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ASSESSMENT OF WATER-ENERGY-FOOD NEXUS TRADEOFFS FOR MINDANAO

Final Report – November 2018

BUILDING LOW EMISSION ALTERNATIVES TO DEVELOP ECONOMIC RESILIENCE AND SUSTAINABILITY PROJECT (B-LEADERS)

IN PARTNERSHIP WITH THE NATIONAL WATER RESOURCES BOARD (NWRB) AND MINDANAO DEVELOPMENT AUTHORITY (MINDA)

November 2018
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ACRONYMS

AHD	Analytical Hydrography Dataset
B-LEADERS	Building Low Emission Alternatives to Develop Economic Resilience and Sustainability
CBA	Cost Benefit Analysis
CCC	Climate Change Commission
CDIT	Climate Data Interpolation Tool
CFSR	Climate Forecast System Reanalaysis
COP	Conference of Parties
CV	coefficient of variation
DENR	Department of Environment and Natural Resources
DOE	Department of Energy
DPWH	Department of Public Works and Highways
EGUs	energy generation unit(s)
ET	evapotranspiration
FAO	United Nations Food and Agriculture Organization
GAMS	Generalized Algebraic Modeling System
GHG	greenhouse gas(es)
GWh	gigawatt hour(s)
HydroSHEDS	Hydrological Shuttle Elevation Derivatives at multiple Scales
IPCC	Intergovernmental Panel on Climate Change
km^2	square kilometers
l/c/d	liters per capita per day
LWUA	Local Water Utilities Administration
m^3	cubic meters
MinDA	Mindanao Development Authority
$mtCO_2e$	metric tons of carbon dioxide equivalent
MWh	megawatt hour(s)
NAMRIA	National Mapping and Resource Information Authority

NASA	National Aeronautics and Space Administration
NCCAP	National Climate Change Action Plan
NCEP	National Centers for Environmental Prediction
NFSCC	National Framework Strategy on Climate Change
NIA	National Irrigation Administration
NOAA	National Oceanic and Atmospheric Administration
NWRB	National Water Resources Board
PAGASA	Philippine Atmospheric, Geophysical and Astronomical Services Administration
PSA	Philippine Statistics Authority
RCP	Representative Concentration Pathways
USAID	United States Agency for International Development
USGS	United States Geological Survey

EXECUTIVE SUMMARY

The water resources of Mindanao vary significantly across geographic regions and over time. The eight major watersheds on the island cover a broad range of topography, climate, and land surfaces, resulting in diverse hydrology across the island. The United States Agency for International Development (USAID) through its Building Low Emission Alternatives to Develop Economic Resilience and Sustainability Project (B-LEADERS) quantified surface water supplies for Mindanao. B-LEADERS applied the The hydrologic resources assessment model to calculate a 20-year, daily surface water balance for 844 subcatchments and aggregated the results to the 8 major priority watersheds[1] on the island. The southern-draining rivers (Davao, Tagum Libuganon, and Bauyan) have the lowest average annual flow and are most vulnerable to long-term droughts. The rivers draining to the northeast (Tagoloan, Cagayan, and Agus) have similarly small drainage areas but receive high amounts of precipitation with heavily forested headwaters, resulting in high average annual flows and low vulnerability to long-term droughts. The two largest watersheds, the Mindanao and Agusan, have very high mean annual flows and diverse watersheds that provide resiliency against low flows.

The modeled climate change scenarios resulted in decreased surface water availability across the island under both moderate (Representative Concentration Pathways (RCP) 4.5) and high (RCP8.5) emissions. The headwaters of most watersheds will be affected, with the Tagoloan, Cagayan, and Davao rivers seeing the greatest declines in mean annual flow. Climate change also drove a significant shift in the timing of flow. Almost all the watersheds will experience a shift from relatively consistent flows of water throughout the year to highly seasonal flow regimes, with most water flowing during a 6-month period.

The study included an additional analysis of the Agus watershed, which contains the largest hydropower and storage project on Mindanao, the largest natural lake on Mindanao (Lake Lanao), and Marawi city. The Agus watershed has a relatively high surface water yield and reliability relative to other river basins on Mindanao, largely due to its high annual precipitation and forested headwaters. Most of the flow comes from the mountains due to orographic[2] lifting, with relatively little flow generation occurring in the lower, northern portion of the watershed. Flow in the river is relatively evenly distributed throughout the year, with 60 percent occurring from June to November and the remaining 40 percent from December to May. Climate change will result in less water for the watershed and a shift in seasonality. Decreases in mean annual flow of up to 20 percent are expected under the downscaled RCP4.5 Moderate Emissions scenario developed by the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). Shifts in timing will intensify as well, with a greater portion of annual flow occurring from June to November. Climate change impacts on surface water yields for the Agus and all of Mindanao can be mitigated through practices such as land cover management and conservation (forested areas provide buffer against swings in surface water supply), construction of storage projects such as reservoirs, interbasin transfers, and demand management.

B-LEADERS also complemented the hydrologic resources assessment model with a hydro economic model to assess water, energy, and food tradeoffs of alternative future development pathways and environmental change scenarios. This economic simulation is a proof of concept

1 A watershed is an area of land that drains all the streams and rainfall to a common outlet.

2 Orographic relates to the position and form of mountains.

analysis to demonstrate a framework and explain that scenario assumptions and input data can be tailored to specific analysis. The simulation framework is a hydro-economic tool that explicitly links hydrologic flow from the hydrologic resources assessment model with an assessment of water demands across different user groups, disaggregated spatially and temporally, as well economic benefits associated with particular water uses, e.g., the value of water used for irrigation. The team estimated the potential economic costs of spatially-disaggregated water deficits given data constraints. Hydro-economic frameworks are increasingly utilized to project potential economic tradeoffs of alternative future scenarios.

Results showed that even in a relatively water abundant region like Mindanao, there are potential tradeoffs of alternative water development pathways, particularly given the historic variability observed in inter-annual flows in the region and the potential pressures of climate change on future supplies. Household consumption is particularly sensitive to increased competition for water supplies and effects of climate change. Results suggested that investing in new water supply capacity and water storage infrastructure can help alleviate potential long term water deficits to household consumptions.

It will later be illustrated that spatial and temporal distribution of water supplies, precipitation, land use, and infrastructure are important factors, and that potential water shortages among the alternative scenarios are not evenly distributed across Mindanao or over the course of a year. B-LEADERS's proposed framework can be used to identify "hot spots," or subcatchments with high potential demands and limited supplies; targeted investments or policy interventions can be developed for these hot spots to more effectively manage their resources and mitigate shortages.

SECTION 1: PROJECT OVERVIEW

A. BACKGROUND INFORMATION

In 2010, the Climate Change Commission (CCC) promulgated the National Framework Strategy on Climate Change (NFSCC), the roadmap for creating a climate-resilient Philippines. The strategy focused on building the adaptive capability of the country to adequately respond to climate change. Because the Philippines has a relatively insignificant global carbon footprint, the Philippine government placed greater emphasis on adaptation measures that would complement mitigation actions. A year following the release of the NFSCC, the CCC developed the National Climate Change Action Plan (NCCAP) to achieve the ultimate goal of the NFSCC through concerted actions across sectors.

The NCCAP identified these seven strategic priorities:

1. Food security
2. Water sufficiency
3. Ecosystems and environmental stability
4. Human security
5. Climate-smart industries and services
6. Sustainable energy
7. Knowledge and capacity development

The Philippines has always been an active participant in international climate change conferences and a widely recognized leader in the Asian region. Despite its inclination to prioritize adaptation, the Philippines submitted its Intended Nationally Determined Contribution on October 1, 2015, leading to the Conference of Parties (COP) 21 held in Paris in November 2015. The Paris Agreement is touted as a landmark global unification effort to reduce greenhouse gas (GHG) emissions through collective GHG emission reduction targets.

B-LEADERS conducted the Cost Benefit Analysis Study (CBA) that evaluated all possible mitigation actions across all sectors, excluding agriculture, to determine the lowest-cost combination of mitigation options that the Philippines can commit to under the Paris Agreement. Despite initial reservations, Philippine President Rodrigo Duterte signed and ratified, through Philippine Congress, the Paris Agreement in March 2017.

To complement the CBA, B-LEADERS conducted a water-energy nexus study to quantify the potential contribution of hydropower plants to the country's committed GHG emission reduction target in light of climate change projections. The study focused on one river basin, the Agus-Ranaw in Mindanao. The lack of quality data required to run the Water Evaluation and Planning system constrained the team from extending the analysis to other river basins.

In 2015, the Philippines hosted the Asia Pacific Economic Cooperation forum. The Philippines was tapped as co-chair with the United States to lead the Task Force on Energy Resiliency. An integral focus of the Task Force was the water and energy nexus. The Philippine Department of Energy (DOE) can use Task Force output to carry out a study and deliver the results during the succeeding Asia Cooperation Dialogue.

B. SCOPE OF WORK

To support CCC updates to the NCCAP in the Philippines, USAID B-LEADERS has developed a framework for evaluating the future baseline for energy and water sector developments, conducting scenario analysis of alternative future development pathways, and estimating water-energy-food-carbon tradeoffs in alternative energy and water management strategies.

This report outlines initial efforts and progress to date in quantifying water resources on Mindanao as a first step to developing the framework. These results are preliminary and will continue to be refined. Future work will incorporate future climate and alternative water-use scenarios developed from partner agencies in the Philippines, including the National Water Resources Board (NWRB), Mindanao Development Authority (MinDA), PAGASA, the Department of Public Works and Highways (DPWH), and the National Mapping and Resource Information Authority (NAMRIA). Further details are provided on the water-energy-food economic analysis that will be built using the water resource assessment.

SECTION 2: HYDROLOGIC MODELING

A. WATER RESOURCE ASSESSMENT FOR MINDANAO

Mindanao is endowed with abundant water resources. The tropical monsoon climate combined with the rugged volcanic topography of the island results in considerable variability in water supply across geographic regions and over time. To quantify water resources for Mindanao, the B-LEADERS team has used a hydrologic resources assessment model, which simulates hydrologic processes over land surfaces to estimate daily precipitation, groundwater recharge, evapotranspiration (ET), and surface water flow across a watershed. More information on the hydrologic resources assessment model is available in **Annex A: Hydrologic Resources Assessment Model Technical Manual** (Moreda, 2018). This section presents the finalized hydrologic modeling input data, approach, results, and interpretation for historical and climate change scenarios. Maps of inputs and tables of results are provided in **Annex B: Maps**.

B. REVIEW OF THE MODELING AREA

To represent the spatial variability of water resources, Mindanao was divided into 844 subwatersheds in the hydrologic resources assessment model using the Analytical Hydrography Dataset (AHD; Rineer & Bruhn, 2013). Inputs and results are provided spatially for each catchment and aggregated to each of the priority river basins on Mindanao (**Figure 1**) that were identified by the Department of Environment and Natural Resources (DENR). Spatial characteristics for AHD cover of Mindanao and each of the priority river basins are described in **Table 1**.

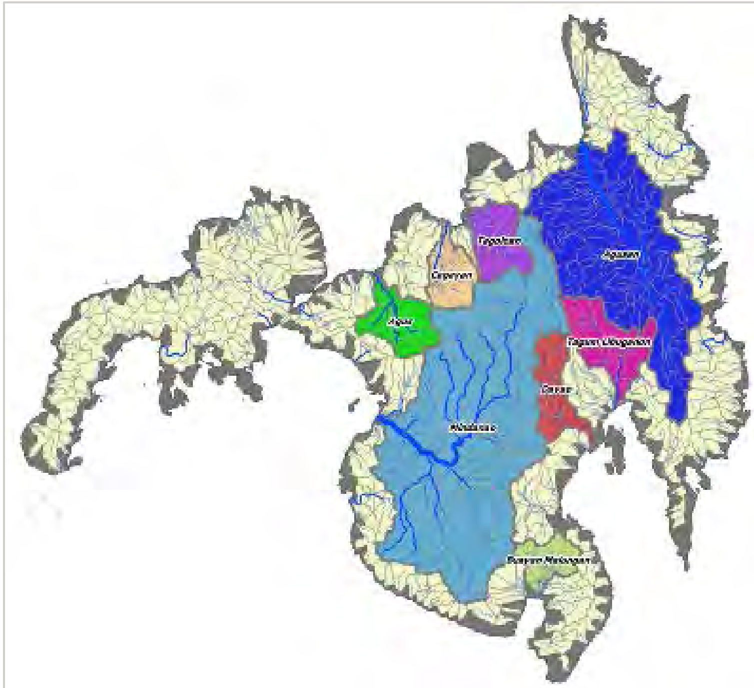

Figure 1. Major River Basins of Mindanao and AHD catchments (catchments in grey were not modeled in Hydrologic Resources Assessment Model)

Table 1. AHD Catchments for Mindanao

Basin	Total Area (km²)	Number of AHD Catchments	Average AHD Catchment Size (km²)
Agus	1,885.1	19	99.2
Agusan	11,741.9	119	98.7
Buayan Malugan	1,160.1	17	68.2
Cagayan	14,69.9	17	86.5
Davao	17,23.8	16	107.7
Mindanao	19,979.2	203	98.4
Tagolaon	1,762.2	23	76.6
Tagum Libuganon	2,431.7	25	97.3
Minor basins	40,353.0	405	99.6
All modeled basins	82,506.9	844	97.8
Excluded catchments	13,917.2	213	63.3

Exclusion of Certain Catchments

When the AHD was created for the island, 213 catchments were generated in coastal areas with no significant upstream drainage areas. The topography of these catchments presents a unique barrier to surface water modeling in Hydrologic Resources Assessment Model. Due to their small area, it was assumed that these catchments have a minimal role in the surface water budget of Mindanao.

Therefore, the 213 catchments were excluded from surface water modeling in Mindanao and are noted on results map as "not included in this analysis." Future projects would benefit from addressing the underlying technical challenges to incorporating these watersheds into surface water models.

Improved Input Data

In the first phase of the water resources assessment, most input data were derived from global satellite observations. These datasets allow models to be parameterized and deployed fairly quickly by standardizing inputs and conducting rigorous quality assurance and quality checks before being made publicly available. However, the global scale of the datasets resulted in lack of local precision and accuracy.

To improve model accuracy, B-LEADERS partnered with local stakeholders to incorporate input data—specifically land use, soil, and climate data—derived using local expertise in partnership with Philippine government agencies including NWRB, MinDA, NAMRIA, PAGASA, and DPWH. **Table 2** outlines each dataset and source. Examples of the updated land use and soil maps are shown in **Figures 2** and **3**, respectively.

Table 2. Hydrologic Resources Assessment Model Input Datasets

Data Type	Source	Notes
Land use	NAMRIA Land Resource Data Analysis Division	Contains geographic information about the physical cover of the earth surface in the Philippines for 2010. Includes grass, asphalt, trees, bare ground, and water bodies. Map is provided in **Annex B, Section 1**.
Soil properties	Department of Agriculture-Bureau of Soils and Water Management	GIS layer containing soil data, including information on soil texture and chemistry. Used to define hydrologic soil type and soil porosity. Map is provided in **Annex B, Section 1**.
Elevation	United States Geological Survey (USGS) HydroSHEDS (Shuttle Elevation Derivatives at multiple Scales)	Elevation data produced by space shuttle observations and derivates. Map is provided in **Annex B, Section 1**.
Streamflow	DPWH	High-quality streamflow records are available for most of the country. Accessed through Streamflow Management system developed through USAID Water Security for Resilient Economic Growth and Stability (BE SECURE) project.
Daily temperature and precipitation	• PAGASA Daily Climate Time Series Observations • USGS Climate Forecast System Reanalysis (CFSR)	• Daily observations of mean temperature and cumulative precipitation at nine locations in Mindanao from 1990–2010. • Gridded, remotely sensed daily rainfall and temperature projections. Used to improve spatial distribution from PAGASA data.

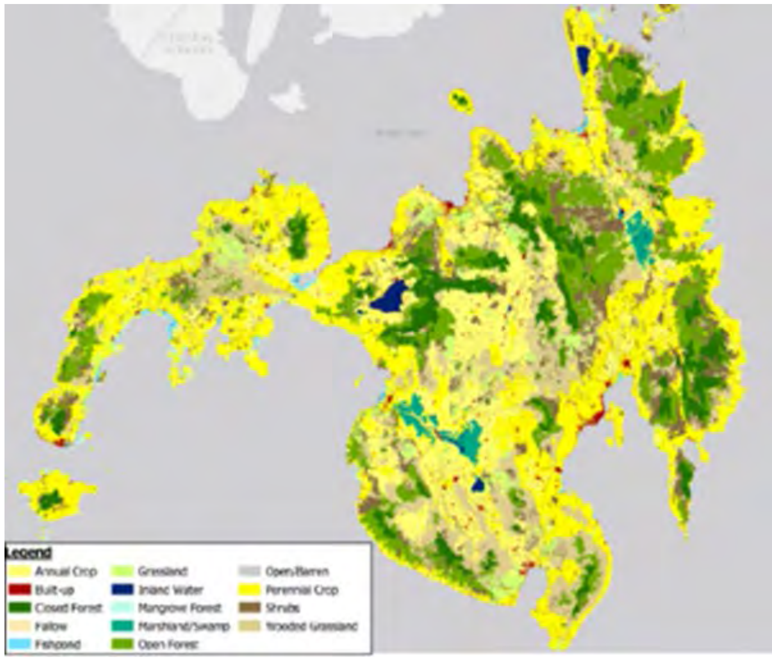

Figure 2. 2010 Land Cover of Mindanao (provided by NAMRIA)

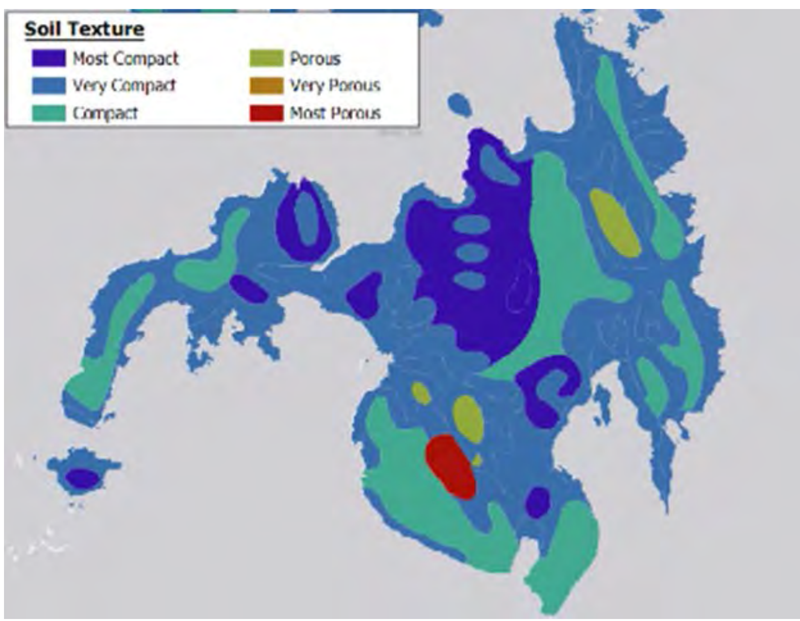

Figure 3. Hydrologic Soil Characterization for Mindanao (provided by NAMRIA)

Climate Data Preparation

The hydrologic resources assessment model requires a daily time series of precipitation and temperature for each of the 844 AHD catchments. Generally, historic climate observations are used to generate these estimates. PAGASA provided historic observations of precipitation and temperature at 10 locations on Mindanao from 1990–2010. (**Figure 4**). Overall, the PAGASA climate data were of very high quality, with few temporal gaps or missing data points. However, 9 out of 10 stations are located on the coastline of Mindanao, and a direct spatial interpolation of climate between these stations and AHD catchments would create an inaccurate representation of the interior climate of Mindanao, particularly that of the high-rainfall, high-elevation mountain ranges in the northwest.

Figure 4. Location of PAGASA Climate Stations (green) in Relation to Priority Watersheds (outlined in black)

To enhance the spatial representation of rainfall on Mindanao, the B-LEADERS team used the CFSR (Fuka et al., 2014) dataset generated by the United States National Oceanic and Atmospheric Administration (NOAA). The CFSR dataset is a multiyear global gridded representation of weather consisting of hourly weather forecasts generated by the National Weather Service's National Centers for Environmental Prediction (NCEP) Global Forecast System. The CFSR–NCEP has a spatial resolution of 0.5º latitude X 0.5º longitude from 1979–2016 and contains worldwide historic expected precipitation and temperature data.

The climate data enhancement process consisted of four major steps:

1. Assess accuracy of CFSR data at PAGASA station locations (PAGASA stations are considered highly accurate for their locations),
2. Derive monthly correction factors for CFSR grid cells to match PAGASA station data,
3. Interpolate monthly correction factors to AHD catchments, and
4. Apply the hydrologic resources assessment model Climate Data Interpolation Tool (CDIT) using corrected CFSR gridded data to generate daily climate for each AHD catchment.

The climate dataset generated from the combined PAGASA and CFSR climate inputs is shown in **Figure 5**.

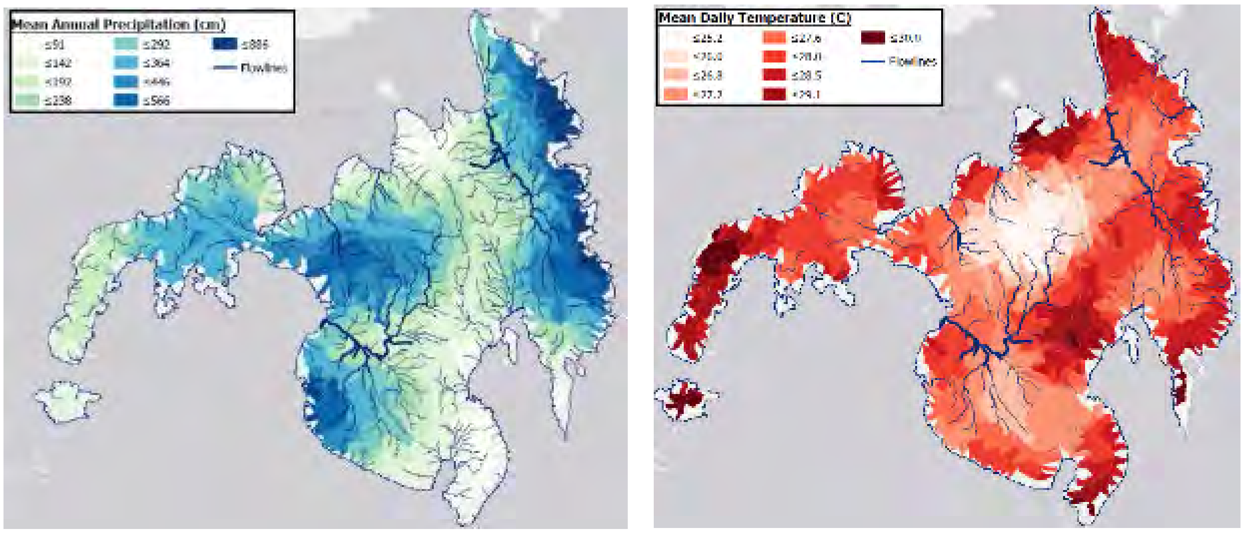

Figure 5. Mean Annual Precipitation (left) and Mean Daily Temperature (right) Estimated From Combined PAGASA-CFSR Dataset

Streamflow Model Calibration

With the modified climate data, the hydrologic resources assessment model was calibrated at seven DPWH streamflow gauge locations (**Figure 6**). The calibrated parameters at each station were then spatially distributed to AHD catchments by proximity and hydrologic connectivity. The distributed parameters were validated against a separate set of seven DPWH streamflow gauge locations to ensure adequate calibration quality.

Figure 6. DPWH Streamflow Calibration (red) and Validation (green) Gauges

Streamflow calibrations at the seven sites were largely satisfactory with the enhanced PAGASA-CFSR climate dataset. **Figure 7** shows the finalized calibration hydrograph and flow-duration curve for the Cagayan River station.

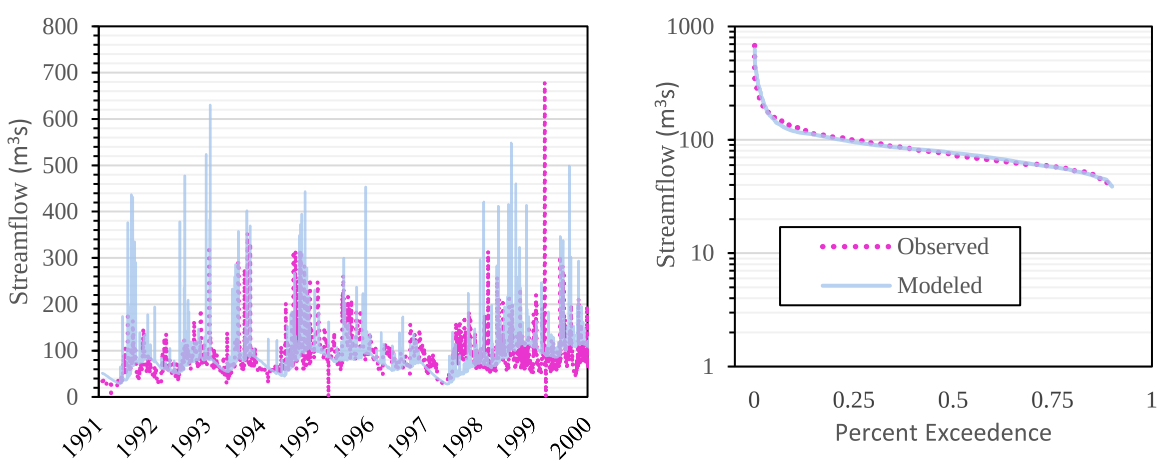

Figure 7. Hydrograph (left) and Flow-duration Curve (right) for the Hydrologic Resources Assessment Model Calibration at the Cagayan River DPWH Streamflow Station

Overall, the calibrations achieved satisfactory estimates of monthly and annual flow volume as indicated by the overall volume error statistic in **Table 3**. However, the correlation and Nash-Sutcliffe Efficiency statistics indicate poor performance for nearly all of the gauges, likely due to errors in timing of flows, with modeled high flows occurring during different times than observed high-flow events. This type of error is caused most often by inaccuracies in the input data. Because the timing of the PAGASA-CFSR dataset is largely derived from remotely sensed sources, the errors were expected. The model calibrations are thus best suited for long-term estimates of water supply at monthly or annual time steps. Modeling of specific hydrologic events at daily or weekly scales would not be appropriate given the errors in timing.

Table 3. Hydrologic Resources Assessment Model Monthly Calibration Statistics for Mindanao

Gauge	Overall Volume Error (%)	Correlation -r	Modified Correlation Coefficient	Nash-Sutcliffe Efficiency
Alubijid	2.71	0.51	0.46	0.13
Cagayan	0.8	0.59	0.57	0.2
Sta. Isabel	0.01	0.59	0.38	0.34
Sindangan	1.77	0.75	0.75	0.5
Buayan	1.39	0.88	0.69	0.61
Kapingkon	2.65	0.54	0.43	-0.21
Libuganon	2.35	0.51	0.27	-1.66

Current Condition Hydrologic Results

Once calibrated, the hydrologic resources assessment model was used to estimate daily precipitation, temperature, runoff, infiltration, groundwater percolation, catchment runoff, and total streamflow for each of the 844 AHD catchments under current conditions (from January 1, 1990, to December 31, 2010). Results specific to each of the eight major basins are also summarized. Detailed maps of water resource modeling results are included in **Annex 2.**

Using the PAGASA-CFSR harmonized climate dataset, NAMRIA-provided soil and land use, and DPWH streamflow, the mean annual water supply under natural conditions was estimated using Hydrologic Resources Assessment Model. The spatial distribution of flow generation (total volume water generated per unit area) is shown in **Figure 8**. Surface water supply is represented for each of the 844 catchments represented in AHD. Streamlines are sized by mean annual flow.

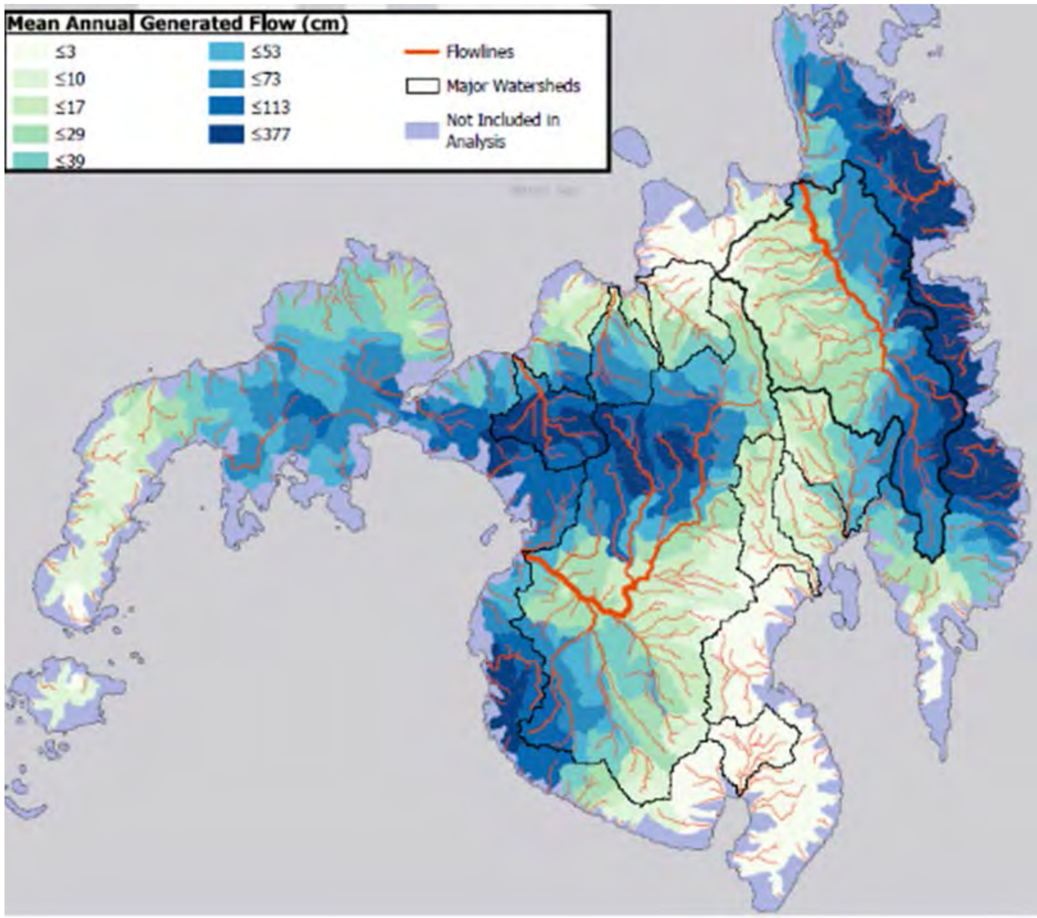

Figure 8. Flow Generation in Mindanao, Normalized to Catchment Area: Catchments in darker shades of blue indicate high yields of surface water

Catchments with the most surface water yield are located in the areas of Mindanao with high elevations and the highest amount of annual rainfall. This correlation can be seen when comparing maps of annual precipitation and the elevation with the mean annual generated volume. Within these wet mountainous regions, the catchments producing the highest yield are areas of forest, marshland, and grassland.

These regions also yield a highly reliable water supply from year to year. **Figure 9** shows the variability of annual streamflow volume from each catchment as the coefficient of variation (CV), a statistical measure of variability. The CV represents the expected difference in water availability from the average flow in any given year. Catchments below 0.5 represent flows that have low interannual variability of streamflow. Water yield in these catchments is relatively stable and is not expected to change drastically from year to year. Conversely, catchments with very high CVs are subject to interannual swings in water availability, and are more vulnerable to both droughts and floods.

Figure 8 is nearly the inverse of **Figure 9**, and shows that areas with high elevations and high annual precipitation produce a relatively constant and reliable water yield. Low elevations, including valleys and heavily farmed lands, contribute relatively little to overall flow in the main rivers, but show interannual high variability. Conversely, high-elevation and high-precipitation areas tend to have lower variability in water yield. These headwater areas have very high relative contributions to flow in the main rivers and can offset variability in lower areas. Of the major rivers, only the Buayan and Davao watersheds do not have areas that provide a buffer against variability.

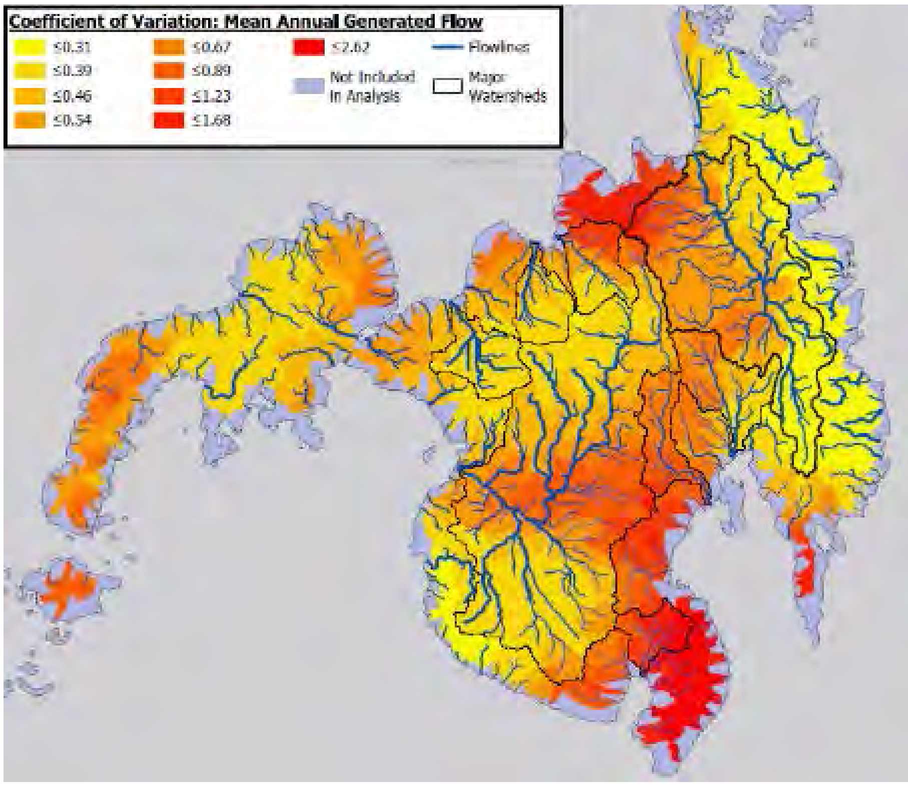

Figure 9. Interannual Variability of Water Supply in Mindanao: Darker areas have more variation in generated flow from year to year

Figure 10 shows annual results aggregated to the priority river basins, revealing patterns in mean total volumes (thick lines) and variability (represented by relative box size) from year to year. The river basins draining to the south (Davao, Buayan, and Tagum Libuganon) have relatively low average annual flows. In particular, the Davao river has the lowest yield of all basins in addition to high variability. These basins have low flows because they have low annual precipitation (**Figure 5**) and small drainage areas (Table 1).

The river basins draining to the north (Tagoloan, Cagayan, Agus, and Agusan) have similar hydrologic regimes characterized by relatively high mean annual flow and low variability (high reliability). These basins drain forested areas with high annual rainfall. The Mindanao River is the largest river basin and has the highest mean annual flow. Its large drainage area and high average basin-wide rainfall yield bountiful water supplies and high reliabilities.

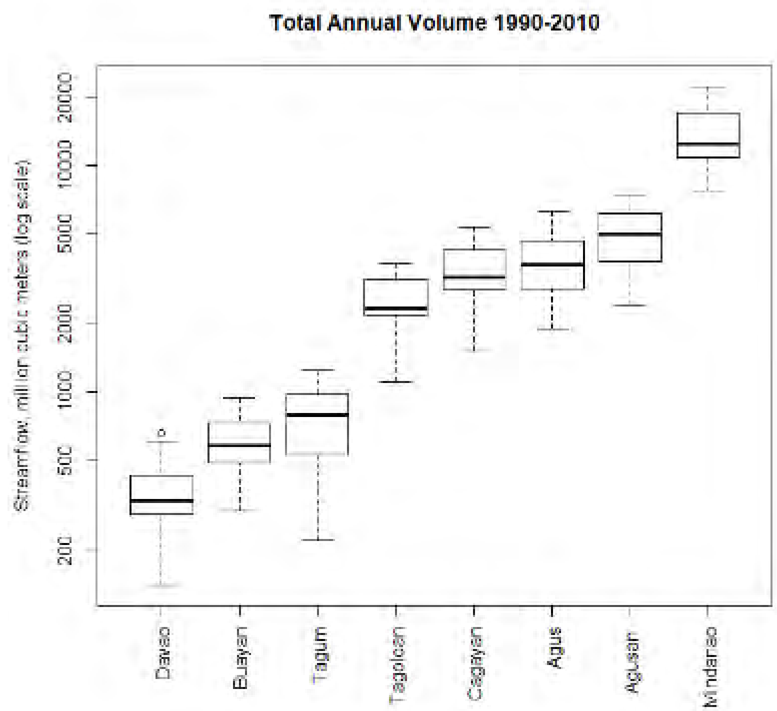

Figure 10. Box Plots of Annual Volume for Priority River Basins of Mindanao (log scale) from 1990–2010: Thick black lines represent the mean annual volume, with size of boxes indicating variability and range of flows

Water availability in Mindanao varies throughout the year, with seasonal distributions varying across the island (**Figure 11**). For the southern-draining basins, flow is relatively evenly distributed throughout the year, with each season generating approximately 25 percent of annual flow. The Tagoloan, Cagayan, Agus, and Mindanao rivers have more seasonal variability. Approximately 60 percent of mean annual flow in the basins is generated from June through November. The driest season is from December through February.

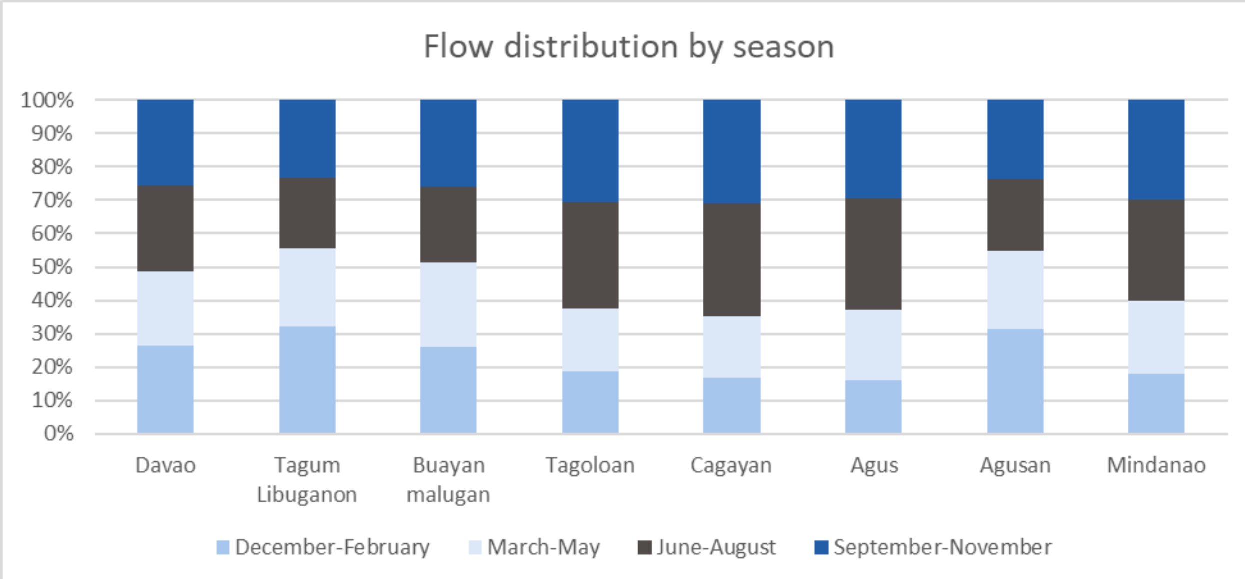

Figure 11. Distribution of Annual Water Availability by Season for Priority River Basins of Mindanao

Future Climate Scenarios

PAGASA provided seasonal, spatially downscaled estimates of change in precipitation and temperature from 2035–2065 for each province on Mindanao (Cinco, Hilario, de Guzman, & Ares, 2013). The projections were developed under two RCP scenarios defined by the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report for moderate emissions (RCP4.5) and high emissions (RCP8.5). **Figure 12** shows the projected average annual changes in precipitation across Mindanao for moderate emissions (RCP4.5) developed from the PAGASA inputs. The hydrologic resources assessment model was used to simulate changes in surface water using the median change values provided for each of the two scenarios.

For nearly all provinces and seasons, the intensity of change was greater for Moderate Emissions scenario than High Emissions scenarios.

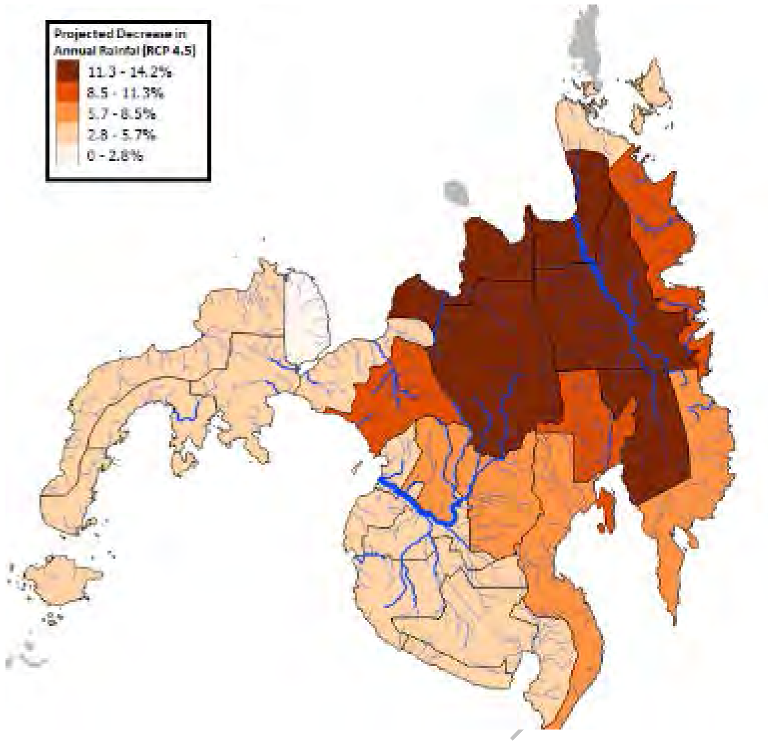

Figure 12. Expected Mid-century Decrease in Annual Rainfall by Province, Developed from Downscaled PAGASA Climate Projections

Future Climate Scenario Results

Climate change will cause a decrease in surface water resources for Mindanao. The combination of increased temperatures and an overall decline in annual rainfall (some seasons in some provinces have slight increases in rainfall) will result in greater ET and decreased streamflow under both emissions scenarios. However, the decreased water yield has significant spatial variability (**Figure 13**).

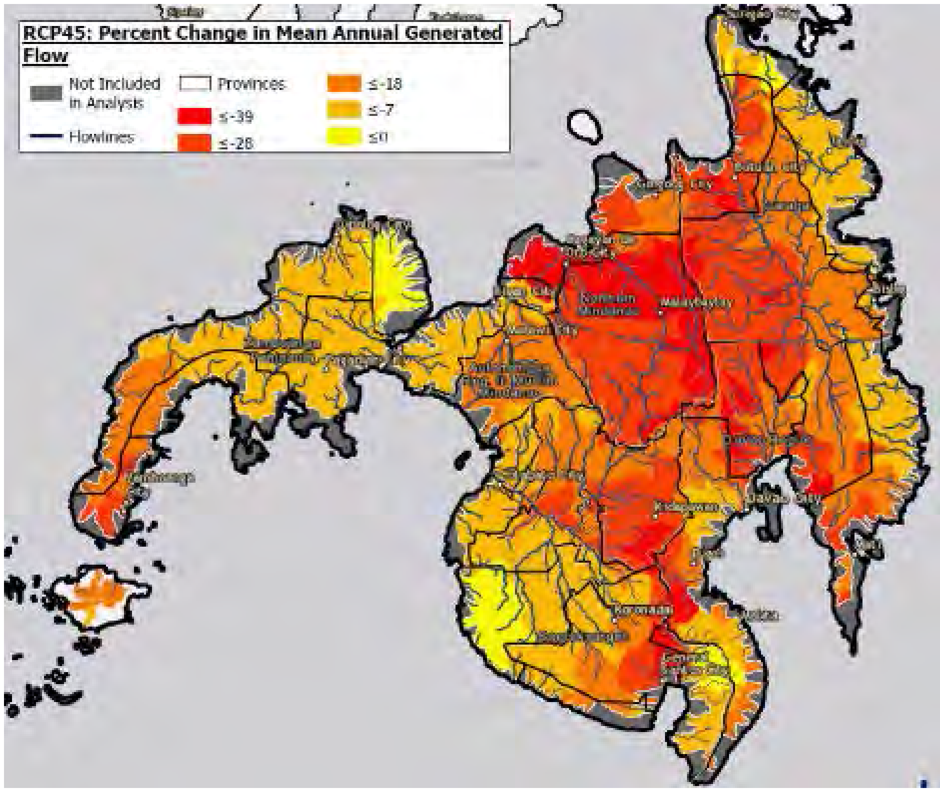

Figure 13. Percent Change in Mean Annual Generated Flow for RCP4.5 Moderate Emissions Scenario

The largest decreases in surface water availability will occur in the central portions of Mindanao, including the headwaters of most of the major rivers and areas of high flow generation (**Figure 8**). All rivers have lower total flow under the climate change scenarios (**Figure 14** and **Table 4**). The Tagoloan and Cagayan basins have the largest expected decrease in mean annual flow under both climate change scenarios. The south-draining rivers (Buayan, Davao, Tagum Libuganon) have the lowest mean annual flow under current conditions and are expected to see up to 25 percent lower flow under climate change scenarios.

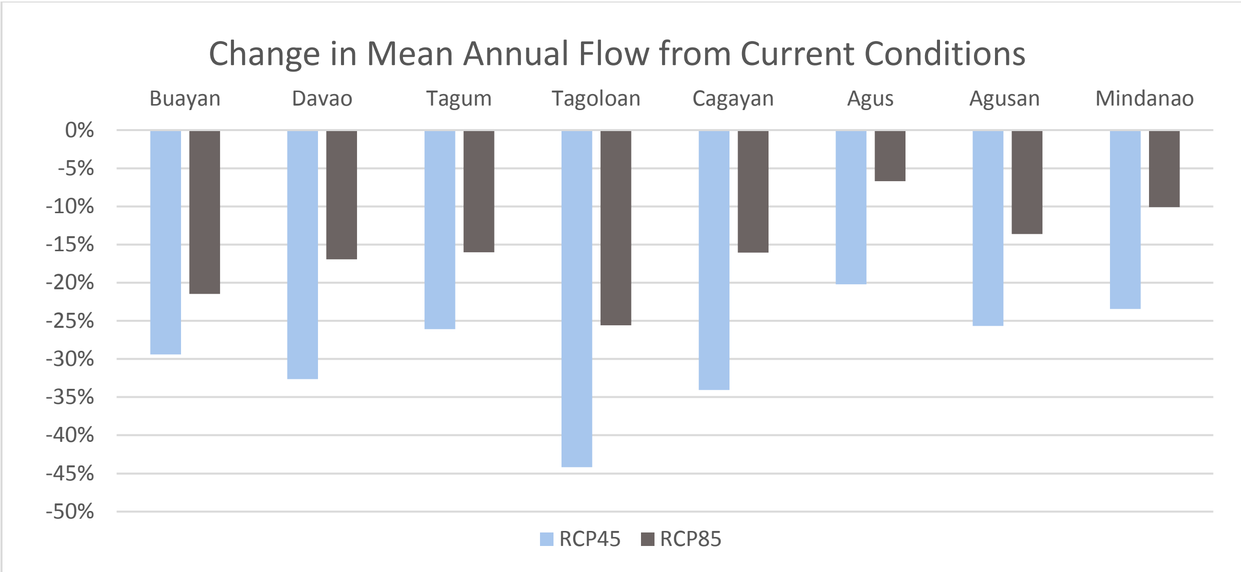

Figure 14. Percent Change in Mean Annual Flow from Current Conditions

Table 4. Expected Change in Mean Annual Flow for Major Watersheds Under Climate Change

	Buayan	Davao	Tagum	Tagoloan	Cagayan	Agus	Agusan	Mindanao
RCP45	-29%	-33%	-26%	-44%	-34%	-20%	-26%	-23%
RCP85	-21%	-17%	-16%	-26%	-16%	-7%	-14%	-10%

The Agus, Agusan, and Mindanao rivers have the lowest expected decreases in flow from climate change. The heavily forested headwaters of these basins, in addition to the less-severe estimated impacts from climate change, provide a buffer against decreased rainfall. Conservation of these forested areas will help limit the impacts of climate change on surface water supply.

Climate change will also cause major shifts in the seasonality of surface water availability on Mindanao. Under current conditions, flow in the major rivers is relatively evenly distributed throughout the year (**Figure 11**). With climate change, most rivers will experience a greater portion of flow from June to November and a decrease in flow in other months. The most drastic changes occur in the Agus, Cagayan, and Davao rivers, which have nearly 70 percent of total annual flow yield from June to November. The eastern-most watersheds, the Agusan and Tagum Libuganon, have a reversed impact, under which the greatest flow occurs from December to May. Shifts in seasonality could result in more frequent seasonal floods and droughts in all watersheds. **Figures 15** and **16** illustrate the expected change in flow seasonality under the two climate change scenarios.

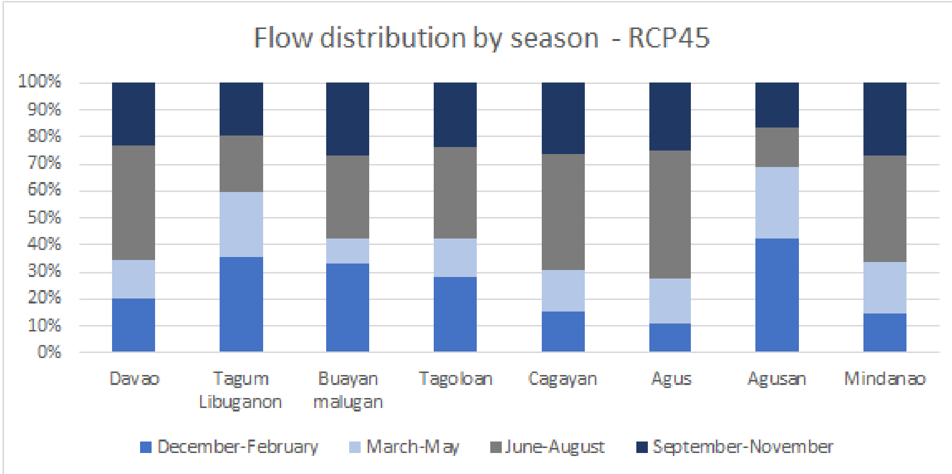

Figure 15. Seasonal Flow Distribution Under the RCP45 Climate Change Scenario

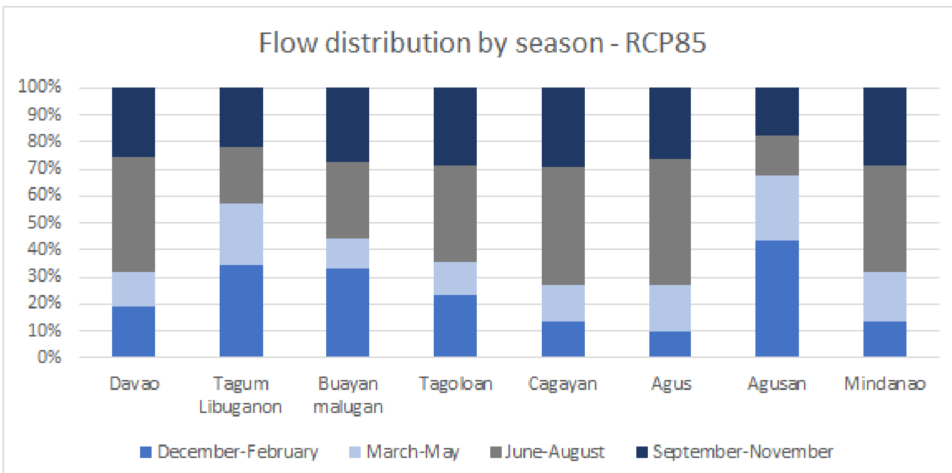

Figure 16. Seasonal Flow Distribution Under the RCP85 Climate Change Scenario

Conclusions, Limitations, and Next Steps

The water resources of Mindanao vary significantly across geographic regions and over time. The eight major watersheds on the island cover a broad range of topography, climate, and land surfaces, resulting in diverse hydrology across the island. The southern-draining rivers (Davao, Tagum Libuganon, and Bauyan Maluguan) have the lowest average annual flow and are most vulnerable to long-term droughts. The rivers draining to the northeast (Talogoan, Cagayan, and Agus) have similarly small drainage areas, but receive high amounts of precipitation with heavily forested headwaters, resulting in high average annual flows and low vulnerability to long-term droughts. The two largest watersheds, the Mindanao and Agusan, have very high mean annual flows and diverse watersheds that provide resiliency against low flows.

The modeled climate change scenarios resulted in decreased surface water availability across the island under both moderate (RCP45) and high (RCP85) emissions. The headwaters of most watersheds will be affected, with the Tagaoloan, Cagayan, and Davao rivers experiencing the greatest declines in mean annual flow. Climate change drove a significant shift in the timing of flow. Almost all of the watersheds will experience a shift from relatively consistent flows of water throughout the year to highly seasonal flow regimes, with most water flowing during a 6-month period. Climate change impacts on surface water yields can be mitigated through practices such as land cover management and conservation (forested areas provide buffer against swings in surface water supply), construction of storage projects such as reservoirs, interbasin transfers, and demand management.

This study assessed surface water supply for Mindanao at 844 locations across the island. Future studies would benefit from higher resolution of watershed delineation, allowing more spatially precise modeling of water resources. However, higher spatial resolution would require improved input data, including more station-based observations of precipitation and temperature in the interior of Mindanao. In this analysis, lack of streamflow gauging stations on the eight priority river basins limited the accuracy of the model calibration. Improved gauge networks would greatly benefit future work. This study did not consider nor quantify the impact of groundwater on surface water supplies. Groundwater and surface water are intrinsically linked through baseflow and are highly interdependent. To accurately model groundwater, high-quality monitoring wells would be needed for calibration and validation. Climate change scenarios were modeled using historic temperature and precipitation time-series with the magnitudes modified. Changes in timing and extreme event frequency were not included. Mindanao is expected to see increased typhoon activity under climate change (Cinco, Hilario, de Guzman, & Ares, 2013), which will increase the risk of floods and can drastically change the flow regimes on the island. Future studies should explicitly incorporate the expected change in typhoon activity.

SECTION 3: FOCUS ON MARAWI CITY AND THE AGUS RIVER

A. ESTABLISHING CONTEXT

In response to an urgent need, the last year of B-LEADERS was focused on providing rapid technical assistance to rebuilding the City of Marawi in the aftermath of the 5-month conflict in the city during a siege involving an extremist group in 2017. To better support efforts of the Philippine Government and USAID in rebuilding infrastructure and rehabilitating Marawi and its neighboring towns, this project conducted additional analyses of the natural water resources of the city and surrounding area, including Lake Lanao and the Agus River watershed.

Review of the Area

Marawi city is located within the Agus River watershed in northwestern Mindanao at the outlet of Lake Lanao (**Figure 17**). The Agus watershed is split between the provinces of Lanao del Sur and Lanao del Norte. It drains the mountainous regions to the north of Mount Piapayungan and discharges to the Bohol Sea, covering an area of 1,925 square kilometers (km^2). In Hydrologic Resources Assessment Model, the watershed is divided into 20 subcatchments, with an approximate average size of 96 km^2.

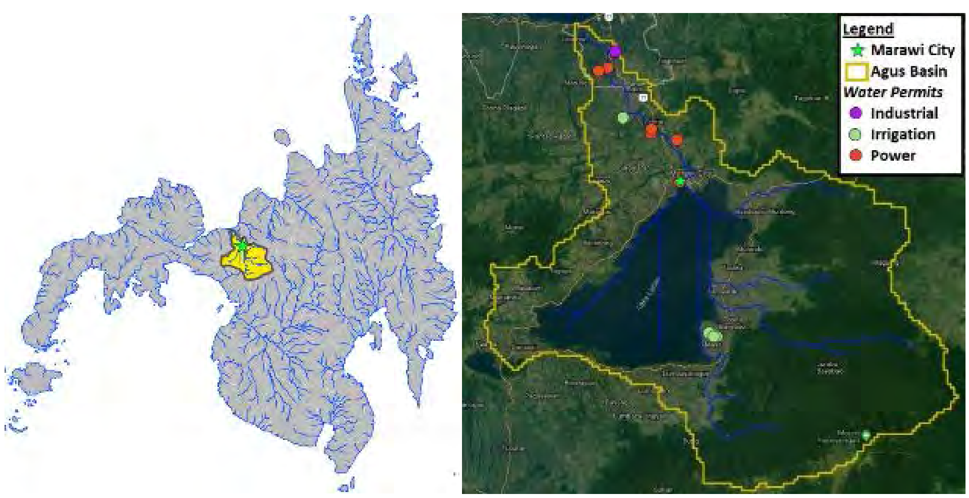

Figure 17. Left: Location of Marawi city (green star) in the Agus River Basin (yellow) on Mindanao, with Major Streamlines (blue). Right: Detail of Agus River Basin with NWRB Permits and Satellite Imagery (provided by Google Maps)

Water in the Agus River basin is used largely for domestic supply, hydropower, and irrigation. According to a preliminary dataset provided by NWRB, 12 surface water diversions[3] have been granted in the watershed, mostly clustered along the main stem of the river north of Lake Lanao. Hydropower generation is by far the largest use of water in the system, with a total permitted withdrawal capacity of 280,000 liters per second. However, most of this water is used to drive turbines, therefore very little water in the basin is actually directly consumed by hydropower. No municipal or domestic use permits were provided in the dataset, possibly because of a gap in the dataset; additional data have been requested from NWRB to more accurately characterize existing permitted water use in the basin.

The Agus watershed has diverse land uses. NAMRIA provided 2010 land use data (**Figure 18**) for parameterization of the hydrologic resources assessment model. The northwestern portions of the watershed are dominated by annual and perennial crop cultivation, with built-up urban areas scattered along the shores of Lake Lanao and the main channel of the Agus River. Lake Lanao covers 340 km^2, approximately 18 percent of the watershed area. The southwestern portions of the watershed are heavily forested and mountainous.

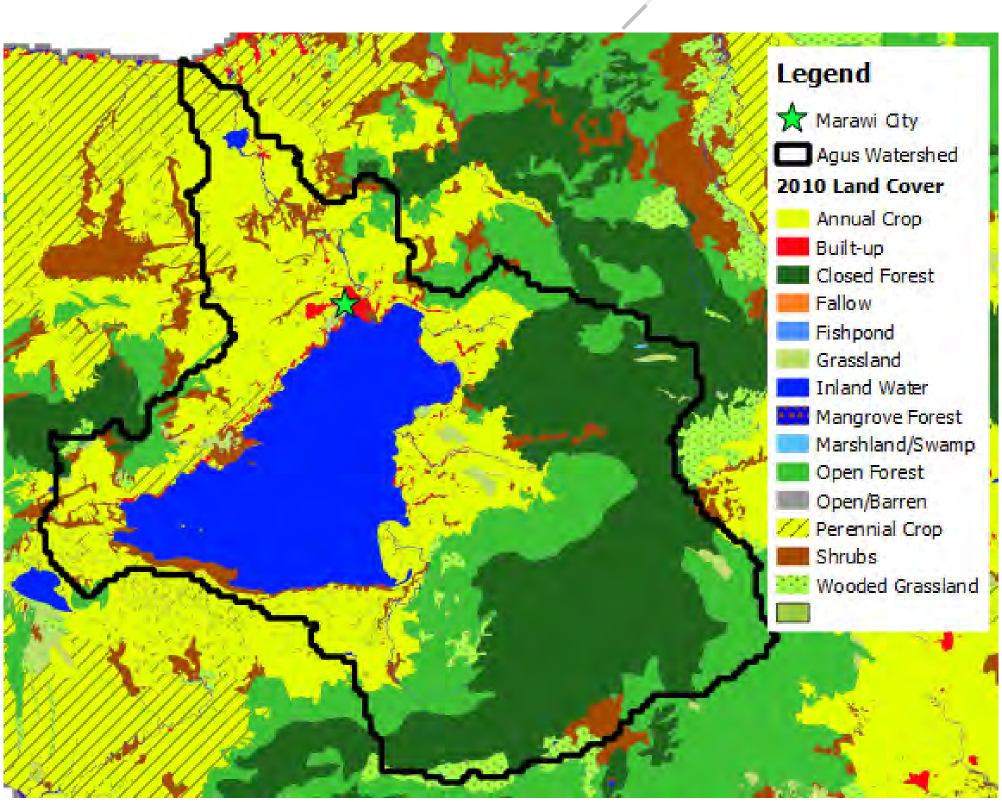

Figure 18. 2010 Land use in the Agus Watershed (provided by NAMRIA)

[3] Water diversions consist of a system of structures and measures that intercept clear surface water runoff upstream of a project site, utilize the resource, and discharge it downstream with minimal water quality degradation.

B. HYDROLOGIC MODELING

Input Data

The hydrologic resources assessment watershed model for all of Mindanao was parameterized using land use and soil data provided by NAMRIA as described above in Section II (Task 3 – Preparing New Input Data). Historical climate data were provided by PAGASA and historical streamflow data were provided by DPWH. Due to the relatively poor coverage of the mountainous interior of Mindanao, PAGASA climate data were enhanced with remotely sensed climate data provided by NOAA's CFSR system (Fuka et al., 2014). **Figure 19** shows mean annual precipitation for the Agus watershed.

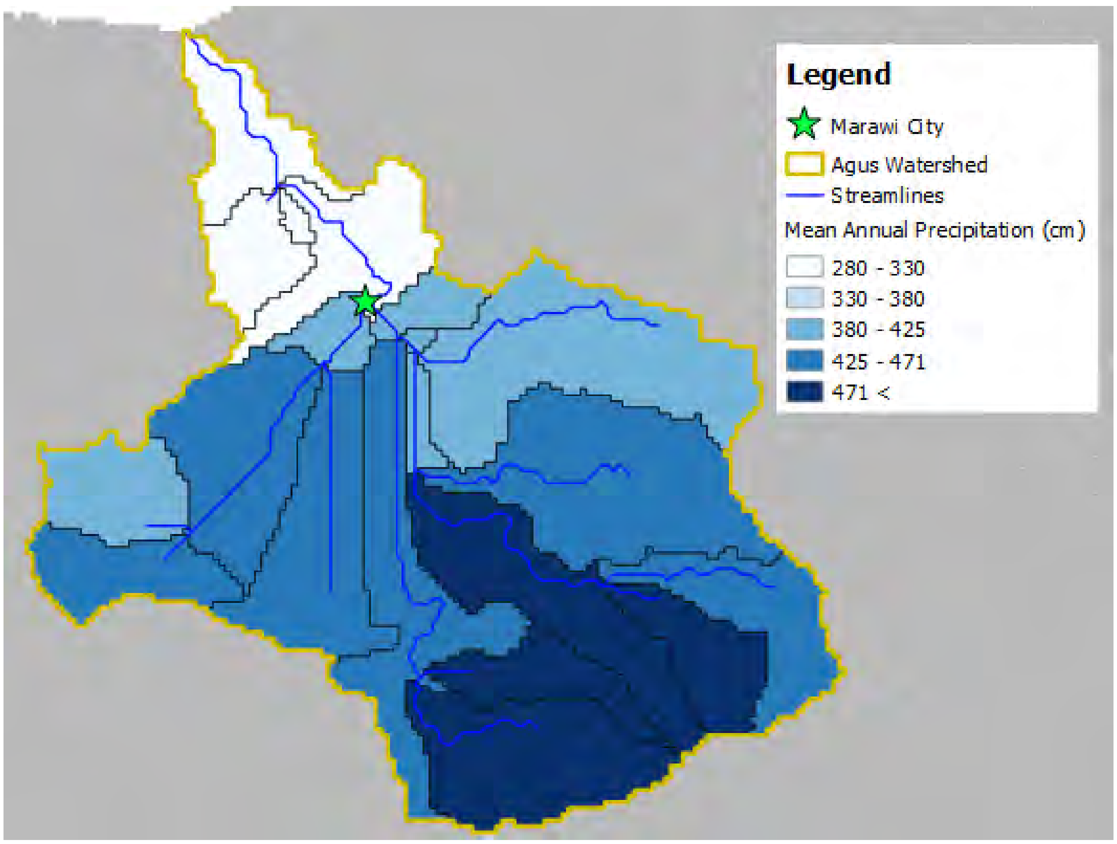

Figure 19. Mean Annual Precipitation Throughout Agus River

Limitations

No streamflow or climate stations have been installed in the Agus River basin, limiting the effort to validate both input datasets (climate) and results (streamflow). Review of results with local insight is critical. Future assessments of water resources would benefit greatly from high-quality observations of climate and streamflow in the watershed.

C. RESULTS

Current Condition Results

The hydrologic resources assessment model was used to generate daily water balances for the 19 catchments in the Agus River watershed from 1990–2010. The aggregated mean annual results, showing areas of water generation and flow accumulation, are shown in **Figure 20**.

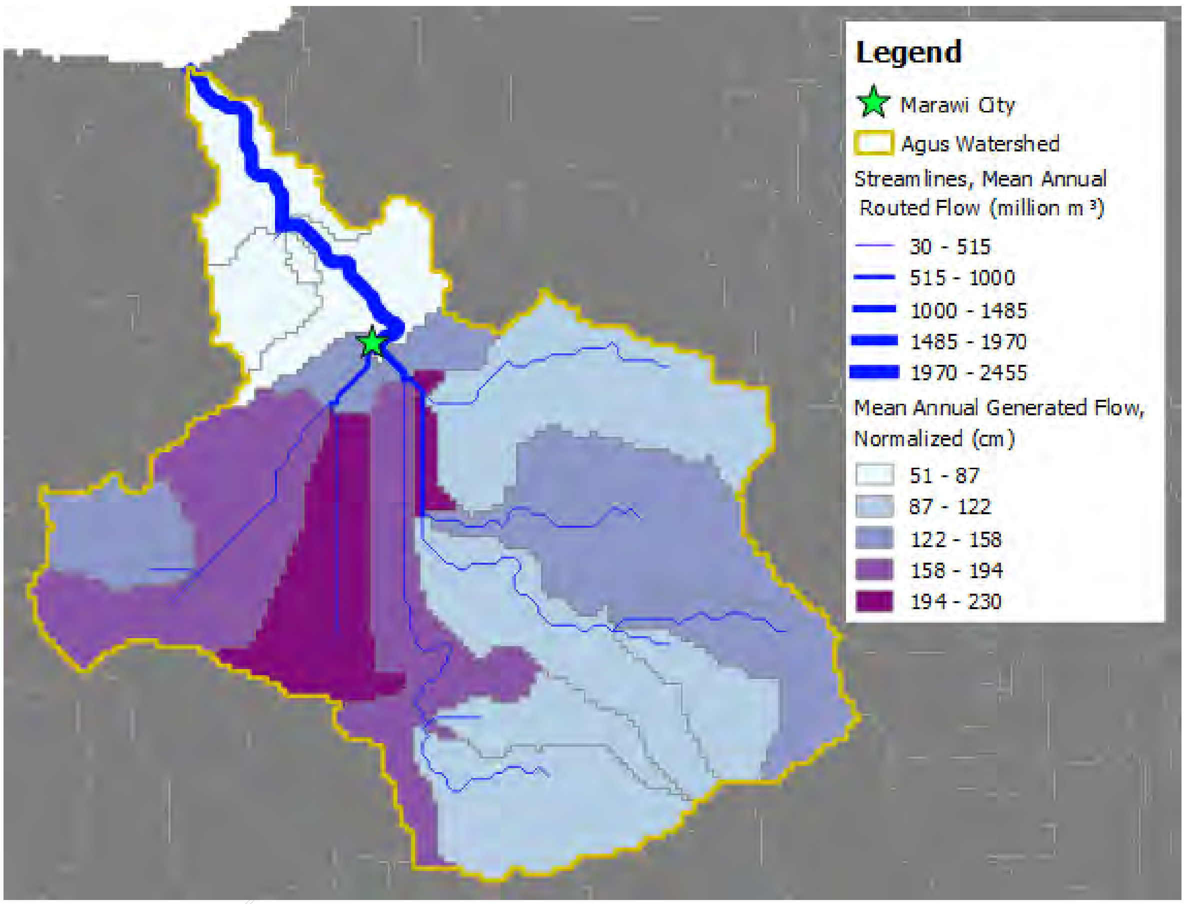

Figure 20. Flow Generation Normalized by Catchment Area and Streamlines of Routed Flow in the Agus Watershed

Flow generation is normalized to catchment area in **Figure 19** to illustrate areas of high water generation. Darker catchments create more water than lighter catchments. Streamlines are sized according to routed flow, representing the accumulation of generated water as it moves through the basin. Most streamflow generation occurs in catchments containing Lake Lanao and the forested, high-elevation areas in the southeastern portions of the watershed.

Precipitation is the only flux of water entering the watershed in Hydrologic Resources Assessment Model. Rain that falls in forested, undeveloped areas either runs off the land surface as surface water or infiltrates the shallow groundwater table. Once in the shallow groundwater table, water can either flow laterally to enter stream channels as surface water or flow downward to enter deep groundwater. The slow percolation of water into stream channels, referred to as "baseflow," creates surface water flow during periods without precipitation and is an important buffer against drought and water shortage. However, water in the shallow groundwater table can be depleted through plant root uptake and ET. By contrast, rain that falls onto impervious surfaces or in open bodies of water runs off directly as streamflow. This form of flow generation is responsible for the large spike in flows after precipitation events.

The forested southeastern portions of the Agus River receive the most annual precipitation in the basin (**Figure 19**) but do not generate the most surface water flow, because of increased ET due to forested plant uptake and groundwater infiltration. In the current Hydrologic Resources Assessment Model, neither of these fluxes occur in the open water of Lake Lanao. The team could later explore methods for improving the representation of Lake Lanao in the overall water budget of the Agus River. The steep, northwestern catchments of the watershed downstream of Lake Lanao have the least precipitation and, correspondingly, generate the least surface water. Nevertheless, it has the highest amount of total streamflow due to the accumulated contributions of upstream flow generation.

The Agus River is seasonal in flow (**Figure 21**). Monthly patterns in streamflow volumes largely match the monsoon timing typical of northeastern Mindanao. Future work in this study will look at interannual variability of flows throughout the watershed to quantify the impact and risk of extreme floods and droughts.

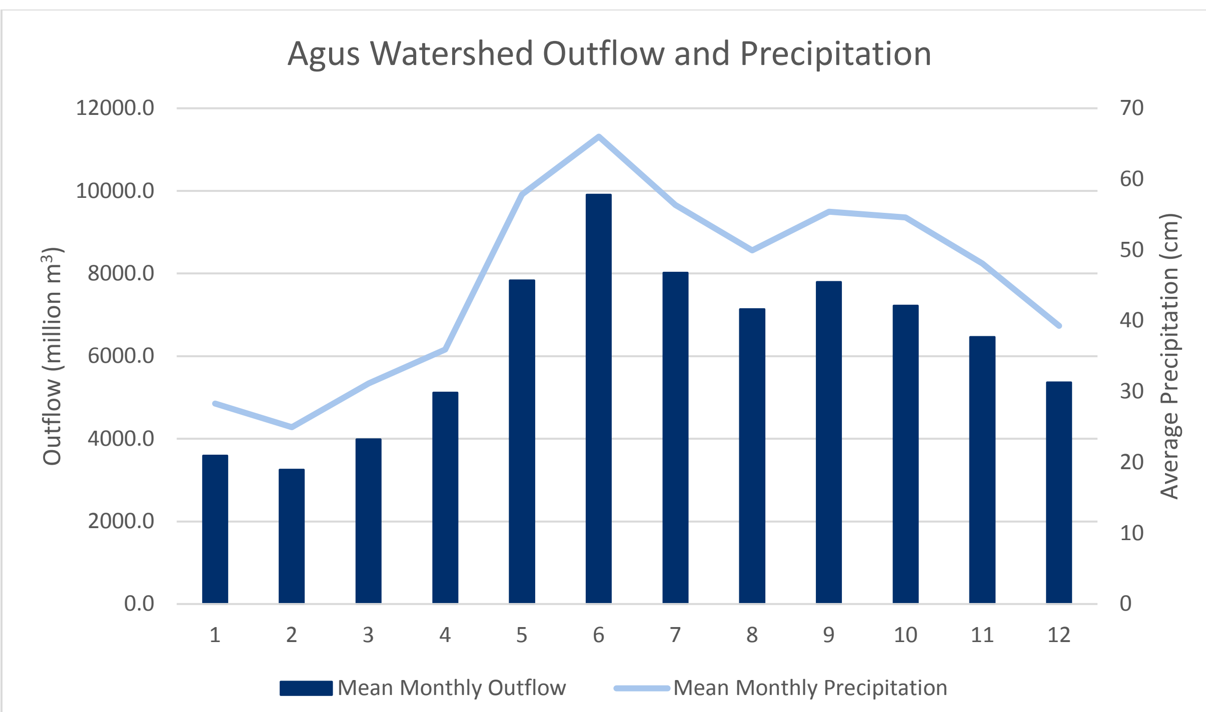

Figure 21. Mean Monthly Outflow and Precipitation for the Agus Watershed

Climate Change Scenario

The Climatology and Agrometeorology Division of PAGASA provided projected mid-century changes in temperature and precipitation under two climate scenarios (RCP8.5, high emissions, and RCP4.5, moderate emissions) for all provinces in Mindanao. The expected changes for the two provinces containing the Agus River (Lanao del Sur and Lanao del Norte) are illustrated in **Figures 22** and **23**.

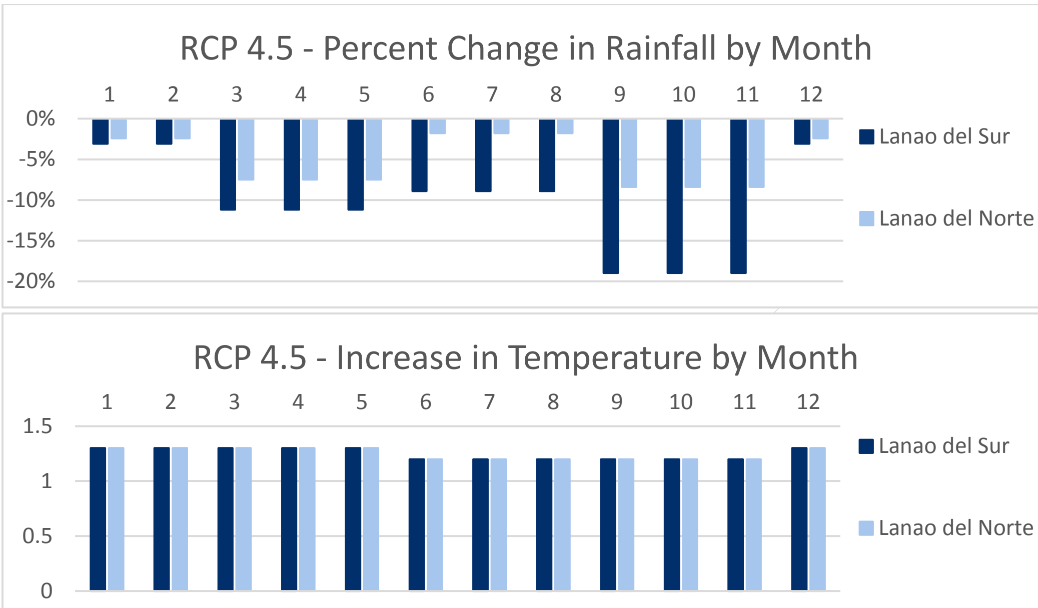

Figure 22. Projected Mid-Century Changes in Temperature and Precipitation for RCP4.5 Moderate Emissions Scenario

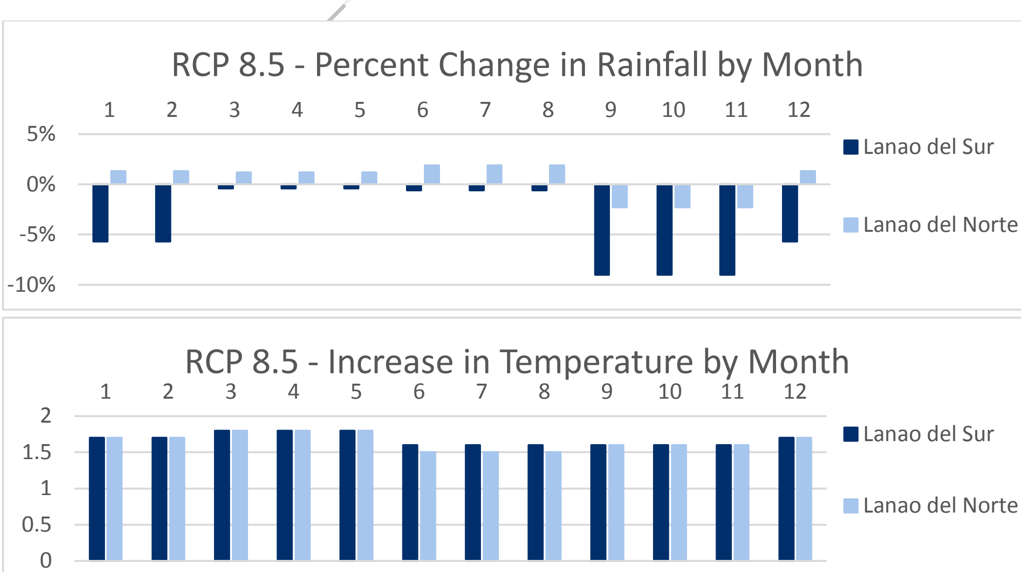

Figure 23. Projected Mid-Century Changes in Temperature and Precipitation for RCP8.5 High Emissions Scenario

Climate Change Results

Under both climate change scenarios, surface water yield is decreased for all of the Agus River watershed. The RCP4.5 Moderate Emissions scenario results in approximately 20 percent lower yield (**Figure 22)**, whereas the RCP8.5 High Emissions scenario results in 7 percent lower yield (**Figure 23**). The decrease in flow is relatively evenly distributed across the watershed (**Figure 24**).

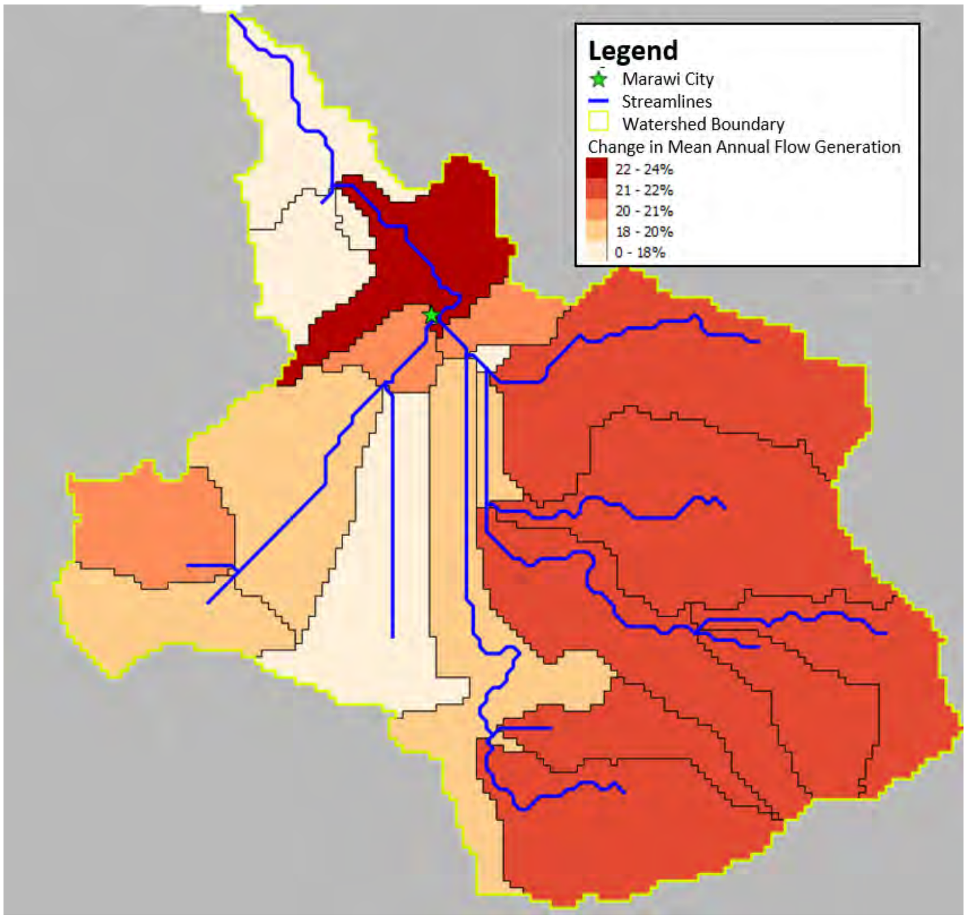

Figure 24. Change in Mean Annual Generated Flow For RCP4.5 in the Agus River Watershed

Seasonality of flow in the river will intensify under both climate change scenarios (**Figure 25**). Although the total volume will likely decrease, a greater portion of the flow will occur from June to November, resulting in lower flow from December to May. The existing storage and hydropower projects on the Agus River will provide some buffer against this shift in seasonality, but careful management will be necessary to mitigate the likely increase in seasonal droughts and floods.

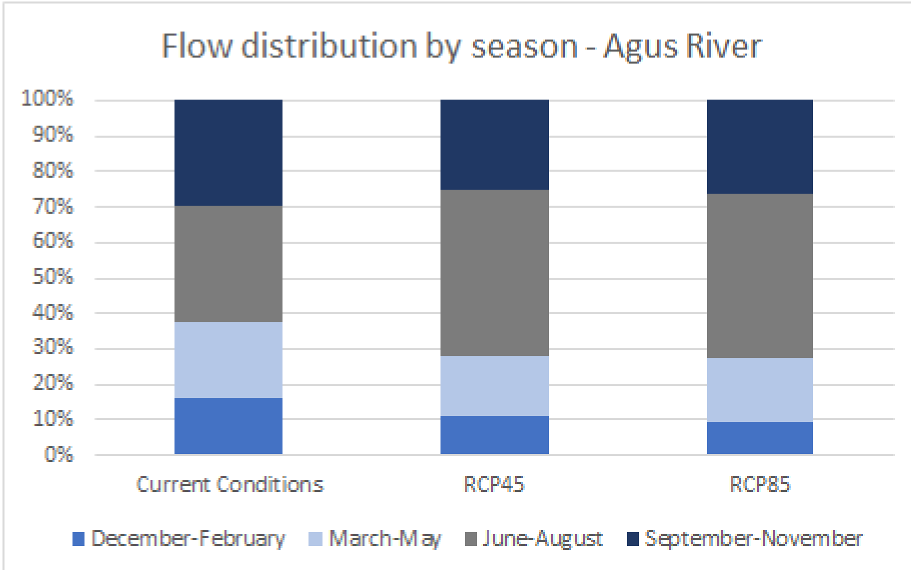

Figure 25. Seasonality of Flow Under Current and Climate Change Conditions for the Agus River

Conclusions

The Agus watershed has a relatively high surface water yield and supply reliability relative to other river basins on Mindanao (Section 2), largely due to its high annual precipitation and forested headwaters. Most of the flow comes from the mountains due to orographic lifting, with relatively little flow generation occurring in the lower portion of the watershed. River flow is relatively evenly distributed throughout the year, with 60 percent occurring from June to November and the remaining 40 percent from December to May. Climate change will result in less water for the watershed and a shift in seasonality. Decreases in mean annual flow of up to 20 percent are expected under the downscaled RCP4.5 Moderate Emissions scenario developed by PAGASA. Shifts in timing will intensify as well, with a greater portion of annual flow occurring from June to November.

SECTION 4: MINDANAO CASE STUDY: HYDROECONOMIC TRADEOFF ANALYSIS

A. INTRODUCTION

B-LEADERS also complemented the hydrologic resources assessment model with a hydro economic model to assess water, energy, and food tradeoffs of alternative future development pathways (and environmental change scenarios). This economic simulation is a proof of concept analysis to demonstrate a framework and explain that scenario assumptions and input data can be tailored to specific analysis. The simulation framework is a hydroeconomic tool that explicitly links hydrologic flow from the hydrologic resources assessment model with an assessment of water demands across different user groups, disaggregated spatially and temporally, as well economic benefits associated with particular water uses (e.g.,the value of water used for irrigation). The team estimated the potential economic costs of spatially-disaggregated water deficits given data constraints. Hydroeconomic frameworks are increasingly utilized to project potential economic tradeoffs of alternative future scenarios.

Hydroeconomic frameworks can be applied at a local scale (e.g., Jeuland et al., 2014; Baker et al., 2016) with greater geographic resolution and a local policy focus, or on a country or continental scale for large-scale resource planning studies (Kahlil et al., 2018). By linking simulated hydrologic flow data from the hydrologic resources assessment model with an economic assessment framework that represents water demand —and, to some extent, costs and benefits of competing uses—the framework can assess potential tradeoffs among water, energy, and food systems under different scenario assumptions.

Based on feedback from several stakeholder meetings held in May 2018 in Mindanao and Manila, hypothetical future scenarios were created to represent differences in possible household water demand (baseline and expanded population growth), energy generation (high renewable energy expansion and high coal expansion), and irrigation (baseline and expanded rice irrigation). Furthermore, we assessed baseline and climate change scenarios using the hydrologic resources assessment model simulations under RCP 4.5 and 8.5 conditions. Different assumptions were tested in interactions with one another to create a large factorial experimental design of alternative future scenarios. Results from hypothetical scenarios were evaluated for relative water deficits and potential economic outcomes resulting from these development or climate change scenarios relative to current water consumption and production patterns.

For each scenario, we analyzed potential water deficits (by month) and total economic costs associated with those deficits. Select results were incorporated into a data visualization dashboard so that users can identify "hot spots" where economic costs from water deficits are most likely to occur. Development steps that have been accomplished since the B-LEADERS team visited Mindanao in late May include the following:

1. Development of scenario design to complete the water-energy-food nexus tradeoff analysis based on stakeholder feedback;
2. Combined water demand analysis with the hydrologic resources assessment model simulation data to simulate "cumulative" water availability from upstream to downstream and in each watershed;
3. Incorporation of facility-level data on generation capacity, water requirements that vary by facility type, and monthly generation;
4. Parameter development of baseline, high renewable, and high coal energy generation scenarios for all facility types;
5. Updated crop water requirements to reflect local stakeholder input and more accurately represent current irrigation practices;
6. Quality-checked spatial allocation of population data in the hydrologic simulation framework against population density maps;
7. Created parameters to account for proportion of domestic water supplied by surface water based on data from the Philippines Statistical Authority (PSA);
8. Added population growth scenarios to the analysis (water demand is simulated at current population estimates, moderate population growth in 2030, and high population growth in 2030);
9. Changed per capita domestic water consumption requirements based on input from the NWRB;
10. Incorporated province-level groundwater consumption data for agriculture to improve demand estimates for surface water for irrigation;
11. Continued development of economic cost and benefit data across alternative water uses and technologies (e.g., crops, energy facility types);
12. Improved hydrologic simulation process to capture cumulative water deficits in different watersheds; and
13. Developed initial data visualization dashboard for simulation results.

B. DATA AND MODEL DESCRIPTION

This section provides an overview of the data and model that were developed for this case study application. We discuss the hydrologic components, including use of the hydrologic resources assessment model to develop pristine inflow estimates, and then present the water demand estimates for the agriculture, household, and energy sectors. Finally, we provide details of the economic simulation model structure and some sample results from key scenarios included in the data visualization dashboard. Please also refer to **Annex C: Tradeoff Analysis Data Tables**.

The Hydrologic Resources Assessment Model

The hydrologic resources assessment model presented above uses an interpolated climate dataset based on temperature and precipitation data from specific locations within the watershed to estimate pristine inflows at the subcatchment level. Within the study region, 844 individual subcatchments are modeled. Pristine inflows at each subcatchment create the supply side of the economic framework. Multiple water availability scenarios are estimated using Hydrologic Resources Assessment Model, with three scenarios included in the economic model (average historical availability, RCP 4.5, and RCP 8.5).

Hydroeconomic Model Description

The following subsections outline the various data sources and structural equations that make up the hydroeconomic simulation model. The hydroeconomic model used in this study takes a simulation approach to estimate exogenous demand targets for the three sectors of interest (households, agriculture, and energy), then calculates a water balance within each catchment based on inflows and total demand for water. Next, an allocation decision across users is implemented within catchments that have a negative water balance. This allocation mimics the priorities set forth by NWRB, which give priority to households, followed by the agriculture sector, and last, the energy sector.

Hydroeconomic Model – Water Flow

Pristine inflow data and the general node schematic (node names and mapping between upstream and downstream nodes) from the hydrologic resources assessment model were transferred to the Generalized Algebraic Modeling System (GAMS) software to parameterize the simulation routine. GAMS uses the pristine inflows as the primary parameter for determining overall water availability in the region. Water flow between nodes is endogenous in the model. That is, the model solves for the amount of water that flows from upstream to downstream based on precipitation, inflows, and water demands within each node. The simulation routine first calculates total demand in each node, then calculates a water balance based on natural routed flow through each node and all upstream demands. This calculation allows for identification of nodes with water shortages. Nodes with greater demand than supply have systematic reductions to the demand sectors.

Hydroeconomic Model – Domestic Sector

Human consumption of water is implemented in the model as an exogenous demand within each catchment. Catchment population is calculated based on a 90-meter resolution population density map from PSA. The populations contained in catchments that are not modeled in the hydrologic resources assessment model were assigned to an adjacent catchment with the highest monthly flow rate. Per capita water use was calculated from 2017 urban water consumption rates collected by the Local Water Utilities Administration (LWUA). In Mindanao, water consumption ranges from just over 100 liters per capita per day (l/c/d) to around 170 l/c/d (**Table C-4** in **Annex C**). PSA also collects data on the number of households using different water sources for each region. With this data we calculated the percent of households relying on surface water resources (**Table C-5** in **Annex C**). Total surface water reliance was calculated as the sum of the protected spring, unprotected spring, and lake rain river and others. In catchments where domestic demand cannot be met even after reductions to the energy and agriculture sectors have been made, equal-sized reductions are made across all users to reach an equilibrium and maintain hydrologic continuity. This approach does not recognize spatial or priority patterns within a single catchment, but instead presents average reductions across all users within a catchment.

Hydroeconomic Model – Agriculture Sector

While most agriculture in Mindanao is rainfed, a significant portion of the productive land area in the region is irrigated due to the seasonality of the climate. Additionally, across the country the agriculture sector is the largest user of water. In 2009, about 82 percent of total consumption was for irrigation (United Nations Food and Agriculture Organization (FAO)[4]). To reflect agricultural demands for water in the study area, an agriculture sector submodel was developed and calibrated to local agricultural production data. The model estimates the production of main agriculture commodities and the water required for irrigated agriculture across Mindanao. Development of the agriculture sector component of the simulation model has two main components:

- Agricultural production possibilities, and
- Estimation of crop irrigation requirements.

Agricultural production possibilities

Agricultural production possibilities are represented for the following 11 crops: banana, sugarcane, corn, coconut, mango, pineapple, rice (palay), cacao, cabbage, tomato, and potato. In total, these crops account for more than 90 percent of crop production area in Mindanao.

Data on agricultural production, harvested area, crop value, and yield for Mindanao were collected from PSA.[5] These 11 crops were chosen because they are the most prevalent crops grown in the study region (by hectares harvested). Coconut, corn, and rice are the most prevalent of the 11 crops, with 1,835,829 hectares, 1,428,897 hectares, and 1,165,268 hectares, respectively, in 2017 (**Table 5**).

Table 5. Harvested Crop Area in Mindanao, 2017

Crop	Harvested Area (hectares)
Coconut	1,835,829
Corn	1,428,897
Rice	1,165,268

[4] http://www.fao.org/nr/water/aquastat/countries_regions/PHL/
[5] http://countrystat.psa.gov.ph/

Crop	Harvested Area (hectares)
Banana	254,580
Sugarcane	114,519
Mango	76,801
Pineapple	53,305
Cacao	15,775
Tomato	4,466
Potato	1,907
Cabbage	1,317

Agriculture area within each catchment was calculated using land cover data from NAMRIA. NAMRIA created a geospatial shapefile that delineates land use across the Philippines. The sum of annual cropland and perennial cropland was used to estimate the total cropland area within each catchment in the study region. Crop-specific data were downloaded from the PSA CountrySTAT database, such as yields, harvested area, and production. These data were collected at the provincial level, then spatially assigned to each catchment based on location. For catchments that overlapped multiple provinces, data were used from the province where most of the catchment area was located. Because of limited data on the spatial distribution of specific crops, crop mix assumptions were made for both rainfed and irrigated agriculture in the region. The crop mix for rainfed agriculture was estimated for each province in the study region using data from PSA CountrySTAT (**Table C-1** in **Annex C**) based on historical harvested area. The crop mix for irrigated agriculture was estimated using country-level data from FAO (**Table C-2** in **Annex C**). The percent of agriculture area equipped for irrigation was assigned to each catchment based on provincial-level data collected by the National Irrigation Administration (NIA) in 2016 (**Table C-3** in **Annex C**). Historical yields for each crop were downloaded from PSA for each province during 2006–2017. Within the model, higher yields were assigned to irrigated crops than to rainfed crops. Irrigated agriculture was assigned the highest historical yield within each province, whereas rainfed agriculture was assigned the lowest historical yield within each province.

Crop irrigation requirements

A standard FAO methodology was applied to estimate reference crop ET. The Hargreaves equation (ETo) was used to estimate ET at each catchment:

$$\boldsymbol{ETo = 0.0023(Tmean + 17.8)(Tmax - Tmin)^{0.5} R_a} \qquad \textbf{Eq. 1}$$

where T_{mean}, T_{max}, and T_{min} are daily mean, maximum, and minimum temperature for each catchment, which were developed from climate station data provided by PAGASA, and R_a is the daily solar radiation from the National Aeronautics and Space Administration (NASA) Atmospheric Science Data Center.

Next, using a crop coefficient approach, a monthly crop water requirement, or crop ET, ET_c, was calculated by multiplying the reference crop ET by a crop coefficient, K_c:

$$ET_c = K_c\, ET_0 \qquad \textbf{Eq. 2}$$

Here, K_c is the crop coefficient that varies by crop type, climate, soil evaporation, and crop growth stages using data from FAO Irrigation and Drainage Paper 56 (Allen et al., 1998). In general (and for this analysis specifically), the crop-growing period is divided into four distinct stages: initial, crop development, midseason, and late season. We estimated crop water requirements for each of these stages and then developed per-hectare irrigation requirements, by month, for each simulation year.

This crop water requirement can be supplied by rainfall, irrigation, or a combination of the two. Crop yield can reach its highest potential yield, Y_c, when the crop water requirement is fully satisfied. Depending on the actual water applied and effective rainfall, actual crop yield, Y_a, is calculated by the following equation (Vaux & Pruitt, 1983):

$$\left(1 - \frac{Y_a}{Yc}\right) = K_y \left(1 - \frac{ETa}{ETc}\right) \qquad \textbf{Eq. 3}$$

where Y_a and Y_c stand for actual yield and maximum yield, respectively, and K_y is the crop yield response factor representing the effect of a reduction in ET on yield losses. K_y is drawn from FAO Irrigation and Drainage Paper 66 (Steduto, Hsiao, Fereres, & Raes, 2012) and ranges from 0.95 to 1.27 for the 11 crops in Mindanao. Cacao and cabbage (K_y = 0.95) are the most resistant to drought, while corn (K_y = 1.25) and banana (K_y = 1.27) are the least resistant. ET_a is the actual crop ET, which is the sum of effective rainfall and effective irrigation water. Based on this equation, we can estimate how crop yield responds to irrigation. For each catchment, climate data are assumed to be same as the climate in the nearest weather station. Based on the precipitation, we calculated the effective rainfall.

Using Equation 3, we estimated yields under three assumed irrigation conditions: high irrigation, low irrigation, and dryland conditions. To estimate high irrigation yields, we took the highest observed yield for each crop and province between 2006 and 2017 and estimated the additional monthly irrigation water requirements that would be needed to meet that yield target in each simulation year. This value was then multiplied by the total area for each irrigated crop within each catchment to estimate total demand for irrigation water every month.

The main advantage to this approach is that irrigation inputs are tied to climate inputs, meaning we can estimate the demand for irrigation water under varying climate scenarios.

In the case that the demand for water from the household and agriculture sectors is greater than available supply, irrigation water is reduced until demand and supply are equal. The reduction in water supplied to agriculture is then applied proportionally to all irrigated crops within the catchment. We assumed that these reductions in irrigation water lead to reduced yield of the current planted crop mix. The proportion of irrigated agriculture land area that does not receive additional irrigation water realizes yields associated with rainfed crops. Because this is a simulation procedure and not an optimization model, crop switching does not occur when reductions to irrigation water supply are made.

Hydroeconomic Model – Energy Sector

The final sector modeled was the energy sector. In Mindanao, surface water is used to generate energy (through hydropower) and is used as an input for thermoelectric facilities for cooling. To estimate water demand for the energy sector, first energy generation units (EGUs) were assigned to their respective catchments. Then, the consumptive use of water for each EGU type was collected from Tidwell and Moreland (2016) (**Table C-6** in **Annex C**). For facilities that are located in catchments along the coast, it was assumed that cooling needs were met using saltwater, and thus consumptive use was set to zero. Data for historical energy generation by EGU were collected from the Philippine Power Situation Report (DOE, 2016). Gross generation by plant type was measured from 2003–2016 for Mindanao. The proportion of total generation by EGU type was calculated, and each power plant in Mindanao was estimated to generate an amount of energy based on the proportion of its installed capacity. Annual generation at each facility was then averaged into a monthly generation total and multiplied by its consumptive use factor to determine total water demand.

When total demand for water in a catchment is greater than water supplied, the energy sector is the first to receive reduced access to water. All EGUs located within shortage catchments are forced to reduce energy generation by 80 percent. This allows facilities to remain open and run a minimum load to protect infrastructure. The reduced generation from these facilities is then assigned proportionally to all other EGUs with capacity based on historical generation amounts.

C. SCENARIO DESIGN

Alternative future scenarios were designed to account for varying levels of development and growth in Mindanao between 2016 and 2030. Three population scenarios, two irrigation scenarios, three energy scenarios, and three climate scenarios were created, for a total of 54 scenarios evaluated. The following sections describe each of the scenarios in each of the sectors.

Climate

Three climate scenarios were included in the tradeoff analysis to incorporate future uncertainty related to GHG emissions. The Baseline scenario uses the average precipitation and temperature results from 1990–2010. The alternative climate scenarios include RCP 4.5 and RCP 8.5 results, which are presented above.

Household

Three household demand scenarios are created, each implementing different population estimates (**Table 6**). The Baseline scenario uses estimates from the population density maps from PSA in 2015 and assumes 1.85 percent annual growth in population[6] to estimate 2018 population in Mindanao. The second scenario, the 2030 Moderate Growth scenario, uses this same growth rate to estimate population out to 2030. The third scenario, the 2030 High Growth scenario, assumes that population grows by 2.5 percent annually until 2030.

[6] 1.85 percent is the annual population growth assumed in the Philippines Nationally Determined Contribution submitted to the United Nations Framework Convention on Climate Change.

Table 6. Estimated Population Totals of Mindanao for Each Scenario

Scenario	Population Served
2018 Moderate Growth	18,636,608
2030 Moderate Growth	22,567,077
2030 High Growth	24,289,418

Agriculture

Two irrigation scenarios were included in the analysis; the first is a baseline irrigated area scenario, the second is an alternative expansion of irrigated area. The Baseline scenario uses NIA 2016 estimates for irrigated area in Mindanao (**Table C-3** in **Annex C**). The alternative future expansion scenario assumes that by 2030, all irrigation infrastructure will increase and the full irrigable land will be equipped for irrigation. By expanding irrigation area, we also assumed that crop mix will shift within each catchment. This is modeled as a shift from rainfed crop mix (**Table C-1**) to irrigated crop mix (**Table C-2**). This shift in crop mix will increase the production of rice significantly in the region (rice is currently produced on almost 90 percent of irrigated land area in the Philippines), which will contribute to the goal of self-sufficiency in rice production set forth by Agriculture Secretary Emmanuel Piñol. For each scenario, the simulation approach calculated total water consumption and production by crop and subcatchment, net benefits from agricultural production, and GHG emissions associated with rice production.[7]

Energy

Three energy generation scenarios were included in this analysis: reference, high coal, and high renewables. Total generation is assumed to grow at 8 percent, consistent with the Philippines Energy Plan 2017–2040 (DOE, 2017). Total generation nearly triples by 2030, from 11,345 gigawatt hours (GWh) in 2016 to 33,322 GWh by 2030. **Table 7** summarizes the relative share of generation by plant type in 2030 across the three energy scenarios.

Table 7. Share of Generation by Plant Type in 2030

Plant Type	Reference	High Coal	High Renewables
Coal	64%	71%	70%
Oil-based	17%	14%	9%
Natural gas	4%	0%	2%
Geothermal	3%	3%	2%
Hydro	11%	11%	12%
Biomass	0.03%	0.03%	2%
Solar	0.23%	0.23%	3%

[7] To calculate rice cultivation emissions per hectare, we used the median value for the Philippines from the following International Panel on Climate Change (IPCC) report, converted to metric tons of carbon dioxide equivalent (mtCO_2e) per hectare: https://www.ipcc-nggip.iges.or.jp/public/gp/bgp/4_7_CH4_Rice_Agriculture.pdf

Plant Type	Reference	High Coal	High Renewables
Wind	-	-	-
Total	100%	100%	100%

Note: Table percentages may not sum to 100 percent due to rounding.

The reference scenario reflects the current capacity expansion plan for Mindanao, detailed in the Philippines Energy Plan 2017–2040 (DOE, 2017). Coal accounted for 43 percent of Mindanao's power generation in 2016. DOE's energy plan calls for significant expansion in coal-based generation capacity over the next two decades, representing nearly 64 percent of total electricity generation by 2030 (**Table 7**). Conversely, generation from renewables experiences only limited growth, accounting for less than 15 percent (11 percent from hydropower) in 2030. The balance comes from oil and natural gas. Biomass, solar, and wind provide only a small portion of projected renewable energy growth relative to hydropower.

The high coal scenario represents an increased share of coal-based power generation above the reference case. For this report, we have assumed that the additional use of coal will lead to a reduction in the use of natural gas and oil for power generation. Generation from renewables is unchanged under the high coal scenario.

Finally, the high renewables scenario reflects high growth in the capacity to supply power from renewables. Under this scenario, renewables account for nearly 20 percent of total generation by 2030. Biomass and solar generation expand rapidly compared with other scenarios, accounting for 5 percent of total generation by 2030. Hydro and geothermal remain fixed over the time period, accounting for 14 percent of total generation. The balance (~80 percent) is still supplied by coal, oil, and natural gas.

D. RESULTS AND DISCUSSION

The following sections present modeled results the Baseline scenario. Next, the analysis presents key results from a sensitivity analysis of each sector-specific scenario deviation. In this section, we compare scenario-specific outputs to the baseline to show consumption changes due to varying levels of sector-specific demand growth and climate change. The population-growth sensitivity scenarios use the average climate scenario and hold demand at baseline levels for the agriculture and energy sectors. The irrigated-agriculture expansion sensitivity scenarios presented use the baseline demand for population and energy sectors under average climate conditions, but include full irrigation expansion. The energy-sector sensitivity scenarios use average climate conditions with baseline demand from the population and agriculture sectors, but implement the high carbon energy future or the high renewable energy future. Finally, the climate-change sensitivity scenarios compare water use and production outcomes in the Baseline demand scenarios across alternative climate futures. These sector-specific results show how investment and macroeconomic changes in individual sectors can induce potential tradeoffs in other water-intensive sectors.

Finally, we provide results of a hypothetical High Water Demand scenario to show tradeoffs when all sectors pursue water-intensive futures (the parameters used for each sector in the Baseline and

High Water Demand scenarios are presented in **Table 8**). The Baseline and High Water Demand scenarios present the highest and lowest demand targets for surface water in the region, and can be thought of as the "bookends" of possible outcomes. There are some inconsistencies in how the High Water Demand scenario is created (e.g., linking a high emissions RCP with high renewable energy expansion); nevertheless, we present these results for illustrative purposes.

Table 8. Summary of Sector Parameters Used in the Baseline and High Water Demand Scenarios

Sector	Baseline Scenario	High Water Demand Scenario
Climate	Average	RCP8.5
Population	2018 Moderate Growth	2030 High Growth
Agriculture	Current Irrigation Extent	Max Irrigation Expansion
Energy	Reference	High Renewables

Baseline Results

Baseline results rely on average historical climate conditions and estimated current demand for water across households, agriculture, and energy sectors. Baseline demand estimates for each sector and baseline water balance are shown in **Figures 26** through **30**, which reflect total annual demand for water across each sector. Water demands are spatially disaggregated to reflect the distribution of existing infrastructure, land use, and populations. Energy sector water demand (**Figure 28**) is confined to just a few subcatchments in the study area, whereas agricultural demand is distributed more evenly across the landscape consistent with current crop production levels. Household demand is clustered around urban and rural populations. In some instances, heavy demand for agricultural water occurs well upstream of population centers, which can increase competition for resources between agriculture and household consumption, and may result in water shortages for households.

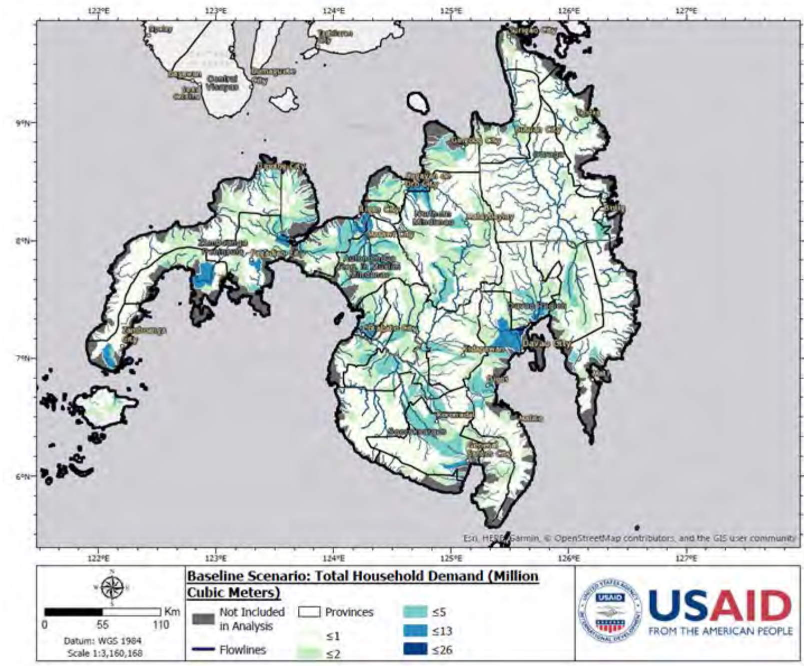

Figure 26. Baseline Scenario: Estimated Total Household Water Demand

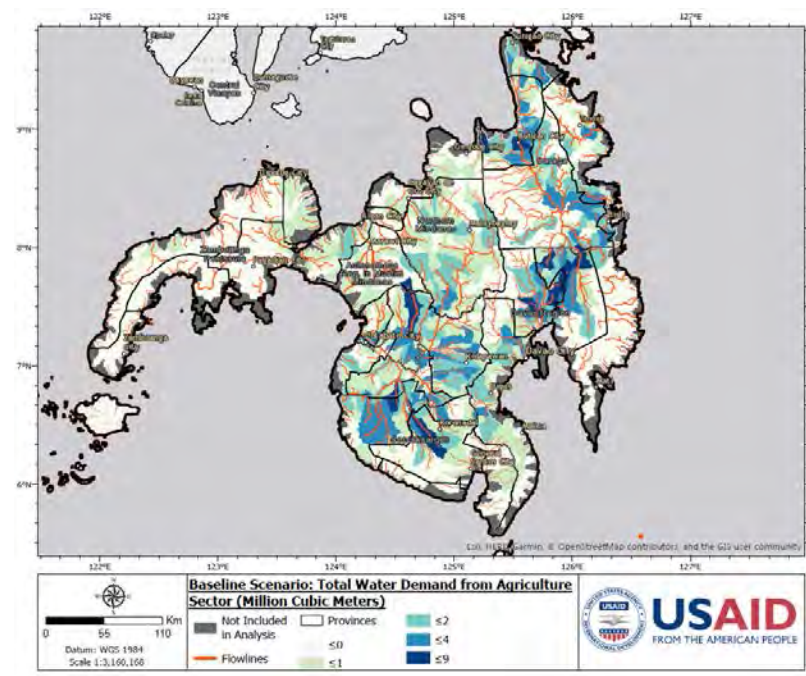

Figure 27. Baseline Scenario: Estimated Annual Agriculture Sector Water Demand

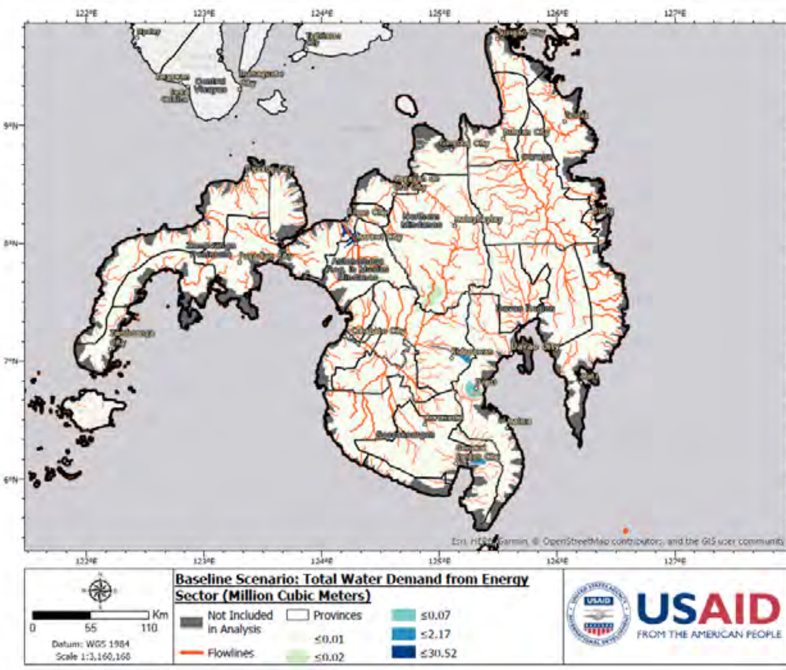

Figure 28. Baseline Scenario: Estimated Total Energy Sector Water Demand

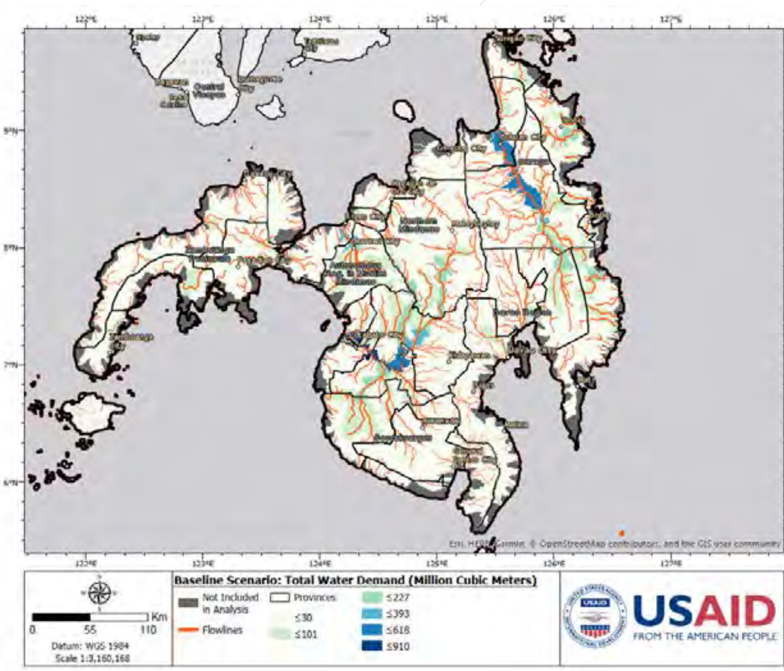

Figure 29. Baseline Scenario: Estimated Total Water Demand

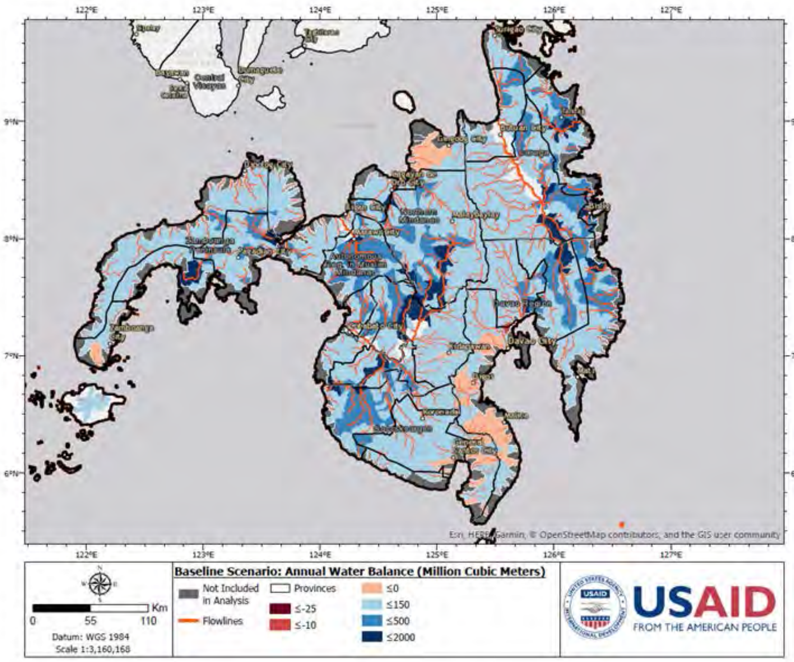

Figure 30. Baseline Scenario: Annual Water Balance

These results are modeled to represent near-current levels of water demand across the three main user groups of water and historical climate conditions. **Figure 30** presents the water balance (annual supply minus demand) in each catchment for the Baseline scenario. Most catchments that have water shortages currently have large land areas dedicated to agriculture with irrigation infrastructure installed. Additionally, heavily populated areas may be vulnerable to water shortages, especially if irrigation needs are high upstream. When shortages occur in a catchment, the hydroeconomic model first restricts water access to the energy sector in that catchment (by implementing an 80 percent reduction in energy generation and reallocating generation to facilities that have adequate water supplies). If the shortage is not resolved, the agriculture sector must then restrict water use in the amount equal to that of the shortage and, ultimately, if this measure does not resolve the shortage, households will be forced to reduce consumption.

In the Baseline scenario, annual demand for water from households is around 600 million cubic meters (m^3). This equals about 88 l/c/d of water supplied by surface water sources. Annually, this exogenous demand target is met about 85 percent of the time (**Table 9**). The lowest rates of water supplied to households occur in March and May, when about 80 percent of demand is met across the region (**Table 10**). March has the lowest routed flow of any month across all of Mindanao; in May, relatively high levels of irrigation are in demand upstream of major population centers.

Table 9. Total Household Demand for Water, Amount of Water Supplied to Households, and Average Per Capital Water Suppied

	Total Demand (million m³)	Total Supplied (million m³)	Demand Met	Total Population Served (million)	Per Capita Water Supply, liters per capita per day (l/c/d)
Baseline	601.89	509.05	85%	18.64	74.83

Table 10. Monthly Per Capita Water Supply in Baseline Scenario

Month	Total Supplied (million m³)	Consumption to Supply Ratio	Per Capita Water Supply (l/c/d)
January	45.77	0.90	79.23
February	41.96	0.91	80.41
March	40.74	0.80	70.51
April	41.05	0.83	73.42
May	40.15	0.79	69.50
June	44.27	0.89	79.18
July	42.91	0.84	74.27
August	42.69	0.84	73.90
September	44.06	0.89	78.80
October	41.53	0.81	71.88
November	41.68	0.84	74.56
December	42.24	0.83	73.11
Monthly Average	509.05	0.85	74.83

The agriculture sector is the largest consumer of water in the Philippines. According to FAO, about 82 percent of water consumed in 2009 was for irrigation and aquaculture. The hydroeconomic model assumes that irrigation requirements are equal to the full water requirement estimates calculated from FAO minus rainfall each month. This assumption that the optimal agronomic amount of water is supplied to each crop on irrigated land does not recognize the marginal benefits from agriculture, but instead treats irrigation as a binary choice. This can lead to higher demand estimates for the agriculture sector than if irrigation rates were treated as endogenous decision variables for each crop and subcatchment.

In the Baseline scenario, about 95 percent of the modeled demand for irrigation water is supplied (**Table 11**). In this scenario, very few catchments are forced to reduce access to irrigation water due to shortages. These catchments are located southeast of Davao city. The modeled results show that, by weight, sugarcane and banana are the most-produced commodities in Mindanao (**Table 12**); however, rice cultivation consumes the largest amount of water. Additionally, rice cultivation produces large amounts of GHG during its growth cycle (an average of 6.75 $mtCO_2e$ per hectare in the Philippines according to the IPCC[8]), and a tradeoff may be necessary to meet the goal of self sufficiency in rice production (estimated CO2e emissions are presented in **Table 13**). By assuming an average emission rate per hectare of rice production, these results do not recognize the mitigation potential of alternative rice production technologies such as alternating wetting and drying—although such production practices could require more net water consumption per hectare.

Table 11. Total Demand for Irrigation Water and Amount of Water Supplied to Irrigation

	Baseline
Total irrigation water demand (million m^3)	588.67
Total irrigation water supplied (million m^3)	557.29
Supply to consumption rate	0.95

Table 12. Modeled Agriculture Production (1,000 Metric Tons)

Crop	Total Production
Bananas	5,170
Cabbage	21
Cacao	4
Coconut	4,263
Corn	2,750
Rice	2,192
Mango	124
Pineapple	2,431
Potato	29
Sugarcane	5,426
Tomato	78

Table 13. Estimated CO_2 Emissions from Rice Production (million $mtCO_2e$)

	Rice Emissions
Baseline	2.30

As a whole, the energy sector is the lowest consumer of water in Mindanao (modeled water demand for the energy sector, total water supplied to the energy sector, consumption to supply ratio, net generation, and GHG emissions from the energy sector are presented in **Table 14**). The water consumed by this sector is used for cooling in thermoelectric generation systems. Additionally, some surface water is lost from hydropower due to increased evaporation of water when reservoirs are built. In the Baseline scenario, the largest proportion of energy is generated from coal power plants

[8] https://www.ipcc-nggip.iges.or.jp/public/gp/bgp/4_7_CH4_Rice_Agriculture.pdf

(**Figure 31**), most of which are located on the coast. Plants located near coasts have access to saltwater for cooling purposes, which limits the need for fresh surface water. Reductions to the energy sector due to water shortages occur mostly in the geothermal power plant in North Cotabato and the solar power facility in Misamis Oriental. To counteract the reductions in energy generation from these plants, biomass, hydro, natural gas, and coal facilities that have access to surface water are used to increase production, with biomass facilities experiencing the largest proportional increase.

Table 14. Baseline Scenario: Selected Results From the Energy Sector

Plant Type	Total Demand (million m^3)	Total Supplied (million m^3)	Consumption to Supply Ratio	Net Generation (GWh)	Emissions (million mtCO2e)
Biomass	0.02	0.08	3.59	39.50	
Coal	55.30	55.61	1.01	21,387.75	19.25
Geo	2.03	0.41	0.20	212.20	
Hydro	46.84	48.42	1.03	3,828.05	
NatGas	4.57	4.62	1.01	1,477.55	0.60
Oil	17.89	16.34	0.91	5,220.98	3.10
Solar	0.09	0.04	0.48	37.19	

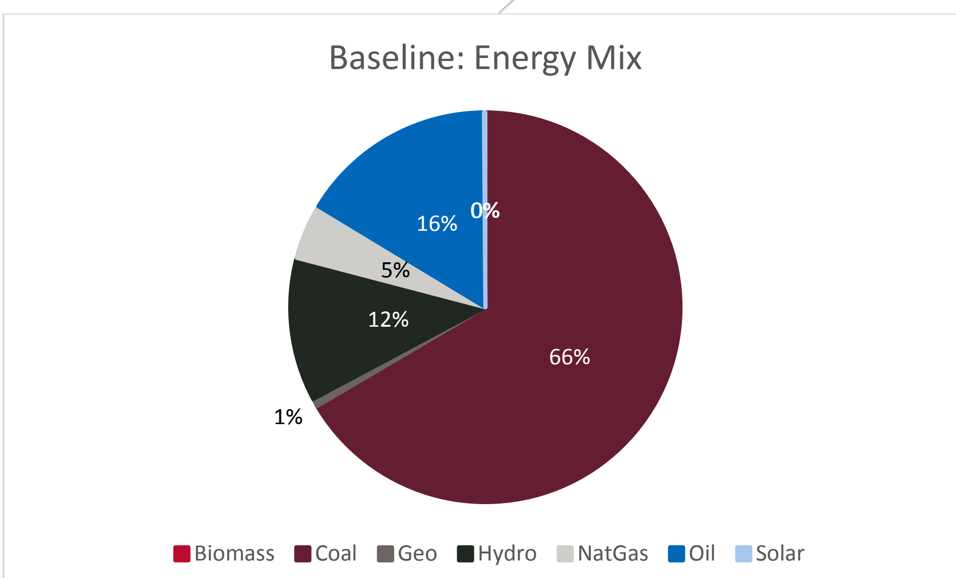

Figure 31. Baseline Energy Mix Based on Available Surface Water

Climate Scenario Results

This section presents the results across the three climate scenarios discussed earlier in this section. Baseline represents average precipitation and temperature. Across the scenarios, population and sector-specific water demands are held constant. We compare water supply and use under RCP 4.5 and 8.5 relative to the Baseline scenario. **Table 15** summarizes the analysis results for the climate scenario.

Table 15. Total Household Demand for Water, Amount of Water Supplied to Households, and Average Per Capita Water Supplied

	Total Demand (million m^3)	Total Supplied	Supply to Consumptio n Ratio	Total Population Served (million)	Per Capita Water Supply (l/c/d)
Baseline	601.89	509.05	85%	18.64	74.83
RCP 4.5	601.89	503.19	84%	18.64	73.97
RCP 8.5	601.89	500.55	83%	18.64	73.58

Table 16 compares the per capita water supply across the three scenarios. Per capita water supply is reduced by nearly 1 l/c/d in the RCP 8.5 scenario compared with the Baseline scenario. Under RCP 4.5, available supply is greater in the summer months than for the Baseline and RCP 8.5 scenarios.

Table 16. Monthly Per Capita Water Supply Across Climate Scenarios

Month	Per Capita Water Supply (l/c/d)		
	Baseline	RCP 4.5	RCP 8.5
January	79.23	77.13	78.73
February	80.41	79.19	78.61
March	70.51	70.99	68.87
April	73.42	71.54	72.10
May	69.50	67.80	67.11
June	79.18	78.30	79.03
July	74.27	75.26	74.08
August	73.90	75.58	73.62
September	78.80	77.35	77.56
October	71.88	70.82	70.00
November	74.56	72.70	72.33
December	73.11	71.65	71.69
Monthly Average	74.83	73.97	73.58

Figure 32 shows the notable decrease in water availability across the climate scenarios RCP 4.5 and RCP 8.5, representing a 1 percent and 2 percent decline, respectively, relative to the Baseline scenario.

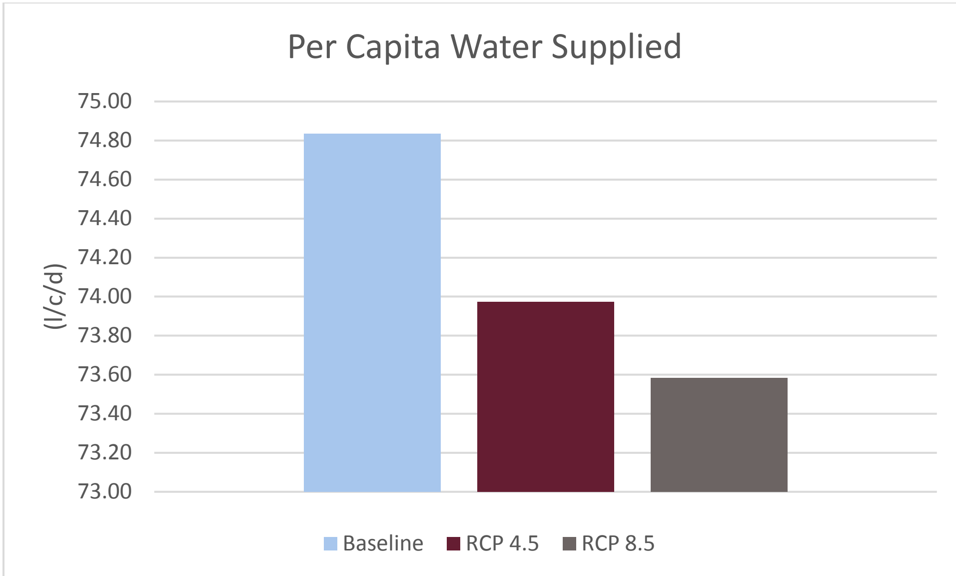

Figure 32. Estimated Annual Per Capita Water Consumption Across Climate Scenarios

Tables 17 and **18** summarize the impacts on the agricultural sector. Under the different climate scenarios, total demand and supply of water for irrigation increase under RCP scenarios. However, the ratio of supply to consumption falls by 2 percent under both RCP scenarios.

Table 17. Total Demand for Irrigation Water and Amount of Water Supplied to Irrigation

	Total Irrigation Water Demand (million m^3)	Total Irrigation Water Supplied (million m^3)	Supply to Consumption Ratio
Baseline	588.67	557.29	95%
RCP 4.5	661.05	612.87	93%
RCP 8.5	674.04	624.32	93%

Table 18 shows production levels across a number of commodities under each climate scenario and **Figure 33** shows the production level differences from the Baseline scenario. A decline in production is evident for all commodities shown below, but bananas, coconut, corn, rice, and sugarcane are the most sensitive to the RCP4.5 scenario. Production levels are only slightly better under the RCP 8.5 scenario.

Table 18. Modeled Agriculture Production (1,000 metric tons)

Crop	Baseline	RCP 4.5	RCP 8.5
Bananas	5,170	5,067	5,067
Cabbage	21	21	21
Cacao	4	4	4
Coconut	4,263	4,166	4,166
Corn	2,750	2,654	2,654
Rice	2,192	2,095	2,102
Mango	124	120	120
Pineapple	2,431	2,429	2,430
Potato	29	29	29
Sugarcane	5,426	5,360	5,361
Tomato	78	77	77

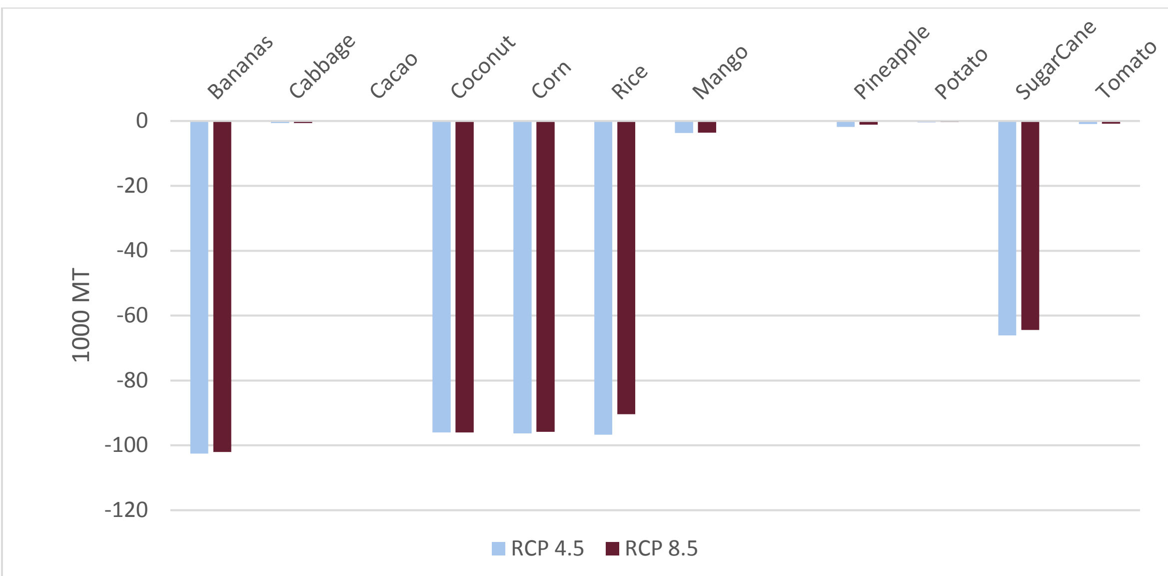

Figure 33. Difference in Agriculture Production in Climate Scenarios From Baseline for Main Agriculture Commodities

Climate scenarios have negligible impacts on the total water supplied and net generation, as **Table 19** shows. The share of generation by plant type remains unchanged across the climate scenarios (**Figure 34 and 35**).

Table 19. Summary of Water Demand, Generation, and GHG Emissions by Plant Type

	Total Supply Water (million m³)			Net Generation (GWh)			GHG Emissions (million $mtCO_2e$)		
Plant Type	**Baseline**	**RCP 4.5**	**RCP 8.5**	**Baseline**	**RCP 4.5**	**RCP 8.5**	**Baseline**	**RCP 4.5**	**RCP 8.5**
Biomass	0.08	0.08	0.08	39.50	39.61	38.70			
Coal	55.61	55.61	55.61	21,387.75	21,387.74	21,387.82	19.25	19.25	19.25
Geo	0.41	0.41	0.41	212.20	212.20	212.20			
Hydro	48.42	48.42	48.42	3,828.05	3,828.04	3,828.12			
NatGas	4.62	4.62	4.62	1,477.55	1,477.55	1,477.56	0.60	0.60	0.60
Oil	16.34	16.34	16.34	5,220.98	5,220.97	5,221.01	3.10	3.10	3.10
Solar	0.04	0.04	0.04	37.19	37.19	37.20			

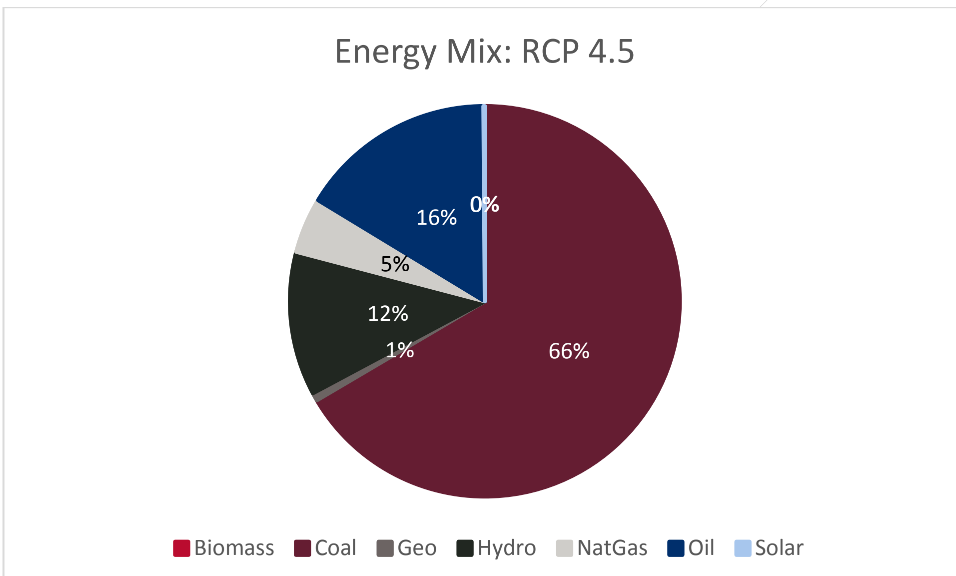

Figure 34. Net Generation by Plant Type under Climate Scenario RCP 4.5

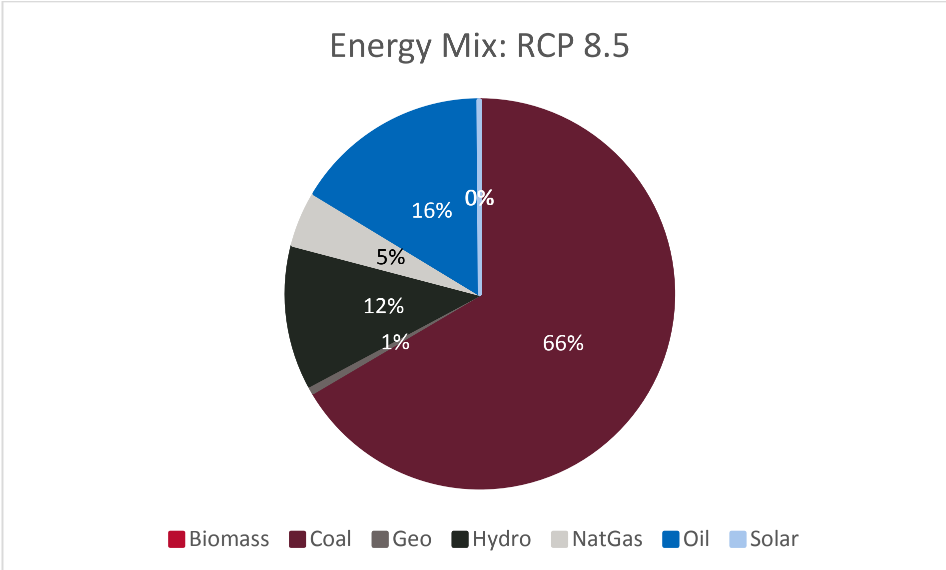

Figure 35. Net Generation by Plant Type under Climate Scenario RC8.5

Household Scenario Results

This section presents the results across the three alternative household demand (i.e., population) growth scenarios discussed earlier in this section. Baseline represents 2018 population, and higher population in 2030 assumes moderate and high growth. **Table 20** summarizes the analysis results for the alternative population scenarios.

Table 20. Summary of Household Water Supply Results under Household Scenarios

	Total Demand (million m³)	Total Supplied (million m³)	Demand Met	Total Population Served (million)	Per Capita Water Supply (l/c/d)
Baseline	601.89	509.05	85%	18.64	74.83
2030 Moderate Growth	728.82	609.33	84%	22.57	73.97
2030 High Growth	784.45	652.81	83%	24.29	73.63

Table 21 shows seasonal variation in water supplied per capita. Relative to the Baseline scenario, the two 2030 growth scenarios are relatively consistent, tracking slightly lower across all months (**Figure 36**).

Table 21. Monthly Per Capita Water Supply across Household Scenarios

	Per Capita Water Supply (l/c/d)		
Month	**Baseline**	**2030 Moderate Growth**	**2030 High Growth**
January	79.23	78.34	78.00
February	80.41	79.43	79.03
March	70.51	69.55	69.16
April	73.42	72.61	72.25
May	69.50	68.65	68.23
June	79.18	78.40	78.06
July	74.27	73.42	73.09
August	73.90	73.06	72.72
September	78.80	78.01	77.72
October	71.88	71.14	70.92
November	74.56	73.71	73.39
December	73.11	72.12	71.78
Monthly Average	74.83	73.97	73.63

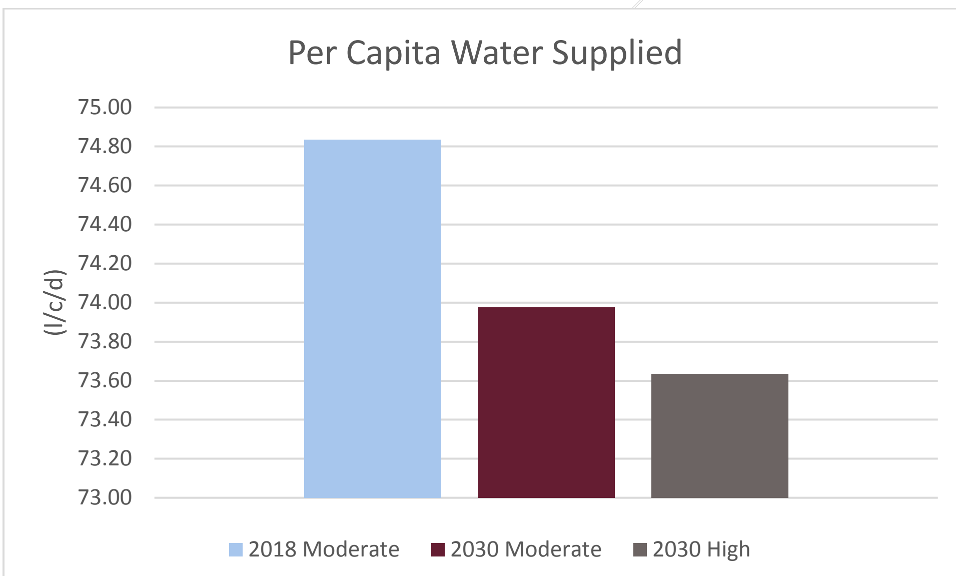

Figure 36. Estimated Annual Per Capita Water Consumption Across household Demand Scenarios

Tables 22 and **23** summarize the impacts on the agricultural sector under alternative household demand scenarios. Water demand for irrigation is fixed, whereas supply decreases slightly under the higher household demand scenarios.

Table 22. Total Demand for Irrigation Water and Amount of Water Supplied to Irrigation

	Total Irrigation Water Demand (million m^3)	Total Irrigation Water Supplied (million m^3)	Supply to Consumption Ratio
2018 Moderate	588.67	557.29	95%
2030 Moderate	588.67	554.92	94%
2030 High	588.67	553.87	94%

Error! Reference source not found.**Table 23** shows production levels across a number of commodities under each household demand scenario and **Figure 37** shows the difference in agricultural production levels from the Baseline scenario. Increased household demand has a marginally negative impact on production levels for most commodities shown, but these differences are close to zero, suggesting that population growth might not affect agricultural production levels.

Table 23. Modeled Agriculture Production (1,000 metric tons)

Crop	Baseline	2030 Moderate	2030 High
Bananas	5,170	5,169	5,169
Cabbage	21	21	21
Cacao	4	4	4
Coconut	4,263	4,263	4,263
Corn	2,750	2,750	2,750
Rice	2,192	2,191	2,190
Mango	124	124	124
Pineapple	2,430.71	2,430.65	2,430.54
Potato	29.30	29.30	29.29
Sugarcane	5,425.69	5,423.72	5,422.90
Tomato	78.11	78.10	78.10

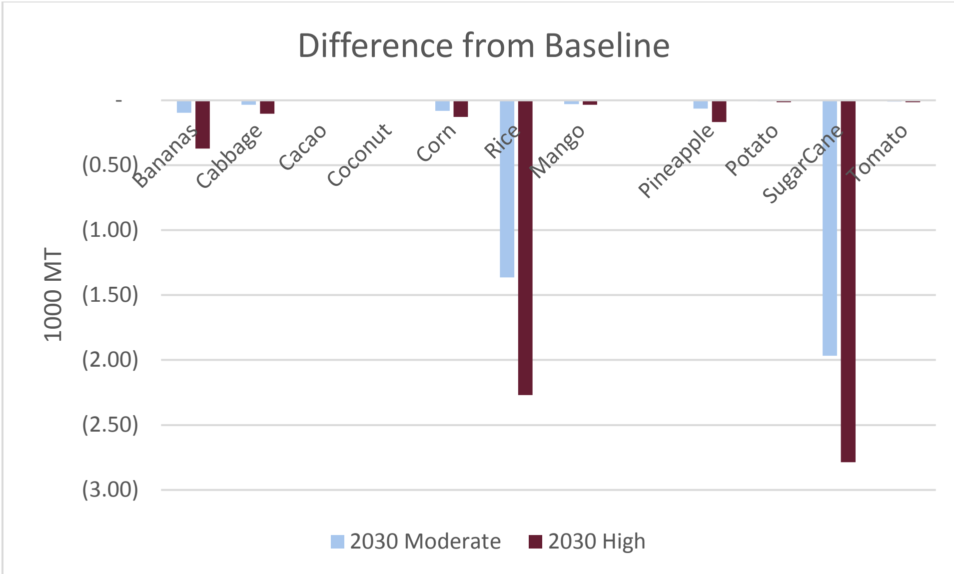

Figure 37. Difference in Agriculture Production in Climate Scenarios from Baseline for Main Agriculture Commodities

Household demand scenarios have negligible impacts on the total water supplied and net generation, as **Table 24** shows.

Table 24. Summary of Water Demand, Generation, and GHG Emissions by Plant Type

	Total Supply Water (million m^3)			Net Generation (GWh)			Emissions (million $mtCO_2e$)		
Plant Type	**2018 Moderate**	**2030 Moderate**	**2030 High**	**2018 Moderate**	**2030 Moderate**	**2030 High**	**2018 Moderate**	**2030 Moderate**	**2030 High**
Biomass	0.08	0.08	0.08	39.50	38.70	38.70			
Coal	55.61	55.61	55.61	21,387.75	21,387.82	21,387.82	19.25	19.25	19.25
Geo	0.41	0.41	0.41	212.20	212.20	212.20			
Hydro	48.42	48.42	48.42	3,828.05	3,828.12	3,828.12			
NatGas	4.62	4.62	4.62	1,477.55	1,477.56	1,477.56	0.60	0.60	0.60
Oil	16.34	16.34	16.34	5,220.98	5,221.01	5,221.01	3.10	3.10	3.10
Solar	0.04	0.04	0.04	37.19	37.20	37.20			

Agriculture Scenario Results

This section presents the results across the two alternative agriculture irrigation scenarios discussed earlier in this section. The baseline represents current demand from irrigated agricultural production. The alternative future expansion scenario assumes that by 2030, all irrigation infrastructure will increase, and the full irrigable land will be equipped for irrigation.

Table 25 summarizes the effects of alternative agriculture irrigation scenarios on household water demand. Due to the prioritization of water for household consumption, the ratio of water supplied to total household demand falls by less than 1 percent in the Max Irrigation scenario relative to that under current irrigation activity.

Table 25. Summary of Household Water Supply Results under Agriculture Scenarios

	Total Demand (million m^3)	Total Supplied	Demand Met	Total Population Served (million)	Per Capita Water Supply (l/c/d)
Current irrigation	601.89	509.05	85%	18.64	74.83
Max Irrigation Expansion	601.89	508.26	84%	18.64	74.72

Table 26 shows that there is a slight reduction in water supplied to households under the Max Irrigation Expansion scenario as compared to the Baseline. **Figure 38** shows a slight decrease (-0.2 percent) in the average monthly supply per capita under the Max Irrigation scenario.

Table 26. Monthly Per Capita Water Supply Across Agriculture Scenarios

	Per Capita Water Supply (l/c/d)	
Month	Baseline	Max Irrigation Expansion
January	79.23	79.12
February	80.41	80.25
March	70.51	70.39
April	73.42	73.24
May	69.50	69.30
June	79.18	79.06
July	74.27	74.16
August	73.90	73.77
September	78.80	78.69
October	71.88	71.80
November	74.56	74.53
December	73.11	73.04
Monthly Average	74.83	74.72

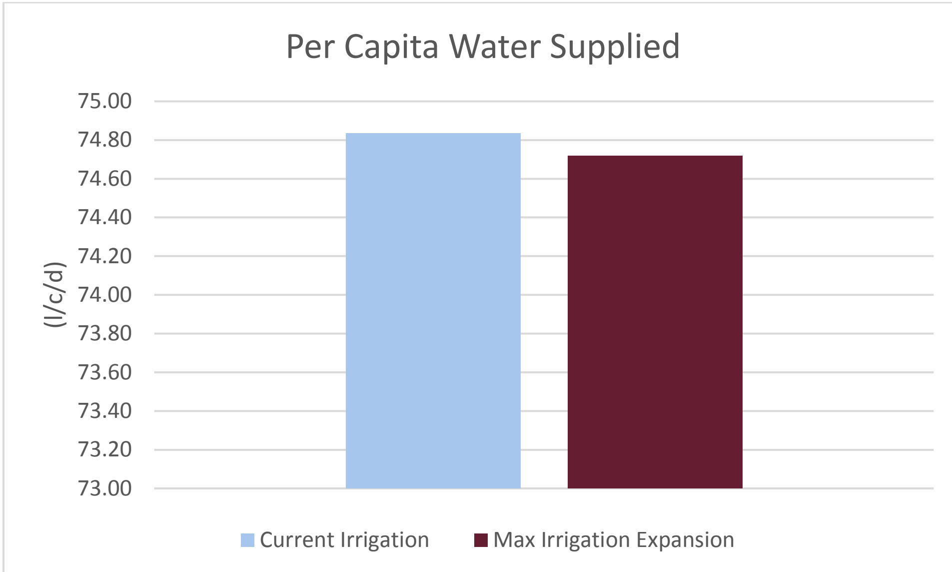

Figure 38. Estimated Annual Per Capita Water Consumption Across Agriculture Demand Scenarios

Table 27 and **Table 28** summarize the impacts on the agricultural sector under the two irrigation scenarios. Total irrigation water demand more than doubles under the Max Irrigation scenario. Total water supplied for irrigation increase is slightly lower, resulting in a 4 percent decline in the ratio of water supplied to consumption under the Max Irrigation Expansion scenario.

Table 27. Total Demand for Irrigation Water and Amount of Water Supplied to Irrigation

	Total Irrigation Water Demand (million m^3)	Total Irrigation Water Supplied (million m^3)	Supply to Consumption Ratio
Current irrigation	588.67	557.29	95%
Max Irrigation Expansion	1,390.43	1,262.86	91%

Table 28 shows production levels across key crops under the alternative irrigation scenarios. **Figure 39** shows the difference in agricultural production levels relative to the baseline (i.e., current irrigation) scenario. Max Irrigation Expansion scenario demand results in significant shifts in crop production. Rice production expands by nearly 80 percent relative to production under current irrigation. **Figure 39** shows that with the expansion in rice production, there are measurable declines in banana, coconut, corn, pineapple, and sugarcane production.

Table 28. Modeled Agriculture Production (1,000 metric tons)

Crop	Baseline	Max Irrigation Expansion
Bananas	5,170	4,370
Cabbage	21	34
Cacao	4	3
Coconut	4,263	3,620
Corn	2,750	2,302
Rice	2,192	3,954
Mango	124	105
Pineapple	2,431	2,115
Potato	29	40
Sugarcane	5,426	5,272
Tomato	78	84

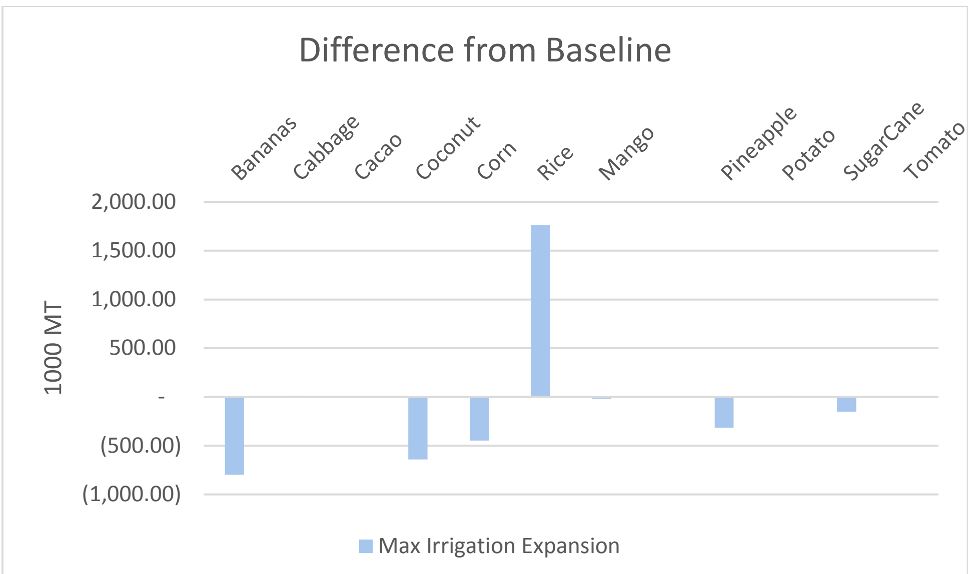

Figure 39. Difference in Agriculture Production in Climate Scenarios from Baseline for Main Agriculture Commodities

Table 29 presents the emissions associated with agricultural production under the two scenarios. The dramatic increase in emissions under the Max Irrigation scenario is driven by the sharp increase in irrigated rice production and its associated methane emissions.

Table 29. GHG Emissions from Agriculture under Alternative Irrigation Scenarios

Scenario	Emissions (million mtCO2e)
Baseline	2.30
Max Irrigation Expansion	5.41

Expansion of irrigable land area has negligible impacts on the total water supplied and net generation (**Table 30**). **Figure 40** shows that there are no notable changes in the share of generation by plant type under the alternative irrigation scenarios.

Table 30. Summary of Water Demand, Generation, and GHG Emissions by Plant Type

	Total Supply Water (million m^3)		Net Generation (GWh)		Emissions (million $mtCO_2e$)	
Plant Type	**Current Irrigation**	**Max Irrigation Expansion**	**Current Irrigation**	**Max Irrigation Expansion**	**Current Irrigation**	**Max Irrigation Expansion**
Biomass	0.08	0.08	39.50	38.70		
Coal	55.61	55.61	21,387.75	21,387.82	19.25	19.41
Geo	0.41	0.41	212.20	212.20		
Hydro	48.42	48.42	3,828.05	3,828.12		
NatGas	4.62	4.62	1,477.55	1,477.56	0.60	0.61
Oil	16.34	16.34	5,220.98	5,221.01	3.10	3.15
Solar	0.04	0.04	37.19	37.20		

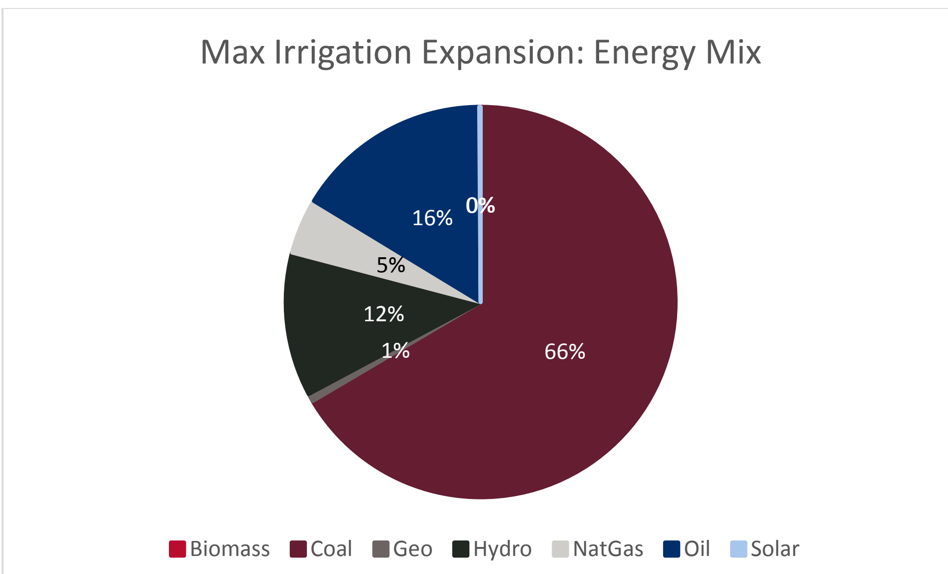

Figure 40. Net Generation by Plant Type under Irrigation Scenarios

Energy Scenario Results

Table 31 summarizes findings on the effects of the alternative energy scenarios on household water demand. Due to the prioritization of water for household consumption, the ratio of water supplied to demand does not change under the alternative energy scenarios (**Figure 41**). **Table 32** shows that the alternative energy scenarios have no impact on the seasonal supply of water to households.

Table 31. Summary of Household Water Supply Results under Alternative Energy Scenarios

	Total Demand (million m^3)	Total Supplied (million m^3)	Supply to Consumption Ratio	Total Population Served (million)	Per Capita Water Supply (l/c/d)
Reference	601.89	509.05	85%	18.64	74.83
High coal	601.89	509.06	85%	18.64	74.84
High renewable	601.89	508.95	85%	18.64	74.82

Table 32. Monthly Per Capita Water Supply across Energy Scenarios

	Per Capita Water Supply (l/c/d)		
Month	**Baseline**	**High Coal**	**High Renewable**
January	79.23	79.23	79.23
February	80.41	80.41	80.39
March	70.51	70.51	70.49
April	73.42	73.42	73.39
May	69.50	69.50	69.47
June	79.18	79.18	79.18
July	74.27	74.27	74.27
August	73.90	73.90	73.87
September	78.80	78.81	78.81
October	71.88	71.88	71.86
November	74.56	74.56	74.53
December	73.11	73.11	73.08
Total	74.83	74.84	74.82

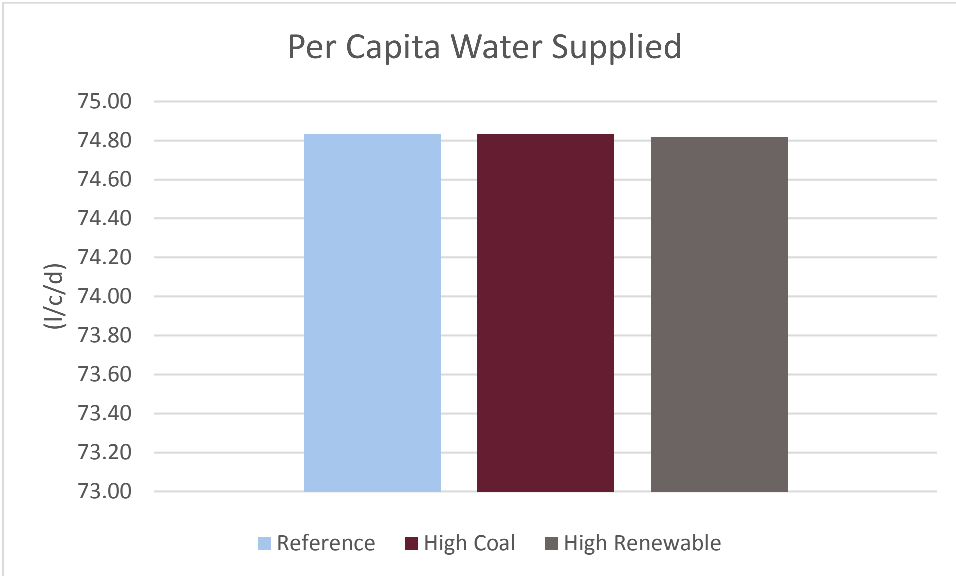

Figure 41. Estimated Monthly Average Per Capita Water Consumption across Energy Scenarios

Results presented in **Table 33** and **Table 34** show that the agricultural sector is not impacted by changes in the energy generation mix.

Table 33. Total Demand for Irrigation Water and Amount of Water Supplied to Irrigation

	Total Irrigation Water Demand (million m³)	Total Irrigation Water Supplied (million m³)	Supply to Consumption Ratio
Reference	588.67	557.29	95%
High coal	588.67	557.29	95%
High renewable	588.67	557.28	95%

Energy scenarios exogenously define the energy generation mix in the power sector. **Table 34** shows the changes in water supply, generation, and GHG emissions under each energy scenario. **Figure 42 and 43** shows changes in the share of generation by plant type under the alternative energy scenarios (i.e., high coal vs. high renewables).

Table 34. Summary of Water Demand, Generation, and GHG Emissions by Plant Type

	Total Supply Water (million m^3)			Net Generation (GWh)			Emissions (million $mtCO_2e$)		
Plant Type	Baseline	High Coal	High Renewable	Baseline	High Coal	High Renewable	Baseline	High Coal	High Renewable
Biomass	0.08	0.06	1.07	39.50	28.02	513.17			
Coal	55.61	62.05	60.67	21,387.75	23,864.06	23,334.17	19.25	21.48	21.03
Geo	0.41	0.41	0.30	212.20	212.20	155.60			
Hydro	48.42	48.31	52.99	3,828.05	3,818.83	4,188.82			
NatGas	4.62	0.36	1.90	1,477.55	115.18	607.35	0.60	0.05	0.25
Oil	16.34	13.18	8.89	5,220.98	4,210.73	2,838.69	3.10	2.50	1.69
Solar	0.04	0.04	0.52	37.19	36.84	455.81			

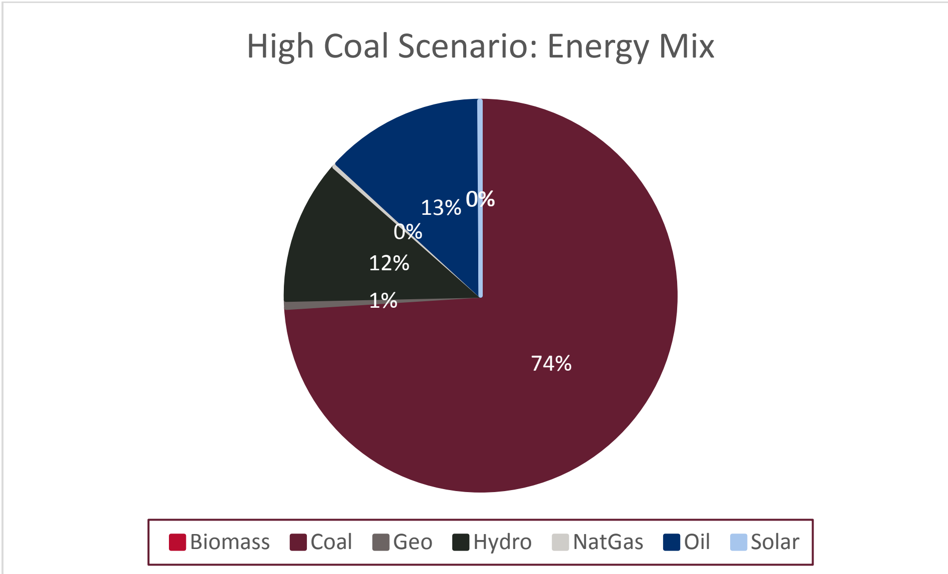

Figure 42. Net Generation by Plant Type under High Coal Scenario

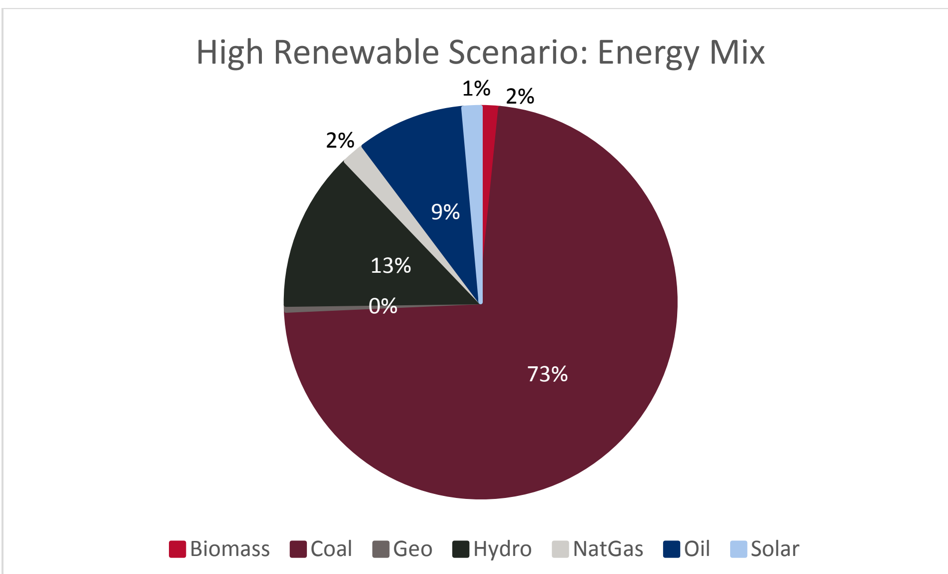

Figure 43. Net Generation by Plant Type under High Renewable Scenario

High Water Demand Scenario Results

The previous sections focused on sensitivity results using different scenario assumptions for each sector (and emissions pathway) independently. Our current framework treats scenario inputs in isolation (e.g., population growth does not drive energy generation), as there are distinct advantages of isolating water supply and demand differences across scenarios to a particular sector, user group, or environmental change phenomenon when conducting tradeoff analysis. Notably, sensitivity analysis that targets water supply or demand changes independently helps with attributional analysis when scenario deviations are interacted. That is, we can evaluate the marginal implications of shifting some input relative to the baseline one at a time, and then compare this outcome to scenarios that combine multiple changes simultaneously. This helps relay the potential relative magnitude of a single sector or supply change relative to the status quo. Furthermore, this study focuses on scenarios to illustrate the potential of this simulation approach for evaluating the water, food, and energy sector implications of alternative development pathways. Users of this framework can adjust scenario inputs as needed to evaluate alternative futures that coincide with shifting policy or private sector priorities or changing climate and environmental conditions.

To illustrate this concept, a final scenario simulates a "high water demand" future (taking the highest water demand projection from each individual sector) and low relative supply (RCP 8.5 climate conditions). This scenario serves as a stress test, a pessimistic future scenario in which high water demands converge with the pressures of climate change. **Figure 44** shows the spatial distribution of potential annual water shortages under this scenario. The first takeaway is that these shortages are much higher than the distribution of annual shortages under any of the sector-specific scenarios.

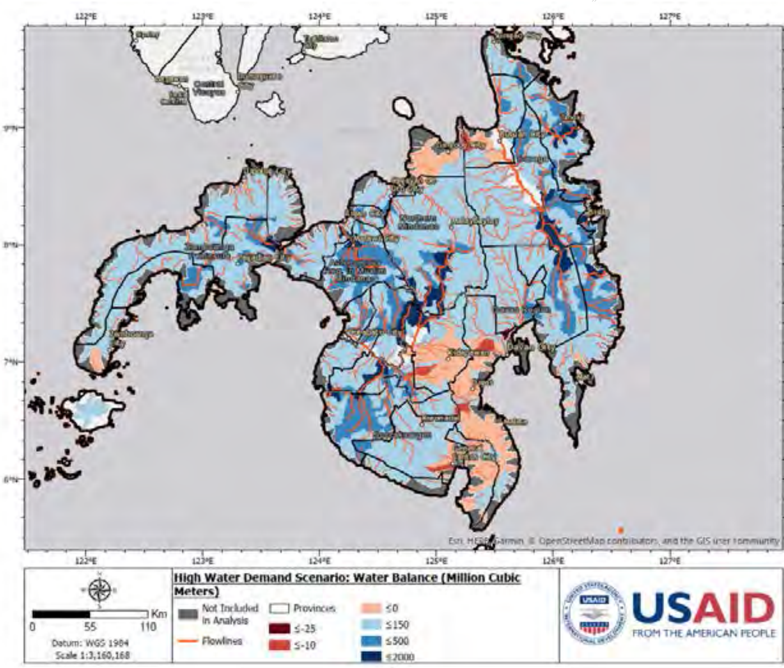

Figure 44. High Water Demand Scenario Annual Water Balance

Figure 45 shows the change in total household consumption between Baseline and High Water Demand scenarios. In general, we find a large change in the total proportion of demand met under the high scenario: 64 percent total, which represents a net change of approximately 25 percent relative to the Baseline scenario (**Table 35**). This change is due to increased competition with alternative users, reduced total water availability under RCP 8.5, and a spatial shift in the supply of water with relatively lower supplies near urban areas.

Table 35. Summary of Household Water Supply Results under Baseline and High Water Demand Scenarios

Scenario	Total Demand (million m^3)	Total Supplied	Demand Met	Total Population Served (million)	Per Capita Water Supply (l/c/d)
Baseline	601.89	509.05	85%	18.64	74.83
High Demand	784.45	499.73	64%	24.29	56.37

We see a similar temporal distribution in per capita water consumption, with the lowest levels seen during peak demands for agriculture (and low precipitation) from March to May (**Table 36**).

Table 36. Monthly Per Capita Water Supply across High Water Demand Scenario

	Per Capita Water Supply (l/c/d)	
Month	**Baseline**	**High Water Demand Scenario**
January	79.23	60.31
February	80.41	60.27
March	70.51	52.65
April	73.42	55.18
May	69.50	51.42
June	79.18	60.54
July	74.27	56.76
August	73.90	56.38
September	78.80	59.45
October	71.88	53.69
November	74.56	55.34
December	73.11	54.95
Total	74.83	56.37

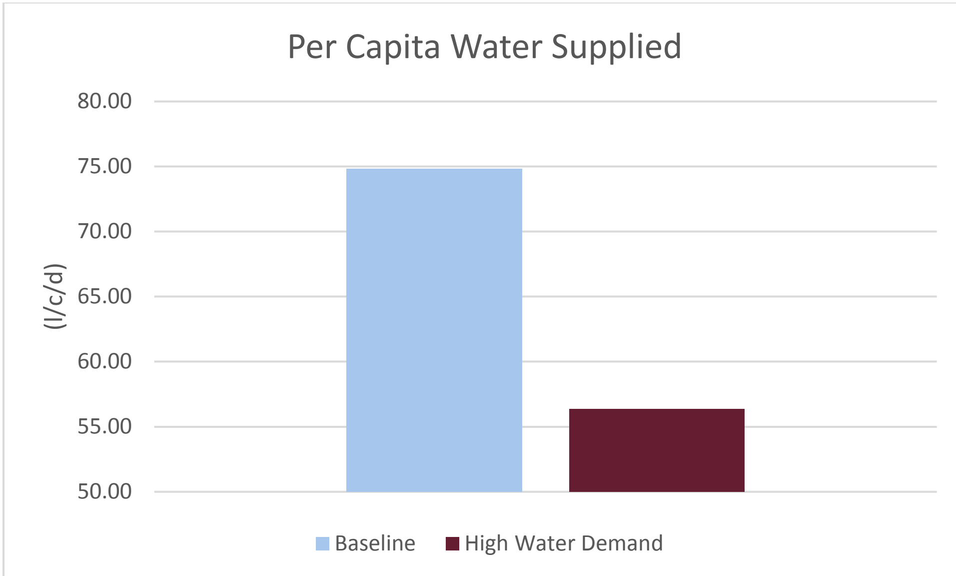

Figure 45. Estimated Annual Per Capita Water Consumption across Baseline and High Water Demand Scenarios

Consistent with the expanded agricultural consumption scenarios, demand for irrigation water supplies expands significantly under the combined High Water Demand scenario (**Table 37**). However, given competition with other user groups (i.e., population growth) as well as reduced water supply, the total proportion of irrigation demand that is met (87 percent) is lower than the 91 percent threshold for the Irrigation Expansion-only scenario presented previously. Thus, climate change and competition with other user groups has considerable impact on the system's ability to significantly expand irrigation. Changes in crop mixes under the combined High Water Demand scenario are also consistent with changes seen for the Irrigation Expansion scenario relative to the baseline, although the net difference in irrigated rice production is smaller for the High Water Demand scenario (**Table 38** and **Figure 46**).

Table 37. Total Demand for Irrigation Water and Amount of Water Supplied to Irrigation under Baseline and High Water Demand Scenarios

Scenario	Total Irrigation Water Demand (million m^3)	Total Irrigation Water Supplied (million m^3)	Demand Met
Baseline	588.67	557.29	95%
High Water Demand	1,578.52	1,370.79	87%

Table 38. Modeled Agriculture Production in Baseline and High Water Demand Scenarios (1,000 metric tons)

Crop	Baseline	High Water Demand
Bananas	5,170	4,295
Cabbage	21	33
Cacao	4	3
Coconut	4,263	3,545
Corn	2,750	2,228
Rice	2,192	3,778
Mango	124	102
Pineapple	2,431	2,111
Potato	29	39
Sugarcane	5,426	5,178
Tomato	78	83

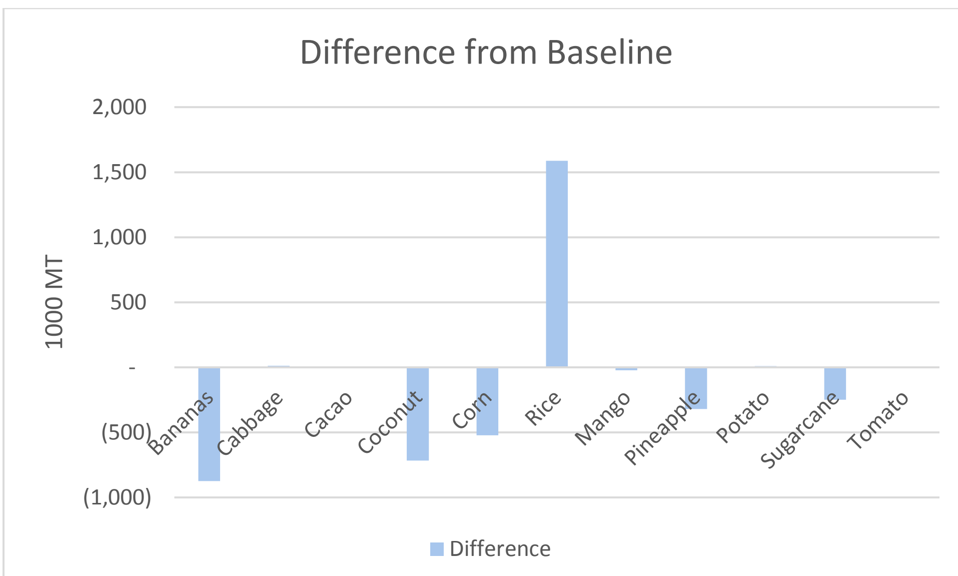

Figure 46. Difference in Agriculture Production in High Water Demand Scenario from Baseline for Main Agriculture Commodities

Results from the High Demand scenario for the energy sector (water consumption and energy generation) do not change significantly relative to the High Renewable Energy scenario evaluated in isolation. Whereas energy receives the lowest prioritization in our framework, energy infrastructure is confined to a few select subcatchments, most of which are located in downstream, high water supply areas. Thus, even with relatively low supply of water and high demand throughout Mindanao, the energy sector is fairly resilient and has similar levels of water availability and output regardless of changes across other sectors. Furthermore, changes in the energy mix or total generation do not appear to induce large tradeoffs across user groups in our simulation results (**Table 39** and **Figure 47**).

Table 39. Summary of Water Demand, Generation, and GHG Emissions by Plant Type in Baseline and High Water Demand Scenarios

	Total Supply Water		Net Generation		Emissions	
Plant Type	**Baseline**	**High Water Demand**	**Baseline**	**High Water Demand**	**Baseline**	**High Water Demand**
Biomass	0.08	0.99	39.50	475.5		
Coal	55.61	60.68	21,387.75	23,337.2	19.25	21.00
Geo	0.41	0.30	212.20	155.6		
Hydro	48.42	53.03	3,828.05	4,192.1		
NatGas	4.62	1.90	1,477.55	607.8	0.60	0.25
Oil	16.34	8.89	5,220.98	2,840.3	3.10	1.68
Solar	0.04	0.52	37.19	455.9		

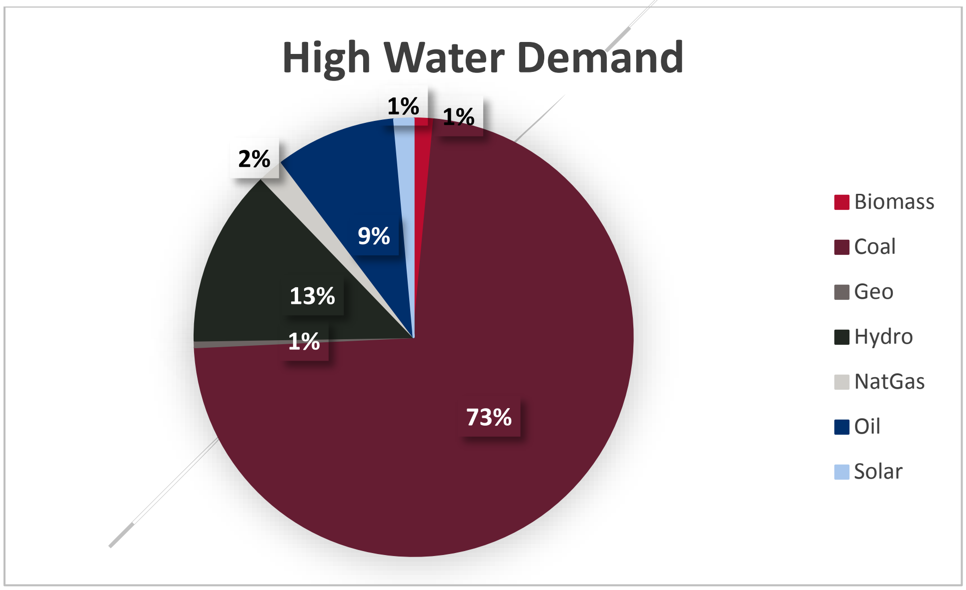

Figure 47. Net Generation by Plant Type under High Water Demand Scenario

Water Valuation

While the simulation framework can provide reliable estimates of water balances under future climate and demand scenarios, it is not designed to provide explicit values of water consumption. However, initial average values of water consumed by irrigation can be estimated based on the marginal gain in yields that farmers receive over rainfed irrigation systems. To calculate the average value of irrigation water, the total revenue from irrigated agriculture is calculate, next the total revenue from irrigated area but with rainfed yields is calculated. By subtracting the revenue received under rainfed yields from the revenue received from irrigated yields, we calculate the total benefits attributed to irrigation water supplies. Finally, the total additional benefits from irrigated water are divided by the total quantity of water consumed by agriculture to derive a per-unit average value of water. This value can be thought of as the annual value of a cubic meter of water allocated to irrigation. Figure 45 presents the Baseline and High Water Demand Scenario average value of irrigation water. In the baseline irrigated water proves a little less than 16 PHP per cubic meter, while under the high water demand the value increases to slightly over 18 PHP per cubic meter.

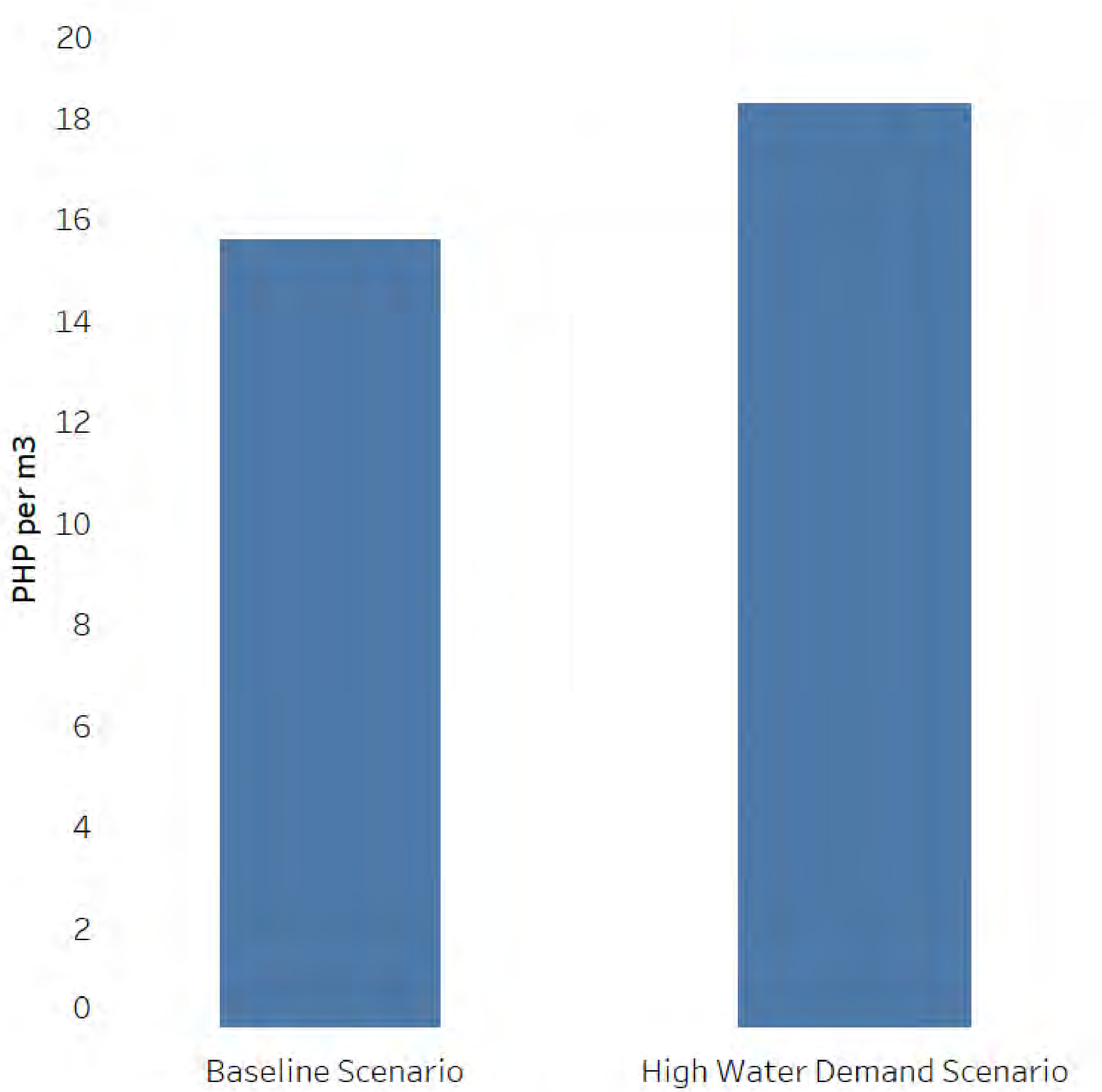

Figure 48. Average Value of Irrigation Water under the Baseline and High Water Demand Scenarios

Conclusions and Policy Implications

This analysis developed a customized hydroeconomic simulation approach to assess potential water resource implications of alternative development futures, focusing on different levels of population growth, energy generation and fuel mix, irrigation expansion, and climate change. These illustrative scenarios were run independently and combined, and then compared with a Baseline scenario. The analysis illustrates how hydroeconomic simulation modeling can be used to simulate the impact of changing scenario assumptions on water, energy, and food production systems, resulting in potential tradeoffs across sectors. Results show that even in a relatively water-abundant region like Mindanao, there are potential tradeoffs in alternative water development pathways, particularly given the historic variability observed in interannual flows in the region and the potential pressures of climate change on future supplies. Household consumption is particularly sensitive to increased competition for water supplies and climate change. Results suggest that investing in new water supply capacity and water storage infrastructure can help alleviate potential long-term water deficits to households.

It is shown that the spatial and temporal distribution of water supplies, precipitation, land use, and infrastructure matter and that potential water shortages of alternative scenarios are not evenly distributed across Mindanao (or over the course of a year). The framework can be used to identify "hot spots," or subcatchments with high potential demands and limited supplies that can benefit from targeted investments or policy interventions to more effectively manage resources and limit shortages.

As with all modeling frameworks, limitations and uncertainties should be mentioned. First, water demands were calculated using the best publicly available data, but additional analysis could be crafted to inform potential uncertainties associated with key parameter inputs (e.g., irrigation response factors for different crops or water requirements for different energy technologies). Although we explored variations in water consumption and agricultural and energy sector outputs across alternative development scenarios, we did not evaluate uncertainty in underlying model inputs.

Furthermore, although scenario inputs for different sectors reflect stakeholder feedback received during in-person meetings, these assumptions are sector specific, and there is no comprehensive underlying analysis used to project alternative development goals, macroeconomic assumptions, and environmental change parameters in a consistent fashion. This is an important area for future research, as policy parameters for a given sector are contingent on assumptions about resource needs and allocation priorities in other sectors.

Finally, although the simulation approach presented in this framework is useful for identifying hot spots for potential water deficits, an optimization approach could provide insight into the ideal allocation of water across location, time, and user groups given various policy goals and environmental constraints. Future research efforts will attempt to translate this framework into an optimization routine that maximizes the socioeconomic benefits of resource consumption to help inform policy planning.

REFERENCES

Adam, J. C., & Lettenmaier, D. P. (2003). Adjustment of global gridded precipitation for systematic bias, *J. Geophys. Res.*, *108*, 1–14.

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). FAO Irrigation and drainage paper No. 56. *Rome: Food and Agriculture Organization of the United Nations*, *56*(97), e156.

Baker, J. S., Cai, Y., Moreda, F., Van Houtven, G., Callihan, R., Lapidus, D., … & Brantlt, G. (2016). Pernambuco Food-Energy-Water Nexus: Integrating Hydro-BID into an Economic Valuation Framework. Prepared for the Inter-American Development Bank.

Cinco, T. A., Hilario, F. D., de Guzman, R. G., & Ares, E. D. (2013, October). Climate trends and projections in the Philippines. In Proceedings of the 12th National Convention on Statistics (NCS), Mandaluyong City, Philippines (pp. 1–2).

Fuka, D. R., et al. (2014). Using the climate forecast system reanalysis as weather input data for watershed models. *Hydrological Processes 28*(22): 5613–5623.

Jeuland, M., Baker, J. S., Bartlett, R., & Lacombe, G. (2014). The costs of uncoordinated infrastructure management in multi-reservoir river basins. *Environmental Research Letters,* 9(10), 105006.

Kahil, T., Parkinson, S., Satoh, Y., Greve, P., Burek, P., Veldkamp, T. I., ... & Krey, V. (2018). A Continental-Scale Hydroeconomic Model for Integrating Water-Energy-Land Nexus Solutions. *Water resources research*.

Moreda, F. (2018). *Technical Manual – First Edition. Hydrologic Resources Assessment Model: An Integrated System for Water Resources Modeling and Management*. Research Triangle Park, NC: RTI International.

Philippines Department of Energy (DOE). (2016). Philippine Power Situation Report 2016. https://www.doe.gov.ph/sites/default/files/pdf/electric_power/power_situationer/2016_philippine_power_situation_report.pdf

Philippines Department of Energy (DOE). (2017). Philippine Energy Plan 2017–2040: Energy Demand and Supply Outlook. https://www.doe.gov.ph/sites/default/files/pdf/pep/pep_volume_1_energy_demand_supply_outlook.pdf

Rineer, J., & Bruhn, M. (2013). *Technical Note 1. An Analytical Hydrology Dataset for Latin American and the Caribbean*. Research Triangle Park, NC: RTI International.

Steduto, P., Hsiao, T. C., Fereres, E., & Raes, D. (2012). Crop yield response to water. FAO Irrigation and Drainage Paper 66. Rome: United Nations Food and Agriculture Organization.

Tidwell, V., & Moreland, B. (2016). Mapping water consumption for energy production around the Pacific Rim. *Environmental Research Letters, 11*(9) 094008.

Vaux Jr, H. J., & Pruitt, W. O. (1983). Crop-water production functions. In Advances in irrigation (Vol. 2, pp. 61-97). Elsevier.

ANNEX A. HYDROLOGIC RESOURCES ASSESSMENT MODEL TECHNICAL MANUAL

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ANNEX C. TRADEOFF ANALYSIS DATA TABLES

TABLE C-1. RAINFED CROP MIX

Province	Palay	Corn	Cacao	Coconut	Sugarcane	Mango	Pineapple	Cabbage	Onion	Tomato	Potato	Banana
Zamboanga del Norte	6.62%	14.01%	0.16%	72.10%	0.01%	4.09%	0.08%	0.00%	0.00%	0.03%	0.00%	2.90%
Zamboanga del Sur	7.27%	36.56%	0.01%	52.87%	0.00%	0.58%	0.01%	0.01%	0.00%	0.04%	0.00%	2.65%
Zamboanga Sibugay	25.20 %	11.89%	0.10%	60.48%	0.00%	0.57%	0.01%	0.00%	0.00%	0.03%	0.00%	1.71%
Bukidnon	3.19%	58.62%	0.05%	2.97%	19.23%	0.73%	7.75%	0.12%	0.00%	0.60%	0.16%	6.57%
Camiguin	0.01%	1.98%	0.19%	89.60%	0.00%	0.73%	0.00%	0.00%	0.00%	0.05%	0.00%	7.44%
Lanao del Norte	3.16%	53.37%	0.17%	37.99%	0.00%	0.99%	0.04%	0.01%	0.00%	0.04%	0.00%	4.22%
Misamis Occidental	1.14%	21.03%	0.04%	72.55%	0.00%	1.66%	0.00%	0.04%	0.00%	0.03%	0.00%	3.51%
Misamis Oriental	0.20%	26.98%	0.01%	60.59%	0.00%	1.18%	0.79%	0.03%	0.00%	0.27%	0.00%	9.95%
Davao del Norte	2.15%	15.05%	2.15%	40.36%	0.00%	1.64%	0.05%	0.00%	0.00%	0.02%	0.00%	38.58%
Davao del Sur	0.28%	28.36%	0.77%	49.50%	5.19%	7.05%	0.00%	0.18%	0.00%	0.16%	0.67%	7.83%
Davao Oriental	1.58%	20.97%	0.47%	71.05%	0.00%	0.61%	0.02%	0.00%	0.00%	0.04%	0.00%	5.26%
Compostela Valley	3.61%	30.27%	2.34%	44.49%	0.00%	0.52%	0.05%	0.01%	0.00%	0.10%	0.00%	18.61%
North Cotabato	13.54 %	51.02%	0.06%	21.68%	3.36%	3.32%	0.15%	0.05%	0.00%	0.22%	0.01%	6.58%
Sarangani	2.24%	39.56%	0.08%	52.07%	0.62%	2.70%	0.40%	0.00%	0.00%	0.02%	0.01%	2.30%
South Cotabato	6.73%	61.44%	0.04%	14.95%	0.22%	1.91%	10.54%	0.03%	0.00%	0.03%	0.02%	4.08%
Sultan Kudarat	14.28 %	57.97%	0.12%	22.11%	1.08%	1.24%	0.22%	0.00%	0.00%	0.06%	0.01%	2.90%
Agusan del Norte	9.47%	13.10%	0.07%	64.42%	0.00%	3.09%	0.12%	0.00%	0.00%	0.03%	0.00%	9.71%
Agusan del Sur	38.97 %	33.03%	0.57%	15.43%	0.00%	0.31%	0.09%	0.00%	0.00%	0.05%	0.00%	11.55%

TABLE C-1. RAINFED CROP MIX

Province	Palay	Corn	Cacao	Coconut	Sugarcane	Mango	Pineapple	Cabbage	Onion	Tomato	Potato	Banana
Dinagat Islands	14.42 %	2.03%	0.09%	81.18%	0.00%	0.71%	0.18%	0.00%	0.00%	0.00%	0.00%	1.38%
Surigao del Norte	7.57%	0.87%	0.10%	89.07%	0.00%	0.36%	0.02%	0.00%	0.00%	0.01%	0.00%	1.99%
Surigao del Sur	8.72%	5.11%	0.09%	79.99%	0.00%	0.35%	0.04%	0.00%	0.00%	0.01%	0.00%	5.68%
Basilan	0.17%	0.35%	0.05%	89.41%	0.00%	0.14%	0.01%	0.00%	0.00%	0.01%	0.00%	9.86%
Lanao del Sur	21.02 %	52.48%	0.12%	22.95%	0.80%	0.02%	0.03%	0.01%	0.00%	0.00%	0.00%	2.58%
Maguindanao	30.26 %	35.94%	0.00%	26.56%	0.00%	2.93%	0.00%	0.01%	0.00%	0.01%	0.00%	4.28%
Sulu	1.62%	1.76%	0.16%	91.26%	0.00%	1.80%	0.01%	0.00%	0.00%	0.01%	0.00%	3.38%
Tawi-tawi	0.31%	1.41%	0.01%	95.57%	0.00%	0.92%	0.03%	0.00%	0.00%	0.01%	0.00%	1.73%

TABLE C-2. IRRIGATED CROP MIX

Crop	Irrigated Crop Mix
Banana	0.53%
Corn	3.58%
Palay	89.84%
Sugarcane	2.41%
Mango	0.04%
Pineapple	0.04%
Tomato	0.35%
Potato	0.35%
Cabbage	0.35%
Onion	0.35%

TABLE C-3. PROVINCIAL-LEVEL AGRICULTURE AREA, 2016 IRRIGATED AGRICULTURE AREA, AND ESTIMATED IRRIGABLE AGRICULTURE AREA

Province	Total Agriculture Area	Irrigated Agriculture Area		Irrigable Agriculture	
	Hectares	Hectares	Percent of Total	Hectares	Percent of Total
Zamboanga del Norte	301,484	7,424	2%	32,072	11%
Zamboanga del Sur	297,129	24,913	8%	42,880	14%
Zamboanga Sibugay	118,755	15,091	13%	15,413	13%
Bukidnon	403,257	38,341	10%	81,984	20%
Camiguin	17,136	735	4%	735	4%
Lanao del Norte	238,103	13,367	6%	13,407	6%
Misamis Occidental	152,948	10,095	7%	10,164	7%
Misamis Oriental	175,396	6,259	4%	13,014	7%
Davao del Norte	121,510	28,466	23%	28,466	23%
Davao del Sur	222,089	17,377	8%	32,773	15%
Davao Oriental	214,902	8,786	4%	17,760	8%
Compostela Valley	122,406	13,407	11%	96,780	79%
North Cotabato	296,786	42,938	14%	140,699	47%
Sarangani	167,127	6,761	4%	6,964	4%
South Cotabato	281,115	34,972	12%	96,772	34%
Sultan Kudarat	227,917	37,526	16%	48,791	21%
Agusan del Norte	75,516	16,322	22%	50,515	67%
Agusan del Sur	131,150	27,842	21%	55,794	43%
Dinagat Islands	7,641	903	12%	928	12%

TABLE C-3. PROVINCIAL-LEVEL AGRICULTURE AREA, 2016 IRRIGATED AGRICULTURE AREA, AND ESTIMATED IRRIGABLE AGRICULTURE AREA

Province	Total Agriculture Area	Irrigated Agriculture Area		Irrigable Agriculture	
	Hectares	Hectares	Percent of Total	Hectares	Percent of Total
Surigao del Norte	81,888	7,242	9%	13,070	16%
Surigao del Sur	118,683	16,804	14%	39,870	34%
Basilan	72,977	578	1%	608	1%
Lanao del Sur	213,546	13,894	7%	47,190	22%
Maguindanao	453,336	30,132	7%	108,595	24%
Sulu	74,305	1,990	3%	2,105	3%
Tawi-tawi	41,914	1,567	4%	1,652	4%
Total	4,629,014	423,731	9%	999,002	22%

TABLE C-4. PER CAPITA WATER CONSUMPTION (L/C/D)

Region	Per Capita Water Consumption
IX	148
X	136
XI	173
XII	138
CARAGA	105
ARMM	140

TABLE C-5. PERCENT OF HOUSEHOLDS RELYING ON FRESH WATER SOURCE

Region	Shallow Well	Dug Well	Protected Spring	Unprotected Spring	Lake, River, Rain, and Others	Peddler	Bottled Water	Other	Total Surface Water
IX	10%	32%	21%	14%	2%	7%	15%	1%	37%
X	9%	14%	28%	15%	3%	3%	27%	1%	47%
XI	13%	9%	26%	10%	6%	15%	15%	4%	42%
XII	27%	22%	23%	10%	4%	3%	10%	2%	36%
CARAGA	14%	13%	19%	9%	12%	6%	26%	1%	40%
ARMM	10%	37%	13%	4%	29%	4%	3%	1%	46%

TABLE C-6. WATER CONSUMPTION FACTORS (ADOPTED FROM TIDWELL & MORELAND [2016])

EGU Type	Consumption Use (m^3/MWh)
Coal	2.6
Oil	3.13
Biomass	2.09
Geothermal	1.91
Hydropower (Reservoir)	17
Hydropower (Run of River)	0
Solar	1.15
Natural Gas	3.13

TABLE C-7. POPULATION ESTIMATES FOR EACH SCENARIO (MILLIONS)

Scenario	Total Population
Baseline	18.64
Moderate Growth	22.57
High Growth	24.29

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