Hydro-BID case study N°2: Modeling the impact of climate change on flows of the Rio Piura using Hydro-BID

Fekadu Moreda
Fernando Miralles-Wilhelm
Raúl Muñoz Castillo
Pedro Coli Valdes Daussa

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HYDRO-BID CASE STUDY N°2:

MODELING THE IMPACT OF CLIMATE CHANGE ON FLOWS OF THE RIO PIURA USING HYDRO-BID

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FOREWORD

The Inter-American Development Bank (IDB) provides financial and technical support for infrastructure projects in water and sanitation, irrigation, flood control, transport, and energy. Many of these projects depend on water resources and may be affected negatively by climate change and other developments that alter water availability, such as population growth and shifts in land use associated with urbanization, industrial growth, and agriculture. Assessing the potential for future changes in water availability is an important step toward ensuring that infrastructure projects meet their operational, financial, and economic goals. It is also important to examine the implications of such projects for the future allocation of available water among competing users and uses to mitigate potential conflict and to ensure that such projects are consistent with long-term regional development plans and preservation of essential ecosystem services.

As part of its commitment to help member countries adapt to climate change, the IDB is sponsoring work to develop and apply an integrated suite of watershed modeling tools known as Hydro-BID. The Hydro-BID modeling system includes hydrology and climate analysis modules to estimate the availability (volumes and fluxes) of fresh water at the regional, basin, and sub-basin scales. It will also include economic analysis and decision support tools to estimate the costs and benefits of adaptive measures and help decision makers make informed choices among alternative designs for infrastructure projects and alternative policies for water resources management.

Phase I of this effort produced a working version of Hydro-BID. As of this writing, Hydro-BID includes the following components:

- An Analytical Hydrography Dataset (AHD) for the Latin America and Caribbean region, representing more than 229,000 catchments and their corresponding river and stream segments;
- A geographic information system–based navigation tool to browse AHD catchments and streams with the capability of navigating upstream and downstream;
- A user interface for specifying the area and time period to be modeled and the location at which water availability will be modeled;
- A climate data interface to generate and apply rainfall and temperature inputs for the area and period of interest;
- A rainfall-runoff model based on the Generalized Watershed Loading Factor model; and
- A routing scheme for quantifying time of travel and accumulating flow estimates across downstream catchments.

Hydro-BID generates output in the form of daily time series of flow estimates for the selected location and period. The output can be summarized as a monthly time series at the user's discretion.

The details of Hydro-BID can be found in three Technical Notes. Source contact: Dr. Fernando Miralles at Inter-American Development Bank.

This document describes the application of Hydro-BID in generating flow time series of the Rio Piura in northern Peru for the period 2011–2060 under two climate projections.

1. OVERVIEW

The Rio Piura basin in northern Peru has a drainage area of 7,000 km^2 and is identified as highly vulnerable to climate change. The Rio Piura basin is one of three watersheds being addressed as pilot basins for analysis and planning under the Water Resources Management Modernization Project funded by the Inter-American Development Bank (IDB).

As part of the project, Peru's National Water Authority (ANA) has prepared a Water Evaluation and Planning (WEAP) model for the Rio Piura basin (**Figure 1**) as a means of examining the current and future allocation of available water among competing users and uses. ANA would like to enhance the Rio Piura basin WEAP model by explicitly accounting for potential changes in the future availability of water that may result from changes in temperature and rainfall under various climate change scenarios.

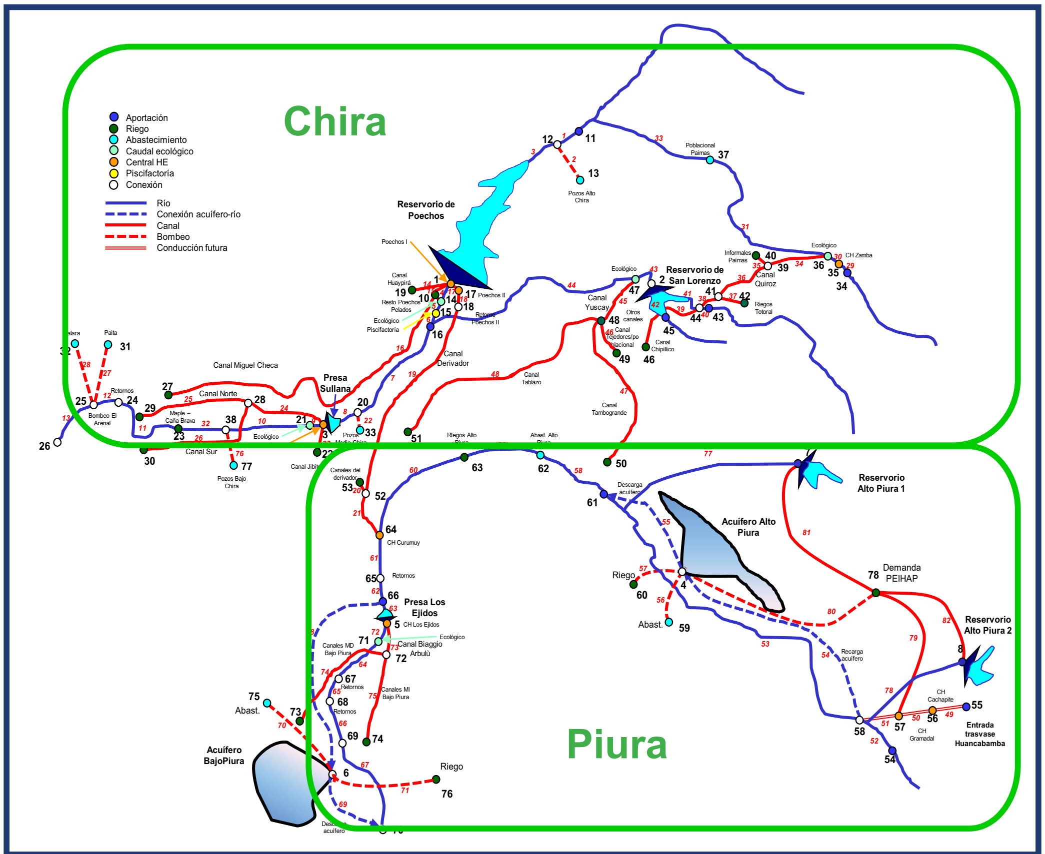

Figure 1. The Chira-Piura basin pilot WEAP model setup

IDB has agreed to sponsor development of a Hydro-BID model of the Rio Piura basin as technical support to ANA and to complement and enhance its work under the Water Resources Management Modernization Project. Hydro-BID is a modeling platform developed by RTI International under contract to the IDB's Infrastructure and Environment sector office, specifically for the purpose of evaluating the potential impacts of climate change on water resources. **Figure 2** presents a schematic representation of the integrated Hydro-BID system for quantitative simulation of hydrology and climate change. The system is built on an Analytical Hydrographic Dataset (AHD) for the Latin America and Caribbean (LAC) region.

Hydro-BID uses the data structure and the catchment and stream network topologies of the AHD. It incorporates data on land uses, soil types, rainfall and temperature within the study area, and observed stream flows for use in calibration. Hydro-BID includes a pre-processor interface to disaggregate monthly climate data into a daily time series of temperature and rainfall, which is the required form of climate data input. The system applies a standard Generalized Watershed Loading Function (GWLF) model, coupled with a novel lag-routing methodology developed by RTI. Model output is generated as a time series of projected water flows, at either a daily or monthly scale. The time series outputs of the model will be used in the other specific water resource application tools. In this case, the time series are used as inputs to the existing WEAP model for the Chira-Piura Basin.

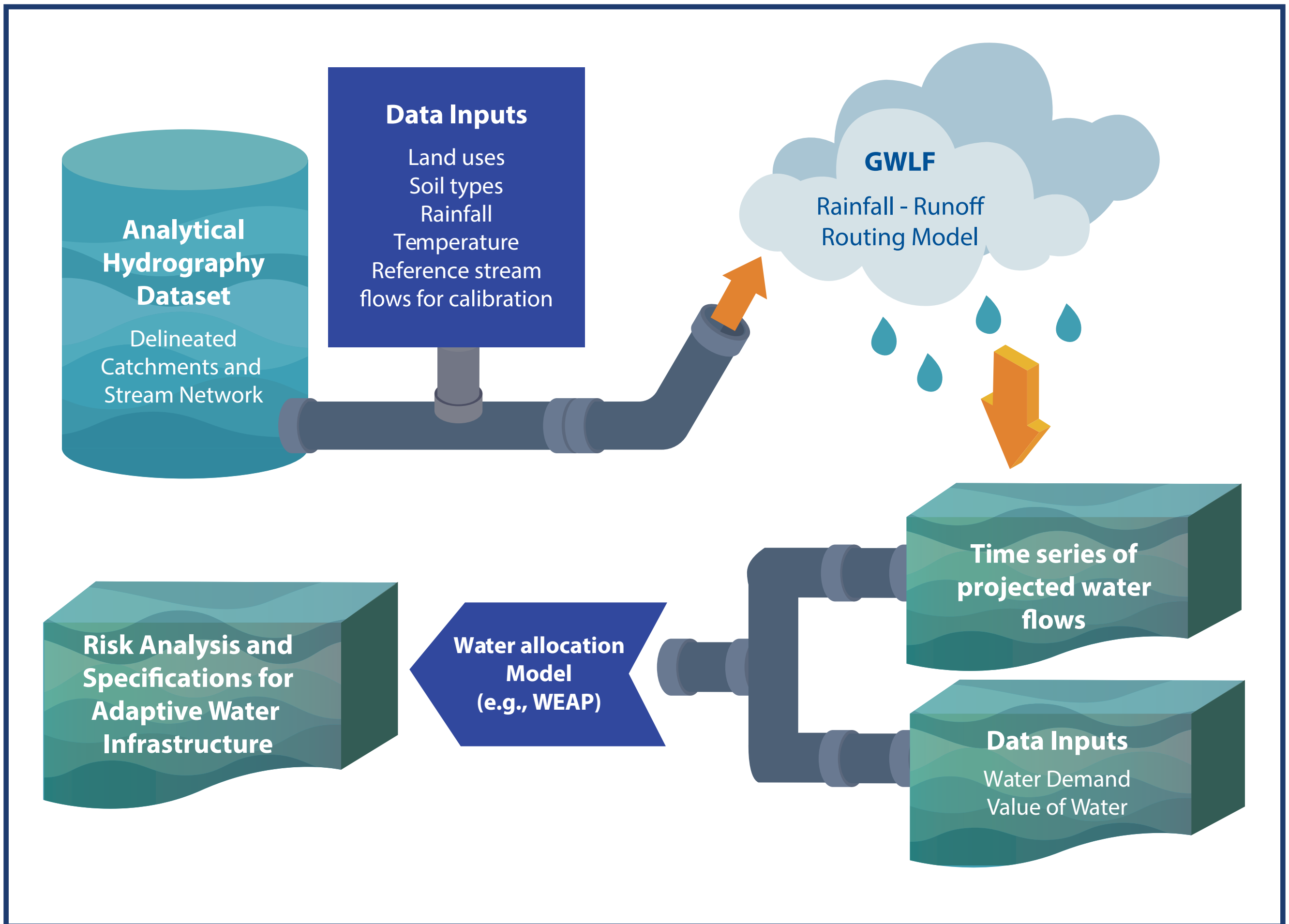

Figure 2. Hydro-BID flow chart.

2. OBJECTIVES OF THE STUDY

RTI will use the Hydro-BID system to prepare a hydrologic model of the Rio Piura basin and project stream flows in the basin for the period 2011–2060, under a limited set of climate change scenarios. RTI will deliver the projected stream flow data to ANA in a format that can be directly incorporated as input data for its Rio Piura basin WEAP model. ANA will use the data on projected stream flows as inputs to its WEAP model and will assess the potential impact of climate change on the allocation of available water resources among users and uses in the Rio Piura basin.

This work will serve as a case study to demonstrate the use of Hydro-BID to enhance planning for integrated water resource management. The specific tasks are as follows:

1. Request and obtain data from ANA. Request (i) historical precipitation, temperature, and flow data for the Rio Piura basin; and (ii) projected precipitation and temperature for the 2011–2060 period, derived from climate change models relevant to the region.

2. Prepare, parameterize, and calibrate a Hydro-BID model for the Rio Piura basin: (i) use the Hydro-BID AHD to define catchment boundaries; (ii) use international data sources for land use and soil cover; (iii) generate catchment-level climate data by applying interpolation methods to historical observations; and (iv) calibrate the Rio Piura Basin model using observed flow data for two or three stations in the basin.

3. Incorporate climate projections into the Rio Piura basin model: (i) reach agreement with ANA on the climate scenarios to be analyzed; and (ii) process and reformat downscaled climate projection data provided by ANA, or derive projections from Climate Wizard.

4. Simulate water flow time series under selected climate scenarios: (i) generate monthly flow time series; and (ii) format files for input to the Rio Piura basin WEAP model and deliver to ANA.

5. Prepare summary report. Prepare a brief report documenting the work performed and the results delivered to ANA.

3. MODEL SET-UP AND CALIBRATION

3.1 DELINEATION OF THE RIO PIURA BASIN

The Rio Piura basin is delineated using the AHD navigation tool as shown in **Figure 3**. Further, the basin is delineated based on the three WEAP model input locations at Punte Sanchez, Tombo Grande, and Punte Nacara as shown in **Figure 4**. The total numbers of catchments delineated in the basin are 84, 64, and 47 for the locations above Punte Sanchez, Tomo Grand, and Pute Nacara, respectively. The characteristics of each of the subwatersheds are given in **Table 1.**

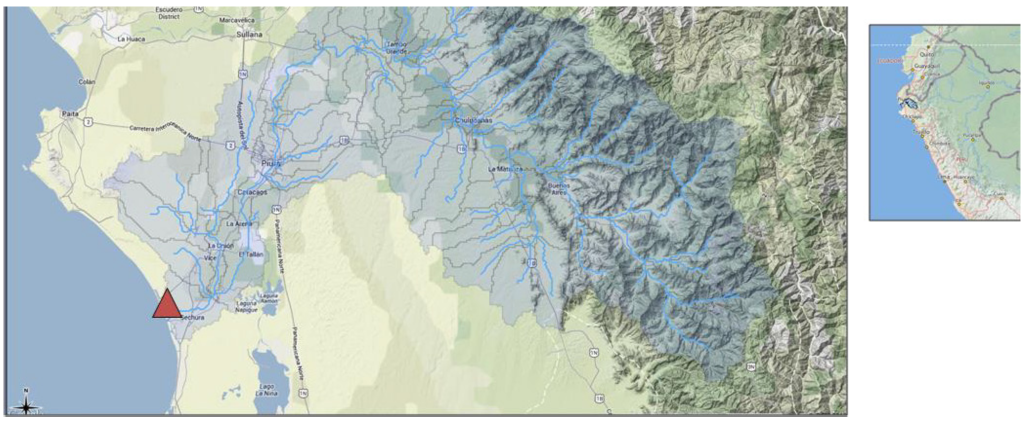

Figure 3. The Rio Piura basin.

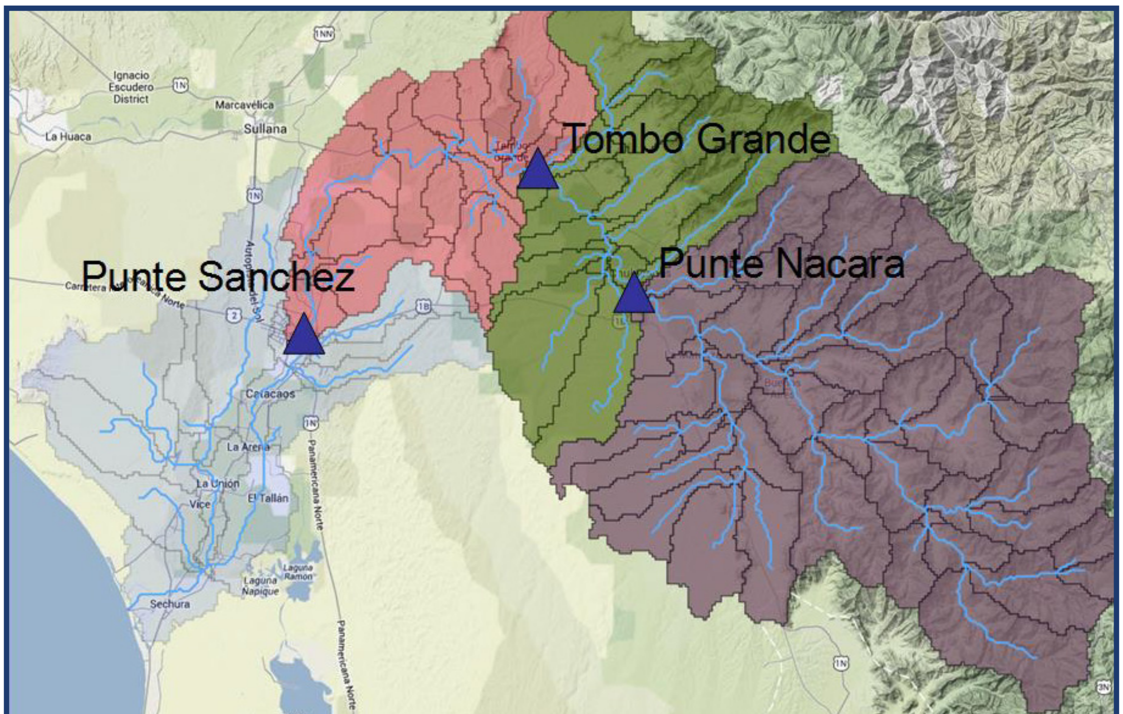

Figure 4. Three subwatershed delineation within the Rio Pirua basin.

Table 1. Characteristics of the three subwatersheds in Rio Piura basin			
Rio Piura Basin	**Punte Sanchez**	**Tombo Grande**	**Punte Nacara**
COMID	305596100	305464800	305553500
Catchment area (km2)	7,538	6,181	4,478
Number of catchments	84	64	47
Average size (km2)	89.7	96.6	95.3
Average stream length (km)	10.4	11.2	10.7

3.2 MODEL PARAMETERIZATION

Hydro-BID is based on the well-known GWLF (Haith, 1985; Haith et al., 1996) and enhanced by the RTI lag-routing methodology. GWLF has been tested and used in watersheds around the world (Schneiderman et al., 2007; Sha et al., 2013). The rainfall runoff model component of GWLF is applied on small catchment units by taking into account the land uses and soil conditions within the catchment. The response of each land use in a given catchment is treated separately to generate an estimate of runoff volume. The flow generated from each catchment, including shallow groundwater contributions or base flow, is routed through stream networks defined by the AHD. The distributed model architecture provides a high level of scalability. Impacts of climate change on water resources can be simulated at scales as small as an individual AHD catchment or across all of the catchments within an entire watershed. This architecture also makes the system very portable across the LAC region.

Figure 5 is a conceptual representation of a catchment with unsaturated and saturated soil layers as used in GWLF. The model computes runoff and base flows by catchment: runoff is generated in the form of excess infiltration and base flow is a gradual release from the saturated layer. After accounting for runoff from precipitation events any water in excess of a calculated evaporation volume is infiltrated to the unsaturated layer. Over time, the infiltrated water percolates from the unsaturated layer downward to replenish the saturated storage. Water within the saturated layer enters the stream channel as base flow where it combines with runoff from the catchment and any inflows from the upstream catchments to provide the stream flow volume for the day. Note that the saturated layer, or water available as base flow, can be depleted by seepage to a deeper groundwater aquifer.

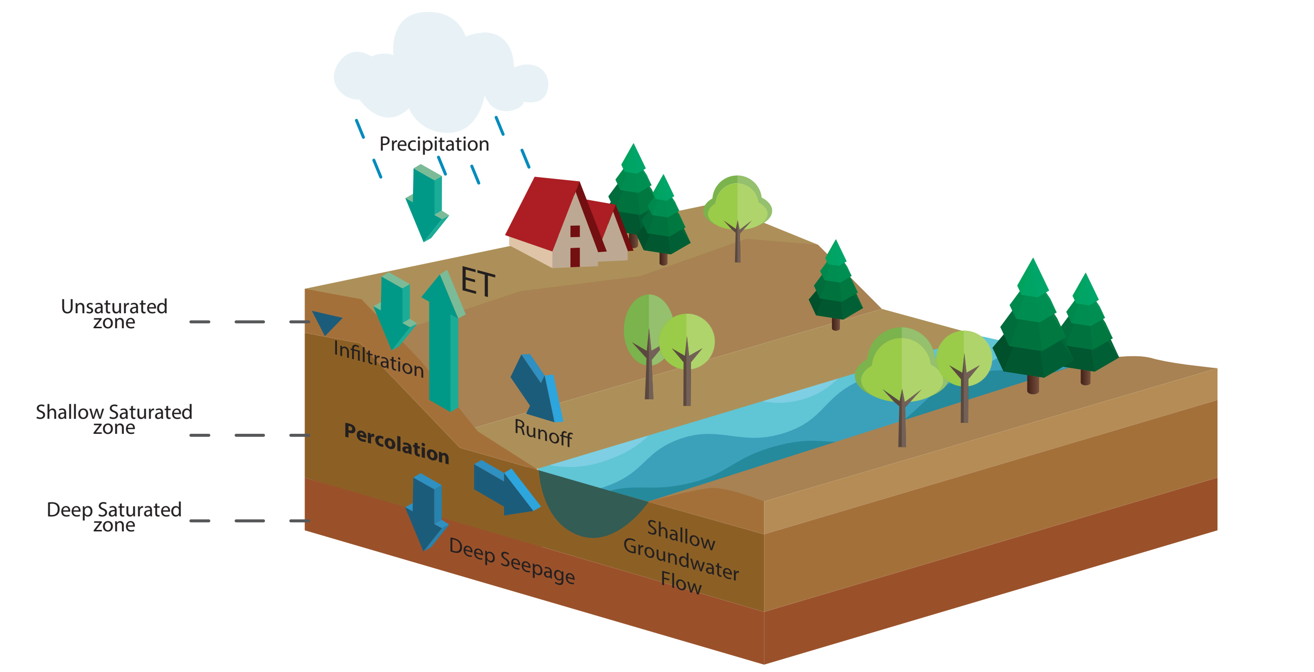

Figure 5. Schematic representation of the GWLF model (modified from Haith et al., 1996)[1]

Parameters of GWLF

Most of GWLF's required parameters are assembled in a database for each of the AHD catchments, including catchment area and stream length. The main parameters of GWLF are described in **Table 2.**

Table 2. Major GWLF parameters that are related to flow generation

Parameters	Description	Estimation Method
Available soil water capacity (U*)	Triggers the start of percolation	Can be estimated from soil characteristics
Curve number (CN)	Controls the initial amount of abstraction; used to compute detention	Chosen using land use and soil type classification
Evaporation curve coefficient (CV)	Represents seasonal variation of evaporation resulting from vegetation growth	Estimated monthly
Groundwater recession coefficient (r)	Controls the rate of ground water flow from the saturated storage	For gauged catchment, can be estimated using hydrograph separation techniques

[1] Request for use submitted to author.

Curve Number

Table 3 is the curve number look-up table. Two sets of data are required to establish a curve number look-up table: land use data and soil data. To determine the curve number for a catchment from the look-up table, the land use and dominant hydrologic soil group are identified, as shown in **Figure 5.**

Table 3. Curve number look-up table (adapted from U.S. Department of Agriculture [USDA], 1986)

Land Use Type	Soil Hydrologic Group			
	A	B	C	D
Urban and Built-Up Land	82	88	92	93
Dryland Cropland and Pasture	64	75	82	85
Irrigated Cropland and Pasture	64	75	82	85
Mixed Dryland/Irrigated Cropland and Pasture	40	64	75	81
Cropland/Grassland Mosaic	40	64	75	81
Cropland/Woodland Mosaic	40	64	75	81
Grassland	49	70	80	87
Shrubland	45	57	68	74
Mixed Shrubland/Grassland	45	57	68	74
Savanna	49	70	80	87
Deciduous Broadleaf Forest	36	60	73	79
Deciduous Needleleaf Forest	36	60	73	79
Evergreen Broadleaf Forest	36	60	73	79
Evergreen Needleleaf Forest	36	60	73	79
Mixed Forest	36	60	73	79
Water Bodies	100	100	100	100
Herbaceous Wetland	49	70	80	87
Wooded Wetland	49	70	80	87
Barren or Sparsely Vegetated	77	86	91	94
Herbaceous Tundra	45	57	68	74
Wooded Tundra	45	57	68	74
Mixed Tundra	45	57	68	74
Bare Ground Tundra	77	86	91	94
Snow or Ice	100	100	100	100

Land Cover Data

The land cover data divide the land surface into different land cover types, including croplands, wetlands, and forests; artificial surfaces; water bodies; and permanent snow and ice (**Figure 6**). The gridded coverage is indexed to the AHD catchments to provide the area of each of the 24 land cover types within each catchment. The land cover grid cells within each catchment are indexed to the soil types they overlay. The land cover data used for this study were obtained from United States Geological Survey global land characterization http://edc2.usgs.gov/glcc/glcc_version1.php#SouthAmerica. The land use classification is described in http://landcover.usgs.gov/pdf/anderson.pdf.

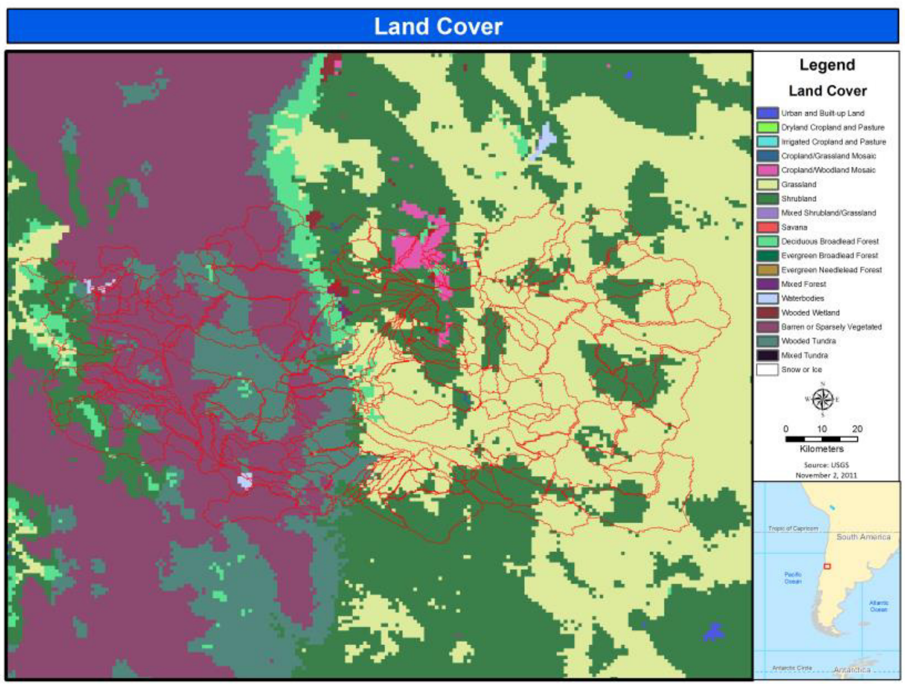

Figure 6. Land cover indexed to catchments

Soils Data

The Harmonized World Soil Database (HWSD) (http://www.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML) can be used to parameterize curve numbers for the LAC region. The HWSD has the necessary soil parameters for the GWLF model for each land use within each AHD catchment. The HWSD combines vast volumes of regional and national updates of soil information with the 1:5,000,000-scale FAO-UNESCO Digital Soil Map of the World. As shown in **Figure 7**, the soil data ayer is overlain on the AHD catchments to determine the dominant soil type in the catchment. Then, the dominant soil type is classified with a hydrological soil group based on the U.S. Department of Agriculture classification. The hydrologic soil group determines the drainage property of the soil. The hydrologic soil group has four types: A, B, C, and D (**Figure 8**.). Type A corresponds to soil with high infiltration, and Type D corresponds to soils with poor drainage and thus low infiltration rates. Types B and C are intermediate classes.

The required soil parameters for the corresponding soil type are indexed to the catchment and land use.

We computed the GWLF parameters for the basin based on the above methodology. **Table 4** shows an example of data populated for a single COMID in the Rio Piura basin. As shown in the table the AHD catchment is characterized by five land use types, mainly dominated by grassland. A total of 12.76 percent of this catchment is covered with Piura city and appropriately assigned a higher value curve number. The variability of land use and corresponding impact in the rainfall-runoff generation is maintained by applying these parameters associated with the land use. Further model calibration of these parameters will be performed as needed by adjusting the parameters at the basin level but keeping the variability.

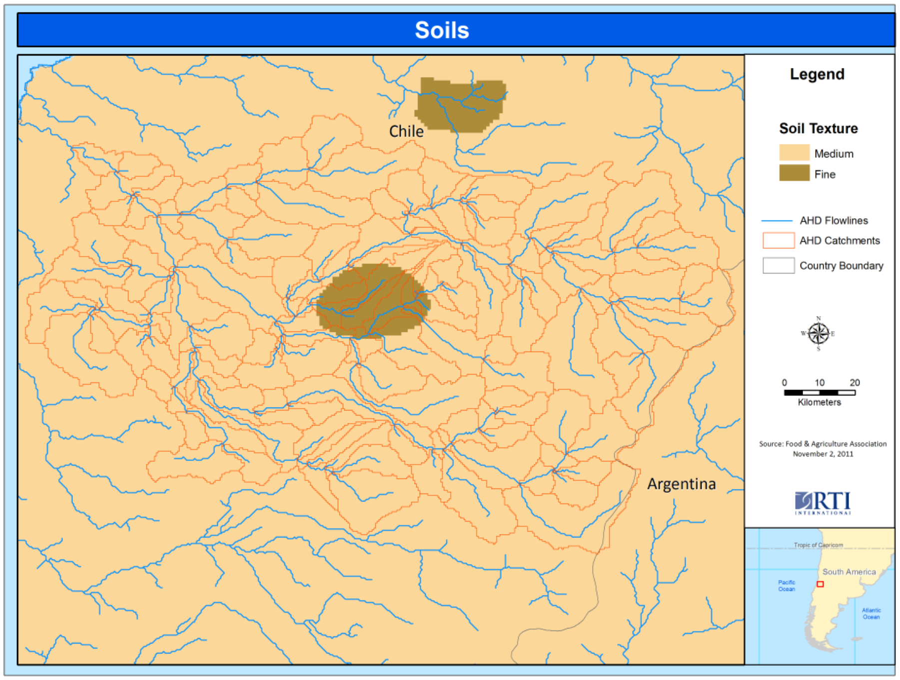

Figure 7. Overlay of soil data over AHD catchments

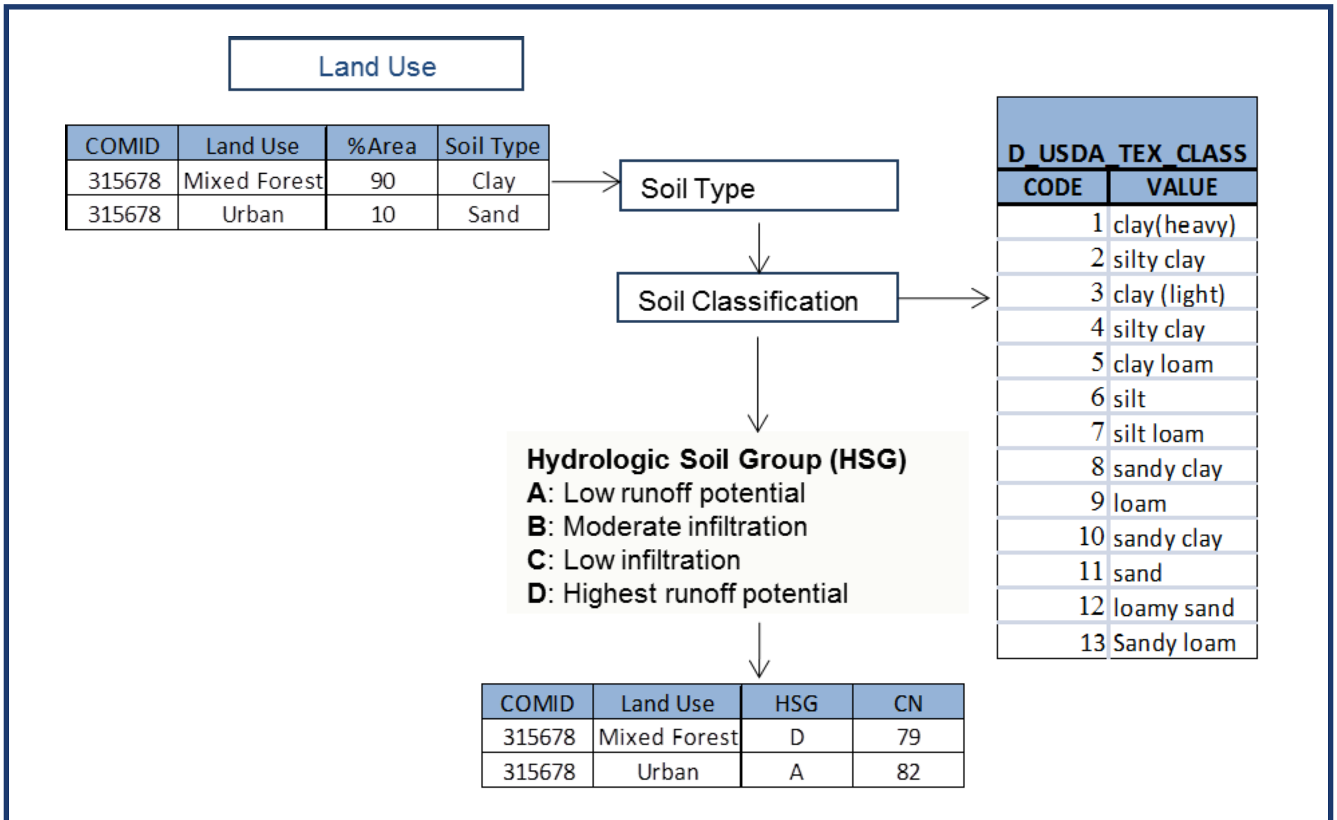

Figure 8. Schematic representation of curve number estimation. The example given here is for a hypothetical single AHD Catchment (COMID=315678), which has two types of land uses (mixed forest and urban); each land use has single dominant soil type.

Table 4. Example of model parameters for COMID 305596100 located at Piura City

COMID	NLCDID	Land Cover Type	Area (km2)	Percent	HydGrp	Curve Number
305596100	1	Urban and Built Up	13.16	12.76	B	88
	6	Cropland/Wood; and Mosaic	29.99	29.08	B	64
	7	Grassland	48.20	46.74	A	49
	11	Deciduous Forest	6.78	6.57	B	60
	21	Wood Tundra	5.00	4.85	B	57

3.3 HYDROMETEOROLOGICAL DATA

Precipitation and Temperature Data

Daily precipitation totals and mean daily temperatures are the main input of the Hydro-BID model. We collected daily precipitation and mean temperature data of stations inside and around the Rio Piura basin from the National Meteorology Institute. There is a relatively high density of stations in the Rio Piura basin, which has good representation of spatial variation of climate. Although some of the records start from the early 1900s, we decided to consider only the period 1980–1990 for the calibration period because of the availability of continuous data for most of the stations. The locations of the stations are provided in **Figure 9.**

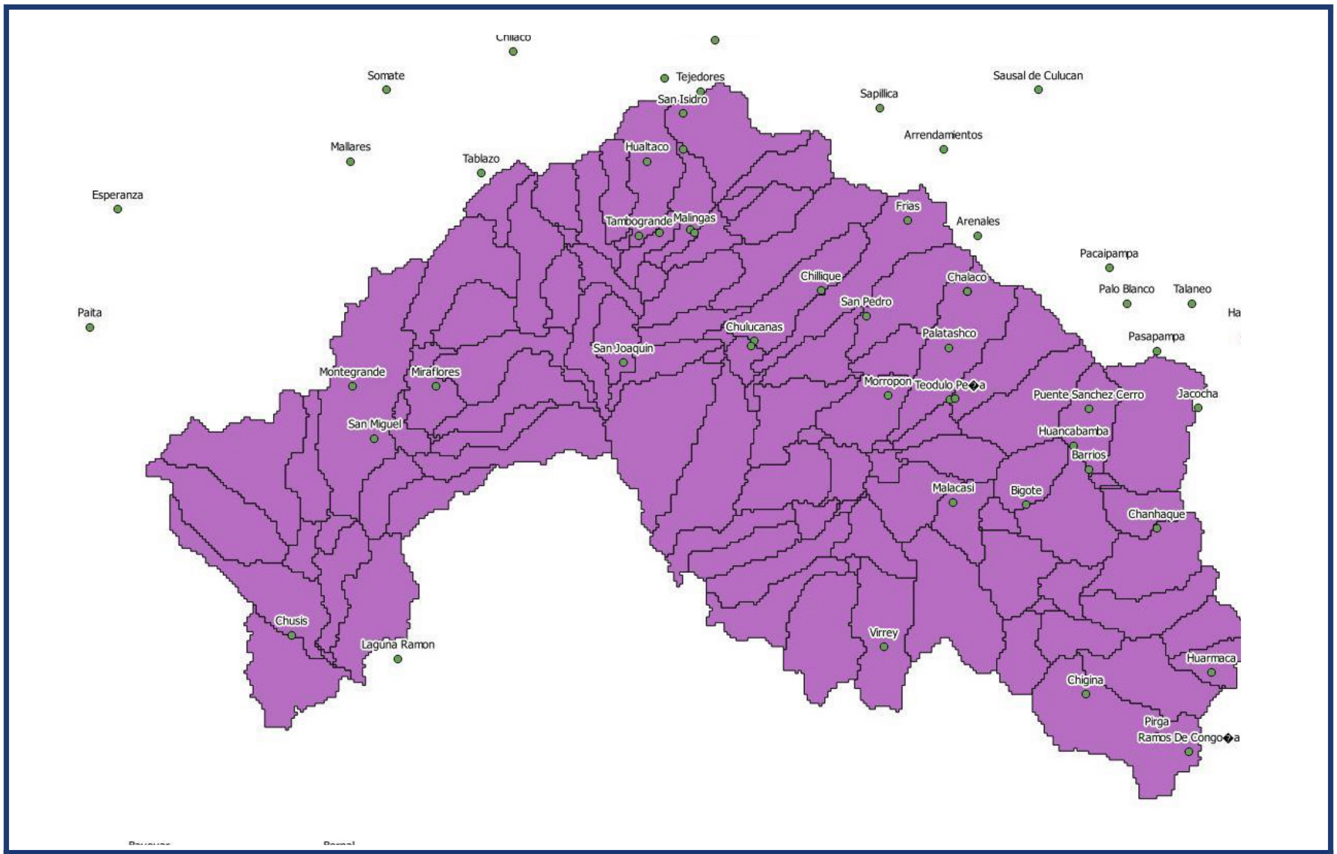

Figure 9. Location of precipitation gages within and around Rio Piura basin

Interpolating the Climate Data Into Catchments

The station precipitation and temperature data are interpolated to AHD catchments in the Rio Piura basin. We used the Climate Interpolating Tool (CIT) developed by RTI to create catchment indexed precipitation and temperature (**Figure 10**).

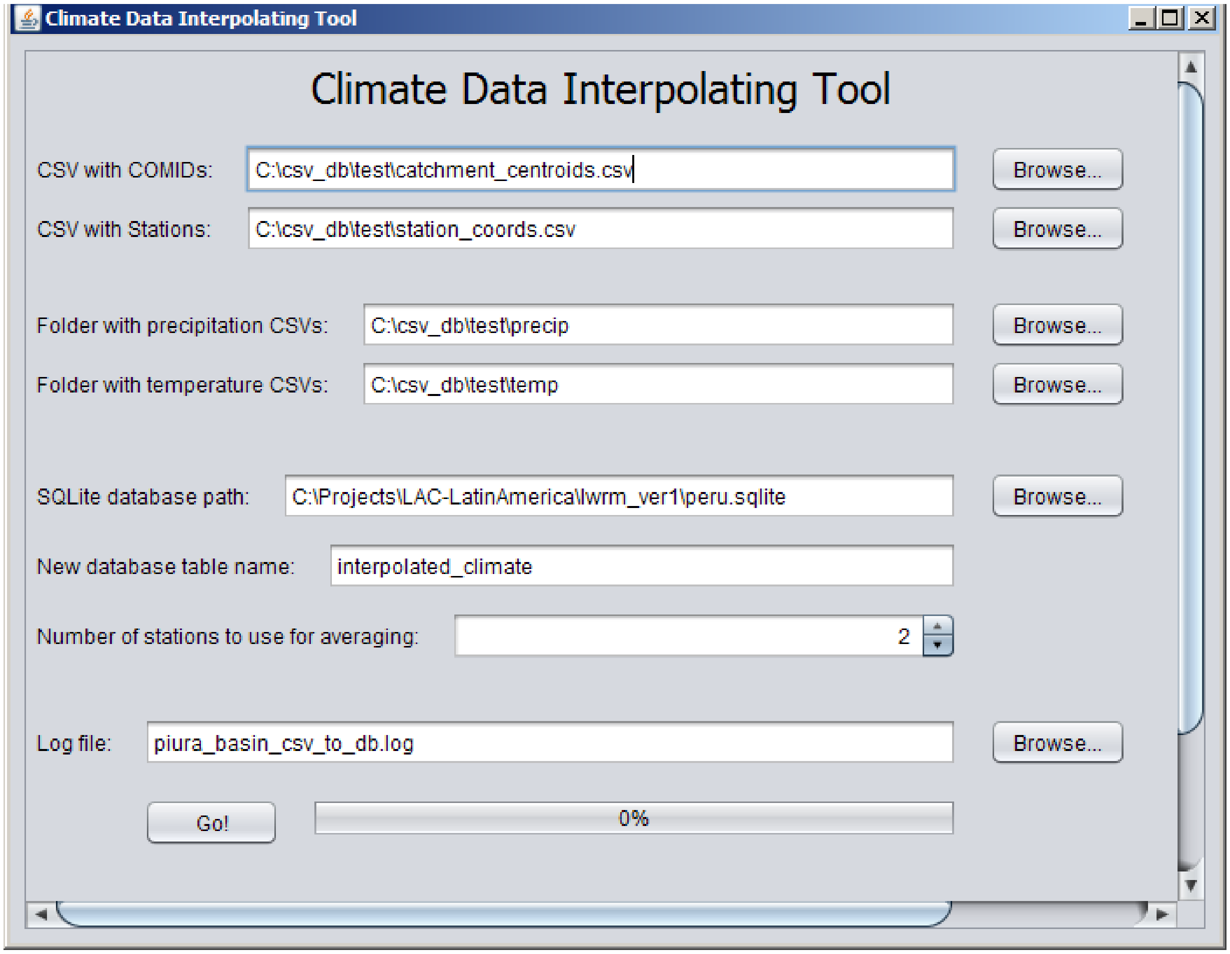

Figure 10. The climate data interpolation tool

The interpolation procedure is described below.

Pre-processing

The original data from ANA are saved in multiple annual tables in a single Microsoft Excel file. We transformed this file into time series data of two columns (date and value) and formatted it as a csv file. These files are then ready to be used by CIT.

Station List

We generated a file that contains the list of precipitation and temperature stations and the location in the form of latitude and longitude (**Tables 5** and **6**). The location description is used in computing the distance between the station and the center of each of the catchments.

Table 5. List of precipitation stations							
Number	Station	Latitude	Longitude	Number	Station	Latitude	Longitude
1	Altamiza	-5.833	-81.017	24	Huancabamba	-5.250	-79.717
2	Chilaco	-4.696	-80.504	25	HaurHaur	-5.083	-79.467
3	Chulucanas	-5.103	-80.166	26	Jacocha	-5.197	-79.542
4	Huarmaca	-5.569	-79.523	27	LagunaRamon	-5.550	-80.667
5	Miraflores	-5.167	-80.614	28	LasLomas	-4.650	-80.250
6	Pacaipampa	-5.000	-79.667	29	Malingas	-4.950	-80.250
7	SanMiguel	-5.240	-80.700	30	Mallares	-4.850	-80.733
8	Tejedores	-4.752	-80.242	31	Paita	-5.083	-81.100
9	Virrey	-5.533	-79.983	32	PaloBlanco	-5.050	-79.642
10	Arrendamiento	-4.833	-79.900	33	Partidor	-4.733	-80.292
11	Bayovar	-5.833	-81.017	34	Pasapampa	-5.117	-79.600
12	Bernal	-5.833	-80.750	35	Pirga	-5.658	-79.600
13	Bigote	-5.333	-79.783	36	RamosdeCongona	-5.681	-79.554
14	Chanhaque	-5.367	-79.600	37	RepSanLorenzo	-4.679	-80.221
15	Chigina	-5.600	-79.700	38	Salala	-5.098	-79.476
16	Chalaco	-5.033	-79.867	39	SanIsidro	-4.783	-80.267
17	Chusis	-5.517	-80.817	40	SanJoaquin	-5.133	-80.350
18	CorraldelMedio	-5.183	-79.883	41	SantoDomingo	-5.033	-79.867
19	Cruceta	-4.833	-80.267	42	Sapillica	-4.775	-79.990
20	Curban	-4.950	-80.300	43	SausaldeCulucan	-4.750	-79.767
21	Esperanza	-4.918	-81.061	44	Somate	-4.750	-80.683
22	Frias	-4.933	-79.950	45	Tablazo	-4.867	-80.550
23	Hualtaco	-4.850	-80.317	46	Talaneo	-5.050	-79.550

Table 6. List of temperature stations							
Number	Station	Latitude	Longitude	Number	Station	Latitude	Longitude
1	Arenales	-4.955	-79.851	6	Chulucanas	-5.103	-80.166
2	Chukucanas	-5.103	-80.166	7	Huarmaca	-5.569	-79.523
3	Montegrande	-5.167	-80.731	8	Miraflores	-5.167	-80.614
4	Morropon	-5.180	-79.978	9	San Miguel	-5.240	-80.700
5	Chilaco	-4.696	-80.504	10	Tejedores	-4.752	-80.242

List of Catchments

After navigating the AHD upstream of the Punte Sanchez, we created a list of catchments within the basin. These catchments will be associated to interpolated precipitation and temperature data.

Method of Interpolation

We used the inverse distance method of interpolation with the constraint of using a user-specified number of stations that are closer to a given catchment. This will allow restricting the interpolation from far distances. In the future, this restriction can be implemented by considering the topography of the watershed. For this case study, we limited the number of stations to three.

Additional Considerations

On a daily basis, the availability of station precipitation data is checked. Stations with missing data for the day are removed.

Flow Data

We collected daily mean flow time series from three stations along the Rio Piura. The two time series have complete data while one station has a number of missing days. The flow time series are used to calibrate and evaluate the accuracy of the model.

Projected Climate Data

Climate change modeling is an inexact science, and the various methods are evolving continuously. Therefore, the estimation of future temperature and precipitation is usually addressed by considering a variety of approaches, including (1) different emission scenarios, (2) different Global Circulation Models (GCMs), (3) the use of global models with grid resolution of 100–200 km, and (4) regional/downscaled models with grid resolution of 50 km. In addition, most climate modeling is currently done using Intergovernmental Panel on Climate Change 4 methodologies.

However, in this study we started with SENAMHI data. ANA provided a set of projected climate data for Peru. The daily precipitation and temperature data were downscaled from the NCAR CSM 1.3 (USA) global climate model. Two emission scenarios were considered.[2]

Dynamic downscaling or regionalization was used by the regional climate model RAMS v4.4. The format of the data is GrADS gridded data.

We extracted these data and generated daily precipitation and temperature following the data description provided in the database. We evaluated the data by comparing the model precipitation values to observed precipitation in the area and concluded that the data in the files are not in the same order of magnitude. Therefore, we requested that ANA provide more explanation on the units or format of the data. Further communication with ANA and IDB resulted in looking for other alternative data to complete the project. Hence, RTI used the Climate Wizard data to generate future precipitation and temperature deviations.

A summary of evaluation of the SENAMHI data is provided in Appendix A.

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[2] http://www.grida.no/publications/other/ipcc_tar/?src=/climate/ipcc_tar/wg1/347.

Projected Climate Data from Climate Wizard

Our next step was to use the online climate projection tool known as Climate Wizard (www.climatewizard.org) to project changes in temperature and rainfall out to the year 2060. This tool, developed by three U.S. universities and two international nongovernmental organizations (with endorsement from the World Bank), has many useful features that allow the user to

- select a time period for analysis, whether historical (using the Climate Research Unit database from the University of East Anglia in the UK) or future, for any given range of years to 2100;
- select a single GCM or an ensemble of GCMs and one or more emission scenarios;
- upload geographic shape-files and receive results in a gridded map format (**Figure 11**); and
- obtain graphical information on annual values of output data over a multiyear scale.

We used Climate Wizard to generate future climate data for the Rio Piura basin, for initially identified GCM and scenario by SENAMHI: NCAR CSM 1.3 (USA) global climate model with two emission scenarios of A2 and B2. A2 is considered high emission and B2 is considered low emission. For each decade we obtained monthly deviation of precipitation in percent and deviation of temperature in degree centigrade from the reference period 1961–1990.

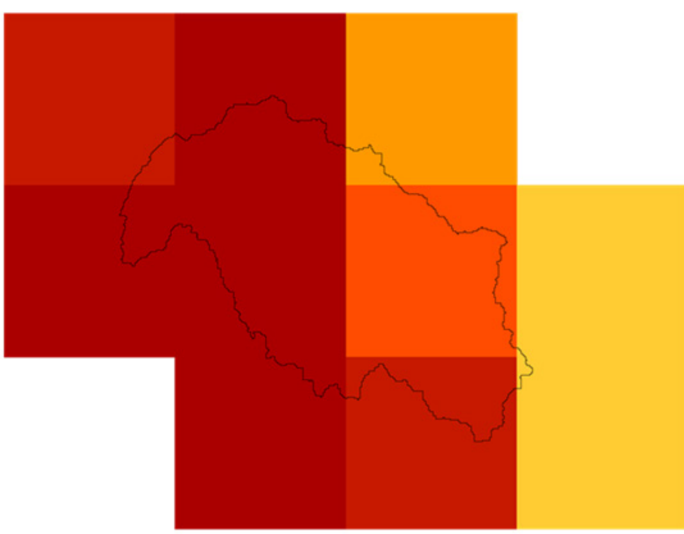

Figure 11. Resolution of the GSM models in relation to the Rio Piura basin.

The next step was to develop climate scale factors to be used in the hydrologic modeling. **Table 7** shows scale factors for precipitation and temperature for the CSIRO A2 scenario. **Table 8** scale factors for precipitation and temperature for the CSIRO B2 scenario. Precipitation scale factors are used as multipliers on the 1980–1990 data, but temperature scale factors are presented as actual temperature change.

Table 7. Scale factors for CSIRO A2

Month	Precipitation Multiplier by 1981-1990 A2-Scenario -High				
	2011-2020	2021-2030	2031-2040	2041-2050	2051-2060
Jan	0.79	0.85	1.06	0.83	0.75
Feb	1.18	0.80	1.16	0.84	0.98
March	1.19	0.85	1.18	1.30	1.59
April	1.04	0.95	0.94	0.86	1.11
May	0.78	0.63	1.07	0.56	0.74
Jun	1.12	0.84	0.80	0.71	0.60
Jul	0.82	0.55	0.79	0.37	0.35
Aug	0.57	0.60	0.47	0.42	0.37
Sep	0.52	0.42	0.50	0.41	0.33
Oct	0.51	0.59	0.51	0.48	0.26
Nov	0.65	0.48	0.50	0.55	0.26
Dec	1.02	0.87	1.27	0.81	0.61

	Temperature deviation from 1980-1990 A2-Scenario -High				
	2011-2020	2021-2030	2031-2040	2041-2050	2051-2060
Jan	0.96	1.05	1.31	1.61	2.08
Feb	0.89	0.94	1.15	1.51	1.85
March	0.77	0.80	1.08	1.38	1.92
April	0.50	0.74	0.83	1.17	1.81
May	0.24	1.12	1.26	1.39	1.40
Jun	0.59	0.69	1.06	0.65	1.22
Jul	0.72	1.14	1.07	1.50	1.75
Aug	0.46	0.75	1.18	1.37	1.86
Sep	0.93	1.11	1.42	1.83	2.14
Oct	1.05	1.39	1.56	1.95	2.14
Nov	0.94	1.29	1.49	1.79	1.92
Dec	0.94	1.23	1.44	1.61	1.78

Table 8. Scale factors for CSIRO B1

Month	Precipitation Multiplier by 1981-1990 B1-Scenario -LOW				
	2011-2020	2021-2030	2031-2040	2041-2050	2051-2060
Jan	0.79	0.75	0.83	0.81	0.88
Feb	0.81	0.73	1.22	1.10	0.86
March	1.05	0.92	1.12	1.29	0.89
April	0.93	0.77	0.77	1.18	1.03
May	1.05	0.78	0.68	0.99	0.77
Jun	0.88	0.84	0.71	0.80	0.78
Jul	0.65	0.69	0.60	0.64	0.55
Aug	0.68	0.50	0.61	0.47	0.72
Sep	0.78	0.51	0.48	0.38	0.54
Oct	0.53	0.48	0.46	0.56	0.55
Nov	0.49	0.63	0.59	0.64	0.57
Dec	0.70	1.03	0.97	0.82	0.72

Month	Temperature deviation from 1980-1990 B1-Scenario _Low				
	2011-2020	2021-2030	2031-2040	2041-2050	2051-2060
Jan	0.61	0.91	0.99	1.31	1.33
Feb	0.76	0.77	0.94	1.28	1.03
March	0.72	0.58	0.85	1.30	1.13
April	0.51	0.42	0.55	0.84	0.90
May	0.64	0.51	0.45	1.02	1.12
Jun	0.66	0.14	0.63	0.89	0.97
Jul	0.82	0.54	0.44	1.06	1.43
Aug	0.85	0.47	0.54	0.90	1.06
Sep	0.98	0.76	0.96	1.21	1.31
Oct	1.05	1.00	1.11	1.33	1.48
Nov	0.96	0.90	1.00	1.47	1.20
Dec	0.90	0.89	0.69	1.21	1.24

4. MODEL CALIBRATION

4.1 MODEL CALIBRATION

Three parameters—curve number multiplier, runoff coefficient, and seepage parameters—are calibrated to obtain a reasonable overall error. The flow time series of Punte Sanchez is used to calibrate the model and the station Punte Nacara is used to verify the model simulation.

Overall, the model simulates the water balance well but overestimates high summer flows. The difference in overall streamflow over the decade 1980–1990 was 4.4 percent for calibration site and 7.5 percent for verification site (**Table 9**). The overall correlation between observed and simulated was very high: 0.87 for daily flows and 0.96 for monthly flows. **Figures 12** and **13** show model results in the form of a comparison of observed and simulated monthly hydrographs for model calibration and verification, respectively.

Table 9. Performance of the model on daily time step

	Piura Calibration	Nacara Verification
Daily		
Correlation	0.87	.84
Overall Error (%)	4.40	7.50
Nash-Sutca	0.65	0.33
Monthly		
Correlation	0.96	0.92
Overall Error (%)	4.40	7.50
Nash-Sutca	0.89	0.75

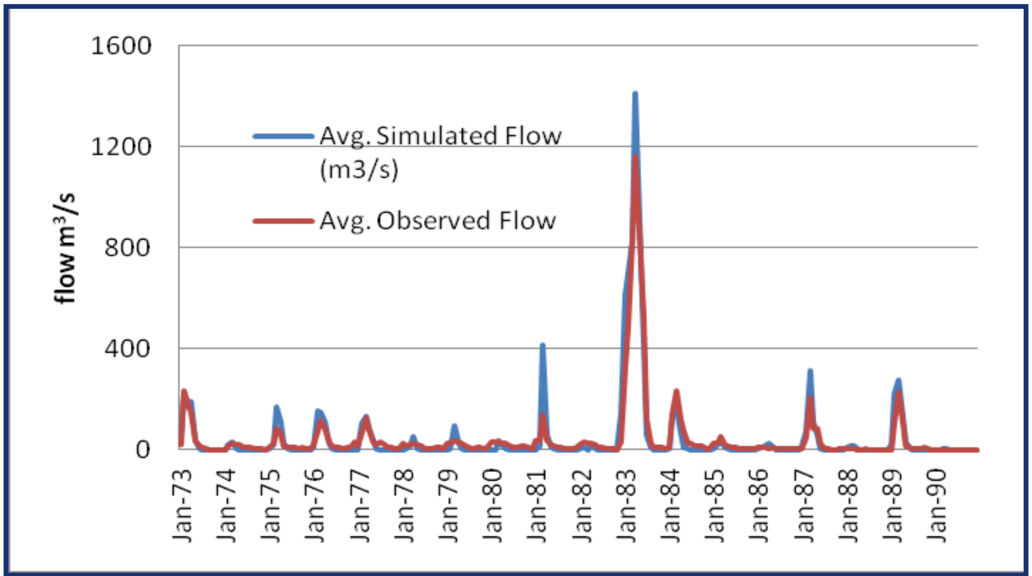

Figure 12. Calibration results: comparison of observed and simulated flow at Punte Sanchez

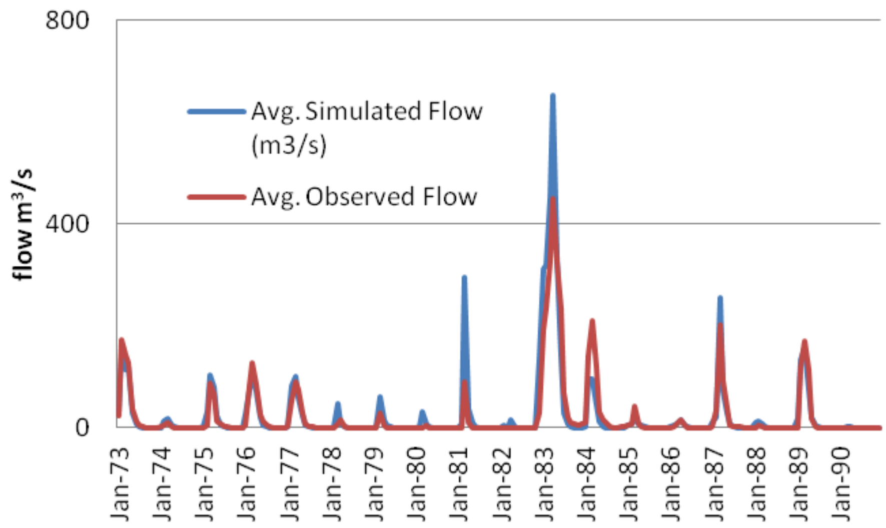

Figure 13. Verification results: comparison of observed and simulated flow at Nacara

4.2 SIMULATION

The period 1981–1990 is considered a reference decade. Computations for future decades are based on future temperature and precipitation from several climate projections, discussed in Section 3. This is accomplished by scaling up or down the monthly temperature and monthly precipitation datasets by linear escalators derived from the Climate Wizard results. All of the climate model results are input to the Hydro-BID model to compute new stream-flow values for the Rio Piura basin.

4.3 MONTHLY TIME SERIES

For each of the WEAP input locations, we calculated the mean areal temperature and precipitation. The daily flows at each location are averaged to create monthly time series for the period 2011–2060.

5. SUMMARY OF THE PROJECT

A working Hydro-BID model was prepared, calibrated, and used to generate flow time series at multiple locations in the watershed. The generated time series can now be used in conjunction with the WEAP model to study the impact of climate change in the water resource of the Rio Piura basin.

5.1 ASSUMPTIONS

The following assumptions were made for the Rio Piura simulation:

- Land use and vegetative cover in the watershed are assumed to remain the same for the period 2011-2060.
- Climate conditions during the reference period 1981-1990 are assumed to represent the climate conditions of 1960-1990.
- The model parameters are adequate to represent the rainfall-runoff generation for the period of simulation.

Note that the simulated flows are not intended to be a continuous prediction for the 2011-2060 period. Rather, the simulation represents one realization of the reference period in the coming decades with a decadal adjustment of temperature and precipitation data.

5.2 CONCLUDING REMARKS

From the hydrological simulation for the period 2011-2060, average annual flows for the Rio Piura tend to increase under the CSIRO –A2 scenario compared to the reference annual average flows, while for the CSIRO-B1 scenario, average annual flows have a tendency to decrease. (**Figure 14**).

The impact of projected climate change on the Rio Piura can be seen most clearly in seasonal flows (**Figure 15**.) The CSIRO-A2 scenario produces more high flows during wet seasons, in sharp contrast to fewer high wet-season flows for the CSIRO-B2 scenario. Inversely, for dry seasons, the CSIRO-A2 scenario produces lower flows than the reference scenario and the CSIRO-B2 scenario.

ANA will use these results to modify its WEAP model of the Rio Piura basin and quantify the impact of projected changes in Rio Piura flows on the water resources in the basin, in terms of seasonal and annual water demands for irrigation, domestic water supply and other uses.

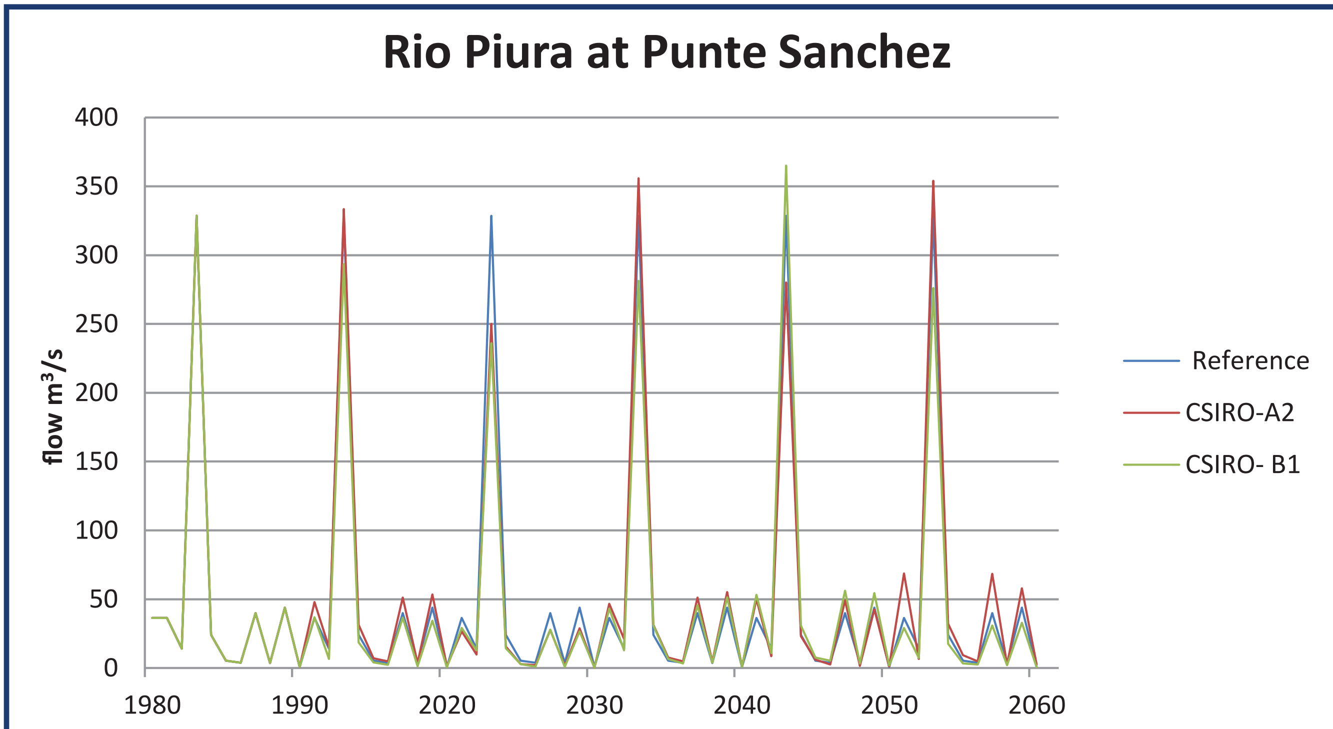

Figure 14. Annual average flows of Rio Piura at Punte Sanchez under reference, CSIRO-A2 and CSIRO-B1 climate projection scenarios.

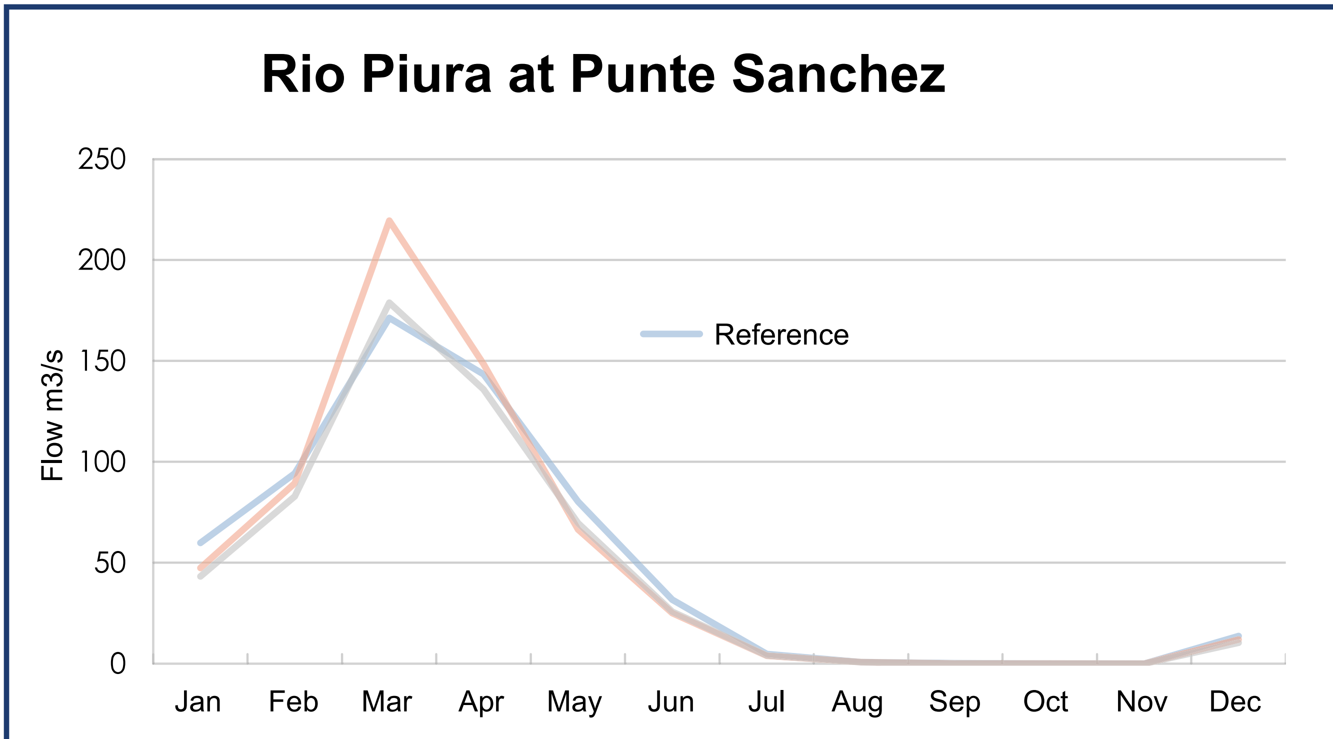

Figure 15. Monthly average flows of Rio Piura at Punte Sanchez under reference, CSIRO-A2 and CSIRO-B1 climate projection scenarios

The flow time series are saved in three files in xlsx format for the three WEAP model inputs. The flows are total generated flow upstream of each location.

Puente_Sanchez_monthly1981_90_2011_2060.xlsx
Puente_Nacara_monthly1981_90_2011_2060.xlsx
Tombo_grande_monthly1981_90_2011_2060.xlsx

Table 10 shows example of the format of the time series data files.

CSIRO A2 scenario:
Column A: Month and year from 1981-1990 and from 2011-2060
Column B: Monthly mean areal temperature (0c) observed (1981) and projected (2011-2060)
Column C: Monthly mean areal precipitation (cm) observed (1981) and projected (2011-2060)
Column D: Monthly mean flow (m3/s) simulated using
Column E: Monthly mean flow (m3/s) observed for 1981-1990

CSIRO B1 scenario:
Column H: Month and year from 1981-1990 and from 2011-2060
Column I: Monthly mean areal temperature (0c) observed (1981) and projected (2011-2060)
Column J: Monthly mean areal precipitation (cm) observed (1981) and projected (2011-2060)
Column K: Monthly mean flow (m3/s) simulated using
Column L: Monthly mean flow (m3/s) observed for 1981-1990

Table 10. Example of the format of time series data file

A	B	C	D	E	F	G	H	I	J	K	L
Month-Year	Avg. Temperature	Precipitation	A2 Simulated Flow (m3/s)	Avg. Observed Flow			Month-Year	Avg. Temperature	Precipitacion	A2 Simulated Flow (m3/s)	Avg. Observed Flow
Jan-81	23.666	2.169	0.109	34.01			Jan-81	23.666	2.169	0.109	34.01
Feb-81	24.643	7.487	12.694	36.282			Feb-81	24.643	7.487	12.694	36.282
Mar-81	24.254	30.237	372.016	137.032			Mar-81	24.254	30.237	372.016	137.032
Apr-81	23.224	5.099	40.72	35.077			Apr-81	23.224	5.099	40.72	35.077
May-81	21.286	0.332	8.696	22.119			May-81	21.286	0.332	8.696	22.119
Jun-81	20.137	0.121	1.572	14.773			Jun-81	20.137	0.121	1.572	14.773
Jul-81	19.146	0.047	0.289	9.823			Jul-81	19.146	0.047	0.289	9.823

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APPENDIX A: EVALUATION OF ANA CLIMATE DATA

Introduction

This document describes the steps taken to process modeled climate data for Peru and the complications that arose because of gaps and other errors in the data. Servicio Nacional de Meteorología e hidrología del Perú (SENAMHI) provided climate model data (Model NCAR CSM 1.3, scenarios A2 and B1) to researchers at RTI International. The data were intended for catchment-level hydrologic modeling in Peru but were found to contain too many errors and deficiencies for scientific use. The data, covering the years 2004–2036 in 6-hour time intervals, contain temporal gaps, empty data files, ambiguous data structure, and seemingly erroneous climate values. Although some issues, such as gaps in the data, might have been overcome, discrepancies in raw temperature and precipitation values ultimately made the data unusable for scientific research.

Data Description

Thirty-two years of climate model data covering a portion of South America (**Figure A-4**.) were delivered to RTI as 1,100 pairs of files comprising 30 gigabytes of disk space. Metadata included with the data described the climate model as NCAR CSM 1.3, Scenarios A2 and B1, with dynamic downscaling or regionalization performed using RAMS v4.4. The data were provided by SENAMHI (National Service of Meteorology and Hydrology of Peru). The files used the Grid Analysis and Display System (GrADS) format, in which each pair of files contained a file of binary data and a control file (Table A-1) describing the binary data file. Each binary file contained up to 11 days of climate data in 6-hour increments. The number of days per file varied depending on the month, or portion of month, being described. A 30-day month was divided into three 10-day file pairs, while months with 31 days contained two 10-day file pairs and one 11-day file pair. Each data file contained 13 climate variables in 6-hour time steps covering a spatial grid, 46x46 cells in size. Each file referenced the same grid. A sample control file can be viewed in **Table A-1**. Researchers planned to use the temperature (K) and precip (mm) variables to perform catchment-level modeling in Peru (**Figure A-5**).

Data Errors

Examining the names of all 2,200 files revealed probable gaps in the dataSome control files did not have a corresponding data file (**Table A-2**)., some data files did not have a control file, and in some cases both control and data files were missing for a given time period. In addition to missing files, there were 39 empty data files.

Using GrADS software to open the files that did contain data uncovered additional data errors. Although the data were theoretically in 6-hour increments (four per day), each file contained an odd number of time steps, usually one additional time step per time period. For example, a file containing 10 days of data in 6-hour time steps should have contained 40 bands of data; however, these files always contained 41 bands. Files of the final 11 days of each 31-day month contained 45 bands of data, and files containing February 21–28 in non–leap years contained 33 bands. In leap years, however, instead of an extra time step, it appeared 2 days were missing from the end of each February. The third file of each leap year February, which should have contained 36 bands of data in 6-hour increments, only contained 27 bands of data, or the equivalent of 7.25 days. This left only 27 complete days for each February in a leap year. Although no explanation was offered for the additional band of data in each file, the first band of data was discarded when RTI realized that all precipitation values were null.

After tallying the missing data and acknowledging the data structure to be somewhat unclear, RTI discovered that many temperature and precipitation values were so extreme as to be deemed impossible. In the first 20 days of 2004, temperatures were as high as 333 degrees Kelvin (60 deg C) for hundreds data points (grid cells); rainfall totals for a 6-hour period were as high as 2,500mm (2.5m) with hundreds of values over 1,000mm. Averaging 2004 temperature values resulted in more normal values, while summing precipitation values resulted in unrealistic totals. RTI hypothesized that the precipitation units may have been incorrectly described in the control files, and that in fact, precipitation was recorded in tenths of a millimeter (Figures A-1 and A-22). However, moving the decimal place one digit to the left still resulted in unusually high annual precipitation totals (**Figure A-3**).

CONCLUSION

Countless errors and irregularities in these climate model data make them unsuitable for scientific research. If the data exist in another format, it should be used to verify the GrADS files and determine whether more accurate data are available. Otherwise, an alternative climate model for the region in question should be considered.

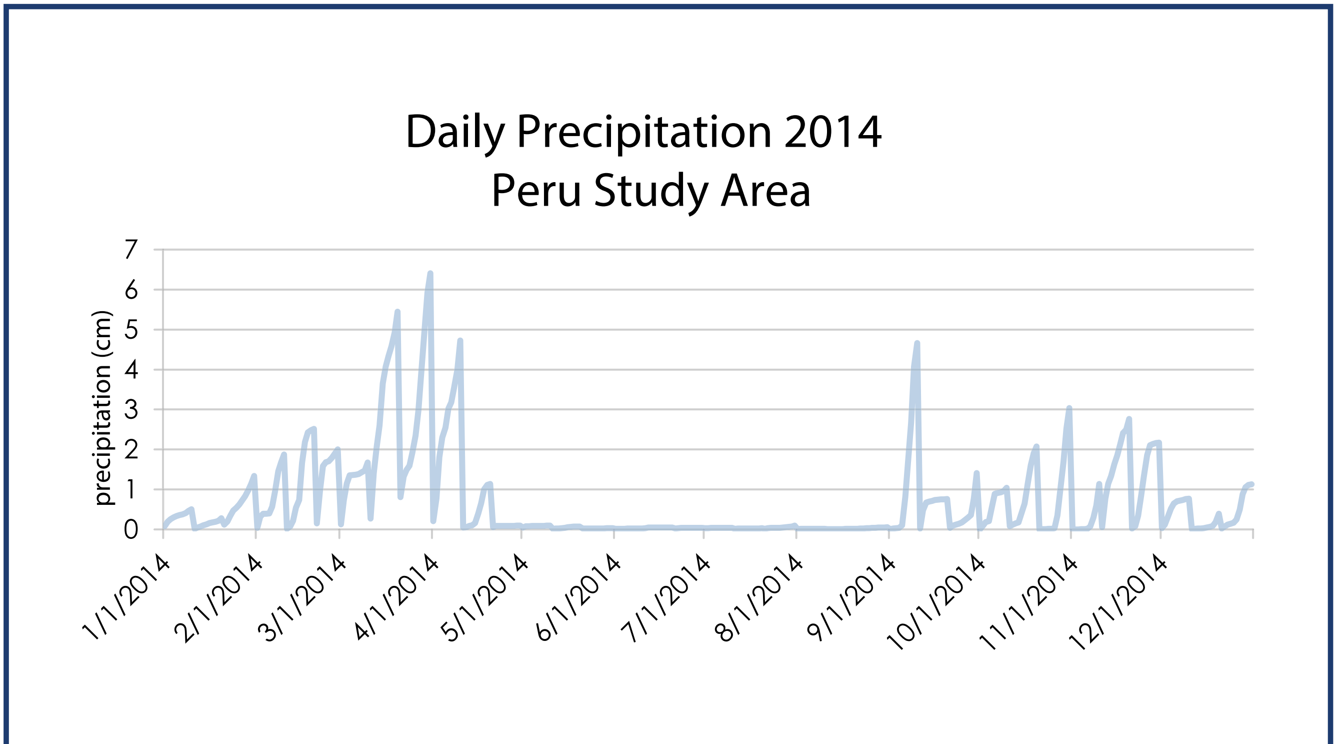

Figure A-2. Daily Precipitation for Peru Study Area, 2014. Units adjusted by factor of 0.1 and converted to cm.

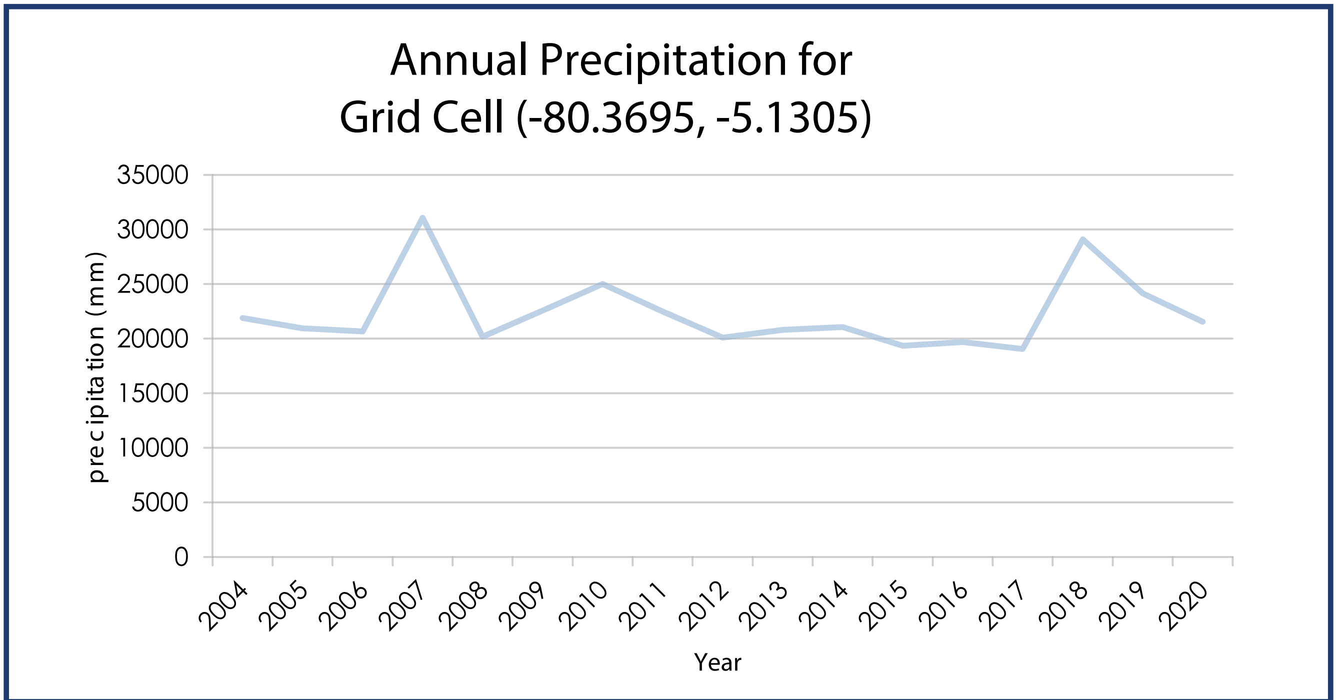

Figure A-3. Annual precipitation for single grid cell, 2004 – 2020. No unit adjustment. Note that annual otal rainfall amounts range from approximately 20,000mm (20m) to 30,000mm (30m). If units are adjusted by a factor of 0.10, range would be 2m–3m per year.

Table A-1. Example Control File:

dset ^2011-01-01.gra undef 1.0e30 options big_endian title RAMS Output xdef 46 linear -85.2291489 0.5399568 ydef 46 linear -22.9490604 0.5399568 zdef 11 levels 1000.000 925.000 850.000 700.000 500.000 400.000 300.000 250.000 200.000 150.000 100.000 tdef 41 linear 00:00Z01jan2004 06hr vars 13 u 11 99 - RAMS : grid relative u [m/s] v 11 99 - RAMS : grid relative v [m/s] w 11 99 - RAMS : w [m/s]	tempk 11 99 - RAMS : temperature [K] dewptk 11 99 - RAMS : dewpoint temp [K] precip 1 99 - RAMS : total accum precip [mm liq] seapress 1 99 - RAMS : sea level pressure [mb] relhum 11 99 - RAMS : relative humidity [pct] geo 11 99 - RAMS : geopotential height [m] topo 1 99 - RAMS : topo [m] soiltemp_ps 0 99 - RAMS : soil/sea temp [C] soilmoist_ps 0 99 - RAMS : soil moisture [m3/m3] tempf2m 1 99 - RAMS : temp - 2m AGL [F] endvars

Table A-2. Missing and Erroneous Data

B.1 Empty GrADS files:
01/01/11 through 05/31/11
20 days from January 2012
Empty Files:

2023-12-21.gra	2027-09-11.gra	2028-02-11.gra	2028-07-01.gra
2024-01-01.gra	2027-09-21.gra	2028-02-21.gra	2028-07-11.gra
2024-01-11.gra	2027-10-11.gra	2028-03-11.gra	2029-07-21.gra
2024-01-21.gra	2027-10-21.gra	2028-03-21.gra	2029-08-11.gra
2024-02-01.gra	2027-11-11.gra	2028-04-11.gra	2029-08-21.gra
2024-02-11.gra	2027-11-21.gra	2028-04-21.gra	2029-09-11.gra
2024-02-21.gra	2027-12-11.gra	2028-05-11.gra	2029-09-21.gra
2024-03-01.gra	2027-12-21.gra	2028-05-21.gra	2029-10-01.gra
2024-03-11.gra	2028-01-11.gra	2028-06-11.gra	2029-10-11.gra
2027-08-21.gra	2028-01-21.gra	2028-06-21.gra	

Figure A-4: Map of data coverage (climate data provided for area in orange grid)

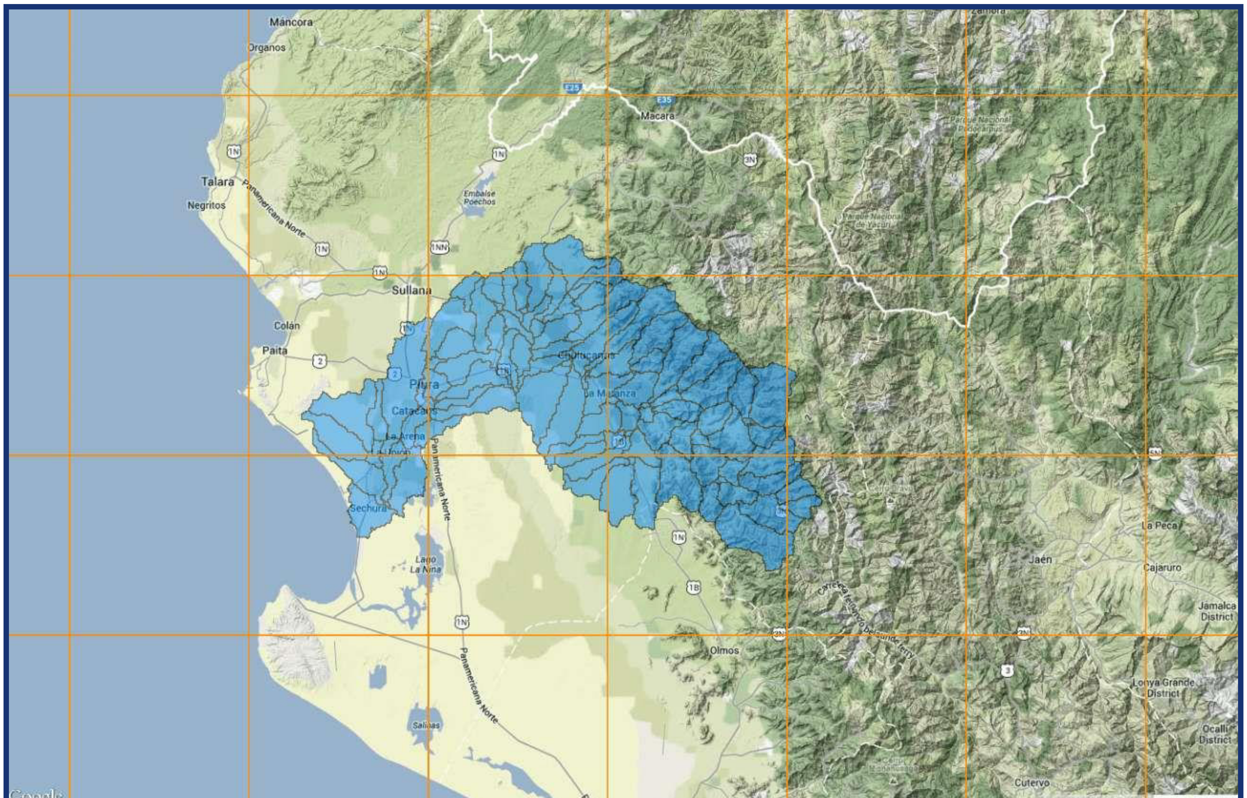

Figure A-5: Map of Study Area with Catchments in Blue, Climate Grid Cells in Orange

Inter-American Development Bank