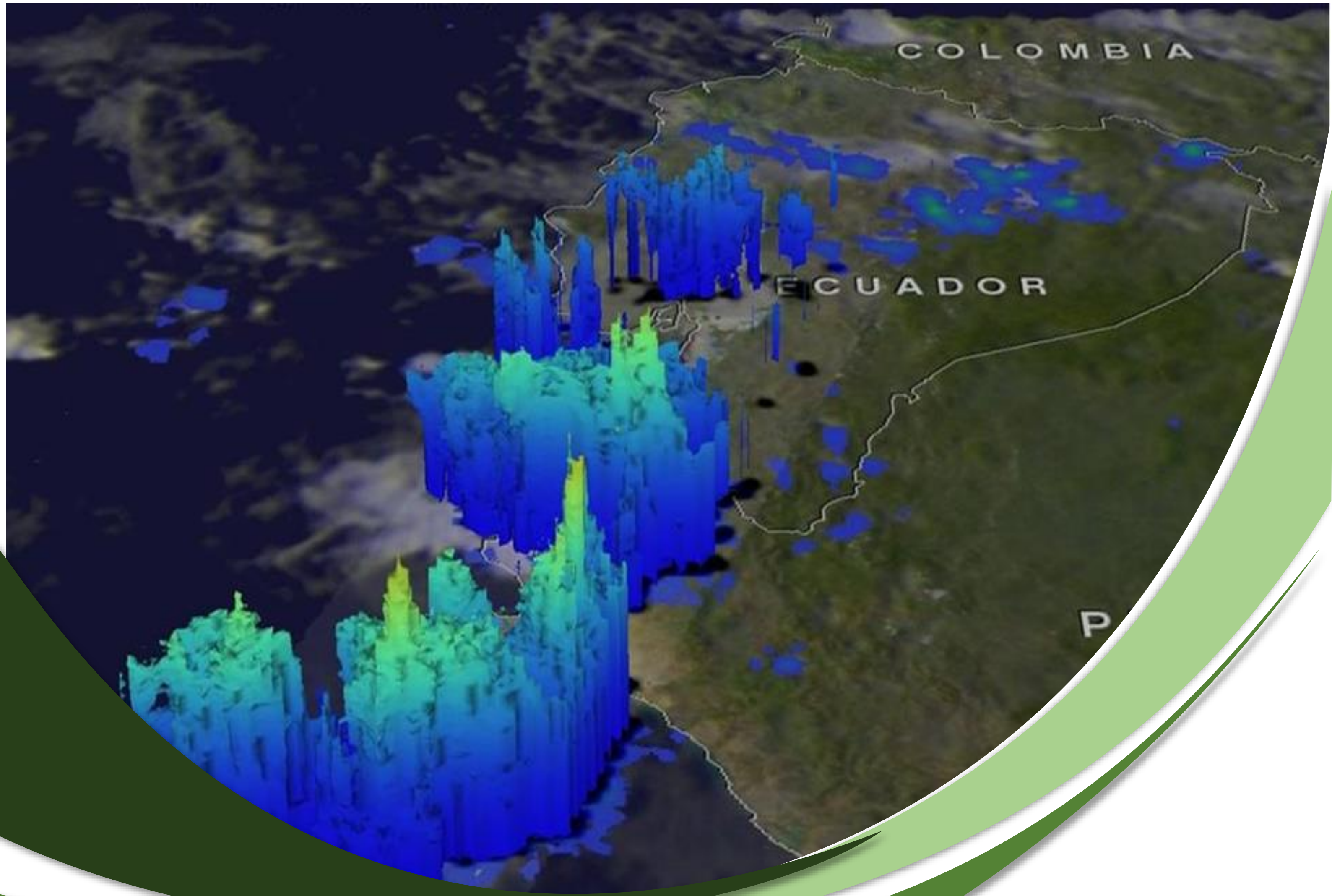

Committee on Disaster Risk Management

Peruvian Association of Professional Engineers

RESILIENCE AGAINST NATURAL DISASTERS:

PIURA RIVER'S EARLY WARNING SYSTEM

TECHNICAL PROPOSAL - ECONOMIC

Lima, 2018

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1 UN SUSTAINABLE GOAL THAT IS BEING PROGRESSED

The present proposal aims at achieving the following UN goals:

- **Objective 6 Clean water and sanitation:** To help to ensure water availability, its sustainable management and waste water treatment systems.
- **Objective 9 Industry, innovation and infrastructure:** To help to build resilient infrastructure, to promote inclusive and sustainable industrialization as well as to promote innovation.
- **Objective 11 Sustainable cities and communities:** To help to achieve safe, resilient, sustainable and inclusive cities and human settlement.
- **Objective 13 Climate actions:** To help to adopt urgent measures in order to combat climate change and its effects.

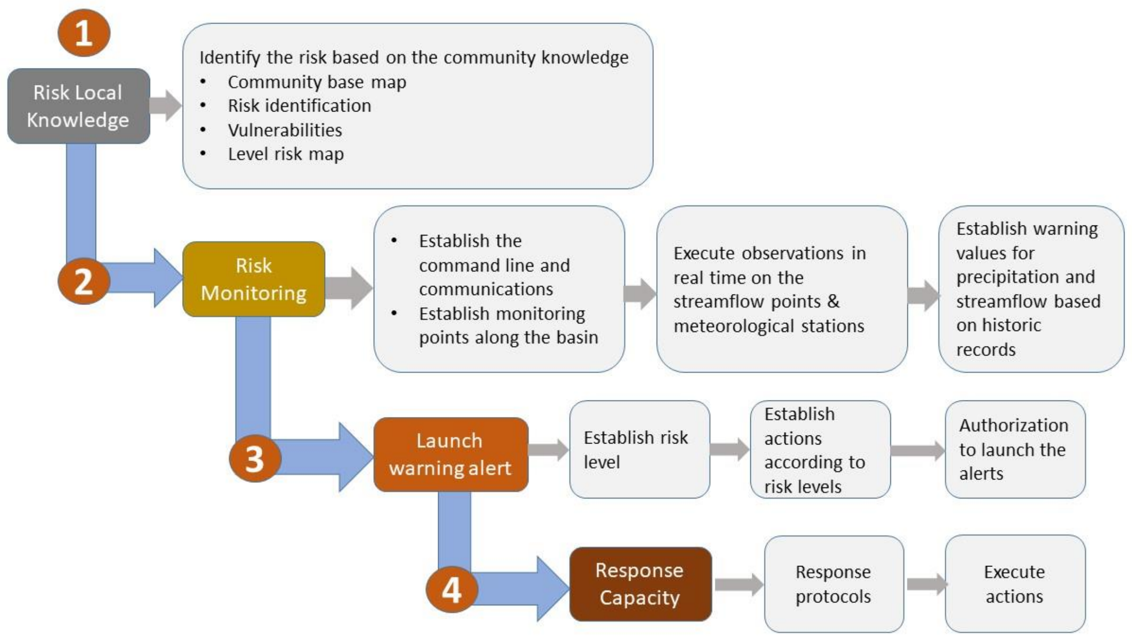
2 PROJECT NAME, OBJECTIVE AND DESCRIPTION

2.1 Project Name: Piura River's Early Warning System

2.2 Objective

To develop an Early Warning System (EWS) in the Piura River's Basin (**Figure 2**) with 10 days of anticipation aiming at preventing social, economic and human negative impacts due to inundations. The EWS will have the following structure.

Figure 1 Structure of the Early Warning System



In order to do so, we will develop a hydrological model with historical precipitation data and streamflow data. Here, we apply state-of-the-art satellite technology and methodologies to overcome the lack of data in this area (**Figure 3**). Then, we will develop a high resolution meteorological model to forecast climate conditions up to 10 days in advance.

This will give us up to 10 days in advance to forecast extreme streamflow (**Figure 4**) to organize the local authorities' and population's mitigation responses. This social aspect will we design by social experts from the UN.

Figure 2 The whole Piura River's Basin, of approximately 12,000 sq. km.

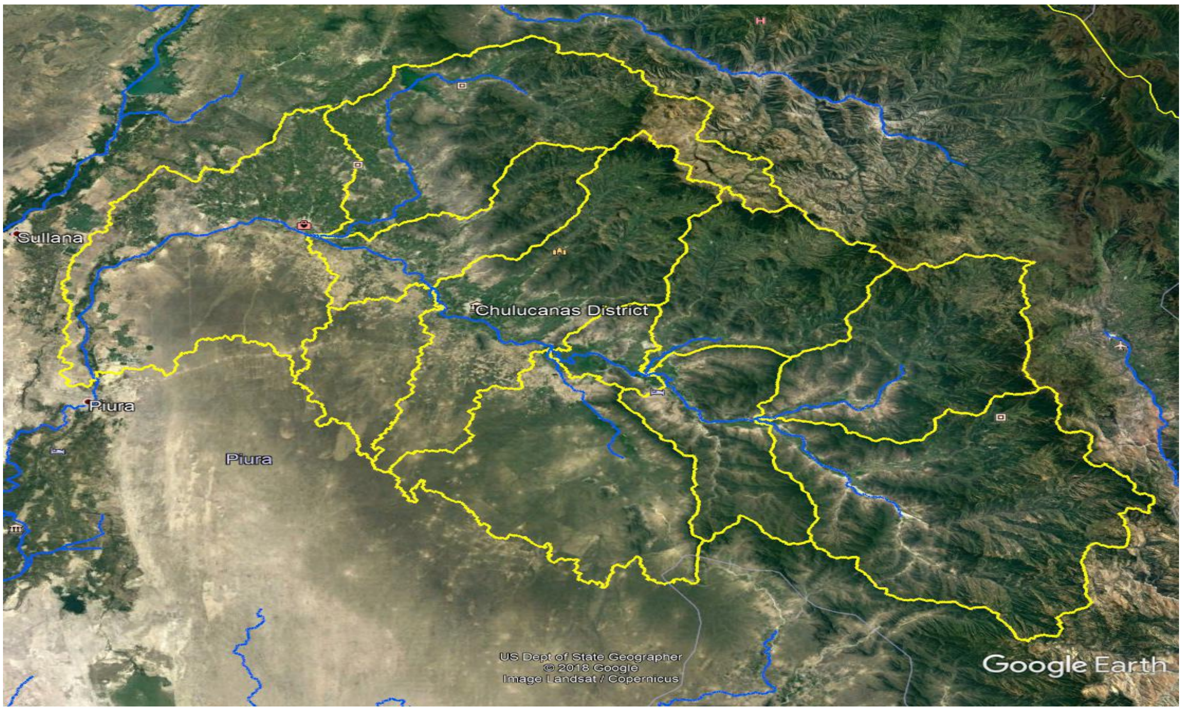


Figure 3 Flooded areas (red) along the Piura river during March 2017 (https://floodobservatory.colorado.edu/Events/2017Peru4450/2017Peru4450.html). Flooded area of one of the small villages along the Piura river.

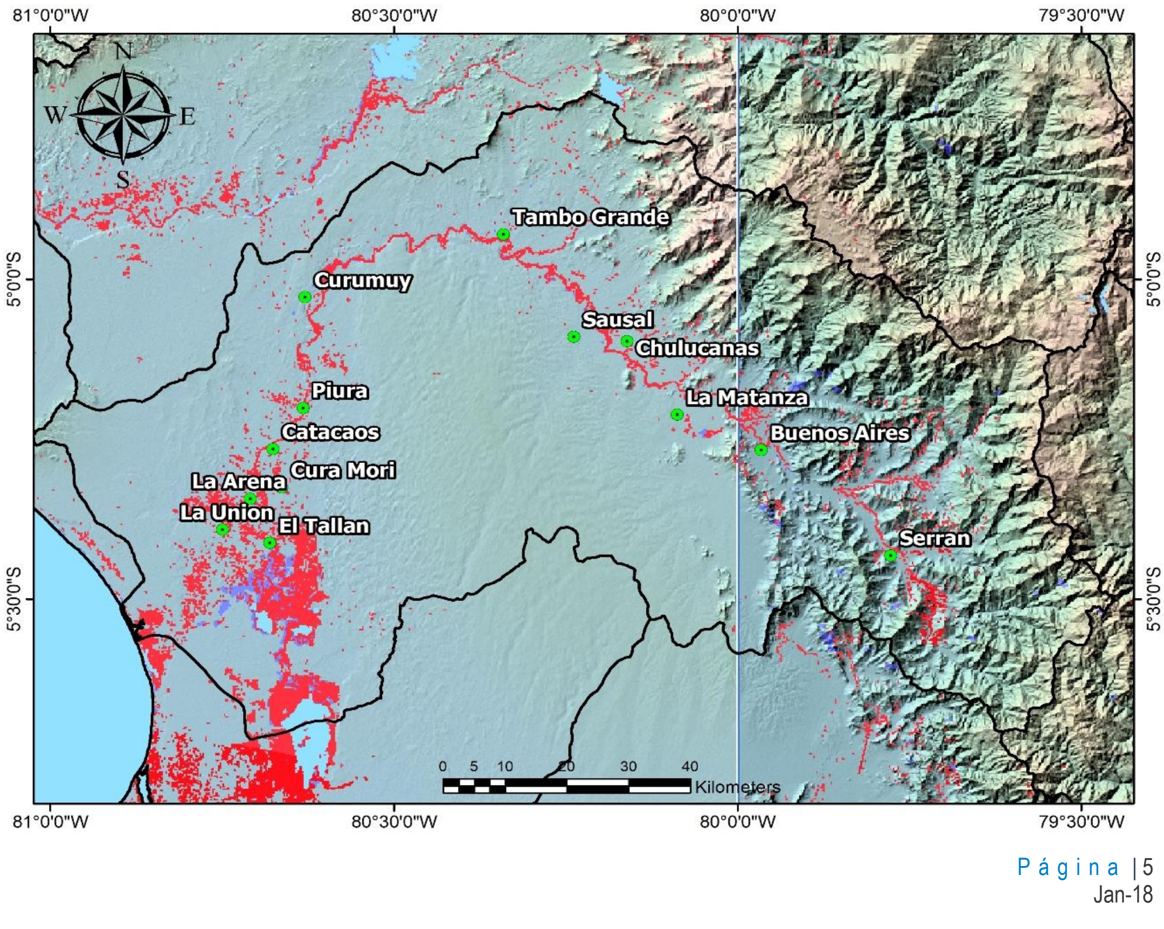
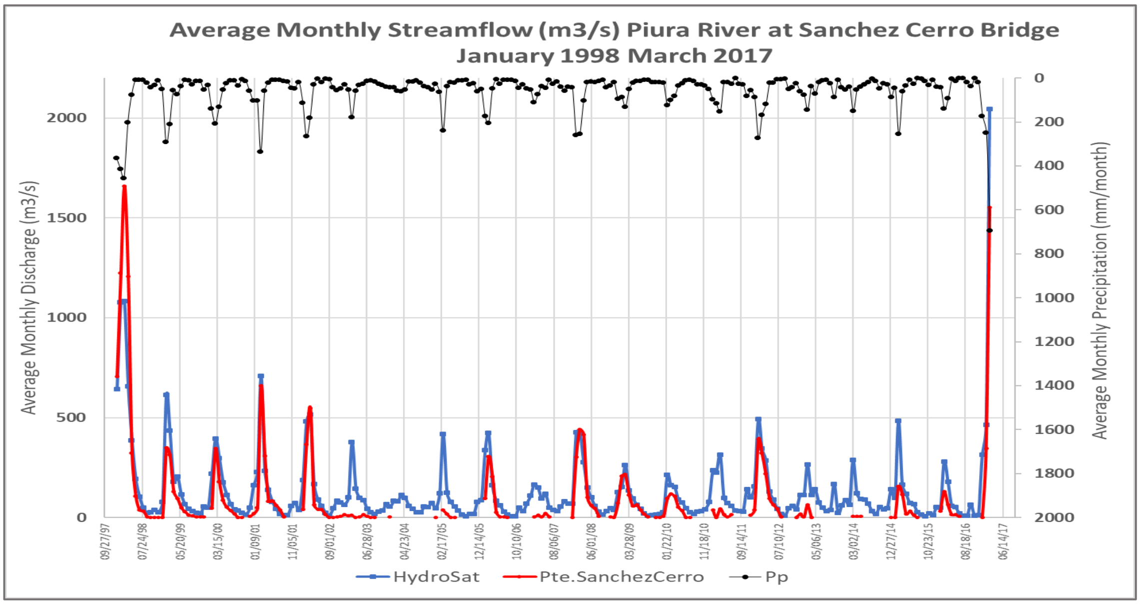


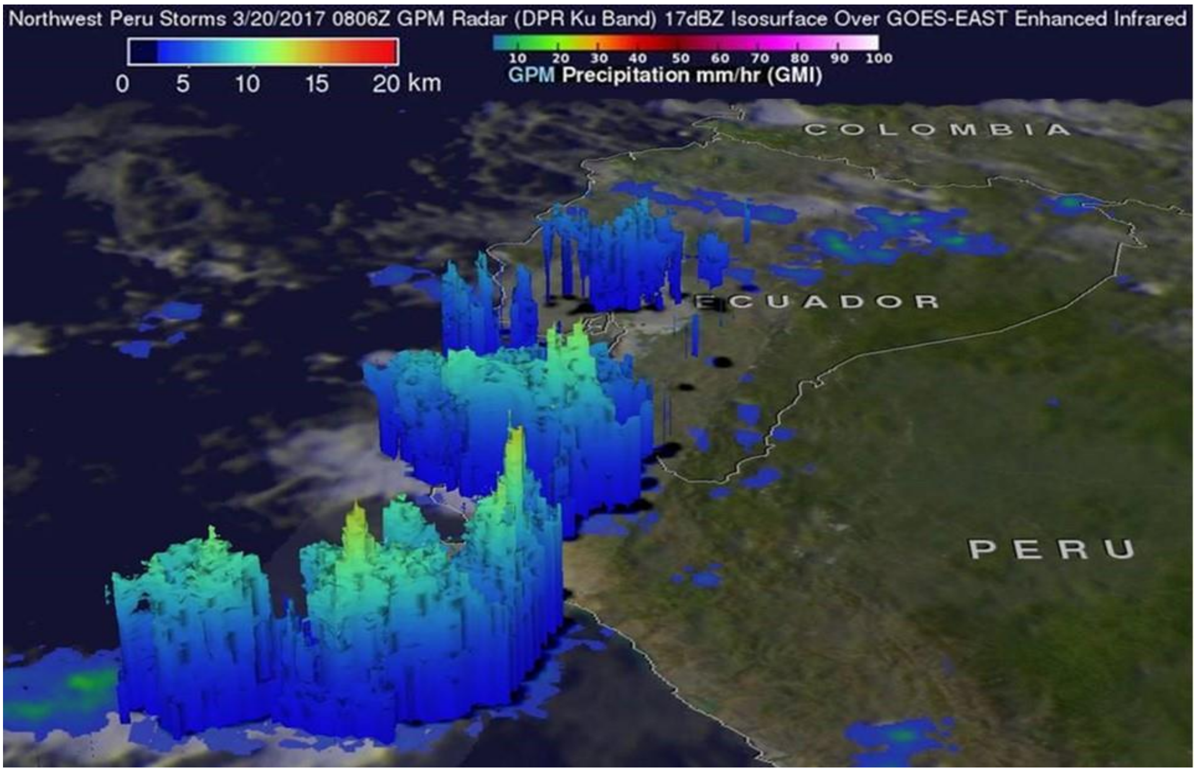
Figure 4 Preliminary comparison between the hydrological model forced with climatic historical data and the available historic streamflow data



2.3 Justification & Description

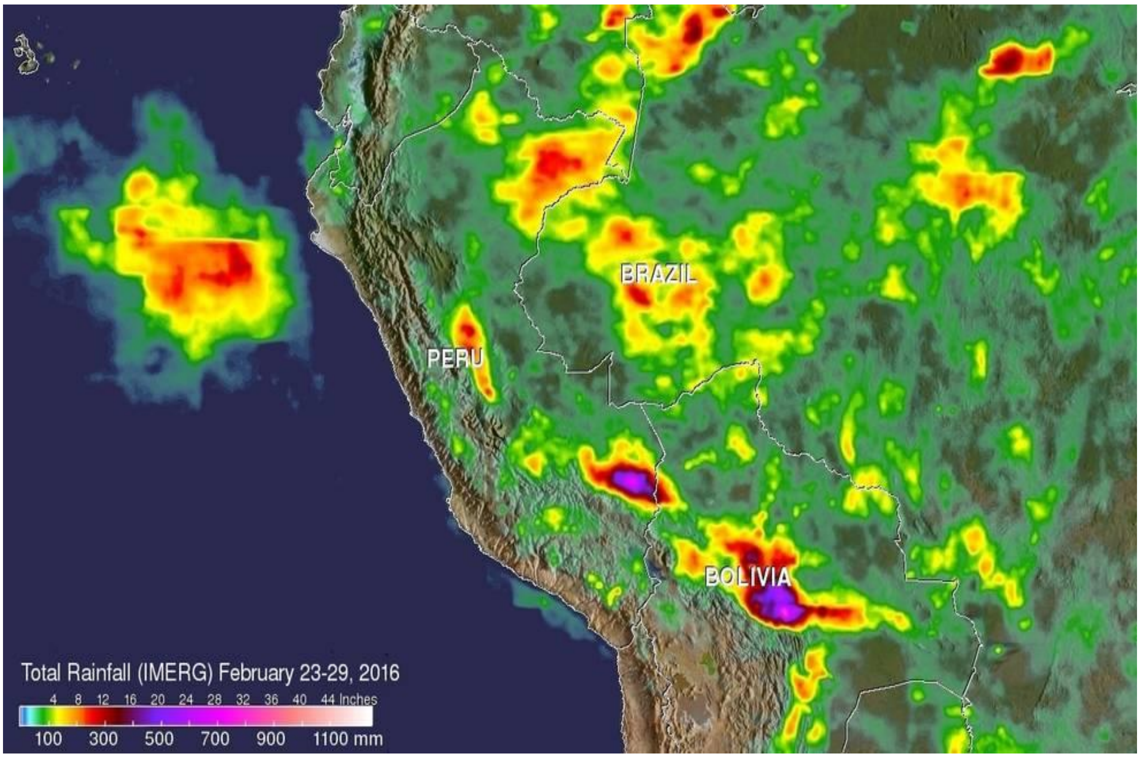
In the recent years, extreme rainy events have taken place in Peru. The most recent one took place between January and March 2017 (**Figure 5**), during the so called "Coastal El Niño" with precipitation intensities up to 30 mm/day in areas where the annual average are in the order of 50 mm/year. These intensities are not present on the available historical records.

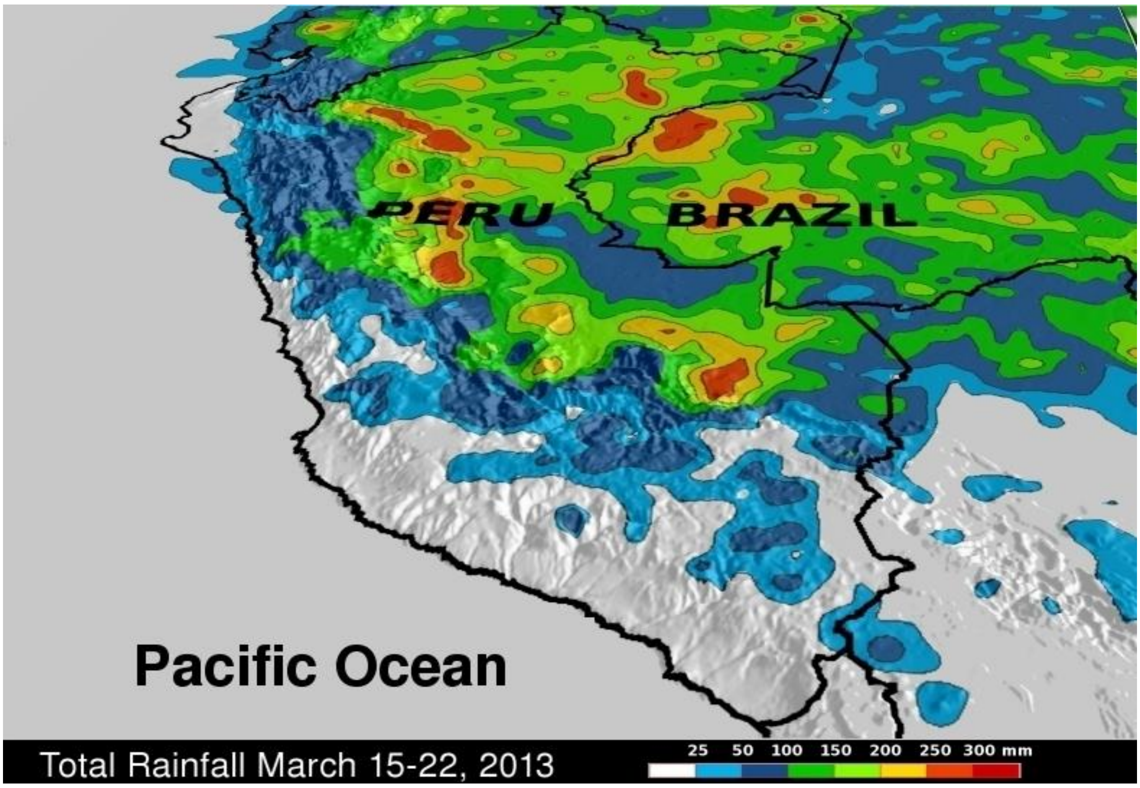
Figure 5 Precipitation intensities on March 20, 2017 (Resource: NASA).



Other extreme events, of out records, took place on February 2016 and March 2013.

Figure 6 Extreme rainy events during February 2016 and March 2013 (Source: NASA)





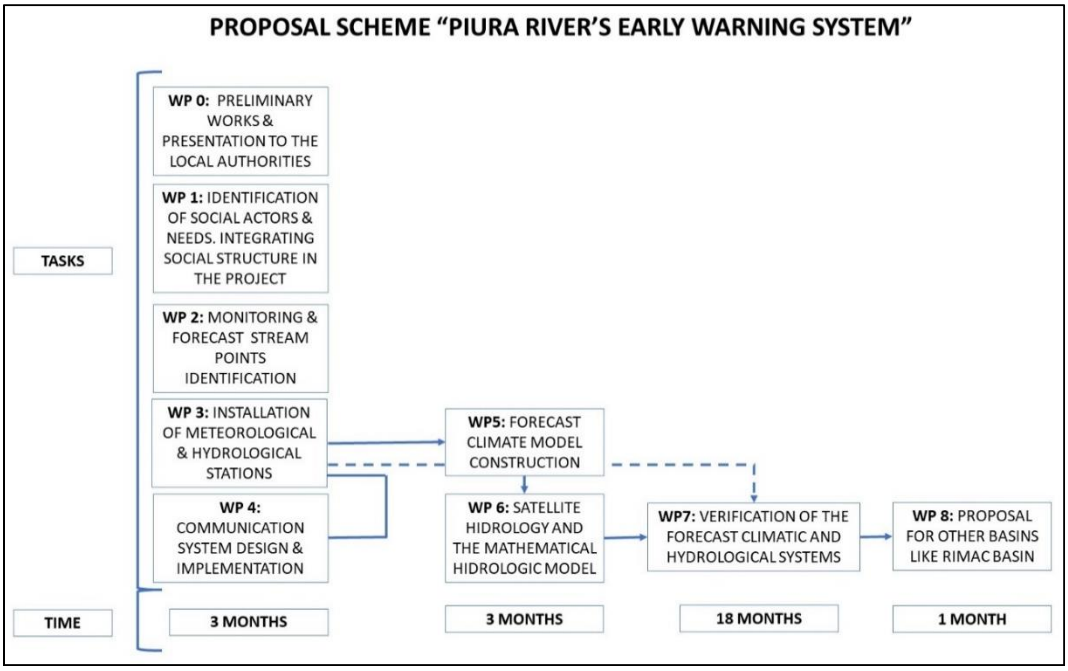
Those extreme events, are most probably, due to Global Warming, and caused important damage on the infrastructure and on the local population.

One of the most important regions affected by those extreme rainy events was the Piura River's Basin of up to 12,000 sq. km.

2.4 Structure of the Project

Figure 7 shows the general structure of the proposal which cons of 8 work packages (WP).

Figure 8 General Structure of the Project



2.4.1 Work Package 0: Preliminary works and presentation to the local authorities

This work package aims to collect information about the effects of the last event "Coastal El Niño" between January and March 2017. This information refers to data about:

- Observed streamflow along the Piura River,
- affected human settlements,
- inundated areas,
- damaged infrastructure,
- economic losses,
- cultivated areas affected,
- etc.

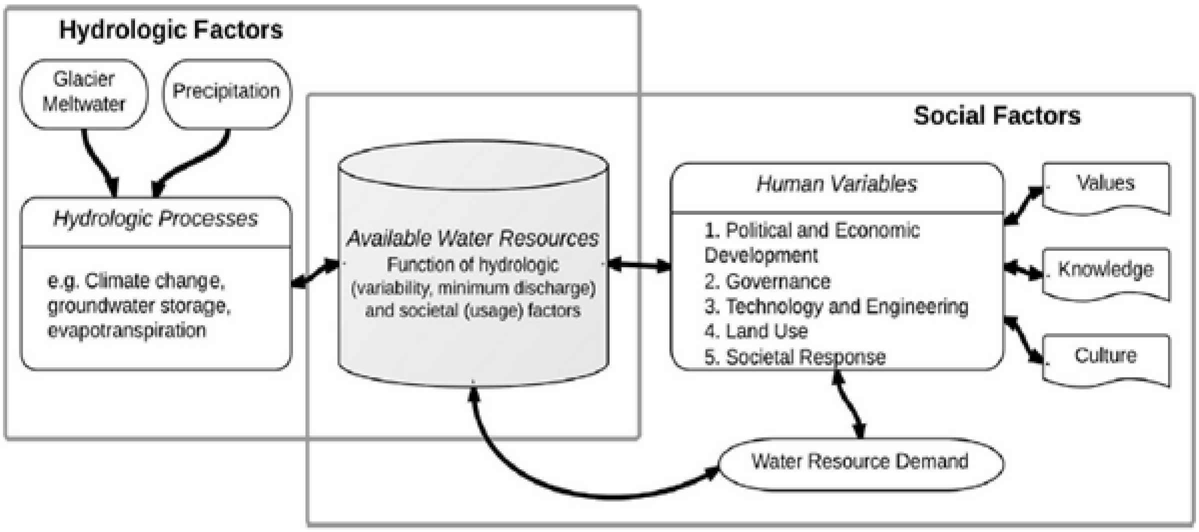
The objective is to collect data that helps the team to design the monitoring & forecast streamflow points along the Piura River that will grant the longest time window possible since the extreme meteorological event takes place and the consequent hydrological response of the river system that can be felt.

2.4.2 Work Package 1: Integrating Social Structure into the Project: Identification of Social Actors & Needs.

Water security is a "sine qua non" condition in order to combat poverty, food security, ecosystem health and energy supply. Climate change incorporation into the developing and management plans and into the business portfolio is imperative. Solutions of the drought and inundations problems require interventions of important magnitude.

Figure 8 shows how the hydrologic scenarios interact with the social factors. The whole integration begins with the identification of key stakeholder and therefore with the analysis of social network. This is the description and measure of the relation and information fluxes among persons and institutions. The Report of USAID "Partnering for Adaptation and Resilience – Agua (PARA-AGUA) Project" (2015), describe the working of this social network in Piura. The Regional Government of Piura is the institution with a central position with the possibility to facilitate the relation between stakeholders and exchange of information. The other 2 important institutions are the "Proyecto Especial Chira-Piura" and The Meteorological and Hydrological National Service (SENAMHI by its acronym in Spanish).

Figure 9 Integrated model analysis for social objectives



This piece of fundamental knowledge will help the project to design management strategies to use the information delivered by the Early Warning System and coordinate the response of the society.

2.4.3 Work Package 2: Monitoring forecast climatic and streamflow points identifications

Based on data gathered during the execution of WP1 we will elaborate maps, together with the local authorities and population, with the possible meteorological and hydrologic monitoring points. It must be kept in mind that a good monitoring system must be minimum but enough to give relevant and sufficient information to make decisions.

Right now, based on historical meteorological data from satellites, precipitation and real evapotranspiration (mm/year) we can identify the areas with the highest potential for streamflow generation – the balance between these two main variables of the hydrological equation.

Figure 9 shows the average annual precipitation (mm) field over the Piura River's Basin. Based on precipitation distribution we proposed the monitoring meteorological points in order to capture the real areal precipitation rate for a given rainy event.

Figure 10 shows the average annual real evapotranspiration (mm) over the same area.

Figure 10 Average annual precipitation (mm) and the a priori proposed monitoring meteorological points (MMP), Piura River's Basin

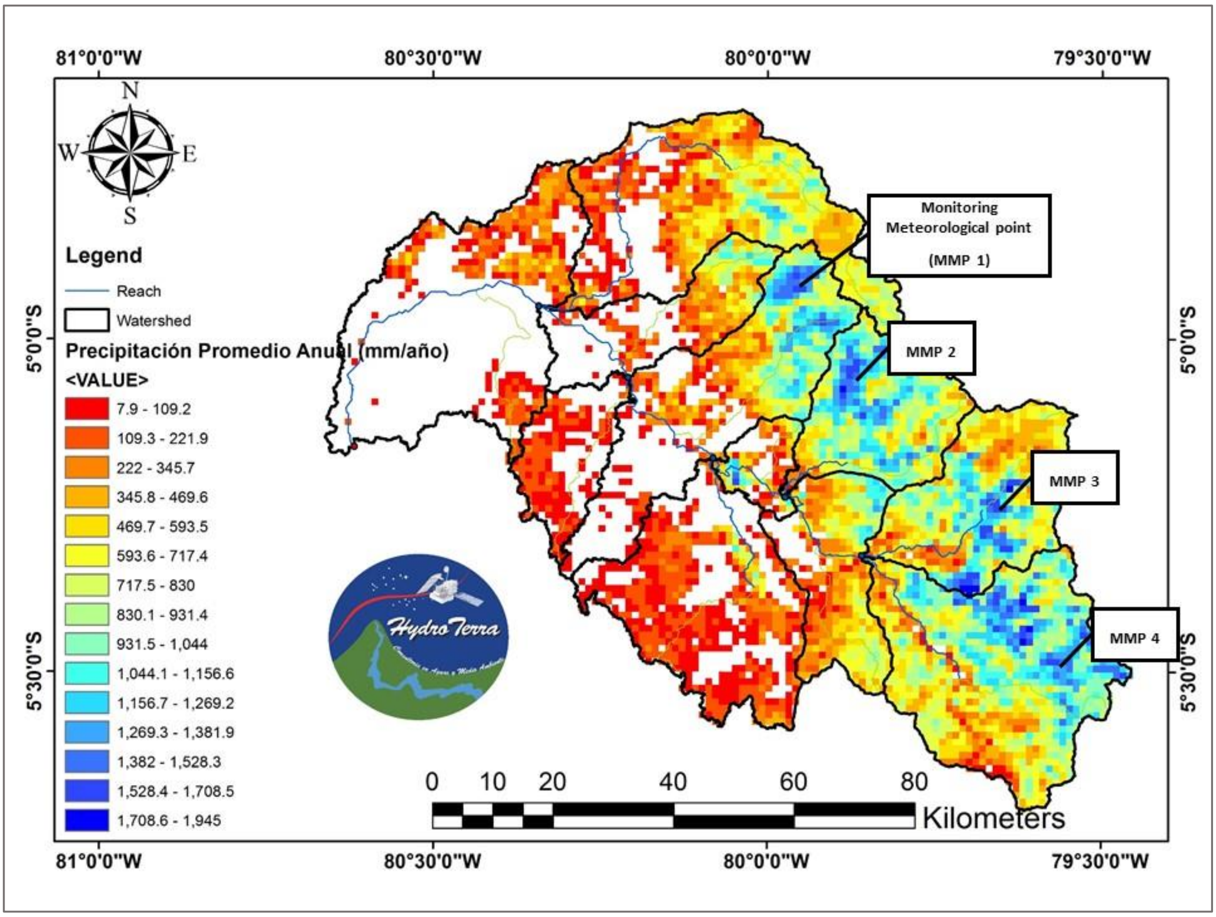


Figure 11 Average real evapotranspiration (mm). Piura River's Basin

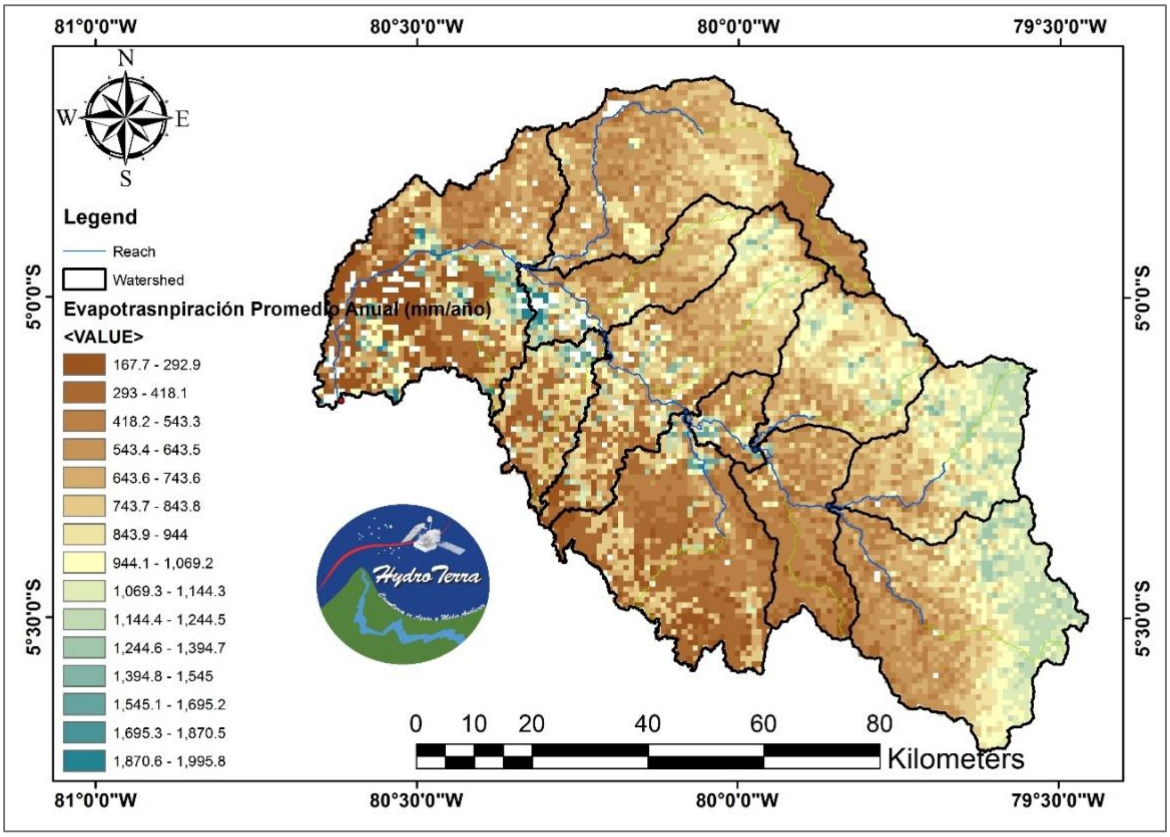
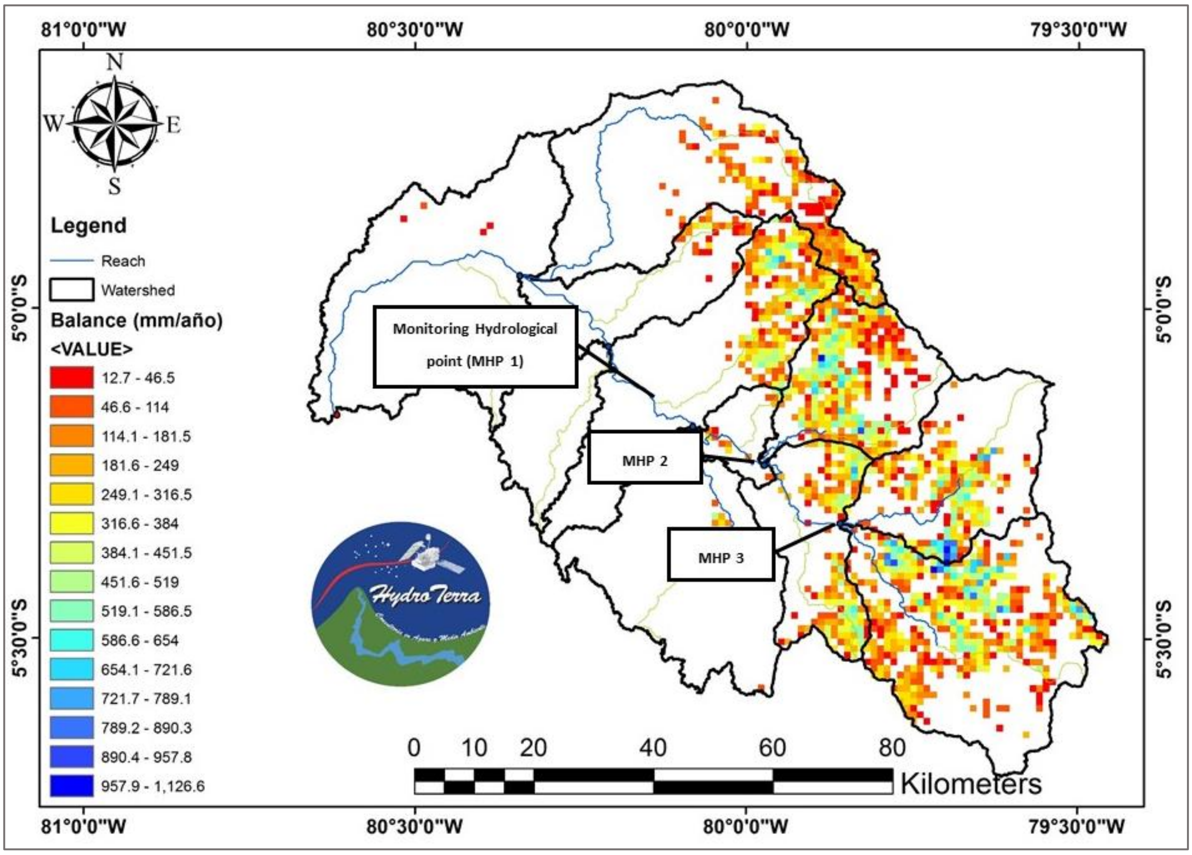


Figure 12 Precipitation minus real evapotranspiration at annual time scale. It shows the a priori monitoring hydrological points (MHP).



2.4.4 Work Package 3: Installation of the meteorological and hydrological monitoring stations

Once the definitive monitoring points have been selected and the best equipment have been chosen and acquired, they will be installed on the fields.

Each meteorological station will count with solar panels and perimetric security systems including a video camera. It should count also with a system against storm electrical discharges.

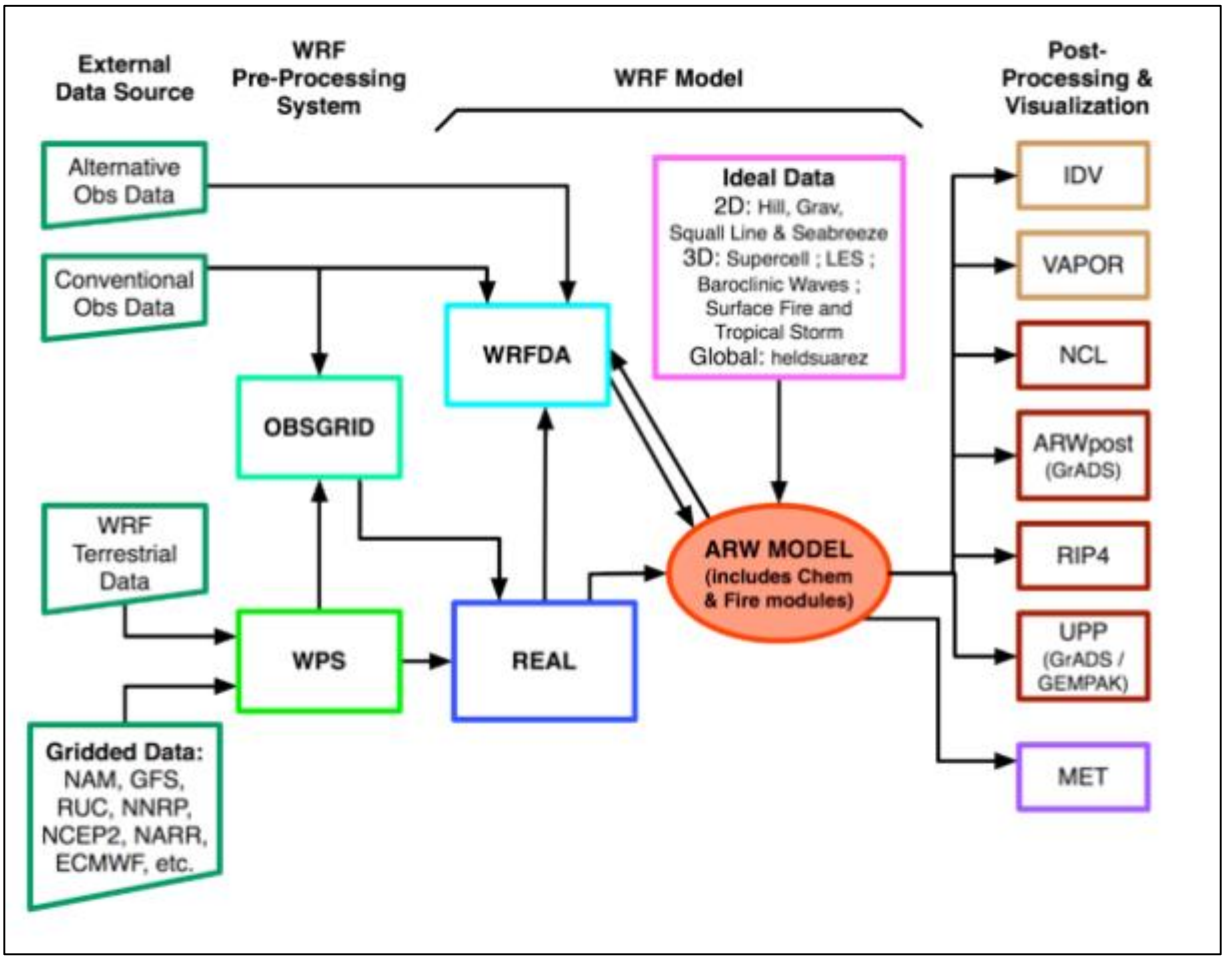
2.4.5 Work Package 4: Communication system design and implementation

In principal de communication system is going to work with free radio frequencies in order to transmits the data in real time.

2.4.6 Work Package 5: Forecast meteorological model construction

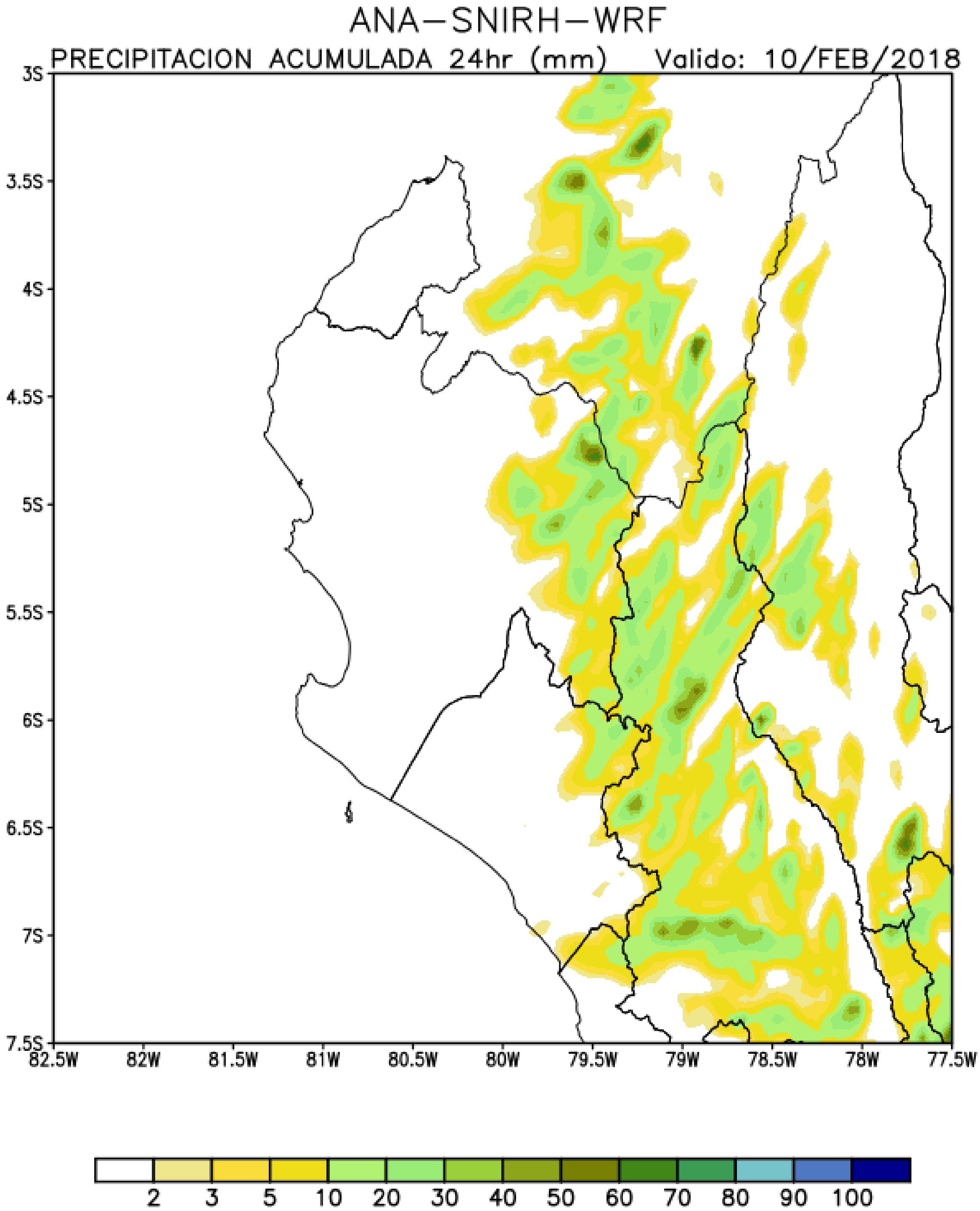
The forecast meteorological model will be implemented for the Piura Region, at 5 km2 resolution. The Weather Research and Forecasting (WRF) model is a numerical weather prediction (NWP). WRF is a state-of-art atmospheric modeling system designed for both meteorological research and numerical weather processes and can run on variety of computing platforms. The WRF Modeling System Flow Chart is representing in the figure below.

Figure 13 WRF Modeling System Flow Chart



WRF allows convective scheme parameters to be adapted to the target location. The proposed model is, nowadays, working at the National Water Authority for 4 priority zones of the country with a 70% qualitative accuracy, for 5 days forecast., in Figure 13, we can observe the forecast for January 10th, 2018. The simulation was run on 5Th January for the North of Peru, Piura.

Figure 14 Forecast for January 10th. The simulation was run on January 5th 2018.



2.4.7 Work Package 6: Satellite Hydrology and Mathematical Hydrological Model

We have constructed daily 1km^2-resolution precipitations fields since 1st January 1998 to April 2017 for the Piura River's Basin (**Figure 9**). We also count with other databases from NASA with daily data for temperature, wind velocity, relative humidity and solar radiation since

January 1983. This will be used to force a process based hydrological model called Soil Water Assessment Tool (SWAT).

The Soil and Water Assessment Tool (SWAT) is a public domain model jointly developed by USDA Agricultural Research Service (USDA-ARS) and Texas A&M AgriLife Research, part of The Texas A&M University System. SWAT is a small watershed to river basin-scale model to simulate the quality and quantity of surface and ground water and predict the environmental impact of land use, land management practices, and climate change. SWAT is widely used in assessing soil erosion prevention and control, non-point source pollution control and regional management in watersheds.

The Model Components are:

- Weather, surface runoff,
- return flow,
- percolation,
- ET,
- transmission losses,
- pond and reservoir storage,
- crop growth and irrigation,
- groundwater flow,
- reach routing,
- water transfer,

SWAT Operates on:

- Daily time step-long term simulations
- Basins subdivided to account for differences in soils, land use, crops, topography, weather, etc.
- Basins of several thousand square km can be studied
- Soil profile can be divided into ten layers
- Basin subdivided into subbasins or grid cells
- Reach routing command language to route and add flows
- Hundreds of cells/subbasins can be simulated in spatially displayed outputs
- Groundwater flow model
- SWAT accepts output from EPIC
- SWAT accepts measured data and point sources
- Water can be transferred from channels and reservoirs
- Nutrients and pesticide input/output
- Windows Interface
- GRASS GIS links to automate inputs

First, the existing meteorological network is not enough to obtain the full range of precipitation variability. This network distribution is limited by logistic restriction like access roads, power supply, etc. Nevertheless, this information will be used to validate the satellite derived precipitation at high resolution. **Figures 14 to 16** show some examples.

Figure 15 Comparison of the precipitation from the existing stations on Huarmaca and the precipitation derived from the satellite at 1 sq. km. resolution.

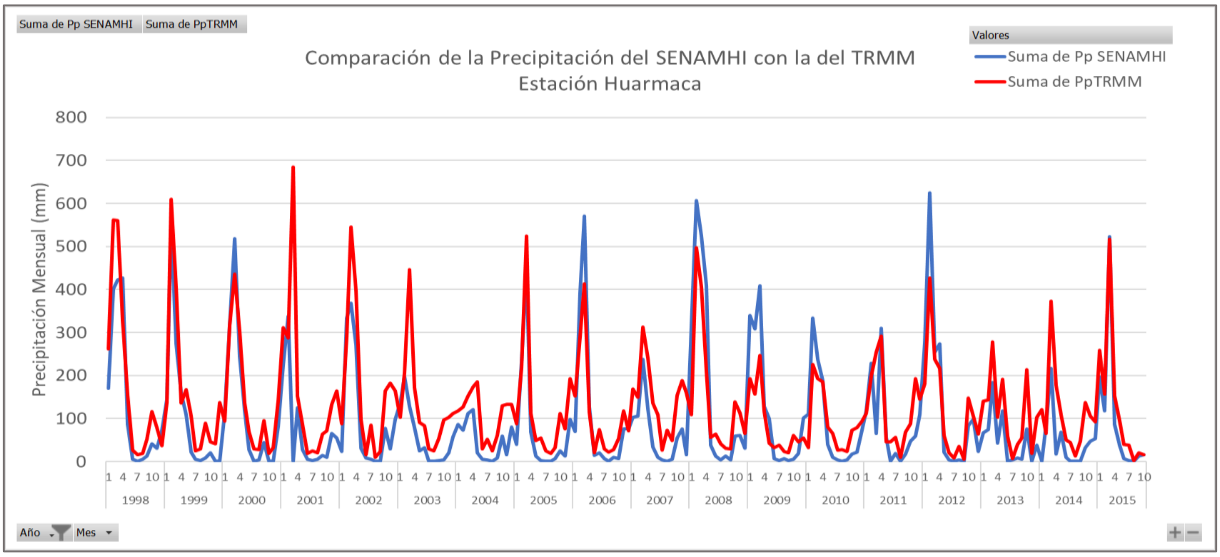


Figure 16 Comparison of the precipitation from the existing stations on Sapilica and the precipitation derived from the satellite at 1 sq. km. resolution.

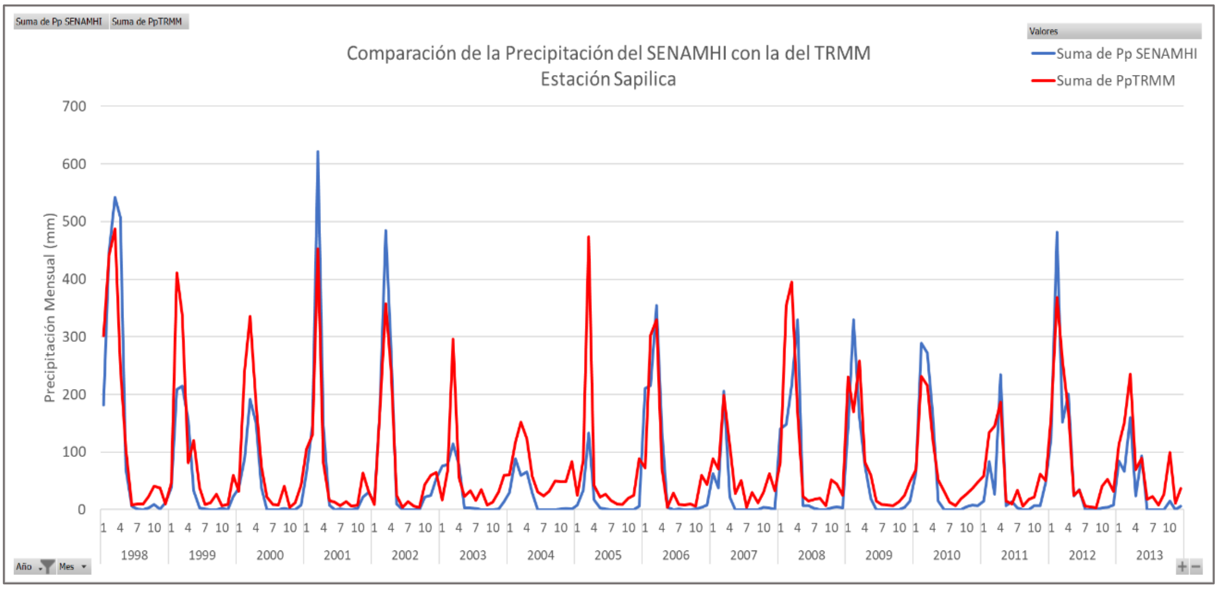
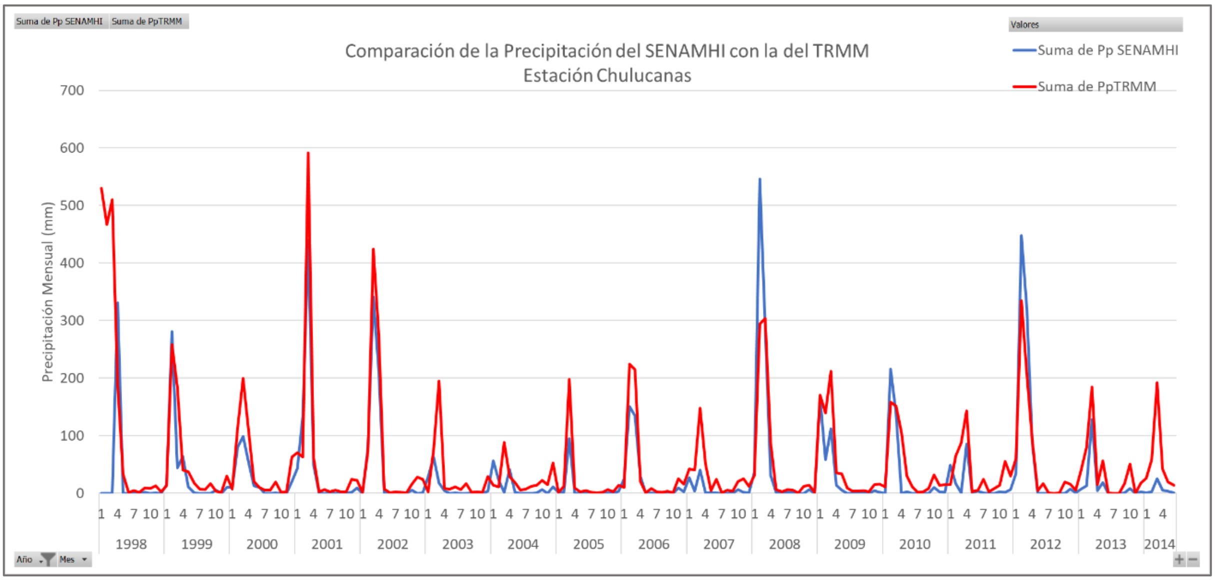
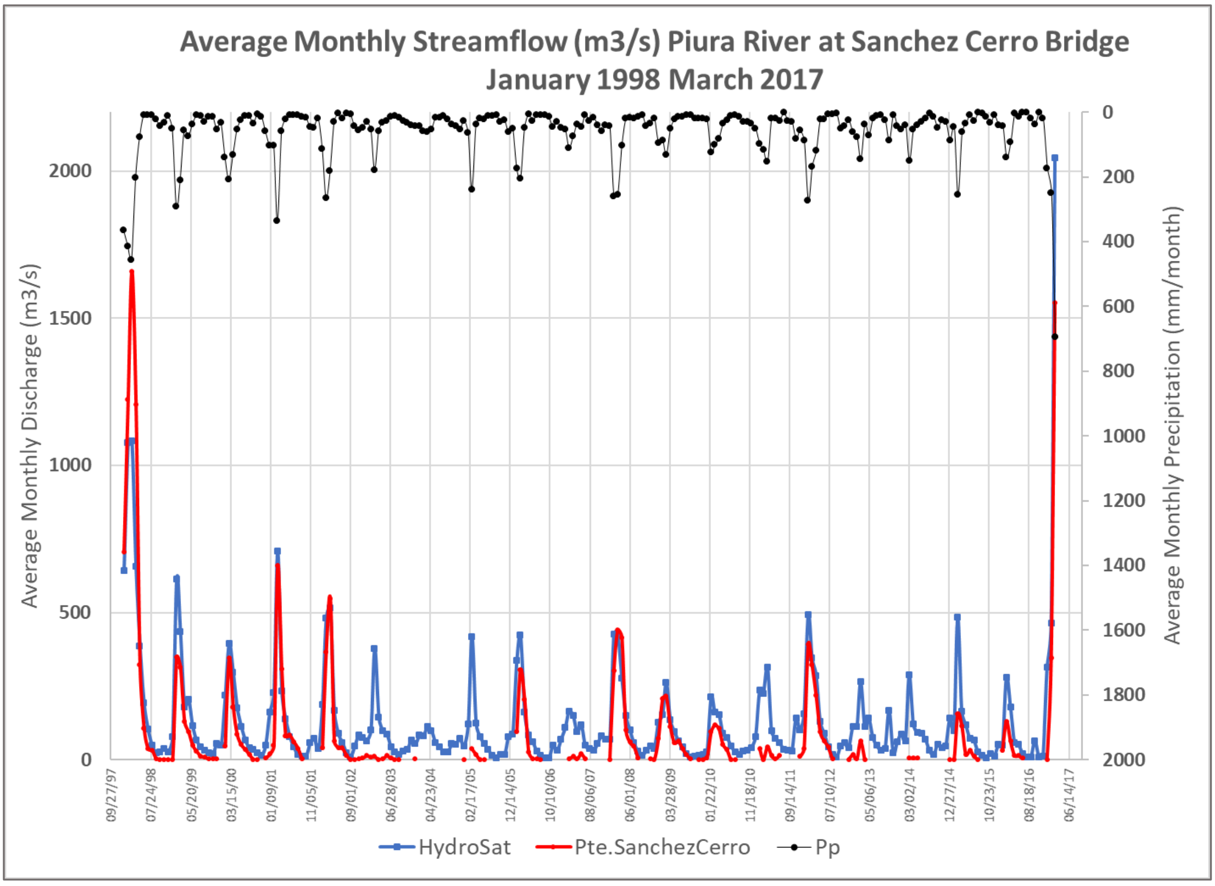


Figure 17 Comparison of the precipitation from the existing stations on Chulucanas and the precipitation derived from the satellite at 1 sq. km. resolution.



Based on all that meteorological data, the SWAT model will be forced to obtain streamflow and they will be compared with historical data of the Piura River. **Figure 17** shows a preliminary comparison.

Figure 18 Comparison of the preliminary results of the SWAT model (blue line) and the historical streamflow data (red line).



Once the model is calibrated, it will be fed with the forecast meteorological data from the previous WP on a daily basis during wet season.

2.4.8 Work Package 7: Verification of the forecast meteorological and hydrologic system.

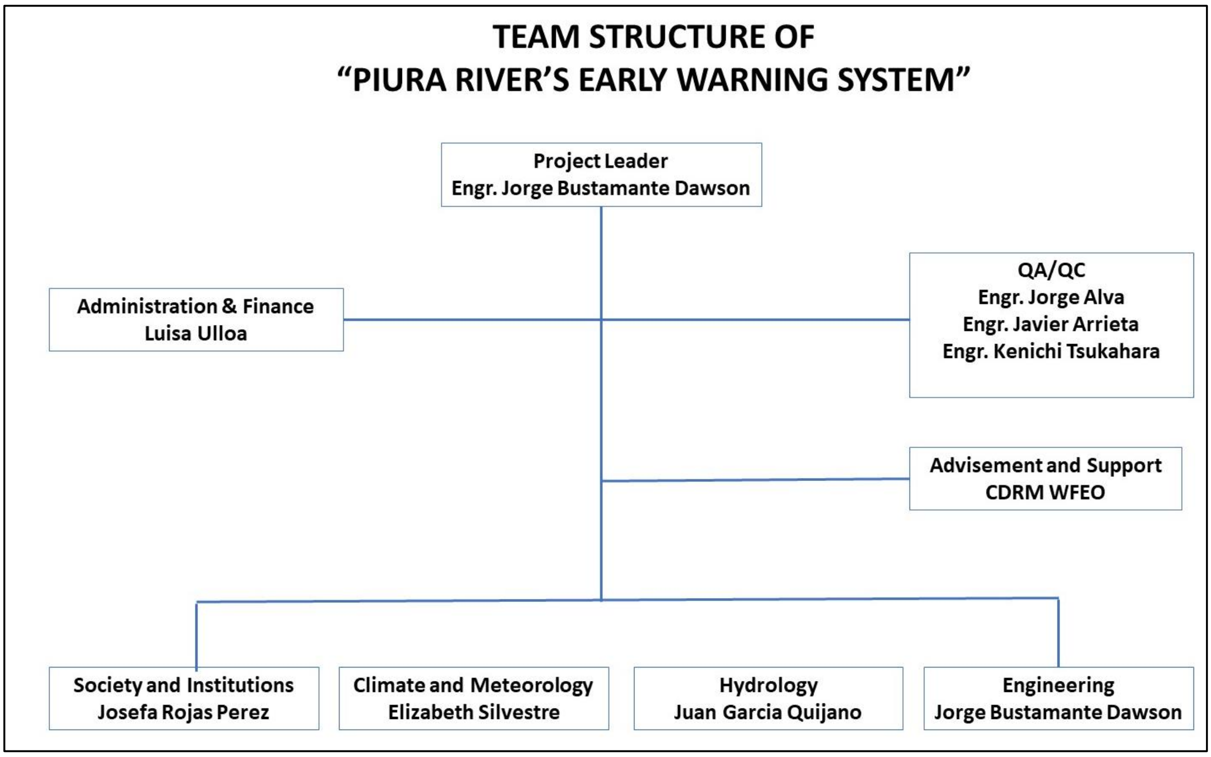
This task will verify, with data of several months from the meteorological and hydrologic systems, that the whole forecast system is working with, at least, a high degree of accuracy and precision.

The first step will be to control de outcome of the forecast meteorological model developed in WP5. Figure 15 shows as an example of the comparison between the modeled streamflow and observations.

The whole idea is to have a working early warning system that will be handed to the local actors (local or municipal governments).

3 PROJECT LEADER AND TEAM

Project Leader: Engr. Jorge Bustamante Dawson (CIP)



Team members

Engr. Jorge Bustamante Dawson

Jorge Bustamante Dawson, is a hydraulic civil engineer from the Engineering National University. He counts with 45 years of experience. Nowadays he is Manager of Engineering at HydroTerra and General Manager of GREINSA. He was QA/QC Chief for several projects.

He used to work at ElectroPeru, the biggest state energy company in the country from 1974 to 1995 as Manager of the Engineering Department, Senior Supervisor of the generation plant and maintenance, and contract administrator.

From 1998 to 2015, was part of MWH, taking part in several engineering projects for the biggest mining operations in Peru. He managed the modernization studies for the Hidrometeorological and Control System of lake regulations of the Mantaro Basin for Electroperu.

Dra. Josefa Rojas (PUCP)

Dra. Rojas is a Social Worker from the Pontifica Universidad Católica del Perú (PUCP 1987) and she specialized in gender and socio-environmental projects in UK in 1993. She obtained an MA in Governance and Development at Sussex University in UK in the year 2000. Nowadays she is a Ph.D. Candidate at the Pontificia Universidad Católica del Perú. In 2013 she obtained a Diploma in Climate Change Adaptation at INTE – PUCP.

She is full professor in Management of Social Projects and Humanities at the PUCP and Management of Risk and Disaster at the Universidad Nacional de Ingenieria (UNI).

Dr. Juan F. García Quijano (HydroTerra SAC)

Juan F. García Quijano has a M.Sc. and Ph.D. from the Catholic University of Leuven in Belgium and advance studies at Harvard University in USA. Juan García Quijano has lead projects for Michiquillay, Glencore, Yanacocha, EDEGEL, multinational and multidisciplinary research projects. He has more than 18 years of experience in ecological and hydrologic modeling. In this context he has programmed and modified sources codes of the models, used satellite information to force and calibrate models. He has developed methods for environmental impact assessment based on objective numerical indicators and Decision Support Systems. His experience includes research projects about the functioning and management of different types of ecosystems, from tropical mountains in Nepal and Equator, low land forests in Bolivia, Mediterranean forests in Spain, subtropical crop plantations in South Africa, to template forest and bioenergy crop plantations in Belgium and The Netherlands. These studies focused mainly on the effects of vegetation/land cover on the hydrologic, energy and carbon balances. He has carried out numerical simulations of these aspects in universities in Europe and America and private companies. His worked has been published in specialized scientific journals of first order. Besides, he has elaborated, execute and coordinate international projects in America, Africa and Europe approved and financed by the European Commission.

Dra. Elizabeth Silvestre

Dr. Silvestre is a Ph.D. in Numerical Modelling of Atmospheric Sciences (Meteorology and Climate) from the National Institute of Space Research (**INPE**) in Brasil. She has been Visiting Reseach at the National Aeronautics and Space Administration (**NASA**) where she specialized in techniques of data assimilation for numerical models. At the *Centro de Previsao de Tempo e Estudos Climáticos* (**CPTEC**) INPE she led the group of meteorological data assimilation. She was Scientific Director of the Meteorology and Hydrology National Service (**SENAMHI**) of Peru. She was also SubDirector of Science and Technology at the National Council for Science and Technology of Peru (**CONCYTEC**).

4 SCOPE OF THE PROJECT, MODE OF COLLABORATION WITH WFEO

The scope of the project is framed in the Strategic Plan 2018 – 2021 of the WFEO Water Committee on Disaster Risk Management (WCDRM).

The WFEO–CDRM shall support the WFEO and the engineering profession worldwide by:

- Encouraging and supporting sustainable engineering approaches that reduce disaster risks;

- Supporting engineering innovation that cannot only prevent a risk from turning into a disaster, but also use the threat as an opportunity to transform society, to achieve a higher level of sustainability;
- Encouraging and supporting CDRM theme leaders to organize international webinars and technical-scientific events related to their work within the strategic plan;
- Developing and promoting DRM policies, strategies and practices to mitigate disasters caused by natural phenomena;
- Communicating to the WFEO and the international community on the work of the CDRM;
- Participating as WFEO representative in the UN System and representing WFEO at meetings on disaster issues;

More specifically, this project aims to achieve the following objectives of the WCDRM:

- Mapping disaster risk for water and climate-related disaster risks (e.g., floods, droughts, hurricanes, frost, torrential rains, heat waves, disturbance of convergence zones, tropical cyclones, El Niño Southern Oscillation-ENSO);
- Promoting the evaluation of the impact of climate change on water-related disasters, finding ways to reduce the disaster risk;
- Promoting the development and use of geomatic technologies related to water and climate for disaster risk management;
- Promoting the spread of knowledge of the direct effects of climate change;
- Promoting the need to carry out hydraulic works as part of a medium and long term program;
- Disseminating the need to exercise Water Management, having as its fundamental elements the river basin and land-use planning, from which the urban expansion and the investments are planned, having clearly defined the river bed areas, margins and flood areas;
- Promoting systems for predicting and establishing early warning systems according to the type of hazard to decision making.

5 PROJECT SCHEDULE

Work Packages vs. Time (Meses)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Work Package 0: Preliminary Works & Local Authorities																								
WP 0.1 Poject Management																								
WP 0.2 Elaboration of preliminary maps																								
WP 0.3 Meeting with the local and regional autorities																								
WP 0.4 Meetings, Coordinations and Advisement with CDRM - WFEO members																								
Work Package 1: Stake Holder Indetifycation & Integrating Social Structure																								
WP 1.1 Meetings with the community																								
WP 1.2 Meetings with agricultures, industries, etc.																								
WP 1.3 Other meetings																								
Work Package 2: Monitoring & Forecast Points (Streamflow & Meteorology)																								
WP 2.1 Gabinet phase for the identification of points																								
WP 2.2 Field verification of the proposed points and corrections																								
WP 2.3 Confirmation with the technical and social teams or participants																								
Work Package 3: Installation of Meteorological and Hydrological Stations																								
WP 3.1 Preliminary logistic works																								
WP3.2 Field campaings																								
Work Package 4: Communication System Design & Implementation																								
WP 4.1 Design of the communitcation system																								
WP 4.2 Adquisition of adequate equipment																								
WP 4.3 Preliminary logistic work																								
WP 4.4 Installation and testing of the system																								
Work Package 5: Forecast Climate Model Construction																								
WP 5.1 Recollection of historical meteo data																								
WP 5.2` Construction of the meteorological model																								
WP 5.3 Running and calibration of the meteorological model																								
Work Package 6: Satellite Hydrology and Hydrological Model																								
WP 6.1 Recollection of historical meteorological and physical data																								
WP 6.2 Review of existing studies of extreme events																								
WP 6.3 Preliminary simulatinos																								
WP 6.4 Calibration of the numerical physical based model																								
WP 6.5 Testing the model with the Forecast Meteo Model and observations in control points																								
Work Package 7: Verification fo the Forecast Climatic and Hydrologic System (EWS)																								
WP 7.1 Testing of the whole Early Warning System																								
WP 7.2 Verification of precipitation events and streamflows																								
WP 7.3 Emission of forecast precipitation and streamflows																								
WP 7.4 Correction and Analysis																								
WP 7.5 Elaboración de informes finales																								

6 PROJECT OUTCOMES

The present project aims at the following products:

- A monitoring and warning meteorological & hydrological system based on a solid scientific and technological bases in order to deliver alerts according to threshold risk levels.
- A socially structured respond protocol and system according to the local reality.
- Improve resilience and respond plans per community according to the local specific conditions and to the risk level identified. For instance, river defenses constructions, evacuation plans, contingency plans for schools, water supply, food security, first aid assistance, etc.

These deliverables will privilege bottom-up approaches with participation of the local population. Respond plans will be as multidimensional as possible making emphasis of female participation.

At the same time, the outcomes and structure of the present proposal will serve as basis to be replicated in other basins like the Rimac river Basin.

7 PROJECT SUMMARY

In recent years' extreme rainy events have taken place in Peru. The most recent one took place between January and March 2017, during the so called "Coastal El Niño" with precipitation intensities up to 30 mm/day in areas where the annual averages are in the order of 50 mm/year. These intensities are out of the available historical records. Those extreme events, are most probably, due to Global Warming, and caused important damage on the infrastructure and on the local population.

The project was conceived based on the UN Sustainable Development Goals and with the aspiration to improve the living conditions of our society and vulnerable populations. The execution of the project will convey International as well as Peruvian experts.

One of the most important regions affected by those extreme rainy events was the Piura River's Basin of up to 12,000 sq. km. Piura is one of the most important cities in the country with huge perspective of economic growth.

This project aims at developing an early warning system in the Piura River's Basin. In order to do so, first, we will develop a hydrological model with historical precipitation data from satellites and streamflow data. Here, we apply state-of-the-art satellite technology and methodologies to overcome the lack of data in this basin. Second, we will develop a high resolution meteorological model to forecast climate conditions up to 10 days in advance.

This will give us up to 10 days in advance to forecast extreme streamflow to organize the local authorities' and population's mitigation responses. This social aspect will be designed by social experts from the UN.

The present project outcomes are:

- A monitoring and warning meteorological & hydrological system based on a solid scientific and technological bases in order to deliver alerts according to threshold risk levels.
- A socially structured respond protocol and system according to the local reality.
- Respond plans per community according to the local specific conditions and to the risk level identified. For instance, evacuation plans, contingency plans for schools, water supply, food security, first aid assistance, etc.

These deliverables will privilege bottom-up approaches with participation of the local population. Respond plans will be as multidimensional as possible making emphasis of female participation.

At the same time, the outcomes and structure of the present proposal will serve as basis to be replicated in other basins like the Rimac River's Basin in Peru.