include:

- Water Duty (lps/ha)
- Design Service Area (ha)
- Optimum Reservoir Capacity (mcm) or Height (m)
- Probable Maximum or Design Flood of Major Structures
- Design Flood for Spillway & Temporary Diversion Works
- Farm Drainage Unit Discharge

The general steps for computing design water duty, based on climate data developed in the previous section, are:

1. Compute probable 10-days rainfall (i.e. equaled or exceeded in five out of five years on average)
2. Perform paddy water balance computation
3. Compare computed water duty.

Some basic considerations are described in the following sections. More detailed information can be found in Maloles (2013) and Maloles (2016).

Cropping Calendar – Tool for Agro-Planning Activities

In order to assess the irrigation water requirement, there is a need to know and analyze the different farming operations associated in planting certain types of crops. One of these tools is the ***cropping calendar.***

A cropping calendar is the schedule of farming activities associated in planting certain type of crops. Table 4 is a typical example of the list of farming activities with the corresponding time of start and durations. The first crop (rice) has eight farming activities and total duration of 4 months while the second crop (vegetables) has four farming activities within a total duration of 3.5 months.

Table 4. Sample Cropping Calendar

Crop types/activities	Farmer/Schedule
First crop – Rice	James Cruz
Land soaking	Jun 1–3
Seed bed preparation	Jun 2–3
Seedbed sowing	Jun 4
Land preparation	Jun 5– 20
Transplanting	Jun 21– 26
Crop maintenance	Jun 26–Sep 9
Drainage	Sep 10–19
Harvest	Sep 20–30
Second crop – Vegetables	
Land Preparation	Nov 3–23
Sowing	Nov 24–30
Crop maintenance	Dec 1–Jan 31
Harvest	Feb 1–20

Presentation of a cropping calendar

The graphical presentation of the cropping pattern in Figure 11 shows the different stages of farm operation. For a single farm, the cropping calendar is represented by a single bar chart. For several farms, this is represented by several bar charts and will be staggered or lagging (not starting at the same time) due to the availability of manpower required to do the land preparation, transplanting and harvesting. Staggering can also be used to improve water management, so that the most water-intensive phases of cropping activities are not all occurring simultaneously. The combined cropping calendar represents the whole irrigation system where each segment is a part of the total area of 100%.

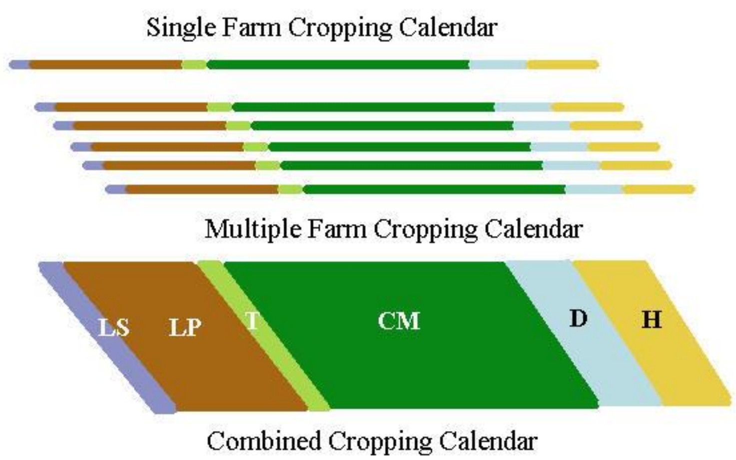

Figure 11. Different stages of farm operation

The staggered period is set considering the ability of the community to perform the various farm activities and the available water supply. If the staggered period is set too short, the capacity of the irrigation facilities will be bigger and more farm workers are in the land preparation and transplanting. On the other hand, if the staggered period is too long, the irrigation requirement will increase due to the longer irrigation period. Table 5 summarizes the recommended staggered period based on the service area.

Table 5. An example of recommended staggered period where the community can perform various farm activities within available water supply

Service Area	Staggered period
STW and Surface Pump	3-5 days
Less than 100 has	20-30 days
100 to 500 has	30-45 days
500 to 5000 has	45- more days

Considerations in preparing the cropping calendar

Many factors have to be considered in the preparation of the cropping calendar, including:

- Type of crops (paddy rice, diversified)
    - Commonly rice, corn and cash crops (vegetables)
    - Growing period will vary on the crop variety
    - Market demand, farm gate price and cost of production, including purchased inputs, should be considered in crop selection.
    - Consultation with the farmers is required
- Start of first and second crop
    - Typhoon season and high winds should be avoided
    - Holiday periods (Christmas, Holy Week and Ramadan)
    - Monthly rainfall and runoff pattern/distribution should be optimized.
- Duration of staggered period
    - Size of irrigable area and labor force available
- Duration of crop stages (manual labor or mechanized).

Computing the Irrigation Water Requirement

There are two basic concepts in the computation of the irrigation water requirement and these are the paddy water balance and the area factor.

Paddy water balance concept

The irrigation water requirement is computed based on the water balance in the paddy field as shown in the illustration below (Figure 12). There are two water sources going into the paddy (rainfall and irrigation supply) while the outflow are drainage, evapotranspiration and percolation. To maintain the water balance, particularly during drying down and harvest periods, the change in storage will be equal to zero and the rainfall and drainage components can be replaced by the effective rainfall. As shown on the substitution of the equation in Figure 12, the effective rainfall is equal to rainfall minus drainage. The final equation computes the irrigation requirement.

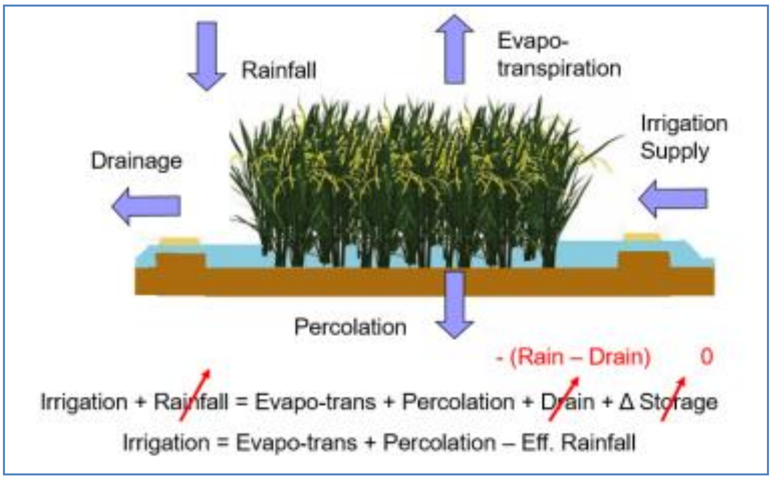

Figure 12. Computation of variables for the Paddy water balance concept

Area factor concept

The area factor is introduced in the methodology to adjust the computation for the effect of portions of the service area being in different stages of farm operations. The vertical line (scale) in the cropping calendar represents the area equal to unity or 1 while the horizontal line (scale) represents the number of days needed for each activity.

Two types of area factor are used in adjusting the computation of the irrigation requirement based on the area under operation. These are illustrated in Figure 13 and Figure 14.

1. Line type: If the duration of the activity is quite short (e.g. 1 to 2 days), then the area factor is equal to the ratio of the line under actual operation to the total length of the whole operation. This is applied to the land soaking and transplanting stages.
2. Area type: If the duration of the activity is more than 2 days, then the area factor is equal to the ratio of the area under actual operation to the total area covered by the whole operation. This is applied to the land preparation and crop maintenance stages. If the area under consideration is under two different stages of operation, the sum of the area factor should be equal to unity (1).

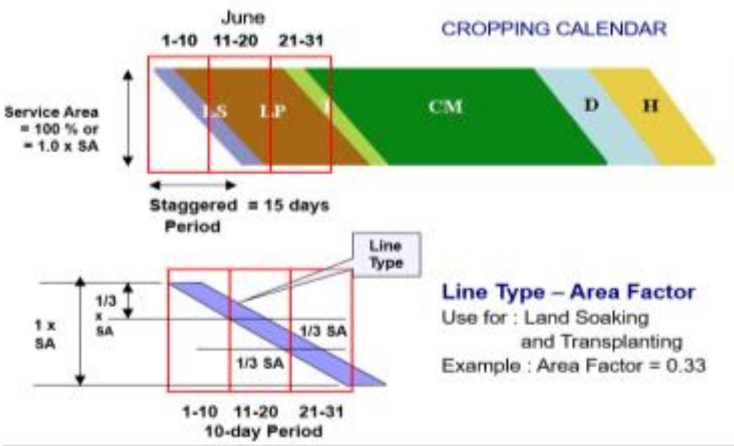

Figure 13. Computation of Area Factor (Line Type)

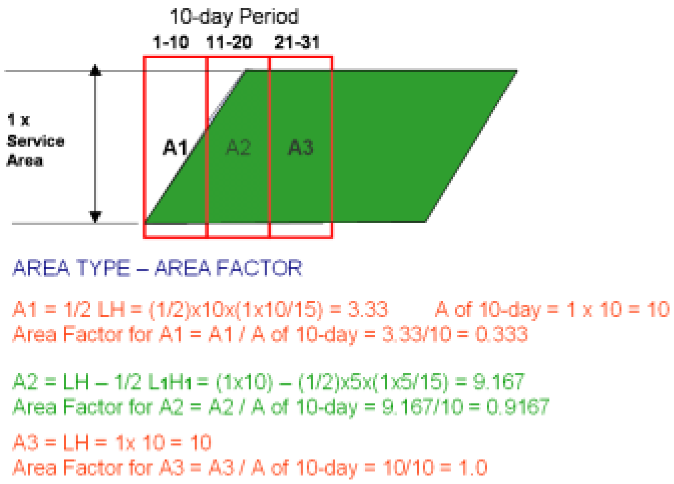

Figure 14. Computation of Area Factor (AreaType)

Other components of the water balance

The other components required in the computations are evapotranspiration and effective rainfall.

Evapo-transpiration and crop coefficient

The amount of water potentially consumed by the crop is stage related; the actual consumption will in addition reflect water availability, and this water is expelled in the atmosphere as evapotranspiration. The evapotranspiration can be computed using the Crop Coefficient (see Figure 15), which is the ratio of the evapotranspiration rate of the crop to the potential evapotranspiration rate. Potential evapotranspiration (PE) is defined as the maximum amount of water that would be vaporized if enough water were available from precipitation and soil moisture. The crop evapotranspiration rate is the amount of water that actually vaporized and is limited by the amount of water that is available (FAO, 1998).

The potential evapotranspiration rate is determined from observed pan evaporation and is equal to the product of the pan evaporation and pan coefficient. In most cases, the potential evapotranspiration is considered equal to 80% of the observed pan evaporation. The potential evapotranspiration can also be computed using climatic data such as temperature, relative humidity, numbers of hours sunshine and wind speed by applying empirical equations like the Modified Penman Method and the currently FAO recommended, Penman-Monteith Method (FAO, 1998).

The crop coefficients of different crops can be obtained through experimentation using Lysimeter. The Crop Coefficient for selected crops are shown in Figure 15. The crop coefficient for each 10-day period is determined by averaging the values over the 10-day interval.

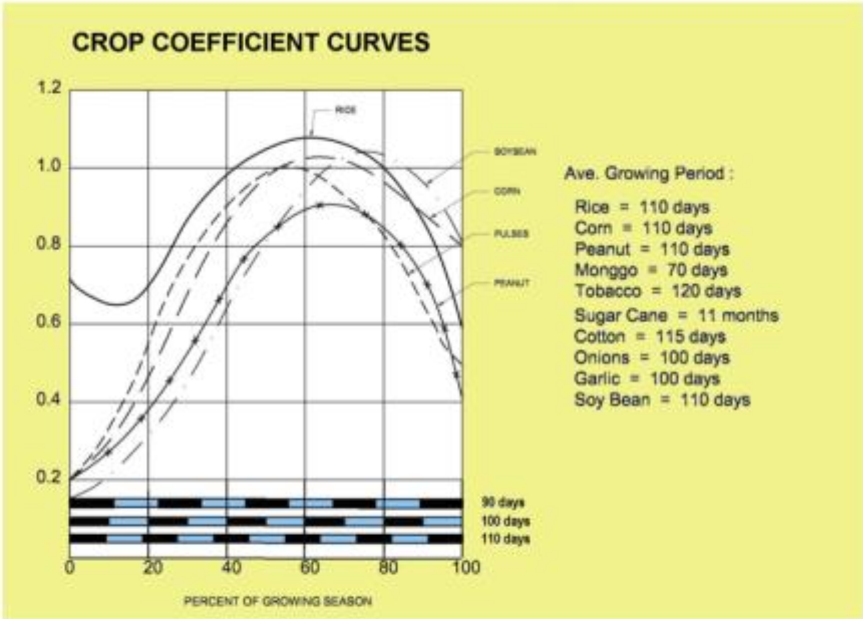

Figure 15. Derivation of crop coefficient

Probable rainfall and effective rainfall

Since the irrigation supply will be based on design level of risk or degree of reliability, this is accomplished by using the probable rainfall in the computation of the irrigation requirement. A return period of 5 years or equivalent to 1 out of 5 years failure is adopted by NIA in the design of the irrigation system. This return period was chosen for the case study which is the acceptable risk the farmer can handle.

The effective rainfall is the contribution of rainfall to reduce the water requirement. Based on the water balance equation, it is equal to total rainfall minus drainage. The effective rainfall cannot be directly determined since it depends on many factors like the condition of the paddy water level, soil moisture, and crop management. Instead, the effective rainfall is computed using the following equations obtained from experimental data.

For diversified crops:

EFF RAIN = 0 IF RAIN < 5

Otherwise, EFF RAIN = (RAIN-5) x 0.7

For paddy rice:

EFF RAIN = 0 IF RAIN < 5

EFF RAIN = RAIN IF 50 > RAIN >5

EFF RAIN = 45 + 0.8 x (RAIN – 50) IF RAIN > 50

where: Rain - Probable 10-days rainfall, in millimeters

EFF RAIN - Probable Effective 10-day rainfall, in millimeters

For the case study, the rainfall data consisted of observed daily rainfall data at Cabanatuan City and projected daily rainfall data generated from regional climate models (RCM) as discussed in the previous section:

- Observed Data – 1971 to 2000
- Baseline or Historic Data – 1971 to 2000 from RCM
- Long-Term Projected Data – 2036 to 2065 from RCM

Computing for the Design Water Duty

As described previously, the water duty is computed separately for the wet season and the dry season. For the design of the diversion works and the main canal, the highest water duty for the wet season or dry season is adopted. The computation is done on a 10-day basis considering that the water stored in the paddy will be sufficient to supply the crop requirement for 10 days with zero rainfall. If no irrigation is provided after ten days, the crop will be damaged or the yield will be significantly reduced.

The following are the steps required to compute the irrigation requirement/design water duty (see Maloles (2013) for more detail):

1. Prepare the input data, i.e. 10-days rainfall with 80% probability of being equalled or exceeded and average percolation rate are placed on the computation form.
2. Draw the cropping calendar for the first and second crops on the tabulation form considering the required stagger period and rainfall distribution.
3. Tabulate the area factor (AF) considering the staggered period and starting date using the standard values given in pre-computed table.
4. Tabulate the crop coefficient considering the type of crop using the standard graph and averaging the value every 10 days.
5. Compute the water requirement for Land Preparation (LP), Evapotranspiration (EP), Percolation (Perc), Flooding after Transplanting (FL) and Field Water Requirement (FWR)
6. Compute the effective rainfall (ER) using the given equations and subtract the amount from the FWR to determine the Net Water Requirement (NWR).
7. Apply the recommended irrigation efficiencies to determine the Diversion Water Requirement (DWR) and convert to the equivalent Water Duty (WD).

Results

The downscaled model data closely matched the monthly mean of the historical data, and preserve the seasonal rainfall pattern (Figure 16). This is most important, especially for the computation of the irrigation water requirement, since it is dependent on the adopted cropping calendar: a shift in the start of the wet season will affect the start of the cropping calendar. There is no indication in the climate modelling that there will be a shift in the seasons. The average of annual rainfall for the historical and the future periods based on climate model data forced using RCP4.5 and RCP8.5 is presented in Table 5.

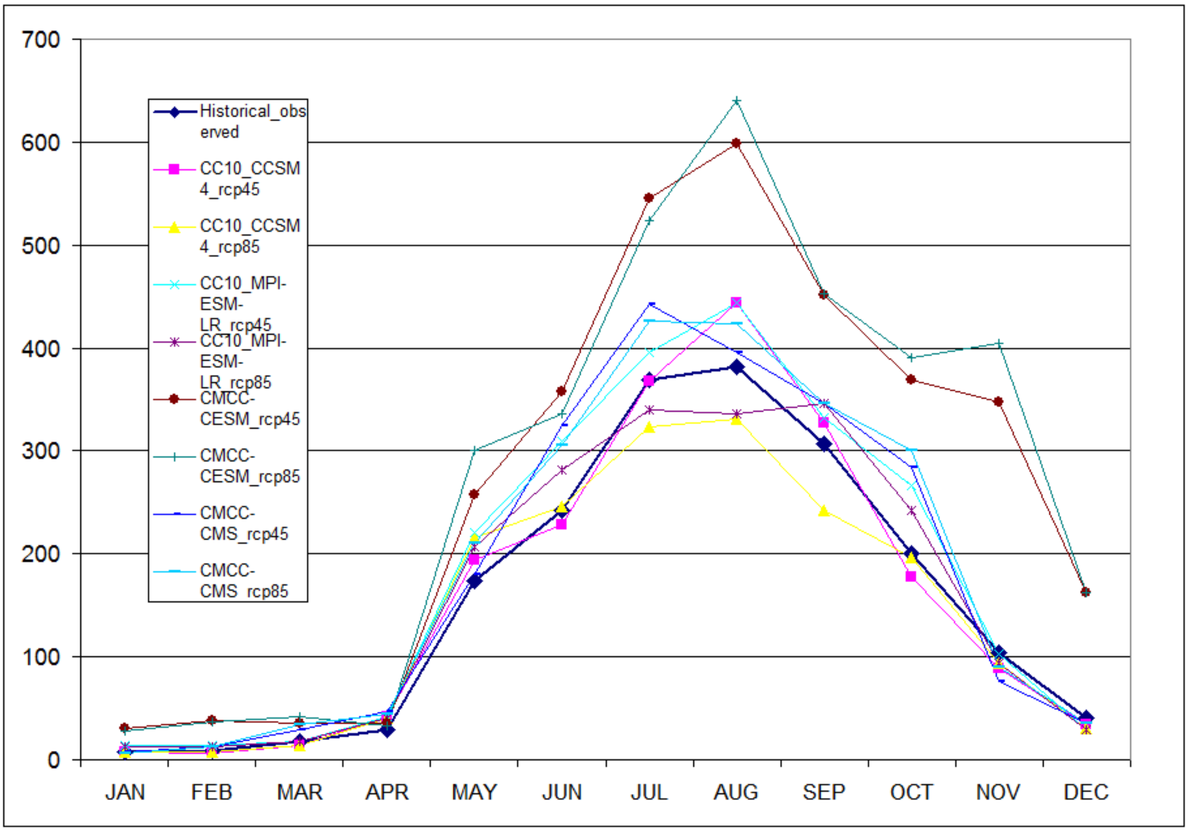

Figure 16. Observed mean monthly rainfall for the period 1971–2000 and projected mean monthly rainfall for 2036–2065 based on the downscaled model data forced with RCP4.5 and RCP8.5.

Table 5. Projected rainfall (in millimeters for the period 2036–2065) and percentage changes in future rainfall (relative to the historical rainfall during 1971–2000) based on the downscaled model data forced with RCP4.5 and RCP8.5.

Observed mean annual rainfall for 1971–2000 (millimeters)	1877.3	
Projected mean annual rainfall for 2036–2065 (millimeters)	RCP4.5	RCP8.5
• CC10-CCSM4	1932.1	1748.5
• CC10-MPI-ESM-LR	2183.3	1960.0
• CMCC-CMS	3228.5	3350.6
• CMCC-ESM	2181.4	2232.6
Projected changes in mean annual rainfall for 2036–2065 relative to 1971–2000 (%)	RCP4.5	RCP8.5
• CC10-CCSM4	+2.8	-7.0
• CC10-MPI-ESM-LR	+16.3	+4.4
• CMCC-CMS	+71.9	+78.4
• CMCC-ESM	+16.2	+18.9

The mean annual rainfall of the climate change data are shown in Table 5. Most of the climate change data are higher than the historical observed rainfall data, except for CC10-CCSM4 (RCP8.5), where there is a reduction in the annual rainfall of about 7 percent. The greatest increase, about 70 to 80 percent, is shown by CMCC-CMS. The mean monthly rainfall for all the climate models were plotted together with the historical observed data. These climate change data have the same seasonal distribution and moderate variation from the historical period, except for CMCC-CMS, which is higher. In general, climate change modelling suggests there will be a wetter future climate at the project site.

The Computed Design Water Duty for the different climate change model data is presented in Table 6.

Table 6. Computed Design Water Duty based on the historical data and on the climate change data for 2036–2065 forced by RCP4.5 and RCP8.5

Historical observed Design Water Duty (Lps per Ha)	**2.04**	
Calculated Design Water Duty for 2036–2065 (Lps per Ha)	RCP4.5	RCP8.5
• CC10-CCSM4	2.01	1.89
• CC10-MPI-ESM-LR	1.68	1.88
• CMCC-CMS	2.47	2.29
• CMCC-ESM	2.47	2.13
Projected changes in Design Water Duty for 2036–2065 relative to 1971–2000 (%)	RCP4.5	RCP8.5
• CC10-CCSM4	-1.5	-7.4
• CC10-MPI-ESM-LR	-17.6	-7.8
• CMCC-CMS	21.1	12.3
• CMCC-ESM	21.1	4.4

Two climate models are lower than the historic data and two are higher. The higher results are significant at about 20 percent for RCP4.5 and 5–10 percent for RCP8.5. Considering the range of values obtained, the average value of 2.10 is acceptable.

To assess the possible impact on irrigation system operation, the annual average irrigation demand was computed for the same set of climate change data (Table 7).

Table 7. Computed annual Irrigation Water Requirement based on the historical data and on the climate change data for 2036–2065 forced by RCP4.5 and RCP8.5

Historical observed annual Irrigation Water Requirement (mm per year)	**1222**	
Irrigation Water Requirement for 2036–2065 (mm per year)	RCP4.5	RCP8.5
• CC10-CCSM4	1226	1188
• CC10-MPI-ESM-LR	1109	1143
• CMCC-CMS	617	612
• CMCC-ESM	1236	1164
Projected changes in Irrigation Water Requirement for 2036–2065 relative to 1971–2000 (%)	RCP4.5	RCP8.5
• CC10-CCSM4	0.3	-2.8
• CC10-MPI-ESM-LR	-9.2	-6.5
• CMCC-CMS	-49.5	-49.9
• CMCC-ESM	1.1	-4.7

The second assessment for the operation of the irrigation system indicates that the effect of the climate change data is not significant for the three climate models since these predicted a wet and wetter future. However, for CMCC-CMS (which predicted a wetter future), there is about 50 percent reduction for RCP4.5 and RCP8.5 in the average annual irrigation demand. In general, there is a wetter future and reduced annual irrigation demand.

DISCUSSION AND SYNTHESIS

The case study demonstrates how to develop climate information and use it in a water paddy balance model to calculate irrigation water duty in the historical and future period. The results can be used to assess climate risk, for instance by looking at the following examples.

1. Use of efficiency threshold

   Irrigation canal reliability or threshold of working efficiency - This is ideally set with the users/stakeholders before failure is experienced. According to the Manual of Operations of the National Irrigation Administration, ***reservoir reliability*** should be >80% for an irrigation project. We can use this threshold to compare present and future reliability.

2. Use of return period

   Climate model generated projections are used to assess changes in the reliability of the irrigation system with specific design parameters. For example, what will happen if the 80% exceedance event (1-in-5-year dry event) becomes 1-in-3-year event in the future?

3. Computing for the risk due to change in drainage discharge

   We can also assess the risk from the change in drainage discharge between the current and future climate. The potential failure/ or success of the existing drainage in the future can then be evaluated and determine whether or not an adaptation is required.

This case study demonstrated the retrofitting/design of irrigation/agriculture infrastructure. Figure 17 shows how the country study fits in with the framework on which the Regional Technical Assistance is anchored to. The first two boxes are the (possible) providers (e.g. National Hydro-meteorological Agency, research institutes) and users of the information (e.g. mandated government agencies such as NIA, BSWM, academe, researchers). Knowledge products of the two groups include training manual and guidance materials.

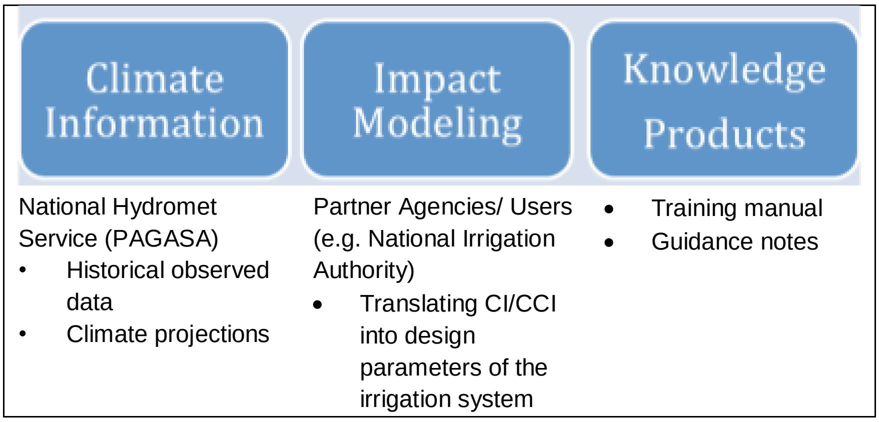

Figure 17. Regional Technical Assistance Framework

Impact assessment

Computing for the water duty (L/sec/ha) aims to enhance water distribution mechanisms to reduce the effects of seasonal climate change and variability of water supply to rice production. The water duty is computed separately for the wet season and the dry season. For clarity, water duty is a metric rather than a method to achieve improved efficiency. It is useful though, as an indicator on how projected climate change might impact a given system relevant to system designers and/or operators.

For the design of the diversion works and the main canal, the highest water duty for the wet season or dry season is adopted.

The case study demonstrated that knowing the efficiency threshold of the irrigation drainage, (e.g. 80%), we could compute for the water duty that can be released in future climate scenario without affecting rice productivity negatively.

The computation is done on a 10-day basis considering that the water stored in the paddy will be sufficient to supply the crop requirement for 10 days ***with zero rainfall.*** If no irrigation is provided after ten days, the crop will be damaged or the yield will be significantly reduced.

Due to limited time, it was only possible to demonstrate the computation of water duty for dry condition. It would be very valuable also to take up the flooded situation and to upscale to other locations/sites/basins for both dry and flooded conditions.

CONCLUSION AND RECOMMENDATIONS

The results of the exercises stressed that water availability versus water requirement, as represented by effective rainfall, is largely affected by seasonal changes or variability rather than long-term climate change. It so happened that the location chosen for the case study (Cabanatuan and Munoz, Nueva Ecija) showed a slight increase in long-term rainfall (wetter regime). The working reliability of the irrigation system in this case is still greater than 80% and can be interpreted as not affected by climate change. In case of severe drought conditions (usually during El Niño), such thresholds (whether through the irrigation reliability/efficiency or through the use of return period) could be breached. Hence in those cases, higher water duty will be needed in order to maintain the required operations in the field.

For this Regional Technical Assistance (REG TA-8359) as a whole, the following are expected to be made available beyond the project's lifespan:

- On-line provision of climate change information for impact assessment
- Generation of corrected downscaled climate values using several bias correction options (e.g. statistical and dynamical)
- Guidance on use of climate projection data and tools on how to choose the appropriate scenarios from various models
- Capacity building to users of the portal through provision of training documents, data and maps

Agriculture is the lifeline of most countries in South East Asia, including the Philippines. Food security and water availability are among the top thematic concerns of the country as expressed in its National Climate Change Adaptation Plan (GoP–CCC, 2011). We can no longer do 'business-as-usual' planning for development. Climate change information has to be integrated into developmental planning where uncertainties are expressed in terms of possible futures. For most people, including some policy makers, climate change is a remote future, but climate variability is a more realistic present. Concerns about current drought or flood events enhanced by long-term climate changes are a more grounded frame of bringing-up possible impacts of climate change in the future.

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APPENDIX

Pre-computed Area Reduction Factor (ARF) and Crop Coefficient (KC)
For Paddy Rice Crop - 110 Days Variety
(Starting at Beginning of 10-Day Period)

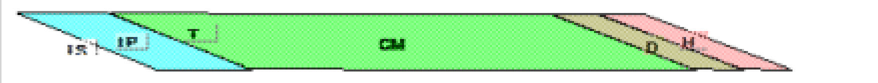
(A)
20 Days Staggered
(Less than 100 has)

Decade	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
ARF for Land Soaking	0.500	0.500																
ARF for Land Preparation	0.250	0.750	0.750	0.250														
ARF for Transplanting			0.500	0.500														
ARF for Crop Maintenance			0.250	0.750	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.750	0.250					
ARF for Effective Rainfall	0.250	0.750	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.750	0.250					
KC for Paddy Rice			0.660	0.780	0.970	1.010	1.070	1.100	1.080	1.030	0.970	0.910	0.730					

(B)
25 Days Staggered
(Between 100 to 500 has)

Decade	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
ARF for Land Soaking	0.400	0.400	0.200															
ARF for Land Preparation	0.200	0.600	0.700	0.400	0.100													
ARF for Transplanting			0.400	0.400	0.200													
ARF for Crop Maintenance			0.200	0.600	0.900	1.000	1.000	1.000	1.000	1.000	1.000	0.800	0.400	0.100				
ARF for Effective Rainfall	0.200	0.600	0.900	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.800	0.400	0.100				
KC for Paddy Rice			0.660	0.660	0.780	0.970	1.010	1.070	1.100	1.080	1.030	0.970	0.910	0.730				

(C)
30 Days Staggered
(Between 100 to 1000 has)

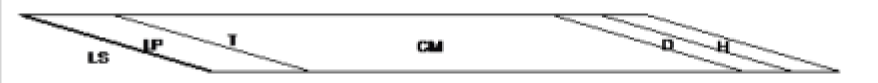


Decade	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
ARF for Land Soaking	0.330	0.330	0.330															
ARF for Land Preparation	0.165	0.500	0.670	0.500	0.165													
ARF for Transplanting			0.330	0.330	0.330													
ARF for Crop Maintenance			0.165	0.500	0.835	1.000	1.000	1.000	1.000	1.000	1.000	0.835	0.500	0.165				
ARF for Effective Rainfall	0.165	0.500	0.835	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.835	0.500	0.165				
KC for Paddy Rice			0.660	0.660	0.780	0.970	1.010	1.070	1.100	1.080	1.030	0.970	0.910	0.730				

(D)
35 Days Staggered
(Between 500 to 2000 has)

Decade	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
ARF for Land Soaking	0.286	0.286	0.286	0.142														
ARF for Land Preparation	0.143	0.428	0.572	0.535	0.286	0.036												
ARF for Transplanting			0.286	0.286	0.286	0.143												
ARF for Crop Maintenance			0.143	0.429	0.714	0.964	1.000	1.000	1.000	1.000	1.000	0.860	0.570	0.286	0.036			
ARF for Effective Rainfall	0.143	0.428	0.715	0.964	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.860	0.570	0.286	0.036			
KC for Paddy Rice			0.660	0.660	0.780	0.970	1.010	1.070	1.100	1.080	1.030	0.970	0.910	0.730	0.700			

(E)
40 Days Staggered
(Between 1000 to 5000 has)



Decade	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
ARF for Land Soaking	0.250	0.250	0.250	0.250														
ARF for Land Preparation	0.125	0.375	0.500	0.500	0.375	0.125												
ARF for Transplanting			0.250	0.250	0.250	0.250												
ARF for Crop Maintenance			0.125	0.375	0.625	0.875	1.000	1.000	1.000	1.000	1.000	0.875	0.625	0.375	0.125			
ARF for Effective Rainfall	0.125	0.375	0.625	0.875	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.875	0.625	0.375	0.125			
KC for Paddy Rice			0.660	0.660	0.780	0.970	1.010	1.070	1.100	1.080	1.030	0.970	0.910	0.730	0.700			

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