Economics of Climate Adaptation

Report 03

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Vulnerability Report

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San Pedro Sula - Honduras Urban Flood Risk

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List of Acronyms

Annual Expected Damage (AED)

Comisión Permanente de Contingencias Honduras (COPECO)

Cross-Section (XS)

Departamento de Investigación y Estadística Municipal (DIEM)

Digital Elevation Model (DEM)

Disaster Risk Management (DRM)

Economics of Climate Adaptation (ECA)

Ecosystem Services Valuation Database (ESVD)

Fondo Hondureño de Inversión Social (FHIS)

German Development Bank (KfW)

German Ministry for Economic Cooperation and Development (BMZ)

Global climate model (GCM)

Hydrologic Engineering Center's - Hydrologic Modeling System (HEC-HMS)

Hydrologic Engineering Center's - River Analysis System (HEC-RAS)

Instituto Nacional de Estadística (INE)

Integrated Risk Management in Honduras (PEGIRH)

Intergovernmental Panel on Climate Change (IPCC)

InsuResilience Solutions Fund (ISF)

Law of the National Risk Management System (SINAGER)

Light Detecting And Ranging (LIDAR)

Mean damage degree (MDD)

Necesidades Básicas Insatisfechas (NBI)

Plan Maestro de Desarrollo Municipal (PMDM)

Representative Concentration Pathway (RCP)

Rossby Centre Regional Climate Model (RCA4)

San Pedro Sula (SPS)

The Economics of Ecosystems and Biodiversity (TEEB)

United Nations Economic Commission for Latin America and the Caribbean (UNECLAC)

United Nations University - Institute for Environment and Human Security (UNU-EHS)

1 INTRODUCTION

Storms, floods, droughts and other extreme weather events can threaten urban and rural areas, from small regions to entire nations. Along with growing populations and economies, losses from natural hazards are rising in the world's most exposed regions as our climate continues to change. The Economics of Climate Adaptation (ECA) is a decision-making support framework that integrates climate vulnerability and risk assessments with economic and sustainability impact studies to determine the portfolio of optimal adaptation measures for diverse climate risks.

The United Nations University - Institute for Environment and Human Security (UNU-EHS) in cooperation with and funded by the InsuResilience Solutions Fund (ISF), is implementing the Economics of Climate Adaptation (ECA) framework in the Municipality of San Pedro Sula (SPS) in Honduras to identify the most cost-effective measures to address the negative impacts of floods. The ISF is funded by the German Development Bank (KfW) and commissioned by the German Ministry for Economic Cooperation and Development (BMZ). Currently, the Economics of Climate Adaptation (ECA) methodology is being implemented in three different countries (Vietnam, Honduras and Ethiopia).

After concluding the inception phase and compiling and validating data with key stakeholders for running CLIMADA during the base data phase, this report presents the final recommendations for adaptation measures to flood events in the Municipality of San Pedro Sula. A major source of information for the study is the Plan Maestro de Desarrollo Municipal (PMDM), which the Municipality carried out through extensive research and data collection. An important part of the socio-economic characterization and costing of the ECA study is based on the PMDM, in addition to a household survey that the Municipality run on historical damages of floods in the vulnerable areas of San Pedro Sula. In the following chapters the reader is provided with an overview of the inputs for CLIMADA in terms of hazards, assets, damage functions and adaptation measures, and further discussions are made to clarify the assumptions and uncertainties involved in the process. This document closes with conclusions and recommendations for the administration and an additional chapter on the last phase of the ECA study which is a pre-feasibility analysis of the measures suggested.

During the last few months, a set of calls and workshops were organized for key representatives of the Municipality to provide input and request clarification on the subjects of the flood model used in the study, asset valuation methods and the modelled adaptation measures. The flood model used for the ECA study was an upgrade from the model developed by COPECO in 2016 for their "Risk analysis

at the municipal and local level[1]", but focused on the floodplains located within the districts agreed with the Municipality during the Inception Workshop, see Chapter 2.

Within the asset valuation workshop, the valuation method was discussed and validated for each of the asset groups identified during the Inception phase. The recommendations from the experts were incorporated and details of the results can be found in Chapter 3. Similarly, the adaptation measures' workshop leveraged the knowledge of the key experts invited, to coordinate a prioritization method that based on a given criteria, scored the adaptation measures to better reflect the local conditions. The outcomes of the workshop and the overall process and results are summarized in Chapter 5.

A total of 14 flood adaptation measures were identified and validated by the Municipality to be run in CLIMADA, including: technological and engineering solutions, ecosystem-based (nature-based) approaches, maintenance/operational measures, instruments and tools that improve baseline hydro-meteorological data, and risk transfer/insurance solutions. All details related to the measures can be found in ANNEX 5 and ANNEX 6.

Chapter 4, presents the damage functions of each asset group, which reflect the sensitivity of them to different intensities of flood. Given the scarcity of data of historical damages, different sources were used to verify and validate the assumptions made, including local surveys, international publications and calibrations through CLIMADA.

The final results coming from CLIMADA, as well as a comprehensive discussion on their expected costs and benefits, and the related uncertainties, can be found in Chapter 6. Chapter 7 compiles the conclusions and recommendations of the report, including some additional suggestions that were not modelled, but that showed a significant potential for the Municipality to improve its ability to prepare and respond for future flood events.

[1] COPECO: Comisión permanente de contingencias. (2016a). Informe V- Hidrología, Producto 1. Análisis de Riesgo a nivel municipal y local, Estimación de Avenidas – Sistemas de cuencas del Municipio de San Pedro Sula Departamento de Cortés. San Pedro Sula.

2 FLOOD MODELLING

2.1 Background and COPECO's Baseline Model

This section presents the setup of a new hydrological HEC-HMS models for Río Blanco and Río Bermejo and an update of the existing HEC-RAS flood model provided by COPECO for the municipality of San Pedro Sula. Using new datasets and a two-dimensional approach, discharge values and flood areas are depicted for the three major rivers Río Chamelecón, Río Chotepe and Río Blanco, including their larger tributaries. The new hydrological-Hydraulic simulation offer two main improvements i) a hydrologic modelling based on three return periods (25, 50 and 100 years) for the present state and the future scenarios agreed with the Municipality during the base data workshop (RCP 4.5 and RCP 8.5) and ii) spatial extension and improvement of the existing hydraulic 1D model to a 2D model approach.

2.1.1 The COPECO Model

In the last years, several studies explored flood hazard in San Pedro Sula region. COPECO conducted a detailed investigation in 2016[2] with the objective to provide a tool to support the municipality of San Pedro Sula in the creation of land management plans. Thereby the purpose was to minimize both, the economic impact of flood events the infrastructure and the live of the inhabitants. Evaluating hydro-meteorological information, flood extends for the return periods 25, 50 and 100 years were estimated, using a hydraulic 1D model (HEC-RAS). With the estimated flow, the topography of the site and the channel characteristics, flood levels were computed. The COPECO-project focused on the areas in proximity to the rivers Río Blanco, Río Bermejo (with Río Chotepe and Canal Sauce as tributaries) and Río Chamelecón, as well as Cofradía.

An additional study was conducted in 2019. It investigated further flooding in the catchment of Río Chamelecón in the Sula Valley. A region, which in the past, was exposed to the hurricane events Fifi and Mitch. These events caused heavy damages, especially in the city of La Lima. In order to update warning thresholds for the Chamelecón River, the hydraulic transit of the flood flows was considered, using HEC-RAS as a hydraulic model. The consideration of the channels Filopo and Maya played a crucial role, since their hydraulic capacity influence flooding significantly.

These studies and their findings were carefully analysed and the provided data was quality checked in order to use the existing models and results for further development of the hydrologic and hydraulic modelling approach. ANNEX 1 presents a detail account of the data used in these studies.

[2] COPECO: Comisión permanente de contingencias. (2016a). Informe V- Hidrología, Producto 1. Análisis de Riesgo a nivel municipal y local, Estimación de Avenidas – Sistemas de cuencas del Municipio de San Pedro Sula Departamento de Cortés. San Pedro Sula.

2.1.2 Main Improvements

The scope of the flood modelling exercise presented below is therefore to improve the existing flood model for the region of San Pedro Sula. The research conducted by COPECO[3] and in 2019[4] constitutes a solid fundament. The following improvements were carried out:

1) Physical improvements of the modelling cascade:
    a. Conversion from a 1D-hydraulic model-setup to a 2D model approach with HEC-RAS for the Rivers Río Blanco, Río Bermejo as well as Río Chamelecón.
    b. Hydrological modelling of the upper catchments as well as inclusion of the canal sauce
    c. Creation of dynamic flood hydrographs by using unsteady flow hydrographs as boundary condition for hydraulic modelling (instead of assuming a steady flow rate)
2) Terrain representation
    a. DEM improvement (5m and 1m resolution) with integrating of cross section data to remove artefacts, obstacles and unnatural elevations in the river bed;
    b. Inclusion of building structures of formal and informal settlements in the DEM
3) Inclusion of climate scenarios
    a. Hydrological modelling of present and future boundary conditions for two scenarios as agreed with the Municipality during the base data workshop (future high RCP 8.5 and future low 4.5)
    b. Simulation of flood footprints for 25-, 50- and 100-year return periods for three scenarios (present, future high, future low)

2.2 Input data and methodology

2.2.1 Data

As in most regions with ungauged catchment, many assumptions are necessary to represent physical processes. However, in this ECA study, we strived to collect the best available data. All input data were carefully quality checked and discarded or improved if necessary. The following sections describe the main inputs. Additional details are available in ANNEX 2.

2.2.1.1 Digital Elevation Model

A Digital Elevation Model (DEM) is one of the most important component in a flood model. The quality of the flood model depends highly on the quality of the DEM. Especially spatial and elevation resolution is important. In the case of SPS, the analysis was carried out with different resolutions based on the raw LIDAR DEM (1m)[5] to rebuild the existing river network. For the flow accumulation spatial resolutions of 5, 10, 25, 50 and 100m were utilized. Depending on slopes and other characteristics, several sub-catchments were allocated several resolution in order to construct a so-called hydrological DEM. A hydrological DEM allows to define rivers, flow accumulation and catchments with high accuracy.

Based on the hydrological DEM, the subdivision of catchments was refined, taking into account changes in altitude and differences in the amount of settlements. For the flood model, the highest

[3] COPECO: Comisión permanente de contingencias. (2016b). Informe Geomorfológico. San Pedro Sula: Municipio de San Pedro Sula Departamento de Cortés.

[4] Abrego Suárez, C. R. (2019). Actualización preliminar de los umbrales de alerta por inundación de Río Chamelecón en ciudad La Lima, Cortés, para el período de observaciones 2010-2018. Tegucigalpa, Honduras.: Master Thesis.

[5] LIDAR (1m) from 2017 provided by COPECO. DTM (5m) provided by COPECO.

possible resolution (1m in the low lands and 5m in the rest of the study area) was used. The highest resolution, ensures flood water flow to be reproduced accurately.

2.2.1.2 Precipitation

In addition to the DEM, precipitation data is one of the most critical input to simulate the water cycle. Unfortunately, the availability of precipitation data with high temporal resolutions (sub-daily) is limited for the Sulla Valley region. Several data sources were carefully evaluated, and the FHIS (2002)[6] dataset provides the best information in terms of temporal resolution. Precipitation stations were quality-checked and their records used to determine precipitation depth for short durations storms.

The applied storm characteristics were based on the following assumptions: The storm will be applied equally to the whole sub-catchment with the same duration and the same precipitation depth over time.

2.2.1.3 Future Scenarios

For the design of the future scenarios, future precipitation changes were examined using the regional climate model RCA4 and the scenarios RCP4.5 and RCP8.5. The regional climate Model RCA4 provides daily precipitation with a spatial resolution of about 0.44° (approximately 50 km). The dataset was separated into a past and a future time period (past: 1950 – 2005; future 2006 – 2100) for a statistical analysis done in cooperation with the UNU to obtain statistical precipitation depths for the return periods 25, 50 and 100 years.

2.2.1.4 Multipurpose Dam

The El Tablón dam, currently in planning, was considered as an additional future scenario. Information about the El Tablón dam is limited but several planned discharge values were made available by the Municipality. Information on storage-discharge, elevation-discharge or elevation-storage was not available. Several assumption, detailed in ANNEX 2, were made in order to introduce the dam. They include:

1) Shifting of Dam location upstream inflow the corresponding watershed
2) Calculating the contributing areas of the dam
3) Locating the discharge peak and adjusting for the reservoir's effect
4) Applying the modified hydrograph to the hydrological model (downstream)

2.2.2 Methodology

2.2.2.1 Hydrological Modelling

Concerning the hydrological modelling, a new model was set up for the rivers Río Blanco and Río Bermejo using the software HEC-HMS, developed by the U.S. Army Engineer Hydrologic Engineering Centre (HEC). For Río Chamelecón an existing HEC-HMS model was enhanced. This modelling approach is especially suitable for ungauged catchments, where no runoff data is available for statistical analysis. With the rainfall-runoff approach it is possible to perform hydrological analyses and to study the consequences of intended man-made changes within the catchment (e.g. landuse change, reservoirs).

Applying a hydrological model for event-based analysis requires the description and parametrization of relevant components of the hydrological cycle. Some components, such as evapotranspiration, may

[6] Fondo Hondureno de Inversion Social Dirrection de Medio Ambiente (2002) manual de referencias hidrologicas de honduras (2002)

be neglected, due to the short timescale of most storm events. The description of the remaining components mainly covers total precipitation, the infiltration loss, the resulting direct surface runoff, the concentration of surface water into the next river (overland flow) as well as the routing of river-water within the channel.

Driven by data availability and data resolution, the hydrological model was set up as a semi-distributed model, dividing the whole basin into a number of smaller sub-watersheds with relatively homogeneous physical characteristics. These physical characteristics were determined on the base of available data (e.g. land use, soil, elevation range/slope) and a GIS-based analysis to derive the parameterization of the physically-based description of the hydrological cycle components. Subsequently, the catchment of Río Bermejo (228 km²) was subdivided into 47 sub-catchments, of which each was parameterized. For Río Blanco (108 km²) a subdivision into 30 sub-catchments took place. The parameterisation of the catchment of Río Chamelecón was provided by the prior existing model and adopted for a short storm duration with less than 24 h.

2.2.2.2 Flood Model

The base for the set-up of the 2D flood model formed the 1D models created by COPECO in 2016 (COPECO 2016a). These models included a DEM, which was used for the 2D hydrodynamic, unsteady modelling process. Before creating the model terrain in HEC-RAS the DEM was re-analysed. Especially the profiles of the rivers were corrected. Additional details in ANNEX 2.

As measured cross-section (XS) profiles were not available, except for a partial section of canal sauce of approximately 2 km, it was decided the use the XS profiles from the 1D COPECO model, which had been extracted from the DEM, to create a plausible, smooth river profile (See ANNEX 2, p29 for additional details). Before doing so, the centrelines of the rivers were readjusted. This was done manually based on satellite data and the available DEM. Subsequently, the bank-stations of the remaining XS stations were adapted accordingly. Having created a consistent channel (the width was also selected based on satellite imagery), it was possible to burn these channels into the DEM. This process was done iteratively for each river, until a plausible channel profile was obtained.

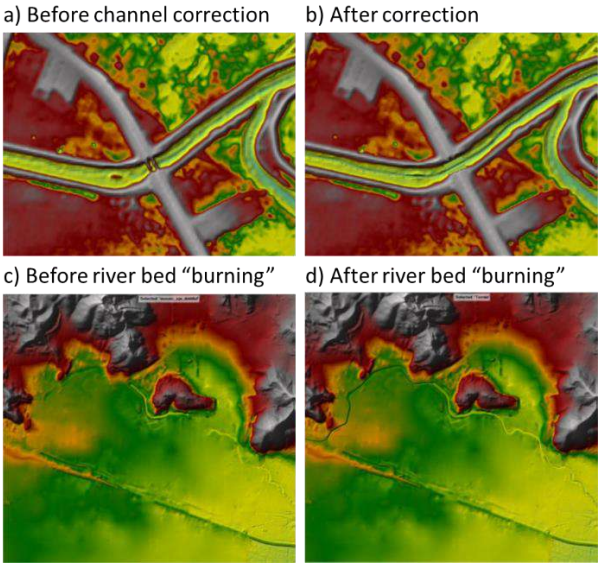

Figure 1 Example of DEM enhancement (before a and c and after d)

The major rivers, which have led to flooding events in the past, posing a risk to San Pedro Sula and its outskirts, are the rivers Río Blanco, Río Bermejo, Río Piedras, Río Chotepe and Río Chamelecón. In

order to efficiently model the effects of flooding for certain events, it was necessary to distribute the rivers of interest into several models. The achievement of results with a high spatial resolution, for a region of interest of this extent, was only possible by the division of the area into three separate models. Río Blanco, Rio Chotepe and Rio Chamelecón. This decision was based on the different catchment extents and the locations of the areas of interests, as well as total number of cells and the resulting computational costs of each model.

For Río Chamelecón, the planned hydropower reservoir "El Tablón" was implemented in the model by considering the resulting changes in discharge. Discharge values were calculated based on the framework of dam planning provided by San Pedro Sula Municipality. Future scenarios were developed on the basis of the mentioned RCA4 Model. RCA4 provides the daily precipitation with a spatial resolution of about 50 km for past and future scenarios. RCA4-was calculating the defined past period (1950 - 2005) and the future period (2005 – 2100). The precipitation change between both of them were analysed and taken via a precipitation factor to the available precipitation statistics of the FIHS and applied to the hydrological models as precipitation input.

2.2.3 Validation

2.2.3.1 Hydrologic Model

Because of the data availability and the general lack of measurement data (e.g. precipitation, runoff, infiltration), the validation of the results was based on the knowledge of local authorities, a plausibility check with literature (USGS, 2002), the Creager envelope curves for extreme floods as well as the results out of the hydrodynamic modelling. The results of the hydrodynamic modelling will be discussed later on. Rio Chamelecón is the most noted catchment, addressed by the USGS Paper (2002).

Validation was therefore possible with restriction against the Creager-Equation (HQ50) and the USGS Paper, analysing the storm event Mitch (USGS 2002). Referenced values are highly different and strongly varying over available studies. The USGS study examined the station Chamelecón el Puente and defined the station as not reliable and deals with the corresponding values carefully. They also carried out a Drainage area relation for the peak flow estimation, calculating a QHQ50 = 2 400 m^3/s whereas based on the statistical analysis QHQ50 measures 1 070 – 2 060 m^3/s. The often-referenced gauge "Chamelecón en puente" is located around 20 km upstream of the analysed model output of this study.

2.2.3.2 Flood Model

Due to scarce data availability, a validation of the hydraulic model results was not feasible. Similarly, a sound validation of the results against the flood event caused by Mitch in 1998 was impossible, due to a lack of available discharge and flood extend data at the time of the study.

The model results were therefore validated on the base of previous studies carried out by local and international organisations such as USGS (2002), COPECO (2016a, 2016b) as well as more recently by Abrego Suárez (2019). Existing 1D model results from these studies as aligned with the improved 2D results of this study. In addition, experts from different governmental offices from the Municipality confirmed the validity of the parameters and assumption made for the calibration of the different models, through a series of calls. The results of the hydrological model described before are used as input for the hydrodynamic modelling. In other words, the hydrographs resulting from the HEC-HMS model, provided therefore the boundaries of the hydrodynamic HEC-RAS model. Because of the data availability and the general lack of observed data (e.g. precipitation, runoff, infiltration), limited statistical validation was possible (Creager envelope curves for extreme floods), expert knowledge and literature review of previous studies.

Comparisons of 50-year flood discharges estimated by different studies and estimates of peak flows during Hurricane Mitch at four municipalities in Honduras shows a strong agreement with the flood model output[7]. At the "Rio Chamelecón en Puente" gauge, located 20km upstream of the Chamelecón catchment outlet, the relation estimated a 50-year flood discharge of 2 485 m3/s and verified this figure with an application of a unit hydrograph model using SCS (Soil Conservation Service, now called the Natural Resources Conservation Service) loss rate parameters to compute a 50-year flood discharge of 2 473 m3/s (Consorcio Lahmeyer International, 1998, p.3-78)[8]. Nevertheless, in the absence of historical discharge gauge, the USGS study indicates peak flows at the outlet ranging of 1 070 - 2 400 m^3/s. A careful Creager envelope curves for extreme events was therefore carried out.

Envelope curves are important tools for the evaluation of floods and for determining the peak discharge in ungauged watersheds. These curves, associated with a mathematical equation, determine the upper line that involves the maximum values of the floods associated with the respective basin areas. The outcomes of this analysis are in close agreement with the discharge simulated for the 50-year flood discharge for the Chamelecon outlet, 1 792 m3/s (Greager 1 475m3/s)[9].

2.3 Results

The HEC-HMS and HEC-RAS models offer a 2D hydraulic simulations of maximum flood extents and water depth, both used as input data in CLIMADA. Results are calculated for three different periods and two climate scenarios. In this section we present only a selection of the results for the sake of clarity. Additional maps are presented in ANNEX 2 for the three return periods (TR25, TR50, TR100) and the different scenarios (present, future high and future low).

The general results show an increase of the flood extend over SPS in simulations with future climate signal. Figure 2 shows a strong climate signal (RCP8.5) returning a larger flood zone especially in the southern part of the city (Rio Chamelecón), but also alongside the Rio Chotepe. More elevated areas (in the northern part of San Pedro Sula) remain unaffected by a change in climate signal, where only the riverbed is affected, with partial flooding of the river banks.

[7] USGS: US Arma Corps of Engineers - Hydrologic Engineering Center. (2002): Flood-Hazard Mapping in Honduras in Response to Hurricane Mitch. Water-Resources Investigations Report 01-4277.

[8] Consorcio Lahmeyer International, 1998, Estudio de factibilidad y diseño final proyecto obras prioritarias en zonas de alto riesgo, Chamelecón Pueblo-Choloma: Report prepared for Gobierno de Honduras, Comisión Ejecutiva Valle de Sula.

[9] USGS: US Arma Corps of Engineers - Hydrologic Engineering Center. (2002): Flood-Hazard Mapping in Honduras in Response to Hurricane Mitch. Water-Resources Investigations Report 01-4277.

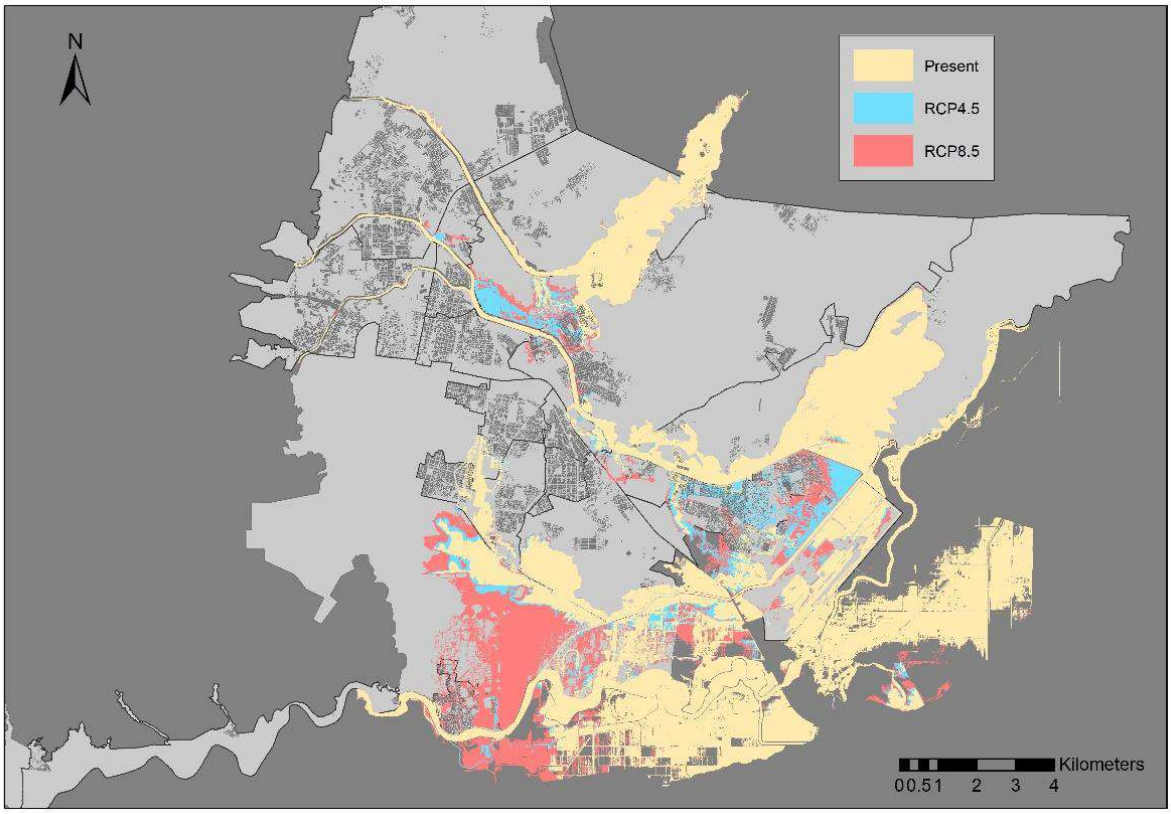

Figure 2 Flood extend for the three different scenarios modelled for the 100yr return period (present, RCP 4.5 and RCP 8.5 scenarios)

Water depth, equally as flood extend are an important input to CLIMADA. We present a selection of results for today's climate and a future scenario, both for large flood events (100yr). For an easier understanding, water depths are classified into three classes. These three classes are determined by the severity of an invent intensity.

- Water depth < 1 m = "low" severity of exposure
- Water depth 1 - 2 m = "medium" severity of exposure
- Water depth > 2 m = "high" severity of exposure

Figure 3 shows three classes of water depths for large floods (100yr) for today's climate. Figure 4 presents the same classes for a strong future climate scenarios (RCP8.5) for large floods (100yr) in the municipality of SPS. It depicts a significant increase in areas suffering from higher water depths values, suggesting larger damages in these areas. In addition, as discussed before, for a strong climate signal, the overall flooded areas is also expected to increase.

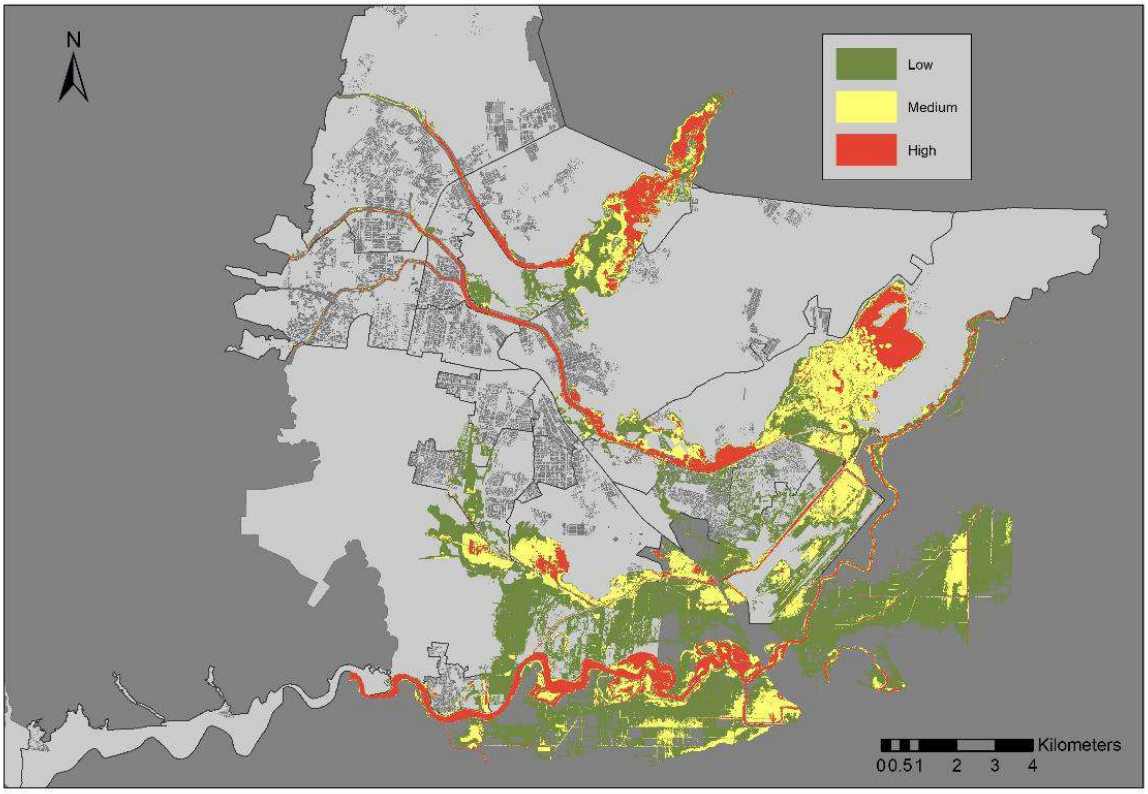

Figure 3 Maximum water depth for the present climate (100yr)

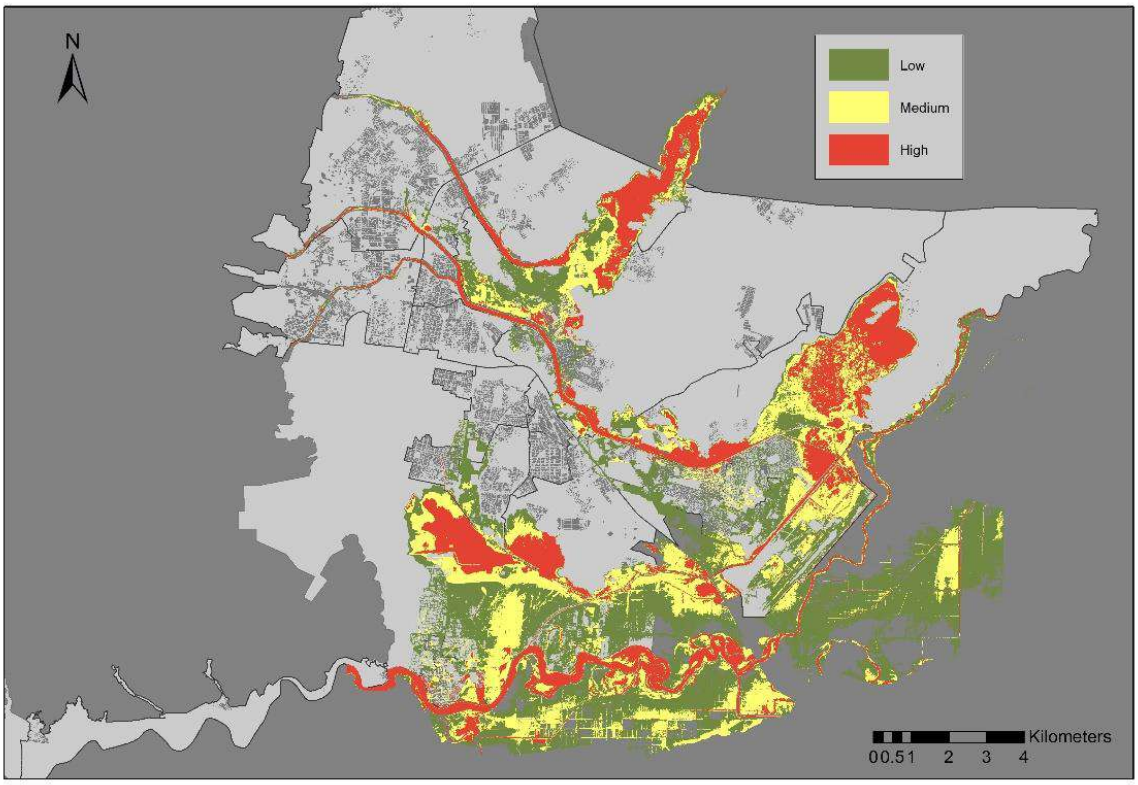

Figure 4 Maximum water depths for an RCP 8.5 scenario (100yr)

Further, we explore the possible impact of the hydropower dam el Tablón (in planning) located in the catchment of the Chamelecón. These results are based on information available to date (further explained in Chapter 7.3 Recommendation for el Tablón) and might change depending on the location

and the final dimension of the dam. However, they provide useful insight for decision regarding further planning. Figure 5 shows the simulated flood extend of flood events for different inundation frequencies (25yr, 50yr, 100yr). The dam shows a noticeable effect on the flood extend in the municipality area, however, with a stronger impact for lower intensity events (25yr and 50yr return) as displayed in Figure 6.

However, with the parameters considered here, flood damage to the airport and other low land areas in the vicinity of the Chamelecón River are still expected to be impacted severely by flood events of large intensity. Possibly, a careful dimensioning of the future project should take place in order to account for the mitigation of stronger flood events.

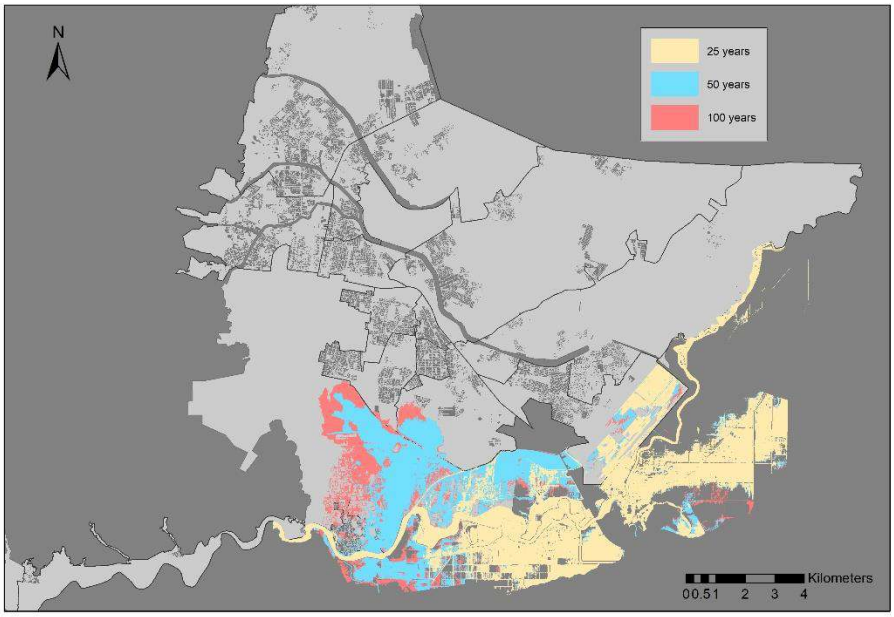

Figure 5 Impact of El Tablón Dam on flood extend for large flood in the Chamelecón sub-catchment

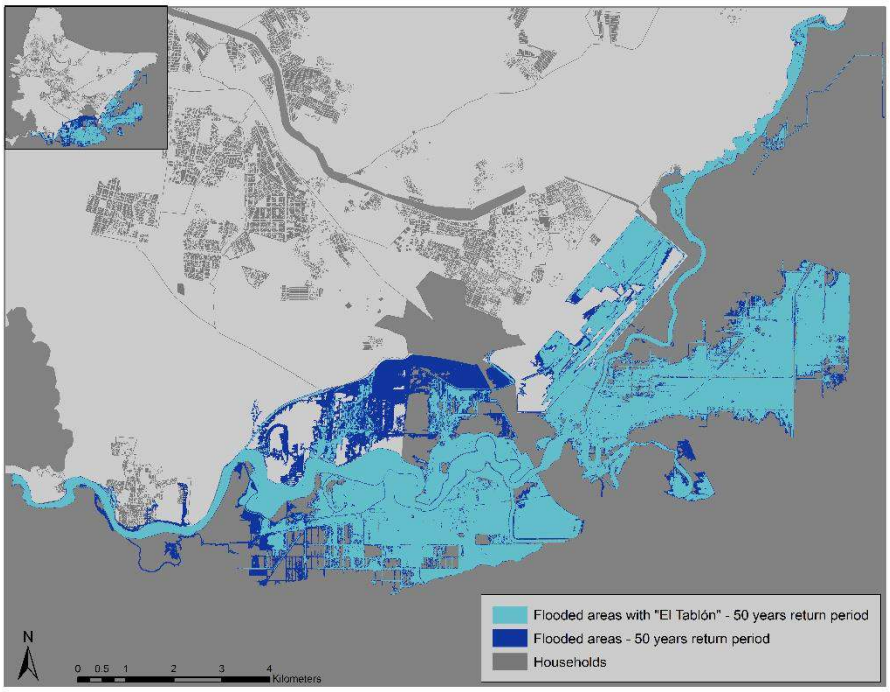

Figure 6 Impact of el Tablón Dam for the RCP4.5 future scenario (50Yr)

2.4 Limitations and Conclusion

This sections present the methods, data and parameters used for the setup of the hydrological and hydraulic models for the municipality of San Pedro Sula. This new set up constitute a significant advance in terms of flood modelling in the region. Nevertheless, an honest and careful discussion regarding limitation and uncertainties linked with the forecasting exercise is necessary to further improve future iteration of the model.

Uncertainties within hydrodynamic modelling generally arose due to the quality of the DEM in some regions. Artefacts, presumably sourcing from data recording as well as from vegetation, were present throughout the whole project area without possibilities for improvement. During the implementation of the river channels in the hydraulic models, several assumptions were made, deflecting real conditions. Uncertainty also arose in the construction of the river channel, since cross sections were not measured but obtained from the DEM. Measured cross sections would have provided a higher accuracy, leading to better results. Additionally, there are several bridges in the area of San Pedro Sula, of which only two were considered. Possible backwater effects could therefore not be taken into account.

Another major source of uncertainty lies in the lack of discharge data. To date, no reliable discharge data exist and this model is based on statistical extrapolation techniques and expert knowledge only. We will come back with recommendations on these aspects later on in this report. Reliable discharge and water level stations are key to a better monitoring, early waring and forecasting of floods in the region.

Precipitation data used in the study constitute also an additional source of uncertainty. Indeed, station data comes with limitations and requires extrapolation technique. For terrains with strong elevation changes, such as in the Sulla Valley, these techniques have a limited validity. Here too, further development of the station network, possibly in combination with remote sensing would improve the reliability of precipitation data.

Finally, climate scenarios, GCM and downscaled data offer a series of bias due to resolution, orographic changes and temporal issues which impairs the forecasting power of flood models in general. In conclusion, the outputs of the study included inundation depth and flood extents for three return periods (10, 50 and 100 years) for the present and the future (RCP4.5 and RCP8.5). In comparison with existing flood model such as the 1D study from COPECO (2016)[10] and Abrego Suarez (2019)[11], significant improvements have been made, in terms of DEM correction, enhancement of details concerning spatial resolution as well as the introduction of several climate scenarios. Finally, the uncertainties considered in this section reflect the challenges existing in data scare regions. Such challenges are intrinsic to any flood modelling. Henceforth, the results of the 2D SPS flood model are explicitly fit for purpose for the scope of this study and, beyond, are also to be considered for a basis to further planning in the region of San Pedro Sula.

[10] COPECO: Comisión permanente de contingencias. (2016a). Informe V- Hidrología, Producto 1. Análisis de Riesgo a nivel municipal y local, Estimación de Avenidas – Sistemas de cuencas del Municipio de San Pedro Sula Departamento de Cortés. San Pedro Sula.

[11] Abrego Suárez, C. R. (2019). Actualización preliminar de los umbrales de alerta por inundación de Río Chamelecón en ciudad La Lima, Cortés, para el período de observaciones 2010-2018. Tegucigalpa, Honduras.: Master Thesis.

3 ASSET VALUATION

3.1 Background and Methodology

The following chapter describes how the different types of assets and their values were estimated. CLIMADA relies on georeferenced data and hence, both, risk scenarios and damage to assets, have to be simulated based on georeferenced information. Therefore all assets were previously geo-located and partitioned where necessary as described in further detail in the corresponding subchapters below.

The following is an overview of the methodologies used in this study to estimate asset values:

- Field surveys: especially with regard to vulnerable population, Los Bordos, and housing,
- Discussions with experts: facilitated through the project's focal person at the Municipality of San Pedro Sula
- Estimation of real estate owned: based on available cadastre data[12]
- Assessment of characteristic and relevant infrastructure and public assets

In addition to the data available online and the data provided by the Municipality, a survey was implemented on the household level in the selected district in order to gain further insights into people's living condition. Data was gathered in reference to households' wealth, income levels, as well as the level of affectation during previous flood events, e.g. affected people and experienced damages on their assets. This survey was implemented by Department of Municipal Research and Statistics of San Pedro Sula (*Departamento de Investigación y Estadística Municipal*, DIEM).[13]

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[12] During the data validation webinar values based on the cadastre estimates were presented for all asset sub-categories that involve buildings. Several participants objected to those values as some of them may be outdated and the year, and hence the corresponding USD exchange rate, are not recorded. During some follow-up discussions facilitated by the Municipality's focal person for the study several experts provided the UNU-EHS team with updated estimates which were then applied and compared. In most cases (Educational and Health Facilities, and Electrical Infrastructure) the changes to the overall sum of the respective asset sub- category did not change significantly. However, in the case of heritage sites, roads as well as airport taxi- and runways the value increased majorly due to the changes. For electric substations the updated estimate based on official project cost estimates reduced significantly. After detailed discussions it was confirmed that those updated values estimates should be applied as those are officially used for planning.

[13] The field survey will from now on referred to as DIEM (2020) when making reference to any of the obtained data and results. The methodological framework of the survey can be found in ANNEX 3.

3.2 Assets Categories

The assets examined in this study were confirmed during an iterative process through (a) the inception workshop and the corresponding report and (b) indirectly through the validation webinar and its report. Although the importance of the drainage and sewage systems are recognised it was decided that due to a lack of data about its state and characteristics the asset 'Drainage' should only cover natural streams and major canals. However, following that line, the drainage system is still considered in the list of potential measures.

Hence, the list of assets and its sub-categories as defined for the analysis are the following:

1. Vulnerable People
2. Informal Settlements (Housing in *Los Bordos*)
3. Housing
    a. Low quality buildings of one story
    b. Medium quality buildings of one story
    c. Medium quality buildings of two or more stories
    d. High quality buildings of one story
    e. High quality buildings of two or more stories
4. Road Network
    a. Minor roads of one lane
    b. Major roads of two or more lanes
5. Public Buildings
    a. Educational facilities
    b. Health facilities (major hospitals and smaller health facilities)
    c. The Ramón Villeda Morales International Airport
    d. Fire brigades
6. Electrical infrastructure
    a. Low voltage power lines for urban distribution
    b. Primary transmission lines of higher voltage (13.8 and 34.5 kV)
    c. Distribution Substations
7. Drainage (natural streams and major canals)
8. Heritage sites
9. Environmental assets
    a. Green areas, forests and parks
    b. Water bodies

Based on the initial results from literature review and the provided data a data validation webinar was conducted with experts and representatives from the Municipality of San Pedro Sula. During the webinar and during some follow-up discussions recommendations were made regarding the updating and refining of the values for some asset categories.

The following sub-chapters will provide further insights into the respective assets location, the selected valuation method and the valuation results. Monetary values are to be understood in 2020 USD terms although challenges in applying the most appropriate exchange rates were faced due to some datasets not recording the date of data collection. The chapter will be concluded with an overview of all the assets in the study region.

3.3 Vulnerable People

The definition of vulnerable people is based on the Intergovernmental Panel on Climate Change (IPCC)[14] which includes the following three main components of vulnerability:

- exposure,
- adaptive capacity
- and sensitivity.

To account for **exposure**, and in line with the guidelines of the IPCC, we inventoried populations living in areas with high flood hazard according to the results from the model described in Chapter 2. Figure 7 shows the areas that are exposed to floods following the footprint of a 50-year event (return period). To address the inhomogeneous delineation a 100m buffer was included.

Adaptive capacity, hence the ability of a system to cope, is being approximated by the percentage of households with unsatisfied basic needs (*Necesidades Básicas Insatisfechas,* NBI)[15] within neighbourhoods. To distinguish between 'vulnerable population' and 'population' in general a cut-off at 30% none unsatisfied basic needs was chosen (0NBI<=30%). In other words, when more than 70% of the households of a given neighbourhood have at least one basic need unsatisfied, the neighbourhood is considered with low adaptive capacity and therefore vulnerable. By definition, all inhabitants of *Los Bordos* were considered as vulnerable.

Finally, **sensitivity**, the degree a system is being affected in case of floods, will be defined by the modelling exercise using CLIMADA.

In order to estimate the number of potentially affected people in each house, including those in *Los Bordos*, a random number of inhabitants was assigned to each household. The random values were generated through a truncated Poisson distribution with values between 1 and 12 and a mean of 4.0 persons per household, based on statistics provided by the Municipality[16].

Figure 7 highlights both, the 'vulnerable population', those households being exposed and living in a neighbourhood of NBI<=30% in red, and further 'exposed' population groups that are exposed to flooding but live in areas of higher basic needs satisfaction. Table 1 summarises the estimated population living in the study area as well as the subgroups of vulnerable and exposed population. For comparison reasons, Figure 8 presents the same applying the foot print of a 100 year return period event.

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[14] IPCC (2014) *Climate Change 2014. Impact, adaptation and vulnerability*. Part A: Global and sectoral Aspects Working Group (WG) II Report

[15] The NBI is an index that was developed in the 1960s and that was adopted by the UNECLAC (United Nations Economic Commission for Latin America and the Caribbean) for poverty monitoring and benchmarking within the region in the 1980s. The four basic needs categories considered by the NBI are: 1) Access to housing, which measures the quality of housing and level of overcrowding, 2) Access to sanitary services, defined as the availability of drinking water and the type of excreta disposal system in the household, 3) Access to education, in terms of attendance of children at school-age to an educational establishment, and 4) Economic capacity, measured as the probability of insufficient household income at any given time. For further details see: Feres, Mancero, (2001). *El método de las necesidades básicas insatisfechas (NBI) y sus aplicaciones en América Latina*. Retrieved from: https://www.cepal.org/es/publicaciones/4784-metodo-necesidades-basicas-insatisfechas-nbi-sus-aplicaciones-america-latina

[16] The value 4.0 persons per household is based on: Secretaría de Salud [Honduras], Instituto Nacional de Estadística (INE) e ICF International. (2013). *Encuesta Nacional de Salud y Demografía 2011-2012*. Tegucigalpa, Honduras: SS, INE e ICF International.

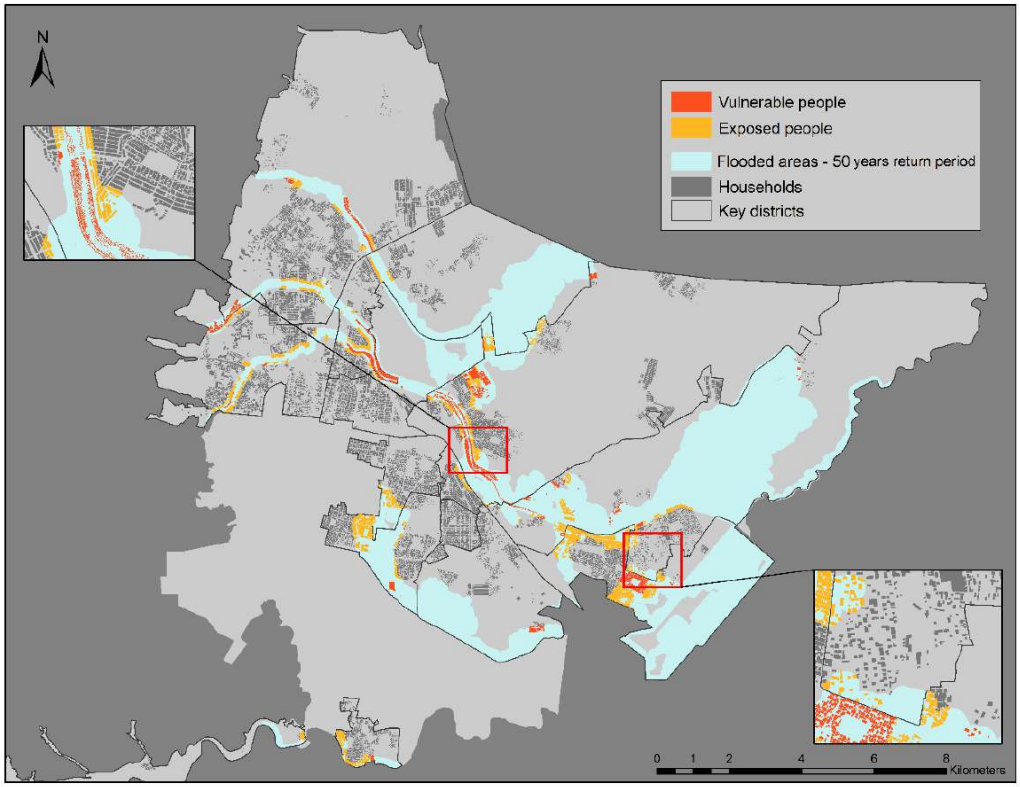

Figure 7 Households exposed to floods for a 50 years return period at the present scenario.
Red: Households defined as vulnerable based on their exposure and an NBI value below 30%, Orange: Households being exposed but with an NBI value above 30%. - Source: Authors' own compilation

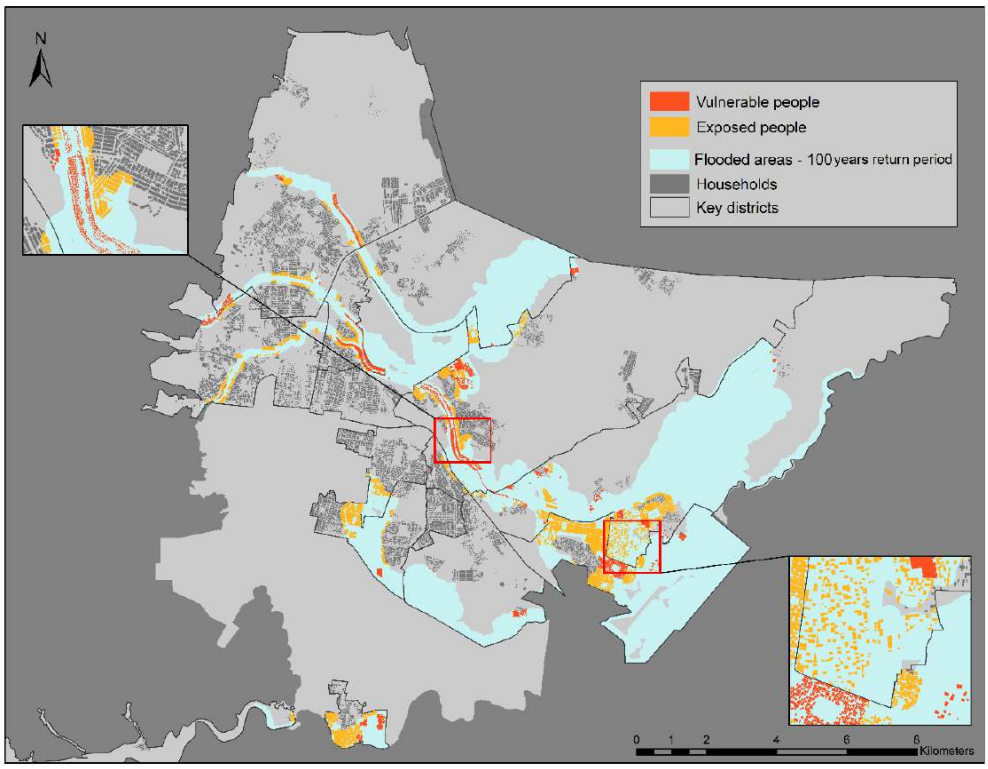

Figure 8 Households exposed to floods for a 100 years return period at the present scenario.
Red: Households defined as vulnerable based on their exposure and an NBI value below 30%, Orange: Households being exposed but with an NBI value above 30%. - Source: Authors' own compilation

Table 1 (Vulnerable) Population estimates (based on a 50 year return period)

	Number of households (% of total)	Total number of people (%of total)
Los Bordos	6 778	27 685
Formal Settlements, total	71 915	293 582
Total Vulnerable Population (Red)	7 603 (9.7%)	30 622 (9.5%)
Exposed Population (Orange)	8 368 (11.6%)	34 168 (11.6%)

3.4 Informal Settlements (Los Bordos)

Informal settlements are by definition less closely monitored and hence cadastre data do not provide a solid base for the analysis. The formerly mentioned field survey by DIEM (2020) however took a focus on households in *Los Bordos* and did provide some information on the location, quality and value of housing as well as experienced losses in three past flood events.

3.4.1 Location

The baseline for the locations of the houses were the sample of surveyed households (700) which included locations and were directly mapped by the Municipality. Since little other information was available, including reliable satellite imagery, for each family[17] a dwelling was randomly generated within the respective boundaries of the *Los Bordos* district which were provided by the Municipality of San Pedro Sula on household density data for each *Bordo*. It is assumed, based on the survey results, that houses generally do not have multiple stories and hence all families live on the ground floor. Although it can be assumed that in some instances more than one family may live in a single house for simplicity reasons each family is represented by an individual house.

Figure 9 below showcases the location and value estimates of housing while rectangles depict actually surveyed houses and circles represent randomly generated houses.

[17] The number of families per *Los Bordos* district was provided by experts of the municipality.

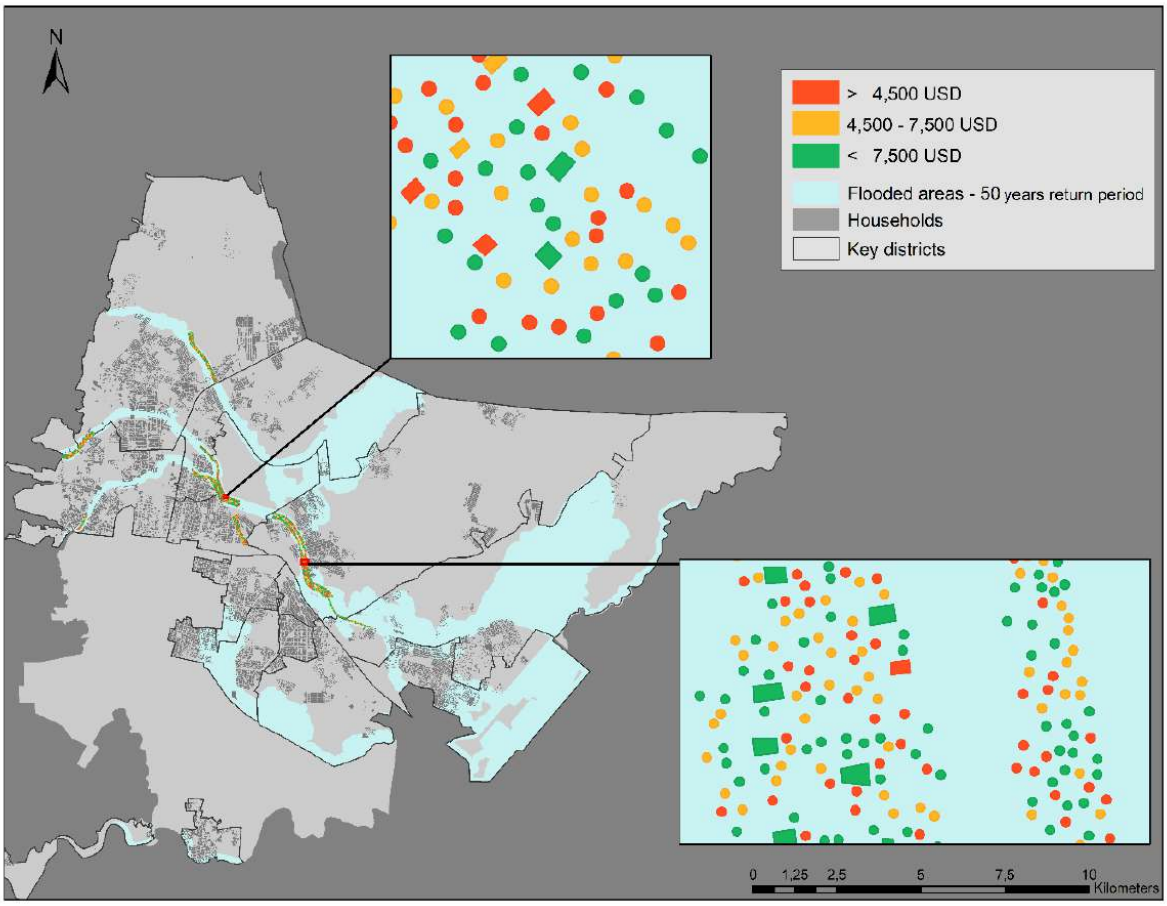

Figure 9 Location and USD value estimates of housing in Los Bordos - Source: Authors' own compilation

3.4.2 Values Estimation

Using the results from the survey, specifically the information on wall and floor material and conditions, a score on building quality was developed and employed as value indicator. Ranging between 0.1155 and 1, the magnitude of the score gets higher as the materials and quality of walls and floor are better[18]. Scores were assigned randomly to the newly generated dwellings[19] applying the same distribution pattern as observed in the 310 surveyed houses. Figure 9 illustrates the random distribution.

A maximum housing value of 5 000 USD was estimated and confirmed during the data validation webinar for a dwelling, it was assigned to the higher score and was proportionally reduced for dwellings with lower scores, i.e. the minimum score corresponds to a value of 577.5 USD. The interior value of the houses, household assets, were also estimated based on the score, assuming that a family who can afford a better quality housing could also afford more and better quality furniture and appliances. Here a maximum value of 5 300 USD was assigned to the higher score and lower scores received proportionally lower values, i.e. the minimum score was assigned a value of 612.15 USD.

[18] Scales and procedure can be found in ANNEX 4 - Valuation of housing in Los Bordos

[19] See chapter 3.2.1 Location for further details

Table 2 Value range and total value estimates for housing in Los Bordos

	No of households	Housing value (USD)	Household asset's value (USD)	Total (USD)
Ranges		577.5 - 5 000	612.15 - 5 300	1 189.65 - 10 300
Estimated total	6 778	19 891 905	21 085 419	40 977 324

3.5 Housing

3.5.1 Location

Just as informal housing, formal housing is one of the key assets of the ECA framework. Other than in the case of housing in Los Bordos, the city's cadastre provides valuable information on location, size and value of buildings and plots. The datasets shared had some limitations, one related to the data updating process that is currently on-going in the Municipality, rendering some values non-representative of the current conditions of the buildings, and another one related to data gaps, with some datasets being more commonly absent like constructed areas.

All considered, buildings identified by the Municipality as no-habitational and those with constructed areas equal or less than 20% of the plot[20] were not considered for this study. Figure 10 illustrates the considered buildings and their total values.

[20] Following a comparison of satellite images and the cadastre data it was realised that buildings smaller than 20% of the plot in most cases were buildings such as guard houses on parking lots or work/ garden sheds in e.g. parks or rather un-representatively large properties.
Buildings with no data on constructed area were validated using satellite images.

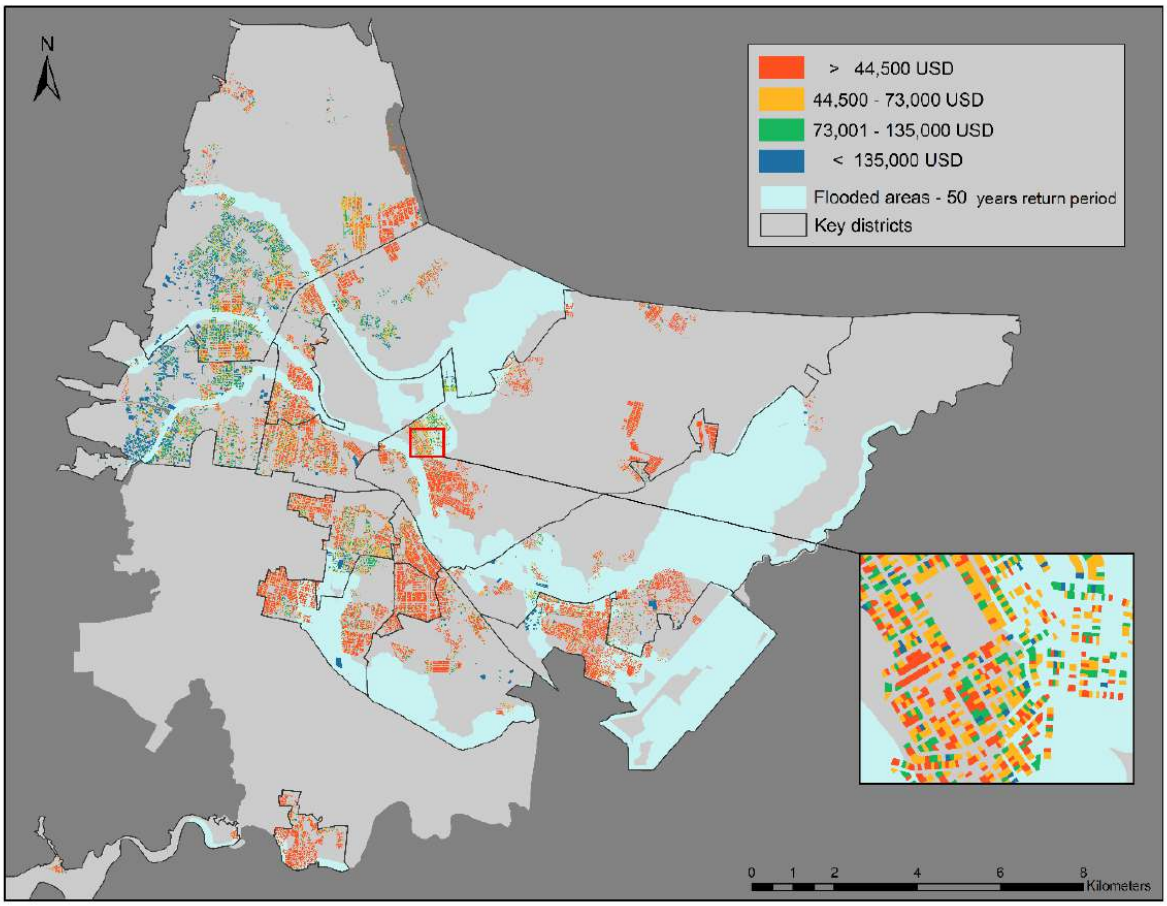

Figure 10 Estimated 2020 USD values for formal housing in San Pedro Sula. Source: Authors' own compilation

3.5.2 Values Estimation

In order to estimate the value of people's housing and the corresponding condition two factors are being recognised. First, the construction value as registered in the cadastre data. And secondly, the household assets in the house, i.e. appliances and furniture.

As there were no reliable data available for interior values, assumptions were made based on two factors. 1) The basic unsatisfied needs index (NBI)[21], which was used as a general wealth indicator, and 2) whether a building has one or more than one story. In case a house has multiple stories a higher standard of living was assumed in comparison to the one-story buildings in the same NBI range. Three NBI ranges (low: <30%, medium: 30-60%, high >60%) were defined. Following this procedure results were classified into five final categories (for all buildings in the NBI range below 30% only one story was assumed), each being assigned a value estimate per m^2 based on regional estimates and confirmed using both, expert interviews and the data obtained through the household survey by DIEM (2020), as presented in Table 3 below.

Table 3 Per square meter value estimates for different classes of housing

NBI range and No. stories	USD per m^2
< 30%, one story	151.43

[21] In this case we used the 0NBI index measured by the Municipality. This presents the percentage of households in a given neighborhood that have all of their basic needs satisfied. Further details of the basic needs studied are presented in footnotes of the first page of chapter 3.3 Vulnerable People

30 – 60%, one story	178.75
30 – 60%, two or more stories	182
=> 60%, one story	254
=> 60%, two or more stories	271.1

Based on the above described methodology and prices, the results are summarized as follows.

Table 4 Housing valuation summary

	No of houses	Average total value in USD	Total in USD
Low	11 099	41 507	460 686 195
Medium	20 965	43 840	919 102 206
High	39 851	53 610	2 136 412 468
Total	71 915	48 893	3 516 200 870

3.6 Road Network

In order to reflect the existence of different roads the Municipality's road network was divided into two different sub-classes, namely *minor roads* of just one lane and *major roads* of two or more lanes. Local experts in the aftermath of the data validation webinar shared estimates used for planning road construction of 2 580 HNL/m^2 (≈ 114.92 USD/m^2). Following an analysis of cross sections of some example roads as outlined in the supporting documents of the Municipality's Development Master Plan (PMDM) a width of 7m for minor roads and 15m for major roads is assumed resulting in the following estimates in Table 5; Figure 11 displays the road network considered in this study.

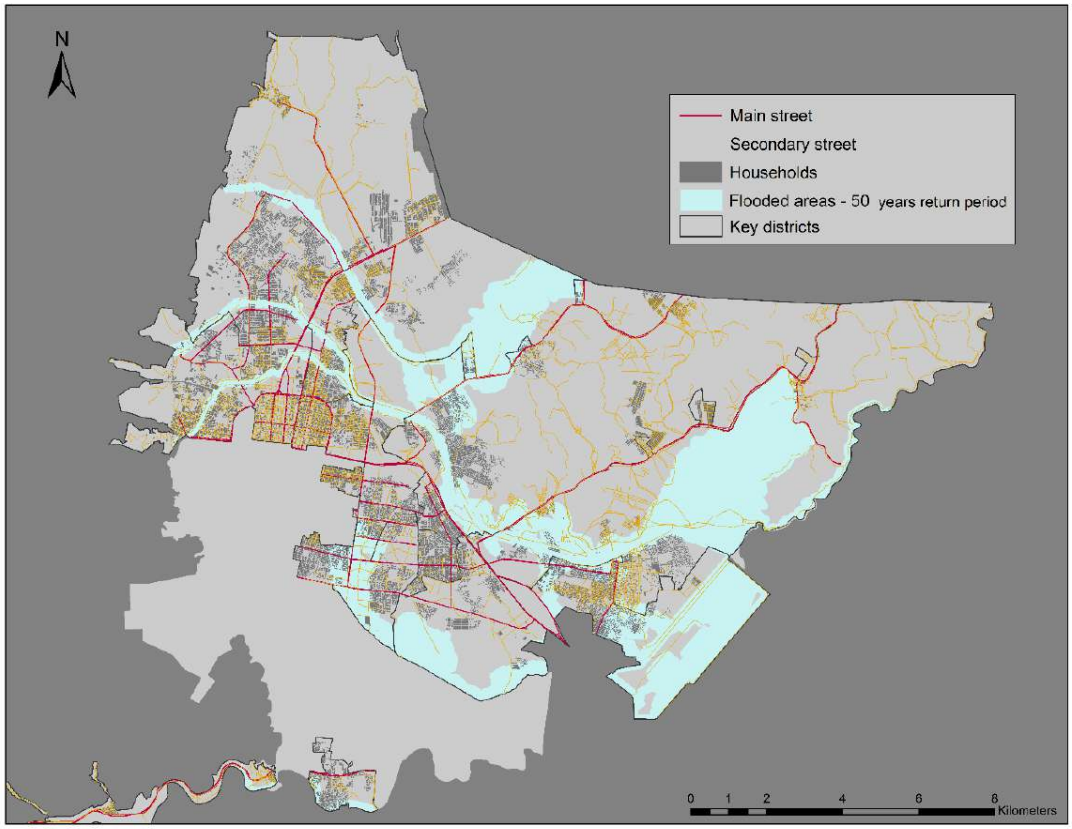

Figure 11 Considered road network. Red: Major roads. Yellow: Minor roads. Source: Authors' own compilation.

Table 5 Road value estimates

	Total length (m)	Total area (m²)	Price (USD/m²)	Total (USD)
Minor roads (7m wide)	780 158	5 461 108	115	627,590,507.43
Major roads (15m wide)	188 036	2 820 534	115	324,135,731.79
Roads Total		**8 281 641**	**115**	**951,726,239.22**

3.7 Public Buildings

In the category of public buildings several different types are being recognised. Those are namely educational facilities, health facilities, and fire brigades. Within the districts in the Municipality selected in the inception and data base workshops (districts 1,2,3,4,7,10,11,12,13,14,15,16,18), the comprehensive cadastre records provided 23 health facilities of different size ("hospitals" and "smaller health centres"), 100 educational facilities, 4 fire brigades, and the Ramón Villeda Morales International Airport were identified.

Figure 12 displays the location of each type of assets in this category. The location and size of the buildings again is drawn from the cadastre files provided.

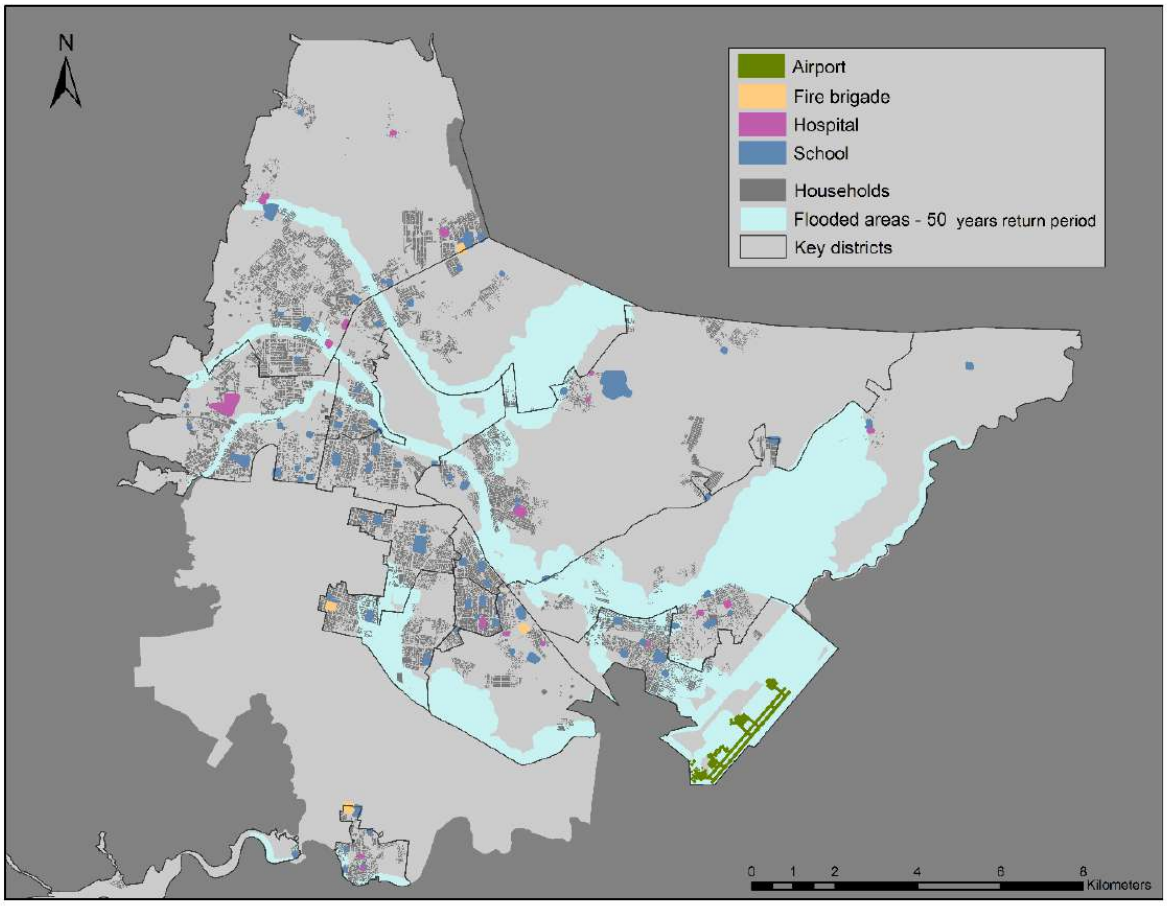

Figure 12 Location of public buildings studied. Source: Authors' own compilation.

In the following sections the different valuation methods employed for the asset sub-categories is being outlined.

3.7.1 Health Facilities

For the 23 health facilities within the selected districts (presented in purple in Figure 12) both construction value as well as the value of the medical equipment and furniture is likely to be damaged by a flood, hence the potential basements and the ground floor of hospitals and health centres are considered. With regard to the structural component, the values provided by the cadastre were updated following the data validation webinar that took place on August 26, 2020, were representative experts suggested the values typically used for planning and tenders purposes (28 635 HNL/m^2 ≈ 1 154.64 USD/m^2). As the result of this study shall serve to make investment decision and hence fit right into the Municipality's planning, this value was deemed most appropriate.

As for the equipment, no estimate for values were made available by the Municipality. The values used are based on a UN-ECLAC[22] report analysing the flood damages on hospitals and smaller health centres caused by Hurricane Mitch. The cost to refurnish and re-equip hospitals differ substantially depending of the size of the health centre: refurnishing and re-equipping larger hospitals is estimated at about 9m USD per hospital (national or regional) while for smaller health centres 180 000 USD per facility. A synthesis of the used values is outlined in Table 6.

Table 6 Value estimates for hospital and health centres

	Number	(Re-)Construction Value USD/m^2	Refurnishing USD/unit	Total USD
Hospital	2	1 155	9 000 000	169 236 634
Smaller health centre	21	1 155	180 000	113 535 293
Health facilities total	23			282 771 928

3.7.2 Educational Facilities

In the same fashion as for the health facilities, for the 100 educational facilities (presented in blue in Figure 12) values for the buildings' structure are based on the Municipality's estimates for planning and tenders (9 000 HNL/m^2 ≈ 362.9 USD/m^2). For estimating refurnishing costs again the UN-ECLAC report on damages caused by Hurricane Mitch is being employed revealing an estimate of 20 USD/m^2 based on damages occurred and the number of affected classrooms. Table 7 summarises the value estimates for educational facilities.

Table 7 Educational facility value estimates

	Number	(Re-)Construction Value USD/m^2	Refurnishing USD/m^2	Total USD
Educational centres	100	362.9	20	356 456 521

3.7.3 Ramón Villeda Morales International Airport

The Ramón Villeda Morales International Airport (presented in green in Figure 12) is located to the east of San Pedro Sula and lies at 27 MAMSL close to the Chamelecon River facing high flood risk.

The value of the buildings of the airport depend on several different components, i.e. internal and external structures, furniture and sanitary/ disposal fittings, heating and air-conditioning units, as well

[22] UN Economic Commission for Latin America and the Caribbean. (1999). Honduras: Assessment of the Damage Caused by Hurricane Mitch, 1998. Implications for economic and social development and the environment.

as electrical, communications and protective installations resulting in roughly 3 678 USD/m^2 which can be estimated as displayed in Table 8.[23]

The only runway of the airport is approximately 2 900m long and 44m wide with a concrete surface. Following the data validation webinar and the presentation of taxi- and runway cost estimates, local experts recommended to use the same estimates as were applied for roads (114.92 USD/m^2) resulting in the values presented in Table 8 with the areas being based again on the Municipality's cadastre data.

Table 8 Cost estimates for Ramón Villeda Morales International Airport

	Cost per m^2 (USD)	Area in m^2	Total USD
Buildings	3 678	61 177	225 008 495
Runway	115	127 191	14 616 789
Taxiway	115	299 802	34 453 249
Tarmac sub-total		**426 993**	**49 070 038**
Airport Total			**274 078 533**

3.7.4 Fire Brigades

As fire brigades (presented in yellow in Figure 12) provide vital emergency relieve services during extreme weather events and especially during flood situations, they were taken up too as an asset to be considered. Building values for the four relevant fire brigades for the scope of the study, are based on the values the cadastre data provided by the Municipality. As fire brigades are a rather specific building type very little academic literature targeted at their furnishing is available, the same estimates as for terminal buildings is being applied under the premise that similar construction requirements and standards, such as e.g. security requirements, have to be followed. Hence, a total value of 1,808 USD/m^2 (consisting of furnishing, sanitary fittings, heating and cooling systems, electrical communication, and protective installations) is being applied.

Table 9 Fire Brigades value estimates

	Number	(Re-)Construction Value	Refurnishing	Total USD
Fire Brigades	4	*As per cadastre*	1 808 USD/m^2	1 711 306

3.8 Electrical Infrastructure

The urban electrical grid in San Pedro Sula largely follows the road network and is carried by either wooden or concrete poles overhead. However, there are some primary distribution lines for distribution on a regional level operating at a medium voltage (13.8 and 34.5 kV) while the urban distribution and customer service drop lines operate at low voltage, i.e. less than 4 kV. Major transmission lines at high voltage are not to be found within the study area. Therefore the electric grid network is here split into two separate types:

- Primary distribution lines: operating at medium voltage, in San Pedro Sula either at 34.5kV or 13.8kV
- Urban distribution lines: operating at low voltage (typically <4 kV) for the distribution to households and businesses

Additional to the electrical grid two electrical sub-substations were identified.

[23] IEA Energy Technology Network (2011). *Aviation Infrastructure*. Energy Technology Systems Analysis Programme. Technology Brief T16.

Figure 13 shows the location of the two identified sub-stations within the electric grid according to the two classifications of primary and urban distribution lines.

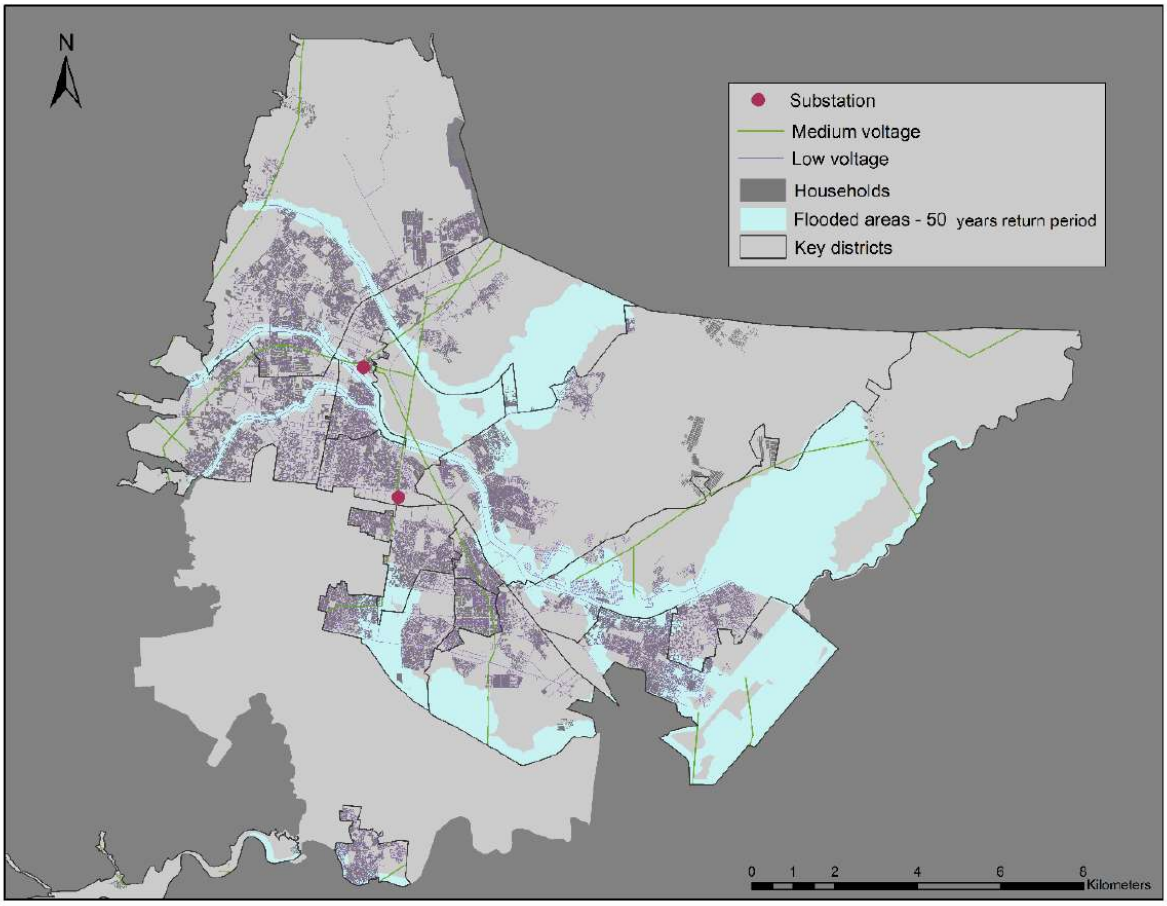

Figure 13 Electrical grid, incl. substations. Source: Authors' own compilation.

For the different types of distribution lines value estimates were provided by local experts with 60 000 USD/km for primary distribution lines and 30 000 USD/km for low-voltage urban distribution lines. The value estimate for the two sub-stations is based on project cost estimates for those and similar sub-stations in and around San Pedro Sula at 625 000 USD per station. Table 10 below summarises the estimates.

Table 10 Electrical Infrastructure values estimates

	Total km	Value estimates in USD/km	Total USD
Primary distribution lines (34.5 and 13.8 kV)	61.39	60 000	3 683 103
Urban distribution lines (low voltage)	1 125.54	30 000	33 766 305
Grid Sub Total	**1 186.93**		**37 449 408**
Substations (USD per unit)	2 stations	625 000 USD/unit	1 250 000
Electrical infrastructure Total			**38 699 408**

3.9 Drainage Channels

As a key system in flood management the natural drainage system, i.e. rivers, are being considered as assets. Namely, relevant parts of the rivers Rio Bermejo, Rio Blanco, Canal Chotepe, and Canal Sauce, are being included with an overall length of 25.33 km within the study area, as displayed in Figure 14.

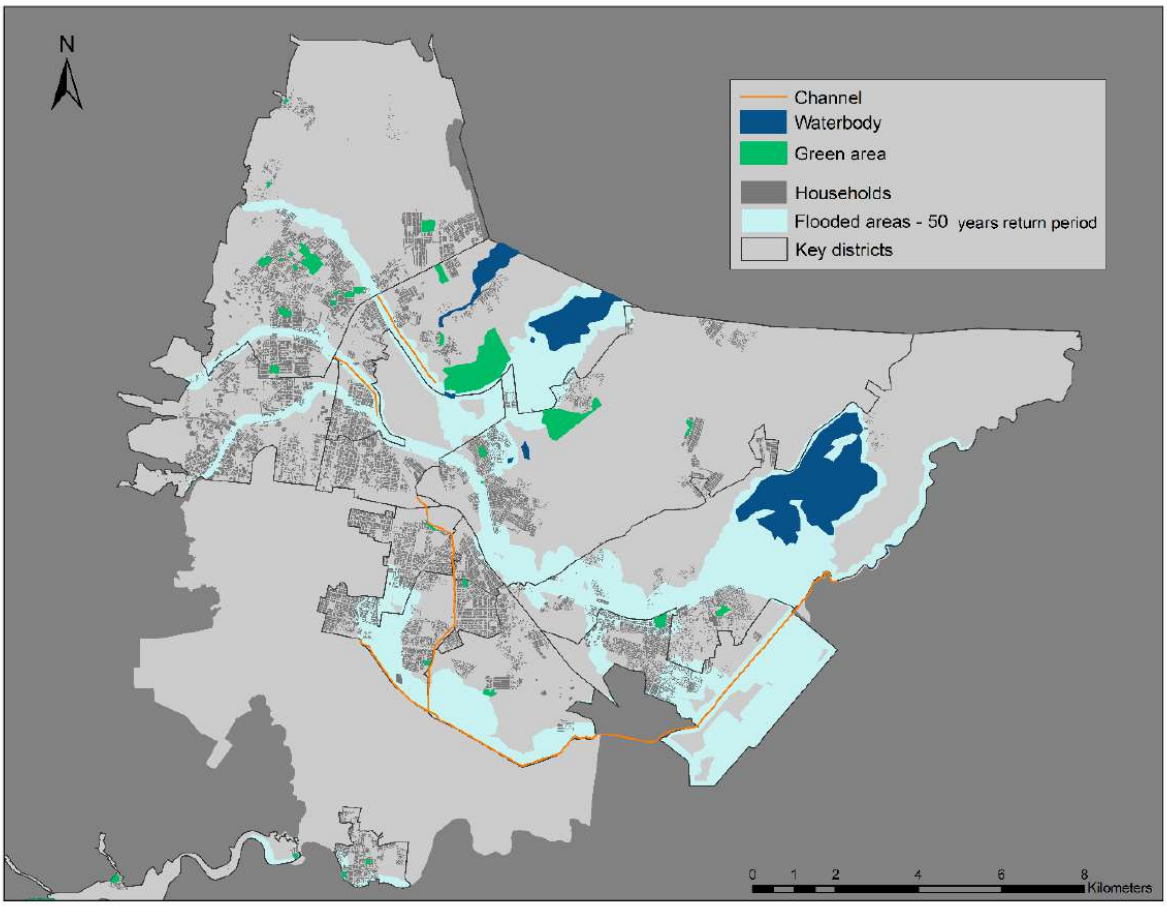

Figure 14 Drainage channels (orange), environmental assets (green), and water bodies (blue). Source: Authors' own compilation.

Since rivers and canals change theirs shape and width over their course, the average width based on the employed flood model, described in Chapter 2, are being applied for simplification. The value estimates are based on reports from exports of the Municipality on prices per m^2 for clearing and reconstruction of affected areas, which is about 201.6 USD/m^2. For the four considered rivers/ canals this translates to the following Table 11.

Table 11 Drainage value estimates

	Length (m)	Average width (m)	Total area (m^2)	Total value (USD)
Rio Bermejo	1 839	25	45 968	9 267 062
Rio Blanco	2 491	30	74 738	15 067 079
Canal Chotepe	15 113	10	151 126	30 466 943
Canal Sauce	5 891	10	58 907	11 875 627
Total	25 333		330 738	66 676 712

3.10 Environmental Assets

Through increased volumes and flow velocity river banks are being damaged and debris and pollution is being swept from e.g. streets and nearby industrial areas into the riverbed. Based on the Ecosystem Services Valuation Database (ESVD)[24,25] which considers as a follow up to "The Economics of Ecosystems and Biodiversity" (TEEB) database a wide range of ecosystem services for different biomes rivers and lakes, water bodies were valued at 108 361 USD/year per km (or hectare in the case of lakes) taking into account the different ecosystem services they provide.

For green spaces and forest areas within the research area, value estimates (5 383 USD/year/ha) are being drawn from the ESVD as well, considering both the material value as well as the value added through ecosystem services such as air quality and climate regulation. In this study only the value for one year is being applied for simplification; Table 12 summarises the value estimates; Figure 14 above displays the identified environmental assets (green) and water bodies (blue).

Table 12 Environmental assets value estimates

	USD/ha	Total ha	Total USD
Lakes/ Water bodies	108 361	690	74 775 592
Forests/ Green spaces	5 383	401	2 156 648
Total		1 091	76 932 240

3.11 Heritage Sites

Sites of cultural heritage are drawn, such as all buildings, based on their location in the cadastre. However, value estimates are not based on the cadastre but again on the advice and internal estimates provided by experts of the Municipality during bilateral discussions to refine estimates (about 483.87 USD/m^2). In total the 41 relevant heritage sites were identified, as presented in Figure 15, taking up a space of 40 067.22 m^2 and with a mean size of about 977.45 m^2. The largest heritage site occupies more than 10 500 m^2 and the smallest only 122 m^2. Table 13 summarises the value estimates for heritage sites.

Table 13 Heritage sites value estimates

	Number	Total area	USD/m^2	Total value USD
Heritage Sites	41	40 067	487	19 387 328

[24] R. De Groot, Brander, L., Solomonides, S. (2020). *Ecosystem Services Valuation Database (ESVD). Update of global ecosystem service valuation data*. FSD report No 2020-06 Wageningen, The Netherlands (58 pp).

[25] R. de Groot, Brander, L., van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L., Hussain, S., Kumar, P., McVittie, A., Portela, R., Rodriguez, L., ten Brink, P., van Beukering, P. (2012). *Global estimates of the value of ecosystems and their services in monetary units*. Ecosystem Services. Volume 1. Issue 1. pp. 50-61. https://doi.org/10.1016/j.ecoser.2012.07.005.

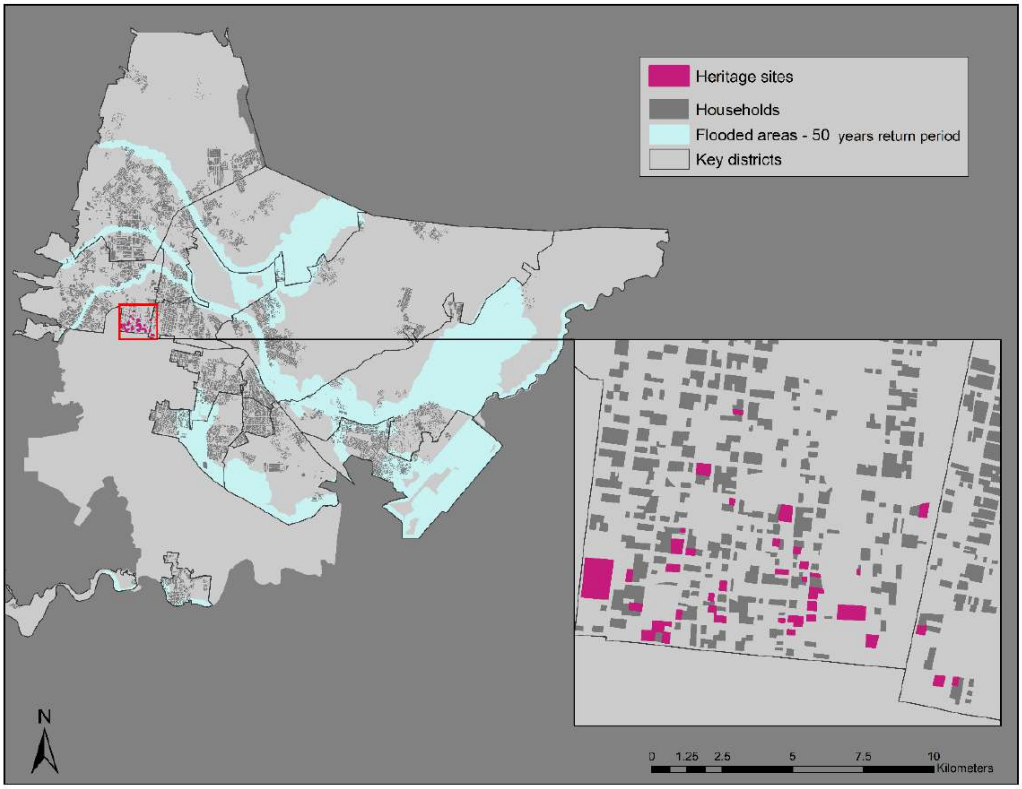

Figure 15 Heritage sites. Source: Authors' own compilation.

3.12 Overview Assets Valuation

To summarise the above sub-chapters on the individual asset categories the following Table 14 provides an overview over the aggregated value per asset category.

Table 14 Compilation of estimated values of assets

Asset Category	Total	Unit	Sample Size
Total Vulnerable Population	30 622	People	30 622
Exposed Population	34 168	People	34 168
Informal Housing (Los Bordos)	40 977 324	USD	6 778 Households
Formal Housing	3 516 200 869	USD	71 615 Households
Roads	951 726 239	USD	8 281 641 m2
Health Facilities	282 771 928	USD	23
Educational Centres	356 456 521	USD	100
Airport – buildings	225 008 495	USD	61 177 m2
Airport - paved areas	49 070 038	USD	426 993 m2
Fire Brigades	1 711 306	USD	4
Electrical Grid	37 449 408	USD	1 187 km
Electrical Substations	1 250 000	USD	2
Drainage	66 676 712	USD	330 738 m2
Lakes and Water bodies	74 775 592	USD	690 ha
Green spaces/ Forest	2 156 648	USD	401 ha
Heritage Sites	19 387 328	USD	41
Total Population	**64 790**	**People**	
Total Asset Value	**5 625 618 408**	**USD**	

4 DAMAGE FUNCTIONS

4.1 Introduction

Potential future damage caused by floods depends on several parameters including: 1) Climatic and socio-economic conditions, which were described in detail within the Data Report, their incorporation into CLIMADA, and their effects on the estimation of damages are explained in Chapter 6. 2) The asset valuation, which is presented in Chapter 3. And 3) Sensitivity to floods, which is commonly assessed using depth-damage curves, also known as damage functions or vulnerability curves, denoting to what degree a certain asset type is being affected at different inundation levels (i.e. the hazard intensity).

Different approaches can be used to design damage curves. One approach uses historical data on both inundation levels and recorded damages, reconstruction cost or depreciated values of the assets. With sufficient data available this approach is very precise within a reference area. Alternatively, it is possible to estimate probable damages based on expert opinions regarding materials, buildings' structures and other characteristics of the respective assets. This method is particularly helpful when no or insufficient historical records are available. Last, one can rely on generic or empirical damage functions and subsequently calibrate them using (household) surveys such as the one performed by DIEM in early 2020.

In any case, an iterative calibration process of the resulting damage functions is necessary to ensure that the damages simulated by CLIMADA reflect historical damages in the region[26].

The following section introduces the damage functions as used in CLIMADA. For the sake of clarity, all figures are displayed in the same format. Even though the ordinate axis reaches up to 120%, the mean damage degree (MDD) cannot exceed 100%. Similarly, damage functions are only shown up to an inundation level of 7m, representing the maximum value in the flood model (see Chapter 2).

[26] Damage functions are one of the most sensitive parameters in CLIMADA. Despite our efforts to approximate them, a calibration of their shape is necessary. The iterative calibration process includes multiple runs of CLIMADA fitting simulated damages with historical events. The parameters linked to the damage functions (shape, threshold etc...) are altered until the overall annual expected damage (AED) simulated offers an acceptable range of the historical AED. The damage functions presented here are the final damage functions.

4.2 Vulnerable People

An S-shaped curve was assumed based on local experts' opinions, the results of the household survey and a literature review[27,28,29]. Two separate damage functions are created. One for the general population of San Pedro Sula (people) and another one for inhabitants of *Los Bordos* (People in *Los Bordos*). Because people living in *Los Bordos* are more vulnerable the same inundation levels inflict damages earlier and they are affected stronger. Therefore, the curve for people in *Los Bordos* displays a MDR with a maximum of 100% (see Figure 16), while a maximum of 80% is assumed for the rest of the population, which is assumed to have a stronger resilience to flood (Figure 17).

Figure 16 Damage function for People in Los Bordos

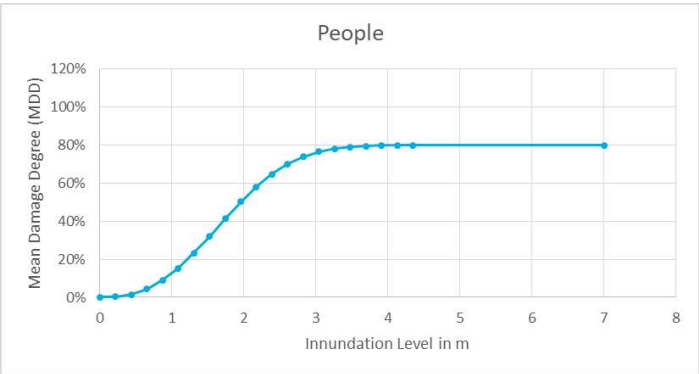

Figure 17 Damage function for People not living in Los Bordos

4.3 Informal Settlements (Housing in Los Bordos)

Informal settlements, i.e. housing in *Los Bordos*, are located within or around the riverbeds. For these assets, an S-shaped curve is recommended[30,31]. With rising waters, damages accumulate

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[27] Jonkman, S. N.; Vrijling, J. K.; Vrouwenvelder, A. C. W. M. (2008): *Methods for the estimation of loss of life due to floods. A literature review and a proposal for a new method*. In Nat Hazards 46 (3), pp. 353-389. DOI: 10.1007/s11069-008-922

[28] Jonkman, S.N.. (2007). *Loss of Life Estimation in Flood Risk Assessment: Theory and Applications*. PhD thesis, Delft University of Technology.

[29] GFA Consulting Group. (2015). Climate Change Adaptation in Urban Areas in Central America. El Salvador. Vulnerability Analysis + ECA Draft Report. Hamburg

[30] See e.g.GFA Consulting Group. (2015). *Climate Change Adaptation in Urban Areas in Central America. El Salvador. Vulnerability Analysis + ECA Draft Report*. Hamburg

[31] K. Zabert et al. (2018*). Development of model for the estimation of direct flood damage including the movable property*. J Flood Risk Management. 11. S527-S540. DOI: 10.1111/jfr3.12255

exponentially before reaching a peak threshold. For informal housing in *Los Bordos*, other than for most buildings, it is assumed that valuables and structures are of poorer quality and will be potentially completely destroyed (maximum MDD = 100%). 80% of MDD is expected already at 2m as presented in Figure 18. This curve was validated using the data obtained through the DIEM (2020) survey covering three historical flood events. Subsequently, the damage functions were adjusted to EM-DAT data in order to produce realistic aggregated values in the context of SPS. These values are presented in detail in Chapter 6.

Figure 18 Damage function for Informal Housing in Los Bordos

4.4 Formal Housing

Following a similar approach, the damage function for housing is S-shaped, with a maximum MDD of 40%. Structures are stronger, build quality is higher and some houses have multiple stories[32,33]. Maximum MDD is expected to be reached at 3m of inundation as presented in Figure 19.

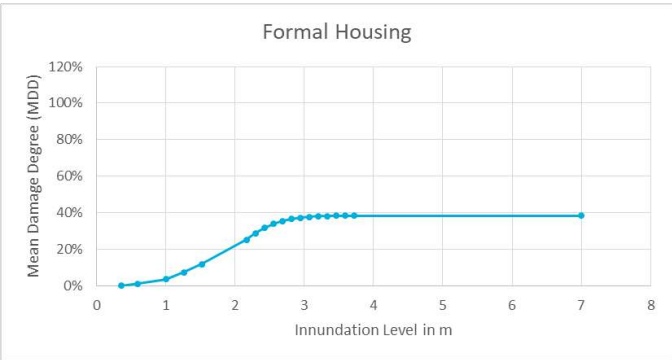

Figure 19 Damage function for Formal Housing

4.5 Road Network

The road network considered in this study is paved with a stronger groundwork. Hence, a maximum degree of damage of just below 50% is assumed, which is reached at a flood depth of 4m. To reproduce

[32] Ibid.

[33] Huizinga, J., Moel, H. de, Szewczyk, W. (2017). *Global flood depth-damage functions. Methodology and the database with guidelines*. EUR 28552 EN. doi: 10.2760/16510

small damages often observed with flood events, 20% of damage occurs with water levels of 1.30m (see Figure 20)[34,35,36].

Figure 20 Damage function for the Road Network

4.6 Public Buildings

The damage curves for the public buildings depend on their specific purpose of the infrastructure. For instance, interior fittings and furniture varies between health centres, schools or fire brigade and are therefore considered in the respective damage functions. In general, damage functions presented here for Educational Facilities, Health Facilities, Airport Buildings, and Fire Brigades are largely based on expert knowledge and desk research in the region[37,38,39].

4.6.1 Educational Facilities

For educational facilities, the damage is expected to rise sharply with increasing water levels. Indeed, furniture, such as tables, chairs, and other traditional school supply are most vulnerable to water rise. Infrastructure is generally more resilient and expected to resist even high level of water. Consequently half of the expected maximum MDD happens at 0.3m whereas the maximum MDD (50%) is reached at 2m (Figure 21).

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[34] Huizinga, J., Moel, H. de, Szewczyk, W. (2017). *Global flood depth-damage functions. Methodology and the database with guidelines*. EUR 28552 EN. doi: 10.2760/16510

[35] M. Kok et al. (2005). *Standard Method 2004 Damage and Casualties by Flooding*. Ministerie von Verkeer en Waterstaat. Rijkswaterstaat.

[36] GFA Consulting Group. (2015). *Climate Change Adaptation in Urban Areas in Central America. El Salvador. Vulnerability Analysis + ECA Draft Report*. Hamburg

[37] Huizinga, J., Moel, H. de, Szewczyk, W. (2017). *Global flood depth-damage functions. Methodology and the database with guidelines*. EUR 28552 EN. doi: 10.2760/16510

[38] M. Kok et al. (2005). *Standard Method 2004 Damage and Casualties by Flooding*. Ministerie von Verkeer en Waterstaat. Rijkswaterstaat.

[39] GFA Consulting Group. (2015). *Climate Change Adaptation in Urban Areas in Central America. El Salvador. Vulnerability Analysis + ECA Draft Report*. Hamburg

Figure 21 Damage functions for Educational Facilities

4.6.2 Health Facilities

For health facilities, the increase of damages is slower because most valuables are not stored directly on the ground but are stored higher. The resulting S-shaped curve is displayed in Figure 22. We propose a maximum MDD of 60% for water levels at about 3m, with 40% of damages occurring already at 2m.

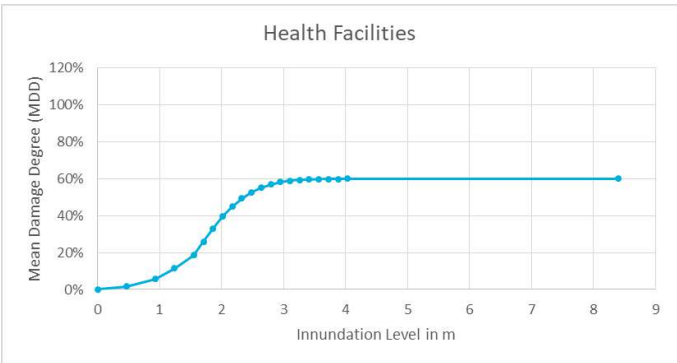


Figure 22 Damage function for Health Facilities

4.6.3 The Ramón Villeda Morales International Airport

The regional airport has been divided in two distinct types of assets i) paved areas (taxi- and runway) and ii) airport buildings. For the paved areas, a linear damage function is applied with a maximum MDD of 90% for 3.5m (Figure 23). The damage function is adapted from Kok et al. (2005). The damage function for other buildings at the airport follows an S-shape similar to the one used for health facilities with a maximum MDD of 95% for 2.5m based on observations of recent damages (Figure 24).

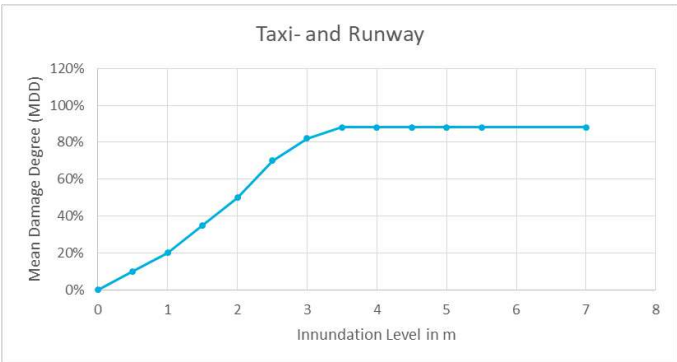


Figure 23 Damage function for paved areas at the Airport (Taxi- and Runway).

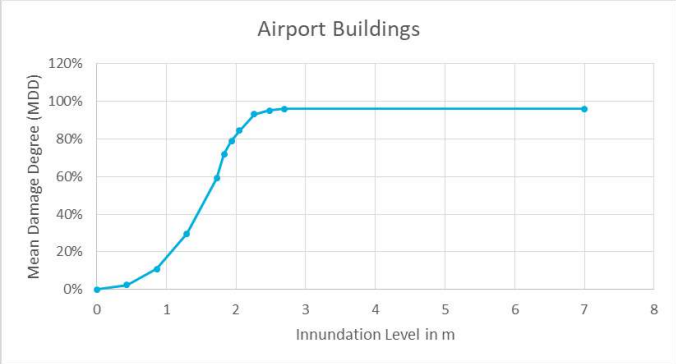


Figure 24 Damage function for Airport Buildings.

4.6.4 Fire Brigades

The damage function for the fire brigades follows an S-shape with a slight increase of damage at lower flood levels, with a maximum MDD of about 50%, see Figure 25.

Figure 25 Damage function for Fire Brigades.

4.7 Electrical Infrastructure

For electrical grid, a linear damage curve is assumed[40] to reach its maximum damage degree of 100% at 3m while a mean damage degree of 50% is reached at about 1.5m (see Figure 26). For electrical substations, with most of them being elevated[41], the maximum MDD of 50% is reached at an inundation level of 4m. The MDD plateaus afterwards with stations being submerged (Figure 27).

[40] See e.g. M. Kok et al. (2005). *Standard Method 2004 Damage and Casualties by Flooding*. Ministerie von Verkeer en Waterstaat. Rijkswaterstaat.

[41] See e.g. Federal Emergency Management Agency, Mitigation Division, Department of Homeland Security. *Hazus-MH, Flood Model, Technical Manual*. Washington, D.C. https://www.fema.gov/media-library-data/20130726-1820-25045-8292/hzmh2_1_fl_tm.pdf, retrieved on 08.09.2020

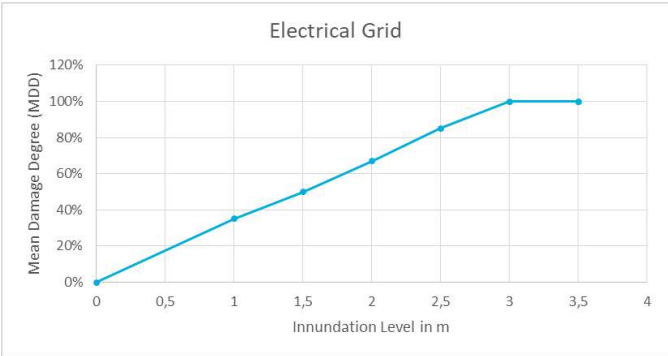


Figure 26 Damage function for the Electrical Grid.

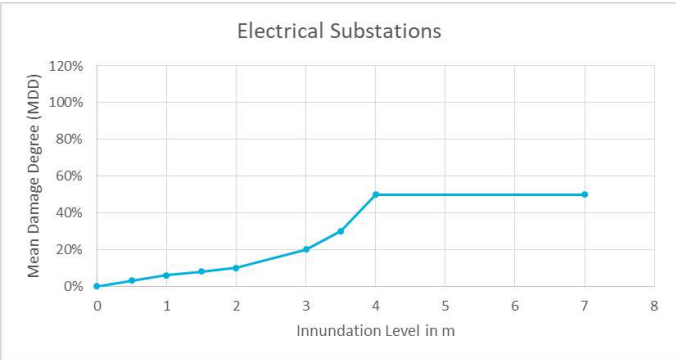


Figure 27 Damage functions for Electrical Substations.

4.8 Drainage Channels

Since the drainage system is limited to some (natural) rivers and canals, which both have the purpose of channelling (flood) waters, a flat damage function has been constructed in line with literature suggesting that little damage should be expected[42]. However, in the light of recent events (Storms Eta and Iota) it has to be assumed that at least some damage is being caused by extreme events. Hence, the damage function displayed in Figure 28 has been constructed. This damage function has the feature of two increasing phases. While initially the MDD is kept at 0% up to 1.5m, water levels that cause no damages to the existing channels, a slight increase toward the first plateau of 10% at water levels between 3m and 4m is achieved before the maximum MDD of 20% is reached at a level of 5m.

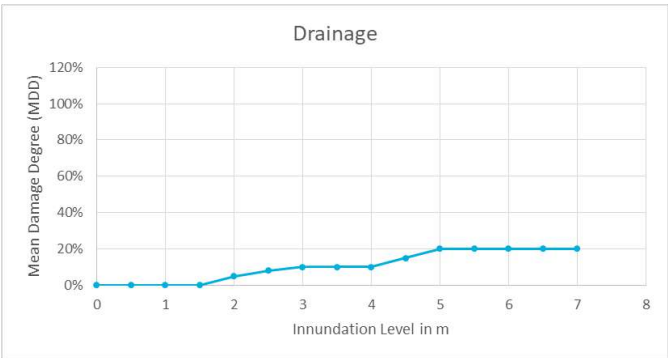


Figure 28 Damage function for the Drainage System.

[42] Ibid.

4.9 Environmental Assets

With regard to green spaces, forest, and parks the approach presented here is adapted after Kok et al. (2005)[43]. The maximum MDD is set at 100% with first a slight, followed by a sharper increase which converges toward the maximum level reached at 4.5m (Figure 29).

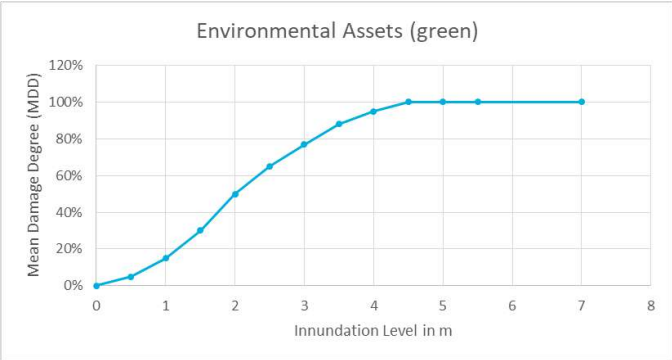


Figure 29 Damage function for green Environmental Assets.

For water bodies different literature sources were consulted with studies suggesting all three, positive, negative and neutral effects for smaller floods[44,45]. Eventually, whether the positive or the negative effects take the upper hand during smaller floods depends on many factors such as seasonal, climatic, and weather conditions prior and after to the flood event or for instance characteristics of the river bed sediments.

Extreme floods, on the other hand, are almost unanimously considered to have no positive effect due to increasing soil erosion, pollutant contamination or organic matter. Based on that the applied damage function is constructed with an initial positive effect (e.g. recharging groundwater and wetlands, creating wildlife habitat, or rejuvenating soil fertility) of small floods with its maximum (5%) at 0.5m flooding up until a level of about 1m before the negative effects outweigh the positive one. From there onwards it follows an S-shape with a maximum MDD of 90% reached at 7m (see Figure 30).

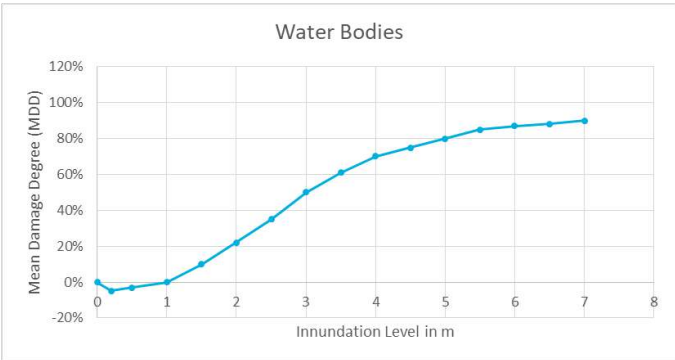


Figure 30 Damage function for Water Bodies.

[43] M. Kok et al. (2005). *Standard Method 2004 Damage and Casualties by Flooding*. Ministerie von Verkeer en Waterstaat. Rijkswaterstaat.

[44] See e.g.: C. J. Talbot et al. (2018). *The impact of flooding on aquatic ecosystem services*. Biogeochemistry 141. 439-461. https://doi.org/10.1007/s10533-018-0449-7

[45] Or see: T. Hrdinka et al. (2012). *Possible impacts of floods and droughts on water quality*. Journal of Hydro-environment Research 6 (2012) 145 - 150

4.10 Heritage Sites

Heritage sites display an S-shaped path with a first increase of MDD at an inundation level of 1m reaching its maximum MDD of 60% at a level of 3m. The shape follows similar buildings related damage functions (Figure 31).

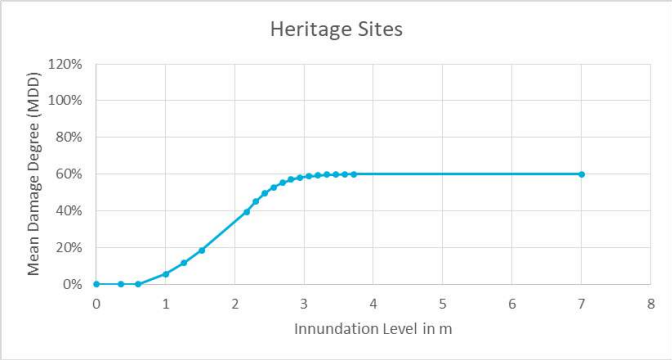


Figure 31 Damage function for Heritage Sites.

4.11 Limitations

Estimating damages in correlation with flood intensities is a difficult exercise asking for a variety of data and information being brought together. While the damage functions developed initially offer a good estimation of potential damages, they have been altered during the calibration runs within CLIMADA (final curves presented here). In addition, their potential in estimating a single asset's damage is limited and they aim at an aggregated representation of the asset category as a whole. By that, they target the *average* asset and should be handled with care if applied in other regions and without calibration.

In general, the field of damage ratios, especially for flood hazard, is subject to discussions on the degree of generalisation and specialisation and the respective components of flood damage functions.[46] The core challenge in constructing damage functions, independent of the considered parameters (e.g. inundation level, flow velocity, duration), is the availability and (public) accessibility of high quality data recorded after similar events which are critical to construct baseline damage functions that can be refined and calibrated in each individual context.

[46] As a good reference on flood damage and its assessment one could consult B. Merz, Kreibich, H., Schwarze, R., and Thieken, A. (2010) Review article. *"Assessment of economic flood damage"*. Nat. Hazards Earth Syst. Sci., 10, 1697–1724, https://doi.org/10.5194/nhess-10-1697-2010

5 ADAPTATION MEASURES

5.1 Introduction

This chapter presents a list of flood adaptation measures identified for the municipality of San Pedro Sula. These measures will serve to reduce the vulnerability of the key assets and population groups selected during the Inception Workshop, by reducing either the number of assets expected to be affected, the intensity of the affectations or in some cases both. The benefit of each measure was linked to the potential averted damage.

The adaptation measures were selected based on a comprehensive literature review, and a consultation process with government officials from San Pedro Sula. In total 47 adaptation measures were initially identified (referred to as "long list") and reduced to 14 (referred to as "short list"), of which 12 measures were introduced to CLIMADA and later 3 were highlighted as optimal by the modelling platform. These 3 measures will go through a more detailed assessment during the last stage of the ECA study, in which prefeasibility analysis is carried through, see Chapter 9 for details.

Reducing the list of measures from 47 to 14 involved a transparent and participative selection process, including several stakeholder assignments and conducting a Multi-Criteria Analysis. A detailed description of the measures selection procedure can be found in ANNEX 5.

5.2 Flood Adaptation Measures

The 14 flood adaptation measures identified and validated by the Municipality (short list) can be classified as follows: 4 as 'Grey' measures, referring to technological and engineering solutions. 5 as 'Green' measures, which refer to ecosystem-based (or nature-based) approaches and make use of multiple services provided by natural ecosystems. 2 as 'Operational' measures whose purpose and focus are on any type of maintenance/operation that is introduced or improved to a specific area. 2 as 'Monitoring' measures, hence including instruments/tools that improve baseline information of existing river and weather conditions and support future predictions of flood events. The final list of measures also includes one 'Insurance' solution, which can provide coverage for at least some of the residual risks remaining after the other measures are implemented. Table 15 depicts an overview of our short list, including their total cost and respective type.

Table 15: Overview List of Flood Adaptation Measures for San Pedro Sula.

#	Name of Measure	Type of Measure	Zone	Total Cost (USD)
1	Establishment of flood collectors (Drainage system)	Grey	A, B, C	34 757 657
2	Water collection in existing buildings	Grey	A	563 257
3	Dry Flood-Proofing (housing)	Grey	A, C	6 243 582
4	"El Tablon" Hydropower Dam	Grey	C	279 489 491
5	Ecological restoration of river bank slopes	Green	A, B	834 721
6	Dry Detention Basins	Green	A	17 588 986
7	Reforestation of green spaces in urban areas	Green	A, B, C	8 226 158
8	Green Roofs	Green	A	22 893 988
9	Vegetated swales	Green	A, C	857 802
10	Flood Awareness & Preparedness Campaign	Operational	A, B, C	1 457 199
11	Community based solid waste management	Operational	A, B	1 794 590
12	Parametric Index Insurance*	Insurance	A, B, C	-

Figure 32 shows the different zones where measures have been allocated. Zone A describes a zone where measures have an influence on the flood plain of the basin from *Río Blanco*, typically, measures constructed upstream in the river. Zone B describes a zone that represents the central flood plain from the river basins of *Rio Piedras*, *Rio Bermejo* and *Rio Chotepe*. Zone C represents the flood plain south of the city from Rio Chamelecón.

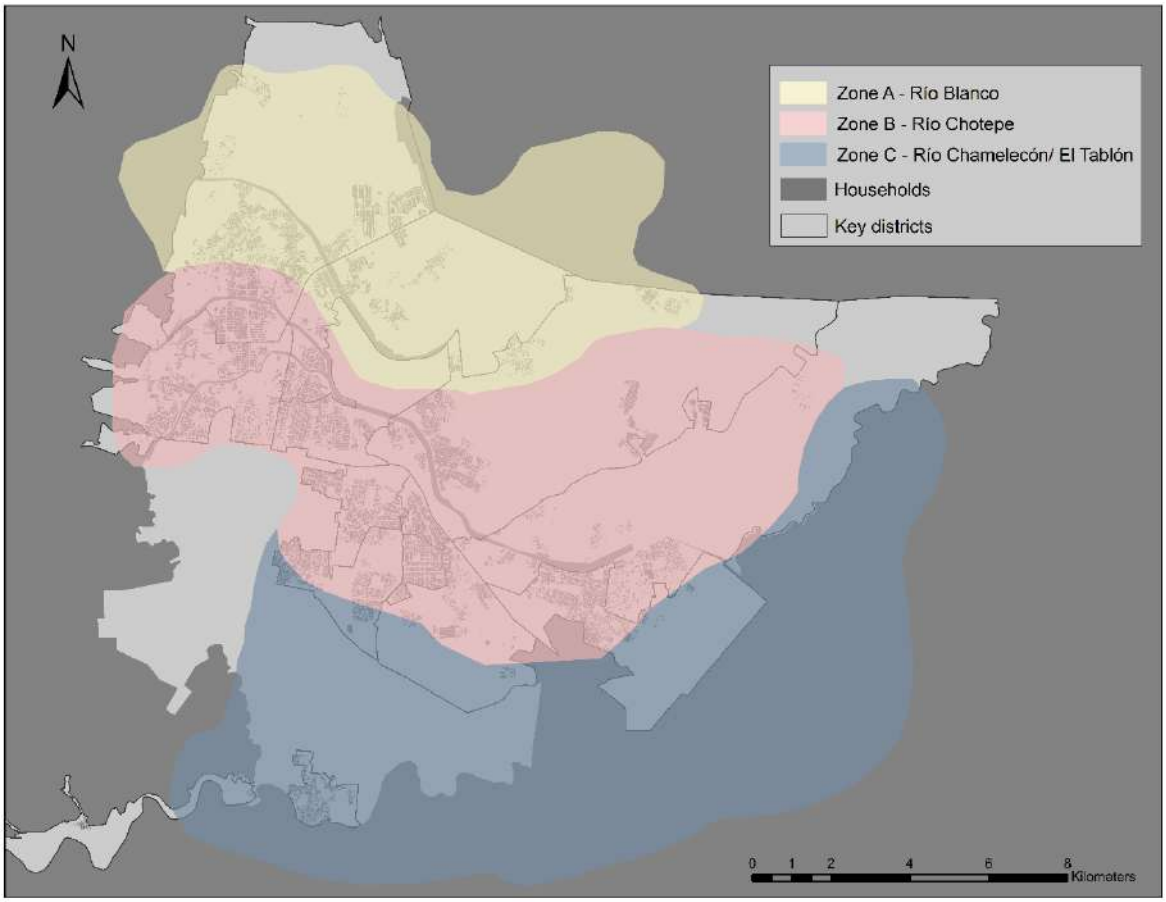


Figure 32: Overview of the zonation: A.) Río Blanco catchment, B.) Río Chotepe, Río Bermejo, Río Piedras and Canal Sauce catchment, C.) Río Chamelecón catchment

The measures are described in brief in the following overview tables (Table 16). Each box provides information about the cost per assigned location (A, B, or C), the implementation time, expected life

span, complexity and maintenance intensity. A more precise description of each measure can be found in ANNEX 6.

Table 16: Description of intended flood adaptation measures (14 measures). For each measure the table provides the cost per assigned location (A, B or C), implementation time, expected life span, complexity of the measure (in high, medium, low) and maintenance intensity (in high, medium, low).

1. Establishment of flood collectors (drainage system)

The Municipality's storm water drainage system is crucial to collect high quantities of water, which accumulate in large amounts on the streets and passages. All systems consist of reinforced concrete channels, mainly of trapezoidal shape. This study considers sections of the drainage system that are in planning and design as well as existing systems that are planned to be improved, i.e. refurbished to ensure a full functioning.

New collectors (designed & planned): In Zone A and B flood collectors will be constructed which have been designed and planned with respective lengths of 1 482 meters and 15 602 meters.

Total Cost (USD)	3 742 701 (Zone A), 29 990 926 (Zone B)		
Implementation Time	2 years	Complexity	Medium
Life Span	20 - 30 years	Maintenance	Medium
Impact Reduction	Low (Zone A), High (Zone B)		

Refurbished collectors (existing): In Zone A, B and C, existing collectors will be refurbished with respective lengths of 5 916 meters, 28 430 meters and 1 110 meters.

Total Cost (USD)	246 769 (Zone A), 607 488 (Zone B), 169 771 (Zone C)		
Implementation Time	2 years	Complexity	Medium
Life Span	20 - 30 years	Maintenance	Medium
Impact Reduction	Medium (Zone A), High (Zone B), Low (Zone C)		

Total Cost (New & Refurbished Collectors) per Zone	3 989 471 (Zone A) 30 598 415 (Zone B) 169 771 (Zone C)

2. Water collection in existing buildings

This measure aims to collect rainwater in public and private buildings that have the capacity to accommodate one or more rainwater collection tanks with a specified capacity of 2 500 liters. These collection tanks will be connected to public storm drainage systems or other waterways for discharge. It is intended to introduce water collection tanks to district 1 and 3. Combined, there is a potential of installation for 1 296 buildings.

Total Cost (USD)	563 257 (Zone A)		
Implementation Time	1 year	Complexity	Low
Life Span	20 - 30 years	Maintenance	Low
Impact Reduction	Low		

3. Dry Flood-Proofing (housing)

Dry flood-proofing involves sealing the exterior of a building to prevent the entry of flood waters. It reduces the potential for flood damage by reducing the probability that the building interior will be inundated. A combination of Three dry flood-proofing measures will be implemented per house: (1) backwater valve (blocker), (2) waterproof coating of walls, (3) installed flood shields over doors, windows and openings. It is intended to adapt houses with dry flood proofing in district 1 and 3 (Zone A) and 18 (Zone C), consisting of 1 424 buildings in total with an average size of 82 m².

Total Cost (USD)	4 543 685 (Zone A), 1 699 896 (Zone C)		
Implementation Time	1 year	Complexity	High
Life Span	>30 years	Maintenance	Medium
Impact Reduction	High (for 1 meter flood depth)		

4. "El Tablon" Hydropower Dam

The "El Tablón" Multipurpose Dam project aims to protect of the Sula Valley against floods caused by the Chamelecón River as well as the generation of electric energy based on renewable resources, with a targeted capacity of 20 MW and yearly energy generation of 99 GWh. In addition, the dam will support planned project components for drinking water supply in the Sula Valley (capacity of 4 m3/sec) and irrigated agriculture in the Naco Valley, covering 3 000 ha.

The dam will be constructed in the Chamelecón River, 1.9 km south of the village El Tablón. The dam will be approximately 20 km southwest of San Pedro Sula and 2.5 km downstream from the confluence with the La Mina ravine, in the department of Santa Bárbara, municipalities of Quimistán and Petoa. The area of the dam reservoir includes jurisdictions of the municipalities of Quimistan, Petoa and San Marcos.

Total Cost (USD)	279 489 491 (Zone C)		
Implementation Time	7 years	Complexity	High
Life Span	>30 years	Maintenance	High
Impact Reduction	High		

5. Ecological restoration of river bank slopes

This measure introduces re- and/or afforestation practices in undeveloped areas close to the riverbanks and slopes to replace grass or fallow land with dispersed vegetation. The purpose is to reduce the run-off volumes, overland flow and potential erosion of slopes. It is planned to reforest river bank slope along the Rio Blanco (Zone A) and Chotepe (Zone B) with native tree species including Pine (Pinus spp), Cedar (Cedrella odorata) and Mahogany (Swietenia macrophylla). In total an area of 191 hectares is targeted for re- and afforestation.

Total Cost (USD)	411 965 (Zone A), 422 755 (Zone B)		
Implementation Time	1 year	Complexity	Low
Life Span	>30 years	Maintenance	Low
Impact Reduction	Medium (Zone A), Low (Zone B)		

6. Dry Detention Basins

Detention basins are dry vegetated depressions in the ground. They are usually designed to provide short term storage of water and remain dry outside of storm periods. Detention basins can retain flood events, reducing peak flows and limiting the risk of flooding. It is planned to establish 10

detention basins in the municipalities area, covering district 1, 3, and 4 which is in the catchment of Rio Blanco (Zone A). Each basin will be designed with a depth of 1 meter to allow the multifunctional purpose of the basins.

Total Cost (USD)	17 588 986 (Zone A)		
Implementation Time	1 year	Complexity	Low
Life Span	> 30 years	Maintenance	Low
Impact Reduction	Medium		

7. Improvement & Reforestation of green spaces in urban areas

Urban green spaces have been identified in the municipality. These public spaces such as, city parks and local parks will be further refined to host native tree species. The long-term goal is to create an urban forest heritage, in which every tree element that is located in public areas will be considered as heritage, so its protection, care and maintenance is important for GHG mitigation and the reduction of the effects of climate change, among other benefits to the municipality. This measure considers reforestation with native species in urban green spaces including Pine (Pinus spp), Cedar (Cedrella odorata) and Mahogany (Swietenia macrophylla). In total, 37 green spaces have been identified with an area covering 361 ha and a suitable planting area of 108 ha, consisting ca. 17 000 trees.

Total Cost (USD)	3 462 444 (Zone A), 1 581 328 (Zone B), 3 182 387 (Zone C)		
Implementation Time	1 year	Complexity	Low
Life Span	> 30 years	Maintenance	Medium
Impact Reduction	Medium (Zone A), Low (Zone B), Low (Zone C)		

8. Green Roofs

Green roofs consist of a growing material placed over a waterproofing membrane on a relatively flat roof. Green roofs not only provide an attractive roofing option but also use evapotranspiration to reduce runoff volume, and provides some detention storage. Green roofs may reduce some pollutants from the rainwater as well, they usually are significant sources of phosphorus due to leaching from the growing media. It is intended to establish green roofs in district 1 and 3, in Zone A (Rio Blanco catchment). There is a potential to introduce 1 269 green roofs, with an average rooftop size of ca. 80 m².

Total Cost (USD)	22 893 988 (Zone A)		
Implementation Time	1 - 3 years	Complexity	Medium
Life Span	> 30 years	Maintenance	Low
Impact Reduction	Low		

9. Vegetated swales

Vegetated swales are frequently used to convey runoff and disconnect impervious areas. A vegetated swale (or bio swale, dry swale) is a broad, shallow, trapezoidal or parabolic channel, densely planted with a variety of trees, shrubs, and grasses. It is designed to attenuate and in some cases infiltrate runoff volume from adjacent impervious surfaces, allowing some pollutants to settle out in the process. This measure proposes the establishment of grass swales of parabolic form to reduce runoff from roadways and/or sidewalks by allowing water to infiltrate. It is planned to establish swales of 2 meters depth and 3 meters width, representing 6 m³ per meter. In total, a length of ca. 140 km is planned throughout the municipality (Zone A & B).

Total Cost (USD)	576 886 (Zone A), 280 917 (Zone B)		
Implementation Time	1 - 2 years	Complexity	Low
Life Span	20 - 30 years	Maintenance	Low
Impact Reduction	Low (Zone A), Low (Zone C)		

10. Flood Awareness & Preparedness Campaign (Impact on persons)

In San Pedro Sula, the flood awareness and preparedness campaign will focus on the most vulnerable group exposed to flood. For this reason, it is intended to strengthen campaign efforts on households living in the "Los Bordos" areas along the urban riverbanks. In total, 6 778 households have been identified. It is intended to enrol every 8 years a flood awareness and preparedness program for the most vulnerable people along the river banks and risk flood prone areas. These campaigns are carried out by municipal agencies in collaboration with respective community associations.

Total Cost (USD)	1 457 199 (Zone A, B, and C)		
Implementation Time	8 years	Complexity	Medium
Life Span	1 year	Maintenance	Low
Impact Reduction	High		

11. Community based solid waste management

Solid waste collections schemes should be organized and scheduled among the communities in the "Los Bordos" areas. Primary goal is to remove accumulating trash within the riverbeds and among the slopes. Attention is given to areas with a high risk of trash accumulation, such as bridges or street culverts. These areas must remain garbage free on annual basis. Such a community waste management and collection scheme for watercourses will also reduce the vulnerability people who live in the immediate proximity of rivers. Such a program will raise social awareness for solid waste management and its relation to urban flood risk. These activities will take place in close liaison with local authorities, social service departments and existing community leadership structures.

Total Cost (USD)	1 794 590 (Zone A, B)		
Implementation Time	1 year	Complexity	Low
Life Span	20 years	Maintenance	Medium
Impact Reduction	Medium		

12. Parametric Index Insurance

Index-based flood insurance is an innovative approach to developing effective pay-out schemes for low-income, flood-prone communities. Index insurance schemes make use of modelling and satellite imagery with other data to predetermine flood thresholds, which could trigger rapid compensation pay-outs. Effective end-to-end solutions will be developed in collaboration with a range of organizations and experts from central and state government bodies, private insurance firms, community-based organizations (CBOs) and nongovernmental organizations (NGOs). Index can be developed for people, housing and road network. For housing and transport we propose an attachment of 0,5m for a cover up to 4,5m, with a pay-out varying per asset (needs to be calibrated).

Insurance Premium (USD)	1Mio/year (Housing), 760K/year (transport), 1.23Mio/year(Persons)		
Implementation Time	1 year	Complexity	medium
Life Span	renewable	Maintenance	low

6 RESULTS

6.1 Introduction

This section presents the results from CLIMADA in three sections as follows: i) the annual expected damage for different scenarios, ii) a cost-benefit analysis of selected measures for inundation, landslides and wind and iii) a comparison of measures according to their mitigation effect in the municipality of SPS.

In the previous chapters, asset values and population estimation have been presented and discussed thoroughly. Further, different climate and socio-economic scenarios have been discussed and introduced in the flood model. Last, a list of measures, specific to the study region and dedicated to mitigation of inundation risk have been designed and parameterized into CLIMADA. This data was processed by CLIMADA against the inundation hazard information described in Chapter 2.

In the ECA Methodology, the benefit of a given adaptation measure is estimated as the expected damage in the future that can be averted by its implementation. Because all measures are therefore allocated a monetary basis, results are comparable, and the measure efficiency (in terms of impact or investment) can be quantified. In doing so, the ECA framework identifies a set of "best" measures that is later considered for a pre-feasibility study prior to investment, se Chapter 9.

6.2 Annual Expected Damage

The annual expected damage (AED) is an estimation of the average foreseeable affectations on assets and people per year, in this case related to floods. This AED can be measured in percentage or absolute values, and incorporates climate change and socio-economic scenarios. Figure 33 shows annual expected damage in the Municipality of San Pedro Sula for assets in USD (*a and b*) and for persons (*c and d*). The first bar (today) in yellow represent the actual AED. The second bar represents the AED due to economic development (for assets) and to population growth (for persons). The light red bar represents the additional AED due to climate change in San Pedro Sula. Last, the dark red bar represents the total aggregated expected damage in 2042, when economic (or population) growth plus climate change are considered.

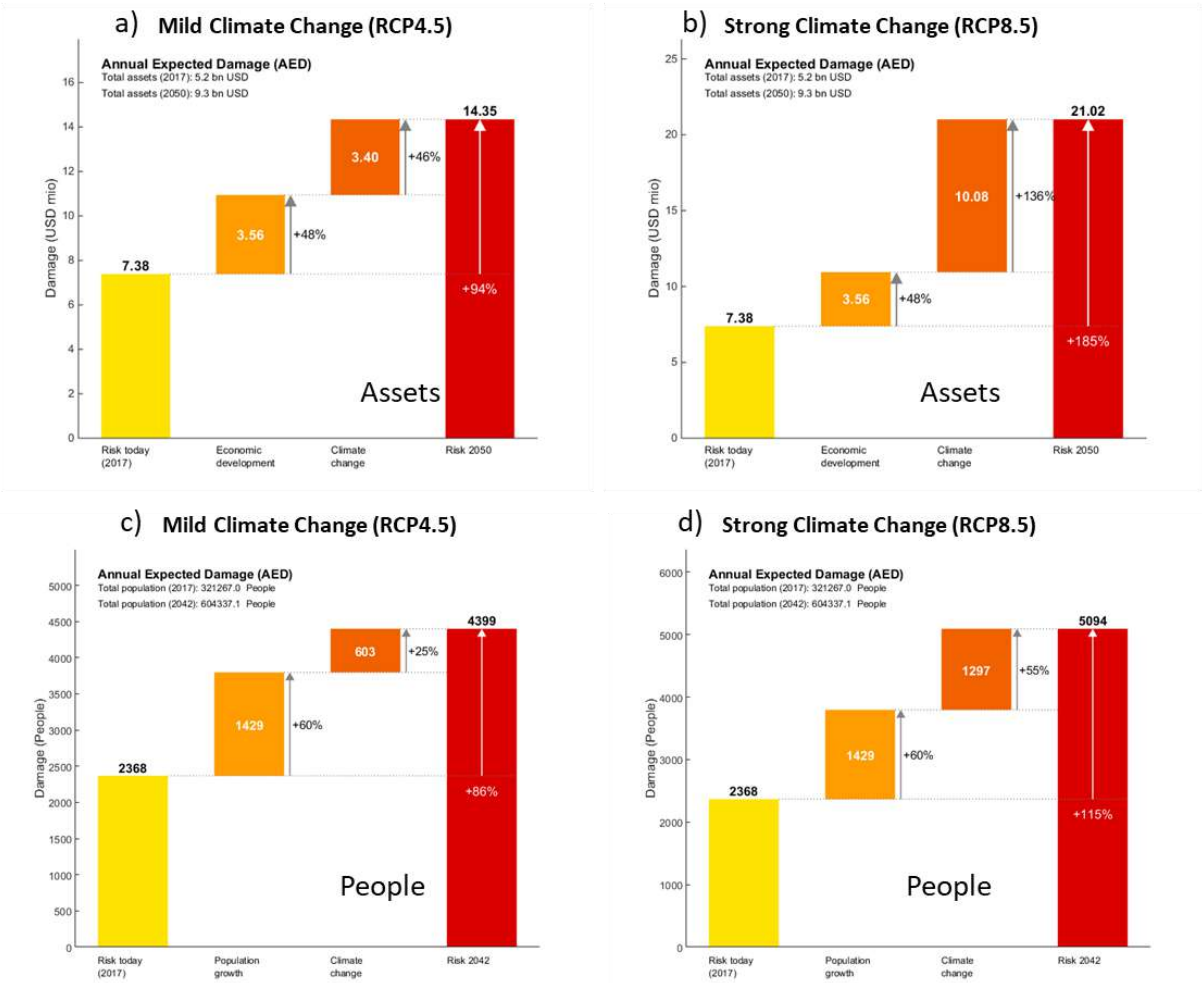


Figure 33 Annual expected damage (AED) in San Pedro Sula for Assets (a, b in USD) and people (c, d in people)

The AED for assets and persons are summarized in Table 17. Results are presented for all scenarios separately and aggregated with today's expected damage. Today is set in 2017 in alignment with the Master Plan for Municipal Development (PMDM) from San Pedro Sula. The total expected damage for assets of USD 7.4m (2017) is projected to rise a 48% due to economic growth[47] and a 46% due to climate change (136% on the extreme climate scenario). A total of USD 14m (USD 21m for extreme climate change scenario) are simulated for the time horizon 2042. The increase in AED in 2042 represents a raise of more than 94% in San Pedro Sula, due both to economic growth (assets will be more valuable) and climate change (hazard will be more frequent and more intense).

Regarding people, more than 2 300 people are expected to be affected by inundation annually in 2017. Despite a relatively low rate of annual population growth is projected for the region, a cumulative increase of 60% is expected by 2042. More intensive climate will affect also increase the number of persons with around 25% more people affected on a moderate climate change scenario and 55% more

[47] For economic growth and the discount rate an average annual rate of 2.24% and 3.3% are applied respectively as described in the preceding data report (Rojas, A, Behre, E, Daou, D, Waldschmidt, F, Sebesvari, Z, Kreft, S, Souvignet, M, (2020), Base Data Report – Honduras –Urban Flood Risk. Report 02. Bonn. UNU-EHS.). For the reader's convenience the details of the economic scenario can again be found in the ANNEX 7.

with extreme climate. A total annual of 4 400 (5 000 for extreme climate) people are expected to be affected in 2042.

Table 17 Summary of annual expected damages in the municipality of San Pedro Sula for different scenarios

ID	Asset Categories	Units	Total Value	AED Today		AED Economic Growth		AED Moderate Climate Change		AED Extreme Climate Change	
101	Population (excl. Los Bordos)	People	293582	2167	*0,74%*	3531	*1,20%*	4098	*1,40%*	4756	*1,62%*
102	Population in Los Bordos	People	27685	201	*0,73%*	266	*0,96%*	302	*1,09%*	338	*1,22%*
201	Housing	USD	3516200870	2603990	*0,07%*	3651220	*0,10%*	5288172	*0,15%*	9511550	*0,27%*
202	Housing in Los Bordos	USD	40977324	1546876	*3,77%*	1584999	*3,87%*	1669661	*4,07%*	1756282	*4,29%*
301	Road Network	USD	40977324	1788828	*4,37%*	2640048	*6,44%*	3235283	*7,90%*	4203732	*10,26 %*
401	Electrical Grid	USD	37449408	83350	*0,22%*	111617	*0,30%*	142948	*0,38%*	213167	*0,57%*
402	Electrical Substations	USD	1250000	-	*0,00%*	-	*0,00%*	-	*0,00%*	-	*0,00%*
501	Health Facilities	USD	282771928	-	*0,00%*	-	*0,00%*	55805	*0,02%*	305234	*0,11%*
502	Educational Facilities	USD	356456521	-	*0,00%*	-	*0,00%*	-	*0,00%*	-	*0,00%*
503	Fire Brigades	USD	1711306	-	*0,00%*	-	*0,00%*	-	*0,00%*	522	*0,03%*
601	Heritage Sites	USD	19387328	-	*0,00%*	-	*0,00%*	-	*0,00%*	-	*0,00%*
701	Drainage	USD	66676712	443287	*0,66%*	1028770	*1,54%*	1144942	*1,72%*	1256757	*1,88%*
801	Airport, Taxiway and Runway	USD	49070038	144002	*0,29%*	318686	*0,65%*	454837	*0,93%*	537549	*1,10%*
802	Airport, Buildings	USD	225008	2477	*1,10%*	3744	*1,66%*	6636	*2,95%*	10369	*4,61%*
901	Environmental Assets, Green (Forest, Green Spaces)	USD	2156648	1456	*0,07%*	2124	*0,10%*	2471	*0,11%*	2966	*0,14%*
902	Environmental Assets, Water Ecosystems	USD	74775592	522598	*0,70%*	1230859	*1,65%*	1686517	*2,26%*	2191809	*2,93%*
All Assets		USD	**4 490 086 007**	**7 382 177**	*0,18%*	**10 942 803**	*0,26%*	**14344315**	*0,32%*	**21 016 569**	*0,47%*
Persons		People	**321267**	**2368**	*0,74%*	**3797**	*1,18%*	**4399**	*1,37%*	**5094**	*1,59%*

Figure 34 highlights the zoning used to determine the set measures to be evaluated. **Zone A** focuses on the flood plain of the basin from *Río Blanco*, typically, measures constructed upstream in the river. **Zone B** encompasses the flood plain from the river basins of *Rio Piedras*, *Rio Bermejo* and *Rio Chotepe*. And **Zone C** represents the flood plain south of the city from Rio Chamelecón. When no zones are specified the Municipality is considered equally impacted. Defining such zones, allows simulating how clusters of assets might or might not be affected by certain measures, and therefore offers a greater level of analysis. Nevertheless, these zones might change during project implementation, due to a higher level of details needed for the exact planning of each measure.

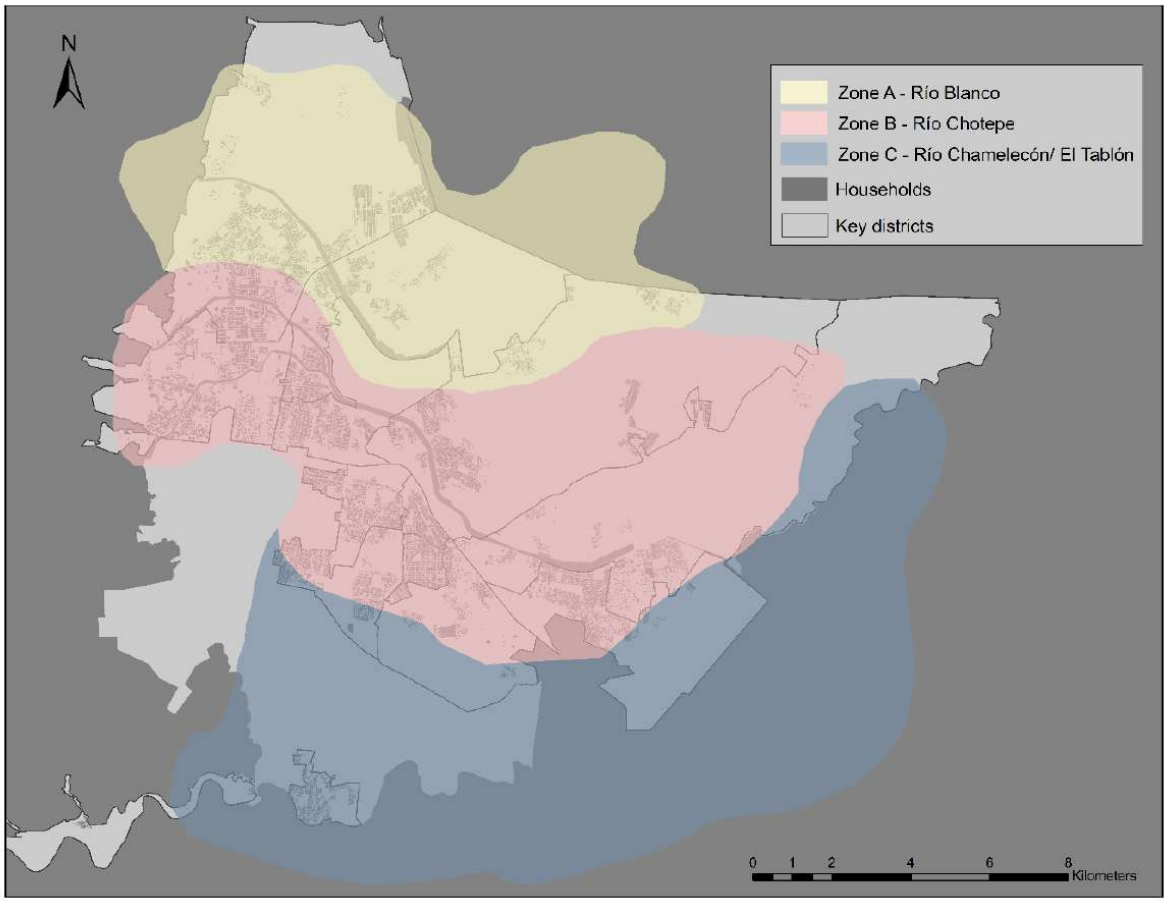


Figure 34 Zones for measures implementation in San Pedro Sula

In order to validate these results against existing events, the annual expected damage (AED) for the Municipality of San Pedro Sula was compared to damage from previous large events. Information about historical events can be found in the open-source EM-DAT data base[48]. Table 18 offers an overview of the last 40 years on record for flood and storm (heavy rain) events in Honduras. Although EM-DAT is an internationally recognized compilation of disaster damages, some local sources propose different figures[49] for overall damages for certain events, which were included in our database.

Table 18 Flood and storm events in Honduras from the EM-DAT international disaster database

Dis No	Year	Disaster Type	Event Name	Total Affected (people)	Total Damages (USD m)
1979-0098-HND	1979	Flood		40 000	13
1990-0115-HND	1990	Flood		48 000	100
1993-0073-HND	1993	Flood		67 447	58

[48] http://www.emdat.be/country_profile/index.html

[49] *For Mitch, the ECFAC estimated the overall cost for reconstruction at $2.5 billion, which was estimated to take four years.* Description of the Damage (1999). Honduras: Assessment of the damage caused by hurricane Mitch, 1998. Implications for economic and social development and for the environment (Report). Economic Commission for Latin America and the Caribbean. April 1999. *Retrieved 2013-06-07*.

1993-0084-HND	1993	Flood		15 000	57
1995-0186-HND	1995	Flood		25 000	4
1996-0265-HND	1996	Flood		75 000	31
1999-0324-HND	1999	Flood		503 001	2
2002-0329-HND	2002	Flood		969	100
2003-0661-HND	2003	Flood		3 000	20
2006-0338-HND	2006	Flood		1 500	8
2014-0447-HND	2014	Flood		3 000	1
1982-0061-HND	1982	Storm	Alleta	20 000	101
1996-0172-HND	1996	Storm	Cesar and Douglas	-	1
1996-0502-HND	1996	Storm	Marcos	-	1
1998-0345-HND	1998	Storm	Mitch	2 112 000	2 500
2001-0603-HND	2001	Storm	Michelle	86 321	5
2005-0640-HND	2005	Storm	Gamma	90 000	16
2005-0567-HND	2005	Storm	Stan	2 869	100
2007-0439-HND	2007	Storm	Felix	19 500	7
2010-0211-HND	2010	Storm	Hurricane Agatha	24 675	90
2020-0474-HND	2020	Storm	Hurricane 'Eta'	1 712 493	-
2020-0495-HND	2020	Storm	Hurricane 'Iota'	3 000 000	-

Source: EM-DAT, The International Disaster Database (2020)

Table 19 summarizes historical events over the last decades in Honduras. Only flood and storm (heavy rain) will be considered in our analysis. As we know that heavy rain leads to flash floods in the region, we will consider storms as well. Hence, damages due to flood over the last 41 years averages USD 393m, whereas damage due to flood and storm together was USD 3.2 billion. With the metropolitan area of San Pedro Sula accounting for more than two third of the GDP of Honduras, mainly because of the concentration of wealth in economic capital, we assume that damages in the Municipality are proportionally distributed with regards to the national historical damages. Population ratio of SPS accounts for 15% (1.4m) of the total population in Honduras, resulting in 2 133 people affected per year over the last 41 year, in strong agreement with CLIMADA.

Table 19 Annual damage calculation for Honduras and SPS metropolitan area

Catastrophe type	Total damage per catastrophe type (USD m/People)		
	Accumulated Damage (41 years)	AED Honduras	San Pedro Sula
Flood (USD m)	393	10	7
Flood (People Affected)	781 917	14 217	2 133
Storm (USD m)	4 113	69	46
Flood + Storm (USD m)	4 506	79	52
Flood + Storm (no Mitch)	713	18	12

The Sula Valley, as described before, is one of the area most at risk for flood damage. Consequently, the historical annual damage in the region should be close to USD 7m for flood. As we have seen previously, the AED as calculated by CLIMADA in San Pedro Sula is USD 7.5m, underlining therefore the robustness of CLIMADA's simulation in the region. Nevertheless, not all assets are captured in our study, and certain assets are captured that are not normally considered in damage calculation (such as environmental assets). The AED today is therefore larger than historical damage in the records available. The model was not calibrated for storm and flood, which return far greater historical damage values (USD 52m) due to the large damages registered for Mitch. Calculating expected damages without Mitch, which can be considered a strong outlier in just 41 years of historical record, returns an expected annual value of USD 12m for flood and storm events in the Municipality. Notwithstanding, Eta and Iota hurricanes have shown that large and rare events, statistically happening every 100 or 150 years might happen more often and in a short amount of time after another.

6.3 Discussion on Uncertainties

In this section we will discuss the uncertainties associated with the simulations done in this chapter. In a modeling exercise uncertainties are inevitable and should be qualified whenever possible. Figure 35 displays uncertainties associated with each component of the ECA modeling chain.

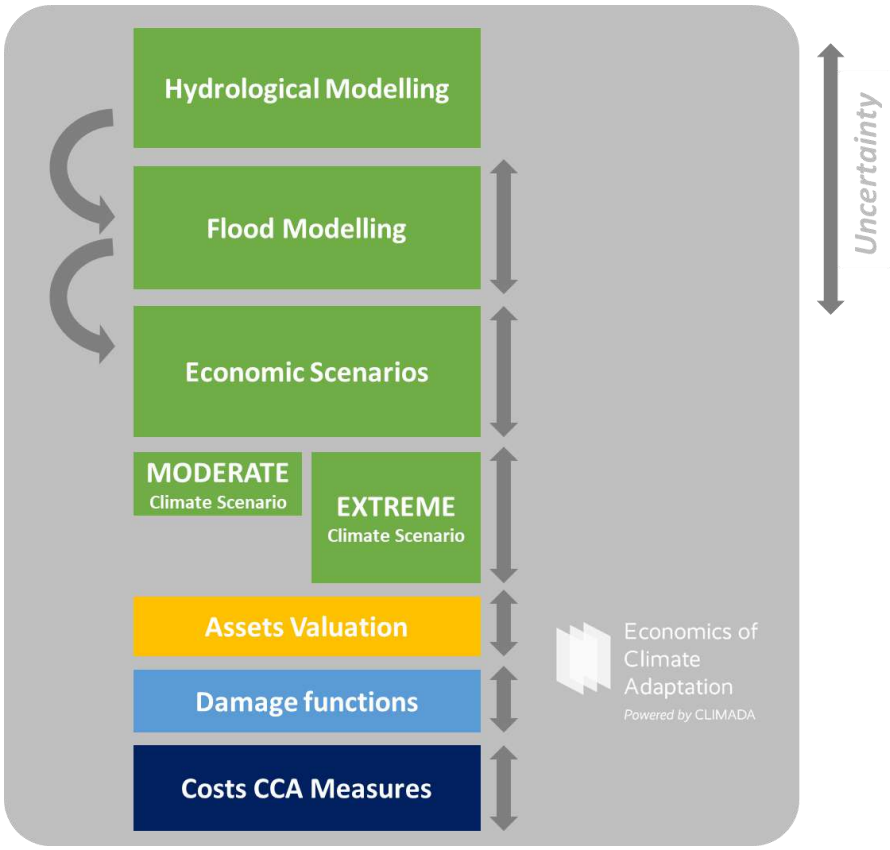


Figure 35 Uncertainty cascade for the CLIMADA modeling chain

The four components are displayed in different colors in order to ease identification of the main sources of uncertainties. Within the component "modeling hazards", disparities exist in how large an uncertainty is between the different models. For inundations, the model uncertainty is dependent on several sources. The first one is the quality of existing rainfall and streamflow observations. The

second source concerns the modeling parameters that should be used for hydrologic and hydraulic modeling. These parameters are not always physically based and therefore introduce uncertainty in the modeling cascade. Nevertheless, trough validation by existing observation, there is high confidence in the outputs of the inundation model.

An important source of uncertainty in the ECA methodology is introduced by economic and climate scenarios. Indeed, producing scenarios always introduce uncertainty in a modeling exercise. The economic and population growth scenarios, although based on actual observations, are simple and do not reflect possible fluctuations. Nevertheless, they provide a good estimation of a mean trend and should be treated as such. Climate scenarios are more challenging to evaluate. Although the scenarios used a based on validated scientific data and models, not all climate scenarios agree in their conclusions. In addition, climate models are seldom calibrated for a certain region and especially precipitation simulations are sensitive to scale. Last, there is usually less confidence in extreme scenarios than in moderate scenarios, the latter being often the results of a consensus among different models.

Asset valuation enjoys on the contrary more confidence and introduces less uncertainties in the modelling chain. Indeed, even if assets do not represent the total value in SPS, there is a high confidence – validated by ground field review – that values assigned to assets are representative of reality.

Further, damage functions are the most sensitive parameter in the ECA methodology. Damage function can be determined by mathematic formula or using expert knowledge. In our case, we have tried to reduce uncertainty in using both approaches. Nevertheless, as damage function cannot be validated we assume a quantitative bias introduced by this component.

The quantification, valuation and parameterization of adaptation measures is a challenging exercise. The location and exact size of an engineering project might influence greatly the cost and benefit calculated. In this study, costs, maintenance costs and parameterization was done in close cooperation with local and international experts in order to achieve a reduced uncertainty related to measures. Nevertheless, unless using time-consuming modeling and engineering tools, the exact estimation of measures introduced in CLIMADA is difficult. We assume therefore a moderate confidence concerning the costs and impact of measures presented in this report.

6.4 Cost-Benefit Analysis

In this section the existing relationship between costs (investment and maintenance) and net averted damage of a given measure is analyzed. As stated before the ECA framework estimates the benefit of adaptation measures based on their net averted damage.

First, an adaptation cost curve plots benefit/cost ratio (axis Y) against aggregated averted damages (axis X) for each measures. The value 1 represents the threshold for the benefit/cost ratio, or in other words, values above it are cost efficient while values below it are not. On the Y axis, the larger a measure is, the larger the damage averted by it, therefore the larger the benefit or the mitigation or adaptation impact of a measure. Hence, with this figure, each measure can be analyzed in terms of mitigation/adaptation efficiency and cost efficiency and compared with one another.

Figure 36 a) and b) displays impacts of measures applied to assets in USD as in 2042 under a moderate and extreme climate scenario. In the case of flood risk, a large number (15 measures in different location adding up to a total of 22 and three (3) parametric insurance) of measures were selected for the cost benefit analysis.

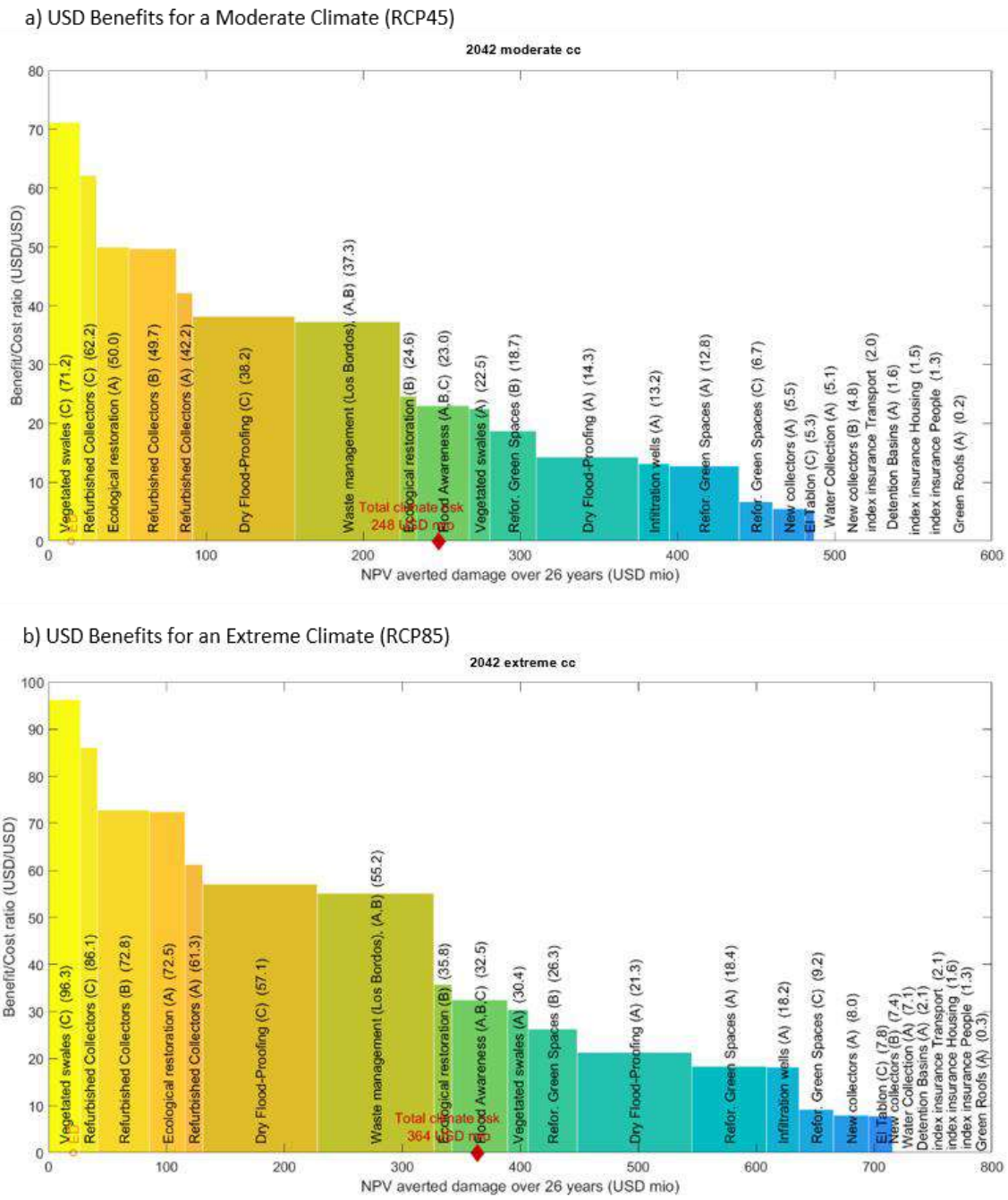
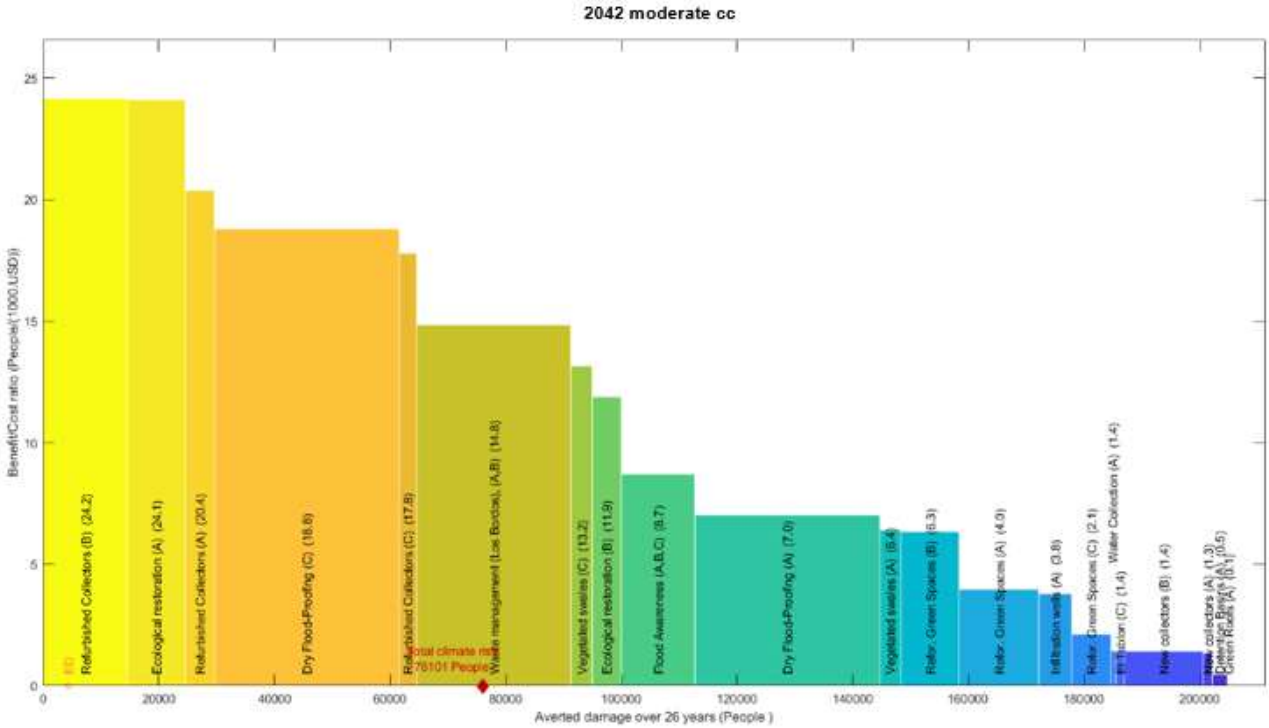


Figure 36 Mitigation cost curve for assets damage inundation in USD a) Moderate Climate and b) Extreme Climate

In Figure 36 a) and b) all measures are cost efficient, with the exception of "green roofs" which return a ratio below one. Altogether and for the time horizon 2042, these measures account altogether to more than 700 Mio USD of averted damage, if combined without overlapping effect. Selected measures offer therefore an efficient adaptation strategy against climate and economic change. Between measures, one can observe large differences in both cost efficiency and benefit (averted damage). For instance, "Ecological restoration" in the upper areas, as a typical green measure, offers both a substantial benefit (> USD 30Mio) and an excellent cost/benefit ratio, where each invested dollars accounts for more than USD 70 of averted damage. In addition, grey measures such as

“refurbished collectors” in different zones offer a good alternative to new and expensive infrastructure work such as “new collectors”.

a) USD Benefits for a Moderate Climate (RCP45)



b) USD Benefits for an Extreme Climate (RCP85)

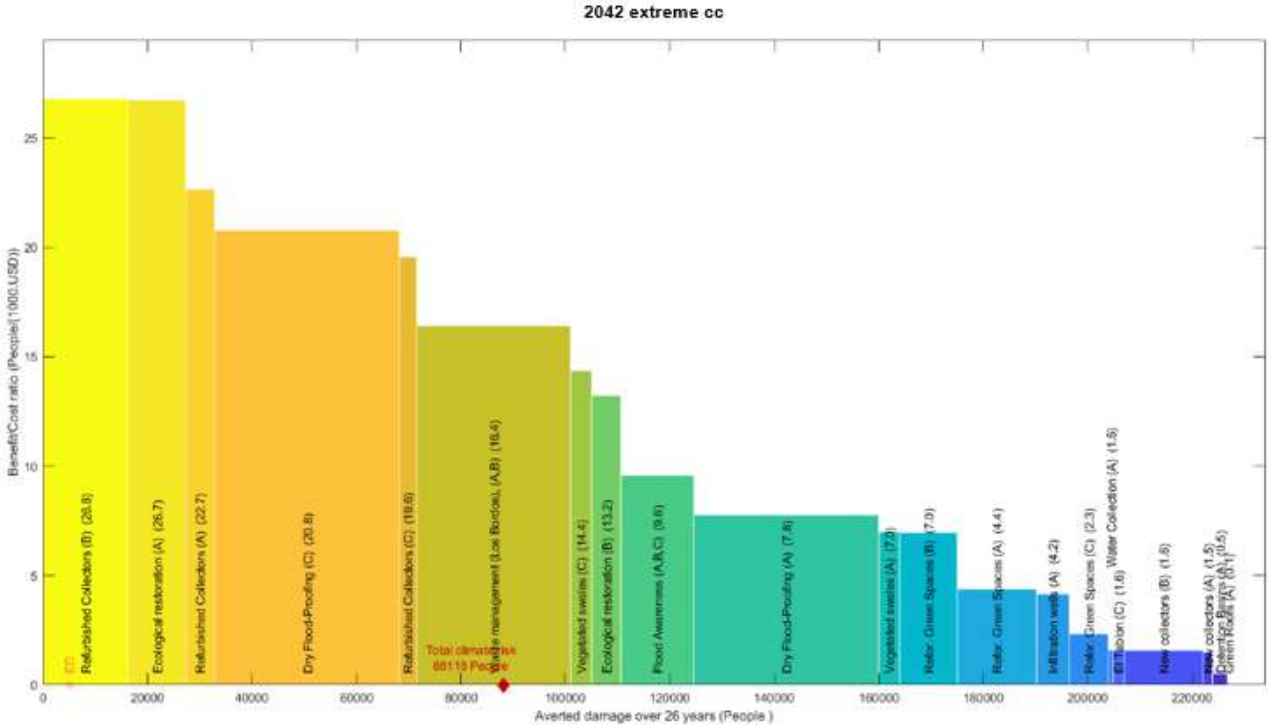


Figure 37 Mitigation cost curve for affected persons a) Moderate Climate and b) Extreme Climate

Other grey measures, such as “dry flood proofing” are typically more efficient in terms of averted damage, but showing a limited cost/benefit analysis for each invested dollar. Interestingly, “waste management” shows a high efficiency and impact for SPS, making this measure worth considering. The measure “El Tablon” is discussed extensively in Chapter 7.3.

Figure 37 a) and b) displays impacts of measures applied to people. The benefit is expressed in averted damaged on people per USD 1000 invested as in 2042 under a moderate and extreme climate scenario. In the case of flood risk, a large number (15 measures in different location adding up to a total of 22) of measures were selected for the cost benefit analysis. Parametric insurance for people are included in people because of the monetary units used for comparison purposes.

In Figure 37 a) and b) all measures are cost efficient, with the exception of “green roofs” and “retention basin” which return a ratio below one. Altogether and for the time horizon 2042, these measures account altogether to averted damaged on more than 200K people (accumulated over the period), if combined without overlapping effect. Selected measures offer therefore an efficient adaptation strategy against climate and economic change. Between measures, one can observe large differences in both cost efficiency and benefit (averted damage). In general, similar measures that were affected for assets are effective for people with the exception of “vegetated swales”. It is explained by the strong effect of this measure on the road network, which is not reflected on the location of people (matching the housing assets). Other grey measures, such as “dry flood proofing” and “waste management” shows similar results as for assets.

6.5 Parametric Insurance

As displayed in Figure 36, Index-based flood insurance is an innovative approach to developing effective pay-out schemes for low-income, flood-prone communities. Index insurance schemes make use of modelling and satellite imagery with other data to predetermine flood thresholds, which could trigger rapid compensation pay-outs. Effective end-to-end solutions will be developed in collaboration with a range of organizations and experts from central and state government bodies, private insurance firms, community-based organizations (CBOs) and nongovernmental organizations (NGOs). Index can be developed for housing and road network. For housing and transport we propose an attachment of 0.5m for a cover up to 4.5m, with a pay-out up to USD 10,000 for people, USD 5,000 for transport and USD 25,000 for housing. In general, combined to adaptation measures, index insurance can help cover the resulting risk for large events. The choice to prioritize insurance over adaptation measures should be driven by the investment ability of the municipality. Adaptation measures require larger investment to be made, whereas insurance runs usually on yearly contracts. Nevertheless, the municipality should be bear in mind that the insurance premium should diminish with an increased number of adaptation measures (mainly because the total risk is reduced). In the case of SPS, index insurance seems to provide only a small protection compared to other type of measures, we would therefore recommend to implement first adaptation measures before considering financial solutions. However, in this report we only considered index insurance, as modelled by CLIMADA, but other types of risk transfer could be also considered (especially pooling risk with other cities or regions). This approach has been successfully implemented in the Caribbean by the Caribbean Catastrophe Risk Insurance Facility (CCRIF).[50]

[50] Further information here: https://www.ccrif.org/

6.6 Spatial distribution of benefits

Figure 38 and Figure 39 show the benefits of a measure, distributed according to the location of the assets that are affected. The benefits are represented by the annual averted damages averaged over a period of 26 year on a certain asset. In Figure 38, we display the benefit of refurbished collectors in different zones for housing. Depending on the initial asset value, the benefit can be different from one asset to the other. Generally speaking, assets with a larger value, for a similar hazard intensity, are expected to show greater damages. Therefore, greater benefits are to be expected on these assets. Figure 39 shows similar results for the asset "road network" (each point represent a 100m section of the road network) for the measures "reforestation" and "vegetated swales". The assets road network are the one that benefit most from these measures and the total accumulated value of the road network leads to large benefits and cost/benefit ratios for these measures. Additional maps for other measures and assets are displayed in ANNEX 9.

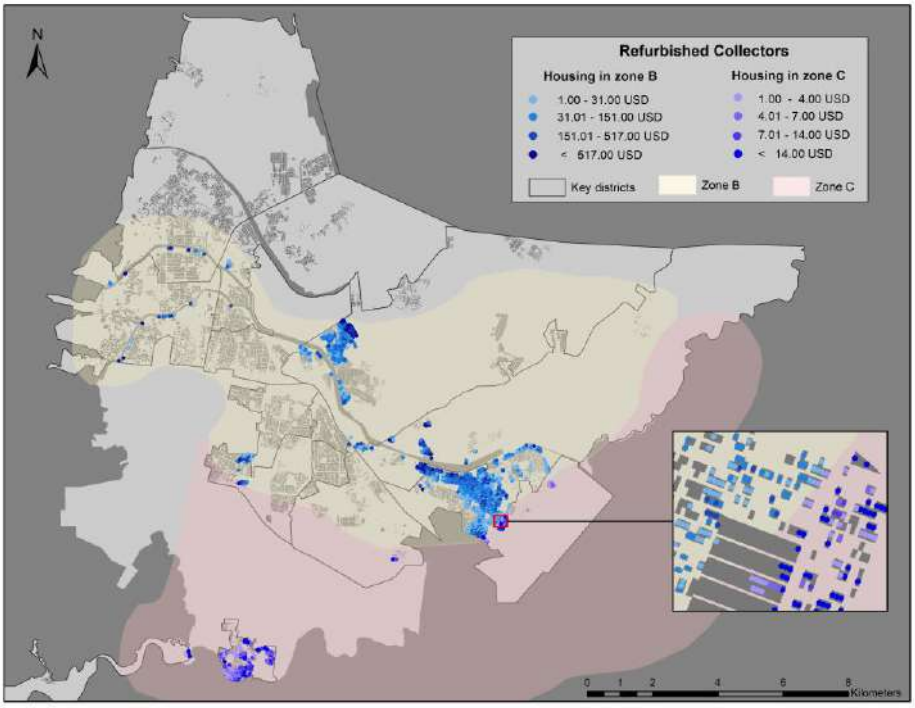


Figure 38 Spatial location of benefits for the measure "refurbished collectors" for housing

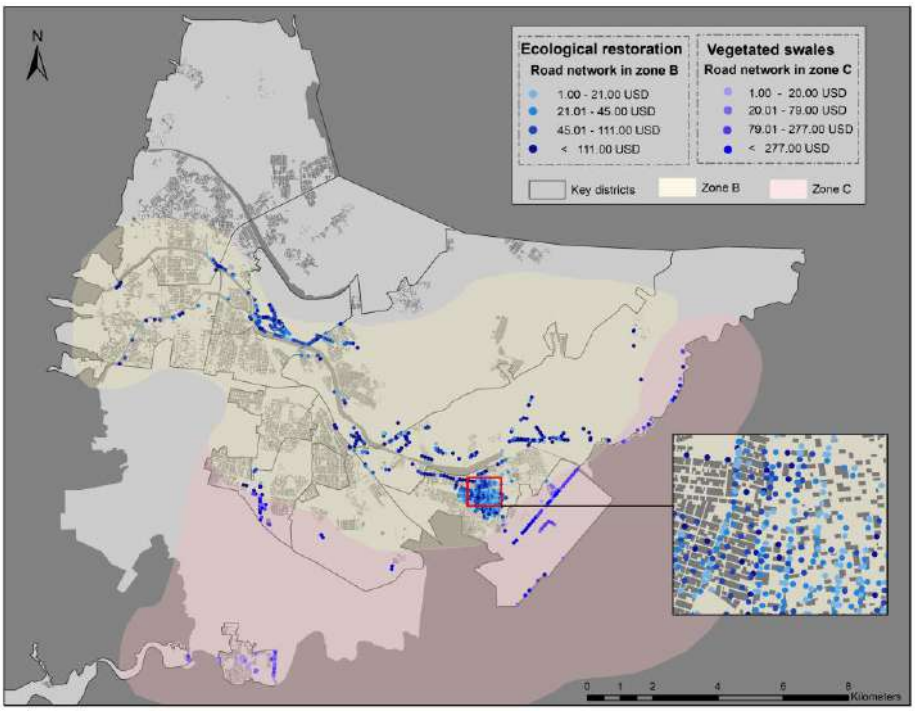


Figure 39 Spatial location map of benefits from the measures "ecological reforestation" and "vegetated swales" for the road network.

6.7 Conclusions

In this section, inundation measures were analyzed in the SPS municipality area (for selected districts) in terms of cost-efficiency and adaptation/mitigation efficiency. A total of 22 measures (14 measures in different locations) were successfully introduced in CLIMADA. The main findings are summarized below:

1) A majority of selected measures are cost efficient for the asset selected;
2) All measures combined are sufficient to account for the total climate risk (although without considering storm risk);
3) By 2042, measures for inundation have a positive impact on asset protection, , especially under extreme climate conditions;
4) Low key grey measures (e.g. refurbished collectors) and green measures (e.g. ecological restauration) a most efficient;
5) Climate index insurance for housing, people and road network are all cost efficient and can be used to cover residual risk after the most effective measures have been implemented.
6) The top three cost-efficient measures are:
    a. "Vegetated Swales"
    b. "Refurbished Collectors"
    c. "Ecological Restauration"

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 General Conclusions

San Pedro Sula, as other urban areas in the world are threatened by floods, droughts and other extreme weather events. Along with growing populations and economies, losses from natural hazards are rising. In this report, we applied the Economics of Climate Adaptation (ECA), a decision-making support framework, to integrate climate risk assessments and optimal adaptation solutions.

In its first part, this report recalls decisions made in coordination with all stakeholders regarding the areas of the municipality to be included, the scenarios (climatic and economic) to be applied and what assets should be impacted. During several workshops and webinars, a portfolio of measures (from a long list to a short list) have been discussed. Values have been validated by stakeholder's concertation and expert interview.

Further, this report presents the results, assumptions and limitation of the development of a flood model for the region of the municipality of San Pedro Sula. The flood model developed for the purpose of this report provides unique improvement in resolution and quality to the simulation of flood in the region. Its integration into CLIMADA, a modelling platform, provide an estimation of impacts of future flood risk impact for the selected assets. These results for future damages have been successfully validated against existing historical observations. By 2042, flood damages in the municipality are expected to rise by more than 100% in San Pedro Sula, due both to economic growth (assets will be more valuable) and climate change (hazard will be more frequent and more intense).

The introduction of a selection of adaptation measures provide insights for the development of a sound climate impact portfolio under the selected scenarios. Green measures and grey measures such as channel refurbishment provide the best return on investment, while offering a good protection against future climatic risks. In the following section, we discuss the effects of el Tablon and the need for additional monitoring station in the region.

Finally, the quantification, valuation and parameterization of adaptation measures is a challenging exercise. The location and exact size of an engineering project might influence greatly the cost and benefit calculated. Although great care has been given to the modelling exercise, the outcome of the study are not meant to replace a more detailed engineering screening of the measures to be introduced and offer a decision support, to be added to other tools and discussion already on-going within the municipality. It is important to consider these uncertainties while making climate impact decisions.

7.2 Recommendation for the Monitoring Network

Flood Management processes are driven by natural processes causing possible loss of lives and property. They have the aim to reduce and to avoid the negative effects of flood hazards to the human sphere by assessing the development of specific flood situation.

The UN Office for Disaster Risk Reduction (UNDRR) "advocates the use of Flood early warning systems (FEWSs) as one of the most common flood-impact mitigation measures. […] Comprehensive FEWS consists of four components, which includes (1) risk knowledge, (2) monitoring and forecasting, (3) warning, dissemination, and communication, and (4) response capabilities."[51]

The occurrence and the progress of specific flood situation itself has to be estimated as good as possible by describing the natural processes with measurements and model simulations to provide a basis for decision makers and emergency relief. Establishing flood warning systems along relevant waterways or water bodies helps to provide critical information for the protection of property and lives. Effective flood warning approaches are composed out of the installation of gages and telemetry equipment and carefully designed procedures to provide early warning about whether a flood is to be expected, when it will occur, and how severe it will be.

Facing this point, measurements of the natural processes as precipitation and discharge are central for an increased preparedness to floods of a city like San Pedro Sula at the confluence of three main rivers with catchments of high relief energy.

In addition to the possible flood warning aspect, continuous measurements and statistical analysis of precipitation, climate data (e.g. temperature, humidity) and discharge will help to understand hydrological behaviour of the catchments better and to monitor undergoing climate change processes within the catchments.

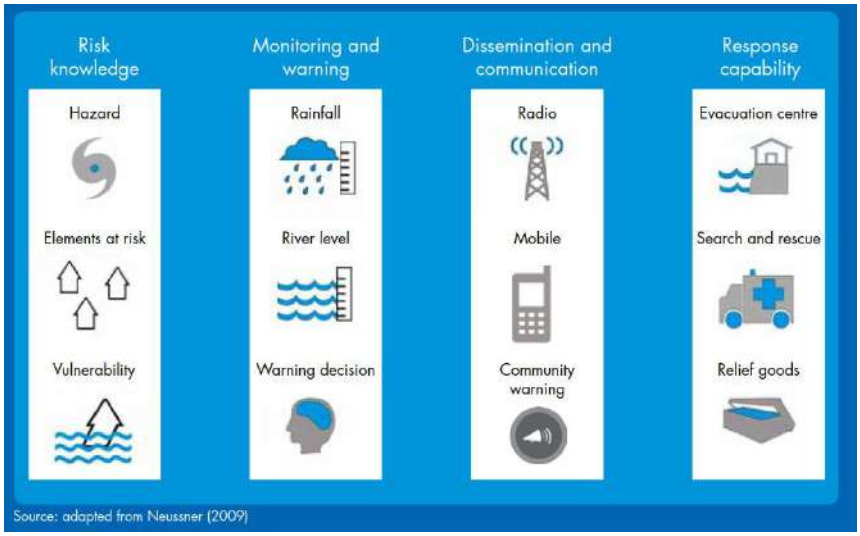


Figure 40 Components of a flood early warning system[52]

[51] Perera, D., Seidou, O., Agnihotri, J., Rasmy, M., Smakhtin, V., Coulibaly, P., & Mehmood, H. (2019). Flood Early Warning Systems: A Review Of Benefits, Challenges And Prospects. Hamilton, Canada: United Nations University Institute for Water, Environment and Health (UNU-INWEH).

[52] Shrestha, M., Kafle, S., Gurung, M., Nibanupudi, H., Khadg, V., & Rajkarnikar, G. (2014). Flood Early Warning Systems in Nepal - A Gendered Perspective. Kathmandu, Nepal: International Centre for Integrated Mountain Development.

Figure 40 presents hydrometric and meteorological monitoring networks which usually include the following components:

1. (Automated) weather station monitoring network / climate data

   Monitoring

   - precipitation (high temporal resolution < 1 h or continuous)
   - additional climate data as temperature, humidity, radiation

   Potential benefits for the river catchment

   - monitoring of time series and statistical analysis (e.g. annual mean, storm duration and pattern, return period/precipitation)
   - monitoring of climate change effects
   - improvement of (sub)catchment behaviour (e.g. discharge volume of sub-catchment and superposition to relevant hydrograph)
   - improvement of Rainfall-Runoff-Calculation and calculation of discharge values for hydrodynamic calculations
   - implementation of early warning systems by alert stations and/or Rainfall-Runoff-Calculation
   - useful for downscaling of (regional) climate model data

2. Stream discharge measurements / gauges

   Monitoring

   - discharge
   - developing discharge rating curve

   Potential benefits for the river catchment

   - monitoring of time series and statistical analysis (Return Periods etc)
   - study of Rainfall/Runoff aspects (e.g. develop ideas about the general effective precipitation in connection to measured precipitation)
   - Modelling improvement and possibility to calibrate/validate models
   - Installation of alert gauge for early flood warning (e.g. triggering eMail dispatch)
   - Management of El Tablon reservoir in connection to precipitation measurements (maybe forecast available) => Management of water volume for flood protection.

To allow the estimation of possible flood hazards and corresponding risks, often model-based simulations are used to create flood hazard maps and to calculate the flooded area and other relevant parameters as water depth, flow velocity, travel time of flood peak or critical water level indicating the need of evacuations e.g. of hospitals or other vulnerable objects. These models rely on data to describe the flow propagation through the river channel. Physical properties are for example cross sections taken from river channel survey to describe the capacity of the river channel to store and to guide the water downstream without flooding forelands. Nevertheless, also hydraulic and hydrological parameters as effective precipitation and discharge volume are important.

One observation out of this ECA study is that the precipitation and discharge measurement network is not dense enough to allow a calibration and validation of hydrological and hydrodynamic models.

Generally, the installation of a measurement network would allow to improve the hydrological simulation e.g. in terms of more reliable precipitation depth applied to the models for the calculation of relevant discharge volumes as well as the more reliable calculation of the hydrodynamic process transforming the discharge volume into a water level. These discharge measurements will ideally be accompanied by a survey of river cross sections (e.g. water body, bridges).

To determine the location and number of monitoring station a more detailed analysis would be needed. Major patterns, should be analysed including:

- main wind directions/storm tracks
- similar reacting sub-catchments,
- analysis of existing HEC-HMS Model (the time of concentration in terms of discharge and superposition of hydrographs)
- topography/exposition
- travel time of flood peak from discharge gauges to San Pedro Sula for localisation of gauge stationing
- needed time for emergency services and protective measures
- first idea about operating warning system
- Reachability / accessibility / connectivity to authorities

Furthermore, sensor technique has to be chosen according to the local condition and determines the corresponding cost. For stream gauge example simple non-contact water-level sensors (Ultrasonic/RADAR) USD 500; Radar can be around USD 3 000. The choice of the technique depends on local conditions that have to be evaluated. Low cost climate station could start from USD 500 for the sensor itself.

Sensors have to be extended with a data collection platform and a system for data transmission (e.g. GSM) and collected within databases and provided to the user via Graphical User Interfaces. These possibilities also have to be evaluated in addition to the above-mentioned location search. Figure 41, shows the principle elements of a FEWS. Within a first study possibilities and costs had to be evaluated according to the requirement for the corresponding station[53].

[53] Further reading: Challenges and Technical Advances in Flood Early Warning Systems (FEWSs) DOI: http://dx.doi.org/10.5772/intechopen.93069

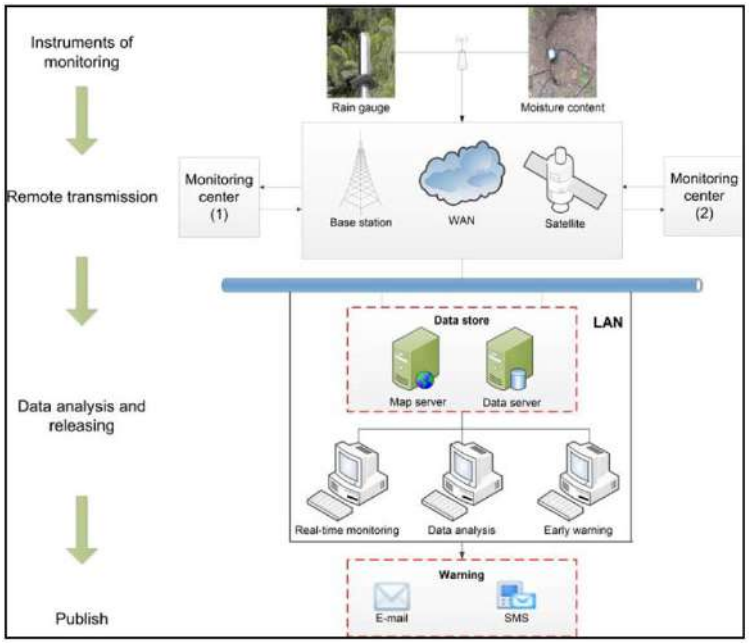


Figure 41 Architecture of the early warning system (modified)[54]

7.3 Recommendation for el Tablón

7.3.1 Modelling of El Tablón Dam

To simulate the effects of the Tablón Dam on the resilience of the Chamelecón River, a hydrological model using the HecHMS software and a hydraulic model with the HecRAS 2D system has been developed. The results allowed to establish of areas at risk under the current conditions for different return periods and to compare them with areas at risk with reduced peak discharges due to the action of the dam. El Tablón was simulated only for future scenarios, which according to what was agreed in the workshops with the Municipality, correspond to the medium (RCP 4.5) and extreme (RCP 8.5) scenarios developed by the IPCC.

7.3.2 HecHMS hydrological model

The input data for the HecHMS model included: 1) the Chamelecón River route, established through the digital elevation model provided by COPECO with a resolution of 1m, 2) infiltration rates according to the curve number method developed by the Soil Conservation Service, which considers uses and types of soil, 3) estimates of the historical depth of short-term precipitation based on the FHIS (2002)[55], and finally 4) projections of future precipitation based on the regional climate model RCA4.

The effects of El Tablón dam were modeled by modifying the hydrological data in accordance with the information provided by the Municipality and presented below:

- Free spillway without intermediate pillars;
- Total length of spillway crest 60 m;

[54] Ju, N.-p., Huang, J., Huang, R.-q., He, C., & Li, Y. (2015). A Real-time monitoring and early warning system for landslides in Southwest China. *Journal of Mountain Science*, 1219-1228.

[55] Manual de referencias hidrológicas de Honduras, elaborado por el Fondo Hondureño de Inversión Social (FHIS) y publicado en 2002.

- Peak level 156 m.a.s.l;
- Maximum level 166 m.s.n.m;
- Maximum capacity approx. 4 000 m3/s.

Tiempo de Retorno	Avenida Pico		Nivel de Embalse	Descarga Pico
Años	m^3/s		msnm	m^3/s
10	1000		158.93	538
20	1330		159.65	767
50	**1880**		**160.61**	**1122**
100	2370		161.39	1450
200	**2960**		**162.29**	**1870**
1000	4740		164.77	3240
10000	8690		168.15	7130
PMF	11300		169.46	10090

Figure 42[56] Downstream peak flow frequency - m3/s

The location of the dam is presented below in Figure 43, including the displacement from the location originally provided by the Municipality to incorporate the effects of the corresponding sub-basin.

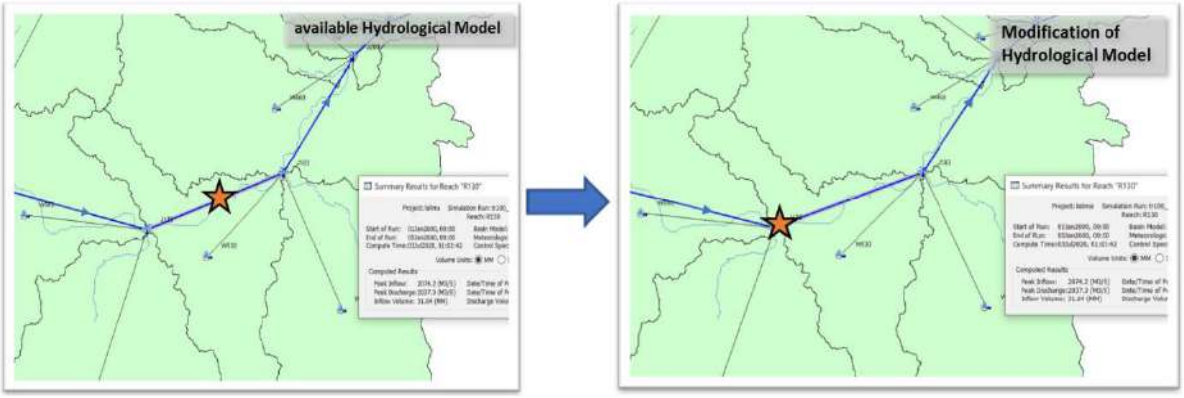


Figure 43 Location of El Tablón Dam in the flood model

Using the data in Figure 42 and the results from the HecHMS model for the Chamelecón River, peak discharges were estimated for the 25, 50 and 100 year return periods, as well as for future scenarios as shown in the figures below. Table 20 presents a synthesis of the peak discharges and the curves show the expected evolution of the discharge. Both illustrations include the effects of the El Tablón dam for future scenarios.

Table 20 Peak discharges in Chamelecón River for return periods (PR) 25, 50 and 10 years, in present scenarios, CPR 4.5 and CPR 8.5

Chamelecón RIVER	PR 25 (m^3/s)	PR 50 (m^3/s)	PR 100 (m^3/s)
Q Present	1 210	1 792	2 108
Q Future Scenario RCP4.5	1 283	1 685	2 213
Q Future Scenario RCP8.5	1 708	2 399	3 470

[56] In comparison, the current capacity of the Chamelecon River in the Sula Valley is 1,900 m3/s.

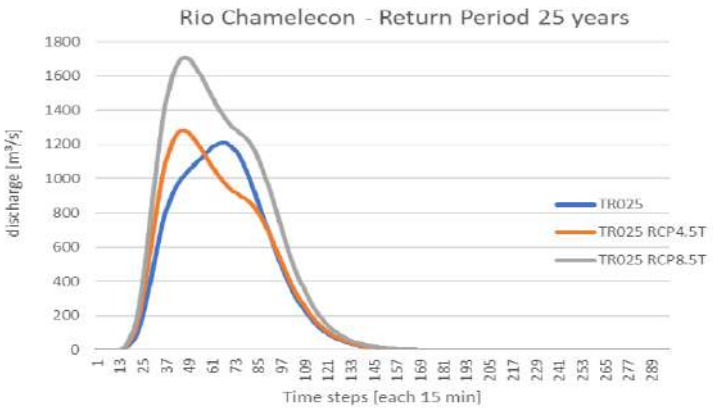


Figure 44 Simulation of Chamelecón River discharges return period 25 years

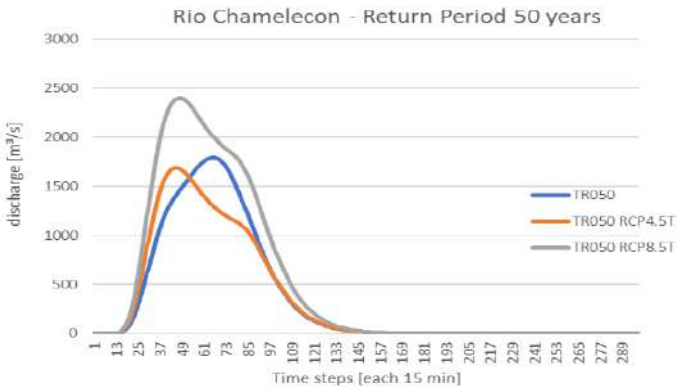


Figure 45 Simulation of Chamelecón River discharges return period 50 years

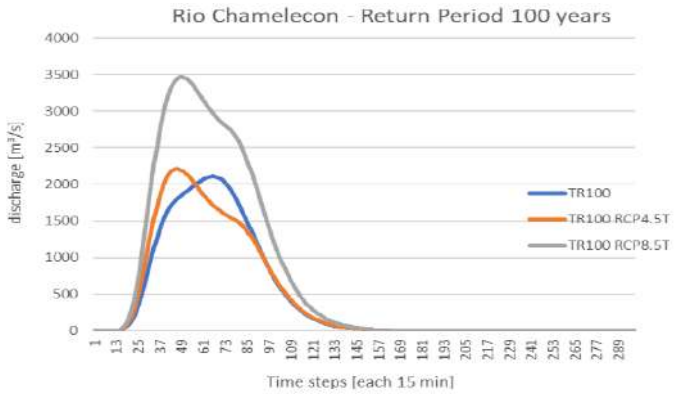


Figure 46 Simulation of Chamelecón River discharges return period 100 years

In this section the estimations of discharge in the Chamelecón River without the El Tablón dam for future scenarios was not included to avoid a misrepresentation of the effect of the dam. In order to have a reliable comparison/validation of the benefits of the dam, further details of the data made available by the municipality are needed including: where the values from Figure 42 come from and how they were calculated, because their validation process was not possible given a lack of additional sources. Additionally, rating curves or/and control units as well as management in the case of flooding are needed. Nevertheless the estimations of discharge are presented in Annex 8.

7.3.3 Validation of the Hydrological Model

Due to the scarce hydro-meteorological measurements (precipitation, runoff, infiltration, discharges, water level, etc...), the validation of the model results was done through third sources. The plausibility

check was based on data obtained from scientific literature and by applying Creager envelope curves for extreme floods. The assumptions were also discussed with local authorities in a series of calls.

When comparing the Creager equation (HQ50) with the data estimated by the USGS (USGS, 2002)[57], it was found that the reference values are very different and vary greatly from the available studies. The USGS study examined the "Chamelecón el Puente" station and defined it as unreliable and treats the corresponding values with care. The relationship of the drainage area to the peak flow estimate was also evaluated, calculating a QHQ50 = 2 400 m³/s while, based on statistical analysis, the QHQ50 measures 1 070 - 2 060 m³/s. The "Chamelecón el Puente" station is located about 20 km upstream from the exit of the model analyzed in this study.

Table 21 below presents a summary of the values obtained for the validation of the model.

Table 21 Comparison of peak flows between model results, Creager envelope and USGS (2000)

Chamelecón River	Results of the model used for this study (J212) (m³/s)	Creager envelope curve (HQ50) "Chamelecón el Puente" (m³/s)	USGS (2000) (m³/s)
RT= 50	1 792	1 475	2 206.26 (Table 10, p 29)
			1 070 – 2 400 (statistical analysis)
			2 400 (drainage area relation)
RT = 100	2 108	-	1 210 - 2 460

In this regard, the use of the quantitative results of the model are indicative and subject to a significant levels of uncertainty. The model allows a comparison in equivalent terms of the benefits of the different measures analyzed, but a full survey is strongly recommended before local authorities start implementation.

7.3.4 HecRAS 2D hydraulic model

The main rivers of the Municipality were modeled in HecRAS 2D and divided into three sub-models to increase the efficiency of the software as well as the total number of cells and the resulting computational costs of each model. The sub-models contemplate: one the Blanco River, another the Chotepe River and finally the Camelecón River as shown in Figure 47. The Chamelecón river was modeled separately (blue area in Figure 47), incorporating the influence of the Bermejo river as input, due to the extension of the basin and the location of the areas of interest.

[57] USGS: US Arma Corps of Engineers - Hydrologic Engineering Center. (2002): Flood-Hazard Mapping in Honduras in Response to Hurricane Mitch. Water-Resources Investigations Report 01-4277.

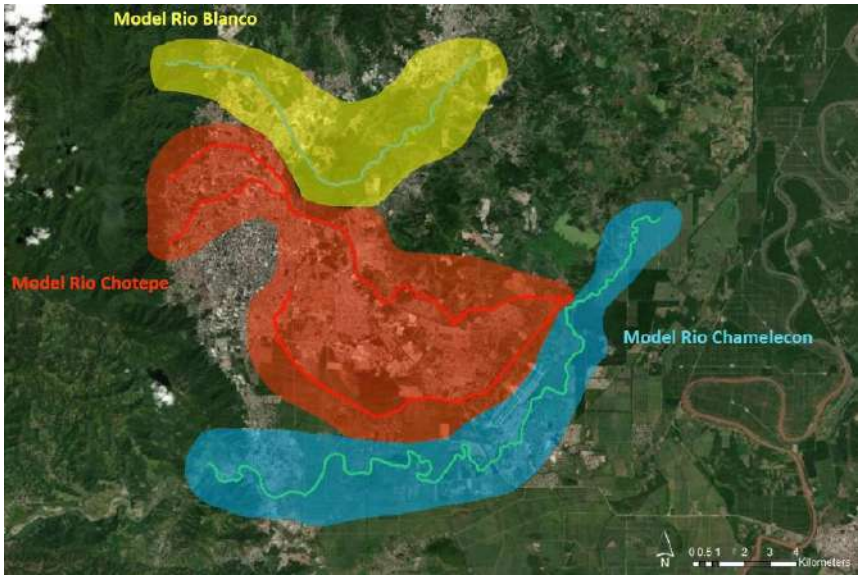


Figure 47 HecRAS 2D Sub models

The basis for the configuration of the 2D model was the 1D models created by COPECO in 2016[58]. These included a digital elevation model (DEM), which was used for the 2D hydrodynamic and instability modeling process. Before creating the HECRAS terrain model, the DEM was analyzed and some impurities and artifacts were identified. Especially the river profiles seemed to be staggered, partially not declining consistently, which was an obstacle to water flow. It was found that the DEM not only represented the terrain, but also included objects of anthropogenic origin, such as bridges. In addition, within the river channel the water surface was not subtracted from the terrain in most parts.

Figure 48 presents the modifications made to the terrain model for the Chamelecón River (marked in pink), to integrate the channel passages and facilitate the flow of water to the Filopo Channel (northwest) and the Maya Channel (southeast).

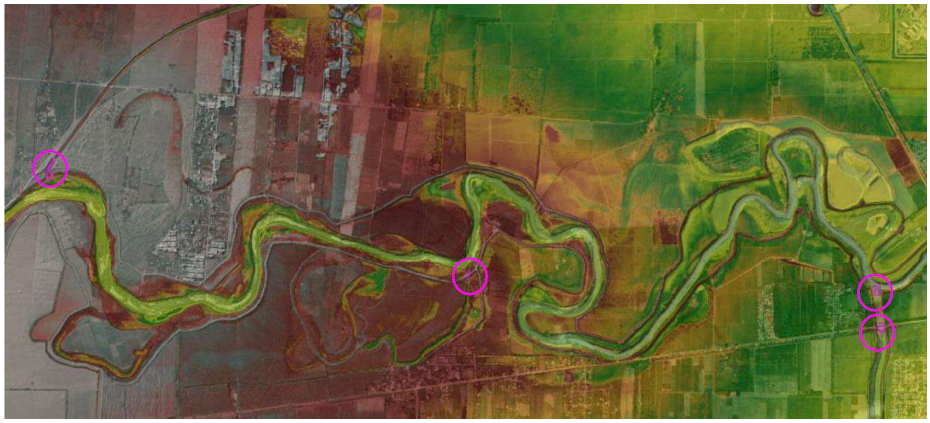


Figure 48 Modifications of the land model for the Chamelecón River

In terms of the configuration of the model, taking into account the large extension of the Chamelecon River floodplain, a grid was worked with a size varying between 10 and 20 meters. The larger grids were used mainly in flat areas without settlements or infrastructure. Additionally, break lines were

[58] COPECO: Comisión permanente de contingencias. (2016a). Informe V- Hidrología, Producto 1. Análisis de Riesgo a nivel municipal y local, Estimación de Avenidas – Sistemas de cuencas del Municipio de San Pedro Sula Departamento de Cortés. San Pedro Sula.

implemented for each model along the walls, levees and any type of structure that would form an obvious obstacle to flow.

Similarly, due to the overlap of the plain with the other sub-models and sub-basins, the extent of the Chamelecón River sub-model was delimited along the perimeters of the 2D area in some regions. Specifically, the delimitations were made in the southwest by El Calan Creek (normal depth limit condition), in the north by the Filopo Channel that acts as an exit and in the south by the Maya Channel. The exits in both channels were validated based on the results of Suárez (2019)[59], confirming the plausibility of the model.

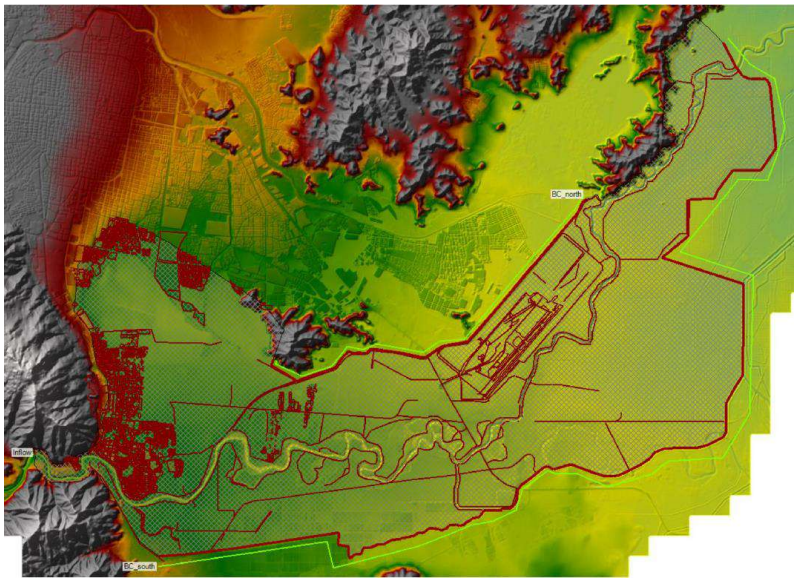


Figure 49 Configuration of the Chamelecon River model, including breaklines (red) and boundary conditions (green)

7.3.5 Hydraulic model validation

Due to poor data availability, it was not possible to validate the results of the hydraulic model. Comparison of the results with the 1998 Storm Mitch flood failed due to lack of data on both discharge and recorded flood plains.

Therefore, the results of the model were compared with the previous studies of Copeco[60], as well as with the thesis of Abrego Suárez (2019)[61]. The available results of the 1D model of these studies confirm quite well the 2D results of this study. Furthermore, Abrego Suarez supported this study with his local expert knowledge and was able to confirm most of the assumptions and results with his experience.

In the Chamelecon River model, the outflow through the Filopo and the Mayan Canal matches well with the discharge values estimated in the Abrego Suarez study (2019).

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[59] Abrego Suárez, C. R. (2019). Actualización preliminar de los umbrales de alerta por inundación de Río Chamelecón en ciudad La Lima, Cortés, para el período de observaciones 2010-2018. Tegucigalpa, Honduras.: Master Thesis.

[60] COPECO: Comisión permanente de contingencias. (2016a). Informe V- Hidrología, Producto 1. Análisis de Riesgo a nivel municipal y local, Estimación de Avenidas – Sistemas de cuencas del Municipio de San Pedro Sula Departamento de Cortés. San Pedro Sula.

[61] Abrego Suárez, C. R. (2019). Actualización preliminar de los umbrales de alerta por inundación de Río Chamelecón en ciudad La Lima, Cortés, para el período de observaciones 2010-2018. Tegucigalpa, Honduras.: Master Thesis.

7.3.6 Results

Below are the differences in floodable areas between simulations with and without the Tablón dam for the return periods described, in the RCP 4.5 scan and for a time horizon of 25 years.

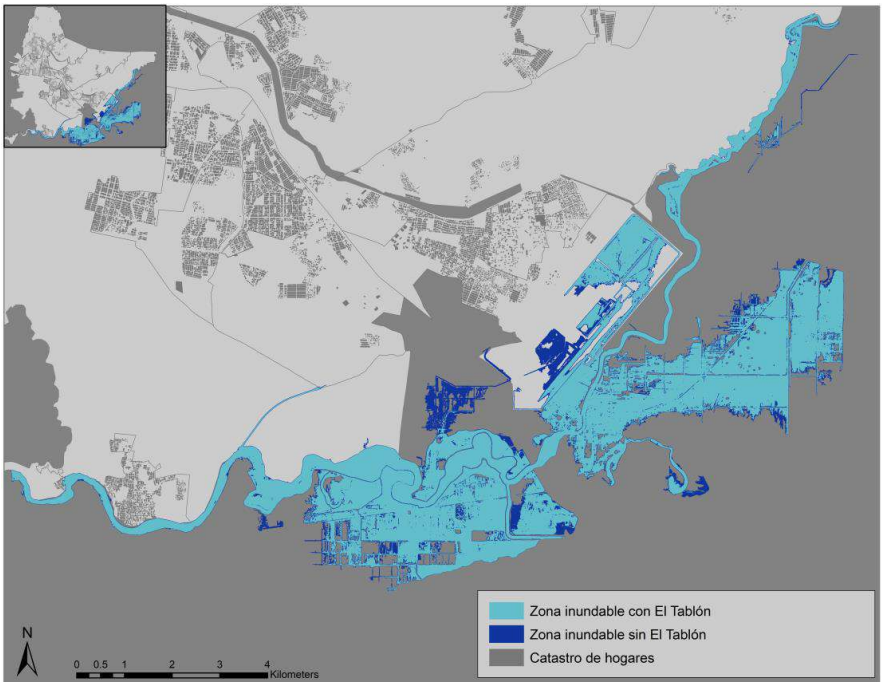


Figure 50 Floodable areas with and without the Tablón dam for a return period of 25 years

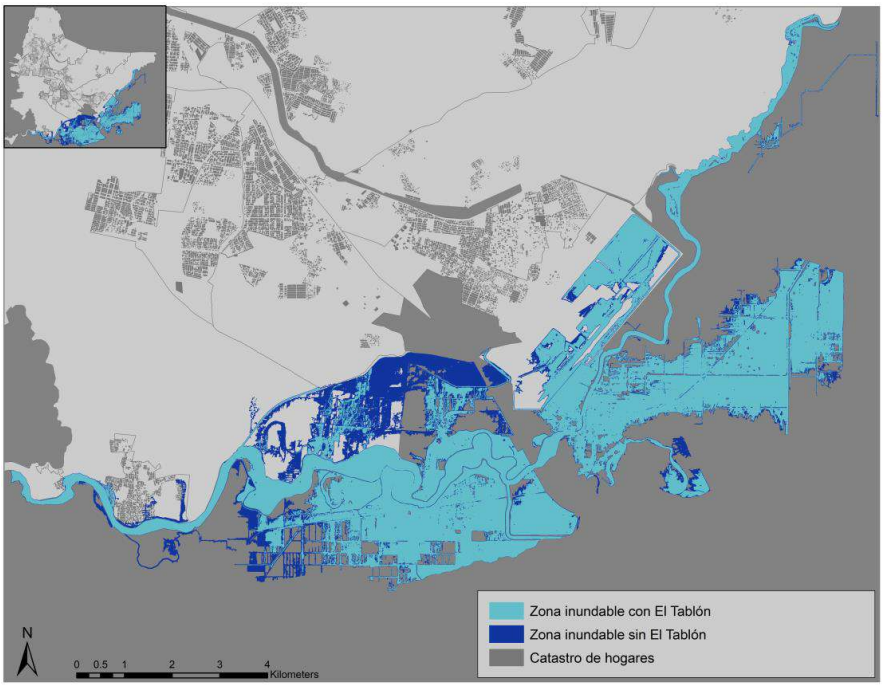


Figure 51 Floodable areas with and without the Tablón dam for a return period of 50 years

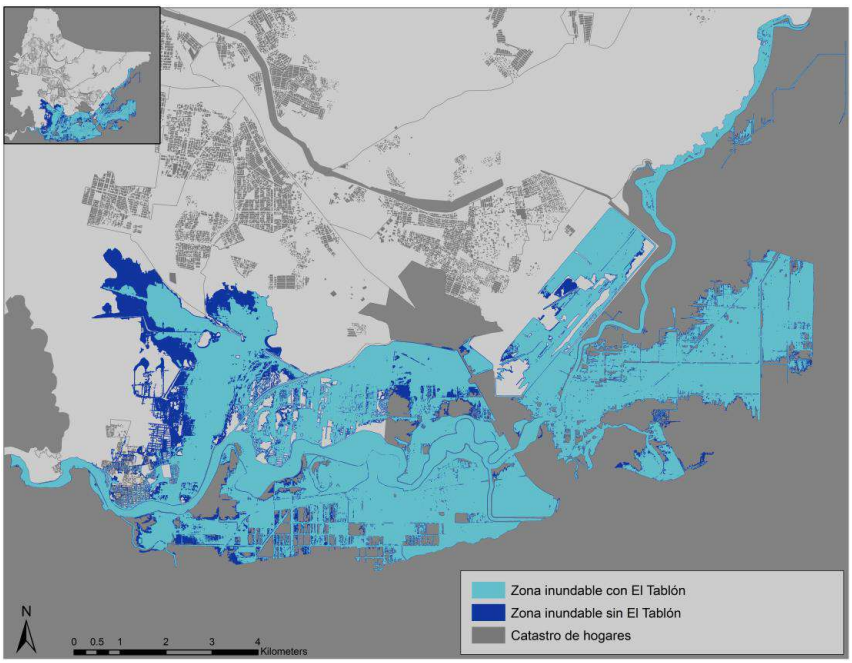


Figure 52 Floodable areas with and without the Tablón dam for a return period of 100 years

Figure 53 presents the changes in the extent of the Chamelecón River floodable areas with and without the Tablón dam. The blue range shows the areas in hectares without the dam and the orange range with the Tablón. In red, the percentage change in areas is observed. It is evident then how the greatest benefits can be expected for less extreme events, such as the 25 and 50 year return periods, and how as the maximum capacity of the dam becomes saturated the percentage reduction in floodable area is less, as in the case of the 100 year return period. The numerical values are presented in Table 22.

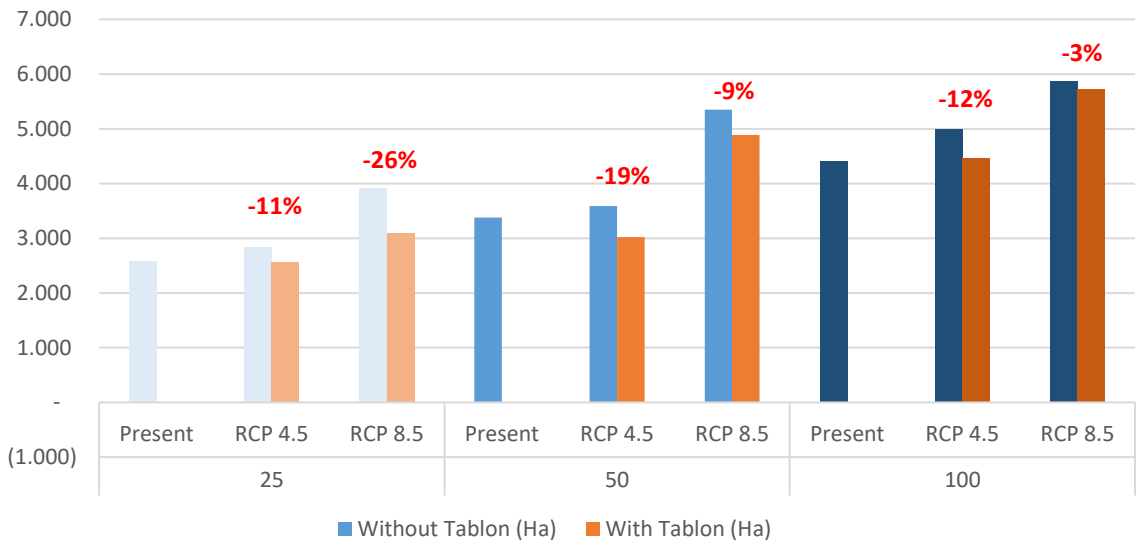


Figure 53 Reductions in floodable areas for return periods 25, 50 and 100 years, for present scenarios, RCP 4.5 and RCP 8.5

Table 22 Chamelecón River floodable areas with and if the Tablón dam

Return period	Scenario	Without El Tablón (Ha)	With El Tablón (Ha)
25	Present	2 578	-
	RCP 4.5	2 846	2 555
	RCP 8.5	3 912	3 096
50	Present	3 376	-
	RCP 4.5	3 586	3 022
	RCP 8.5	5 350	4 889
100	Present	4 406	-
	RCP 4.5	5 003	4 458
	RCP 8.5	5 874	5 729

7.3.7 Conclusions

The result of the Tablón dam modeling shows that its effect on flood extent is much more relevant for minor events. Given the effects of climate change, and the expected increase in the frequency of Eta and Iota type events and even larger ones, our recommendation would be to resize the dam design considering much stronger events than had been predicted in the past.

The challenge of doing such planning with the limited availability of reliable historical hydro-meteorological data is the high level of uncertainty that must be managed when making the corresponding calculations. In this order of ideas, it is recommended to manage strong safety margins in the design of the infrastructure that incorporate the diversity of intensity estimates for return periods available in the literature. The location of the dam may also need to be reconsidered to incorporate changes in design storm intensity.

Additionally, it should be noted that with the exception of the Ramon Villeda Morales Airport, most of the assets and those with highest economic value to the Municipality are located in the city center. The dam effect brings some benefits to this area as it releases capacity for the rivers that cross it to discharge into the Chamelecón during extreme events, but this does not significantly reduce flood risks. The cost-efficiency analysis of the Tablón should then be carried out based on the surroundings of the Chamelecón River and for the other areas of the Municipality, other measures take priority as they have greater effects.

In terms of costing, it is recommended to reconsider the multipurpose character of El Tablón. By focusing the role of the project on flood management and not in energy production, for example, the costs of construction could be significantly reduced, improving the benefit/cost ratio. Similarly by updating the design, which was provided from a 2010 version, other cost could also be optimized and the protective capacity of the project could be improved.

8 PROPOSAL FOR PRE-FEASIBILITY STUDY

8.1 Introduction

This chapter contains the work plan for the pre-feasibility analysis that will be carried out as the last stage of the ECA study on the Municipality of San Pedro Sula. With the goal of facilitating the implementation of the identified adaptation measures discussed in the vulnerability report, the analysis will cover the technical, economic, environmental, social and regulatory frameworks relevant for this case study. These further analyses meets the demands of international donors, such as KfW, to evaluate possible investments.

Regarding the scope of the pre-feasibility study, it will include a: background, beneficiary and feasibility analysis, an institutional analysis of the executing agencies and a budget and execution schedule. The following sections provide some further details.

8.2 Background Analysis

For this study the background analysis covers the institutional context, ongoing programs and initiatives, challenges and opportunities relevant to Disaster Risk Management (DRM) and its interdependence, both at the regional and local levels. These items entail:

- **Institutional context:** Identification of the institutions best equipped to carry out the adaptation measures suggested by the ECA study, in terms of efficiency, effectiveness and accountability. These could be entities from the centralized public sector, from the deconcentrated sector in the department of Cortés or from the municipality of San Pedro Sula, among others.
- **Ongoing programs and initiatives:** Verification of the ongoing programs and activities related to climate change, of the Government of Honduras and the Municipality of San Pedro Sula in cooperation with international organizations, such as the World Bank, the Inter-American Development Bank, the Central American Bank for Economic Integration, the United Nations Development Program, etc.
- **Problems and potentials for DRM:** Preliminary risk classification both in Honduras and in the Municipality of San Pedro Sula and its urban area, through the analysis of available information on flood hazards in the region.

8.3 Beneficiary Analysis

This analysis will include both direct and indirect beneficiaries, considering for aspects of gender, poverty, peace and conflict.

- **Direct beneficiaries:** Defined by local population in the intervention area, and disaggregated by gender, age group, socioeconomic characteristics, etc.
  It will also include the institutions that have received, are receiving or will potentially receive institutional strengthening and actively participate in the implementation of the proposed measures.
- **Indirect beneficiaries:** Constituted by the general population of San Pedro Sula, disaggregated as well by urban or rural location, gender, socio-economic characteristics, etc. Local businesses will also be included, as well as the main existing equipment and infrastructure.

8.4 Feasibility Analysis

This analysis will be carried out to establish the feasibility of at least three of the priority measures proposed by the ECA Vulnerability Report for the municipality of San Pedro Sula. Considering technical, economic, environmental, social and legal aspects.

- **Technical feasibility:** Assessment of the availability of technical and technological means within the Municipality to carry out the measures. The following four topics will be included:
  - Applicable regulations, guidelines of good design practices and other instruments that regulate the technical aspects of the project.
  - Existence of base studies of the land in terms of topography, geotechnics and hydrology, among others.
  - Available technology in terms of accessibility to technological knowledge to implement and operate the measures, as well as the capacity to supply inputs, capital goods including civil work and equipment, labor and maintenance services.
  - Sustainability, which includes the identification of possible failure modes, as well as the ability to obtain funding sources to cover project costs throughout its life cycle.
- **Identification of co-benefits.** Assessment of co-benefits that could occur during the design, implementation and operation of the proposed priority measures. That is, additional positive impacts such as increased employment, increased income, reduction of negative health effects and other qualitative co-benefits, especially in the urban area of San Pedro Sula.
- **Environmental and social risks.** Assessment of possible negative social and environmental impacts that could occur during the implementation and operation of the proposed measures will be identified, as well as the methods available to mitigate or prevent them.
- **Legal feasibility:** Assessment of the current Honduran legal framework that the measures of infrastructure and institutional strengthening, as well as of education-communication and citizen organization that will be proposed in the pre-feasibility study.

8.5 Proposed Executing Entity

In this section, an in-depth analysis of the institution identified as executing agency for the proposed measures and the recommended strengthening needs will be carried out. This analysis will ensure that that such institution has the proven capacity to manage the infrastructure project cycle and citizen management, as well as the adequacy of its procurement and contracting rules and procedures, accounting records and accountability. However, the study will also identify the types of support it needs as an executing agency to successfully implement the proposed measures.

In order to establish the execution structure, a matrix of roles and responsibilities will be prepared to assign these functions to each of the actors involved in the planning, execution and operation of the measures.

8.6 Budget and Execution Schedule

This section will define the scope of the program through a broken-down work structure, to which time and resources will be allocated to develop the schedule and budget for its implementation.

- **Breakdown of work structure:** It will consist of the hierarchical decomposition of the work to be done to achieve the program objectives and the required products.
- **Project schedule:** It will consist of the presentation of all the logical sequence and the steps to be followed to deliver the program's products or results.
- **Program budget:** It will consist of the allocation of the financial resources of the program, to complete and achieve the objectives and products.

8.7 Feasibility Report

The feasibility report will be the final step of the study, for which a vulnerability workshop will be held in San Pedro Sula beforehand.

ANNEX 1 - COPECO: Flood Analysis of San Pedro Sula 2016

ANNEX 2 - ECA: Flood Analysis of San Pedro Sula 2020

ANNEX 3 - Survey Methodological Report

ANNEX 4 - Housing Value Los Bordos

ANNEX 5 - Measure selection procedure

ANNEX 6 - Detailed description of measures

ANNEX 7 - Economic scenario as applied in CLIMADA

ANNEX 8 - Estimations discharge in the Chamelecón River with and without El Tablón dam for return periods 25, 50 and 100 years

ANNEX 9 - Geographical benefit distribution from the adaptation measures

ANNEX 10 - All maps from the report

ANNEX 1

COPECO: Flood Analysis of San Pedro Sula 2016

4.2. ELEMENTOS EXPUESTOS: AMENAZA A INUNDACIONES, CENTRO URBANO SAN PEDRO SULA

Para la determinación de los elementos expuestos a la amenaza de inundaciones en barrios y colonias del centro urbano seleccionado, se ha utilizado como base, el levantamiento de infraestructura crítica realizado al inicio de este estudio en el año 2015. El período de retorno considerado ha sido de 50 años

A continuación, se muestra el porcentaje de área expuesta en cada uno de los barrios y colonias del centro urbano de San Pedro Sula.

Tabla 33. Área expuesta de barrios o colonias a amenaza a inundaciones, centro urbano San Pedro Sula

Sector	Nombre de barrio o colonia [a]	Área total barrio[a] km²	Amenaza a inundación[b]	Área expuesta barrio [b] km²	% de exposición del barrio
Noreste	Andalucía	0.09	Baja	0.03	32.90
			Media	0.002	2.76
	Bordo Universal-Las Vegas	0.11	Baja	0.01	11.47
			Media	0.01	10.42
			Alta	0.01	11.04
	Brisas No. 3	0.05	Baja	0.004	8.89
			Media	0.01	18.69
			Alta	0.01	25.00
	El Sauce	0.27	Baja	0.03	12.32
			Media	0.01	4.18
			Alta	0.002	0.66
	Esquipulas No.2	0.03	Baja	0.01	28.22
			Media	0.01	28.65
			Alta	0.01	19.25
	Florida	0.10	Baja	0.01	8.61
	La Esperanza	0.08	Baja	0.0001	0.07
	Las Vegas	0.14	Baja	0.03	21.47
			Media	0.0001	0.09
	Modelo	0.23	Baja	0.003	1.53
	Odilón Ayestas	0.46	Baja	0.02	3.67
			Media	0.003	0.67
			Alta	0.001	0.28
	Bogran-2do. Anillo	0.92	Baja	0.01	1.37
			Media	0.03	3.18
			Alta	0.03	3.35
	Guadalupe-2do. Anillo	0.11	Baja	0.004	3.28
			Media	0.005	4.44
			Alta	0.03	28.45
	Villas del Bosque III Etapa	0.30	Baja	0.0004	0.15
			Media	0.0005	0.17

Sector	Nombre de barrio o colonia [a]	Área total barrio[a] km²	Amenaza a inundación[b]	Área expuesta barrio [b] km²	% de exposición del barrio
			Alta	0.0004	0.12
Noroeste	Agua Caliente	1.14	Baja	0.0001	0.01
	Armenta	0.87	Baja	0.02	2.23
			Media	0.01	1.21
			Alta	0.01	1.15
	Bella Vista	0.42	Baja	0.0002	0.06
			Media	0.0001	0.03
			Alta	0.0004	0.09
	Bermejo	0.30	Baja	0.001	0.37
			Media	0.001	0.43
			Alta	0.00002	0.01
	Bosques del Merendón	0.43	Baja	0.001	0.26
	Cementos de Honduras	0.06	Baja	0.001	1.28
			Media	0.001	1.04
			Alta	0.0003	0.46
	El Campo	0.01	Baja	0.0001	1.07
			Media	0.00003	0.31
	El Playón	0.46	Baja	0.001	0.12
			Media	0.0004	0.09
			Alta	0.0002	0.04
	ETAHSA	0.02	Baja	0.003	15.08
	Finca Vieja	0.02	Baja	0.0001	0.33
	Hernández Morel	0.20	Baja	0.001	0.41
			Media	0.001	0.25
			Alta	0.0003	0.14
	Juan Lindo	0.63	Baja	0.001	0.10
			Media	0	0
	Nova	0.11	Baja	0.005	4.11
	Nueva Esperanza	0.01	Baja	0.001	5.00
			Media	0.0003	2.48
			Alta	0.0003	2.39
	Pena Blanca	1.06	Baja	0.003	0.29
			Media	0.01	0.53
			Alta	0.002	0.17
	Rancho El Coco	0.30	Baja	0.0001	0.02
			Media	0	0
	Álamos-Nova	0.18	Baja	0	3
	Santa Ana-MCR	0.81	Baja	0	0

Sector	Nombre de barrio o colonia [a]	Área total barrio[a] km²	Amenaza a inundación[b]	Área expuesta barrio [b] km²	% de exposición del barrio
			Media	0	0
			Alta	0	0
	Universidad	0.28	Baja	0	1
			Media	0	0
			Alta	0	0
	Zerón	0.31	Baja	0	0
			Baja	0	0
	Zona Cervecería	0.83	Baja	0	1
			Media	0	1
			Alta	0	0
Sureste	Buena Vista	0.06	Baja	0	30
			Media	0	0
	El Paraíso	0.02	Baja	0	10
			Media	0	13
			Alta	0	5
	Hermosa Provincia	0.06	Baja	0	1
			Media	0	0
	Islas del Yoro	0.12	Baja	0	12
	Islas del Progreso II	0.21	Baja	0	1
			Media	0	1
			Alta	0	0
	La Sabana	0.13	Baja	0	28
			Media	0	1
	La Unión	0.34	Baja	0	3
	Las Palmas	0.60	Baja	0	33
			Media	0	1
	Los Ángeles	0.74	Baja	0	12
			Media	0	1
			Alta	0	0
	Mi Única Esperanza	0.07	Baja	0	22
			Media	0	25
			Alta	0	11
	Monte Fresco	0.30	Baja	0	19
			Media	0	4
			Alta	0	1
	Monte Fresco Centro	0.10	Baja	0	68
			Media	0	2
	Monte Fresco Este	0.29	Baja	0	27
			Media	0	1

Sector	Nombre de barrio o colonia [a]	Área total barrio[a] km²	Amenaza a inundación[b]	Área expuesta barrio [b] km²	% de exposición del barrio
	San Jorge de Sula	0.06	Baja	0	8
	San José de Sula	0.30	Baja	0	29
			Media	0	0
	Saturno	0.05	Baja	0	1
	Segundo Anillo-Desvió a El Limonar	0.32	Baja	0	31
			Media	0	6
			Alta	0	1
	Valle de Sula	0.47	Baja	0	2
			Media	0	0
	Villa Ernestina	0.42	Baja	0	3
			Media	0	2
			Alta	0	3
	Villa Olímpica	0.21	Baja	0	23
			Media	0	1
			Alta	0	0
	Villeda Morales	0.11	Baja	0	1
			Media	0	1
			Alta	0	2
	Zona Ind. Contiguo Col. Paz	0.29	Baja	0	7
Sub Urbano Este	6 de Mayo	0.27	Baja	0	5
	6 de Mayo (Asentamiento)	0.38	Baja	0	51
			Media	0	36
			Alta	0	9
	Alfonso Lacayo	0.20	Baja	0	43
			Media	0	31
			Alta	0	5
	Altamisales	0.86	Baja	0	17
			Media	0	7
			Alta	0	2
	Bordo 6 de Mayo	0.34	Baja	0	12
			Media	0	44
			Alta	0	8
	Brisas del Aeropuerto	0.03	Baja	0	0
			Media	0	63
			Alta	0	37
	Cablotales	0.71	Baja	0	33
			Media	0	19
			Alta	0	3

Sector	Nombre de barrio o colonia [a]	Área total barrio[a] km²	Amenaza a inundación[b]	Área expuesta barrio [b] km²	% de exposición del barrio
	Campo Alegre	0.04	Baja	0	83
	Central	0.49	Baja	0	17
	Centralita	0.17	Baja	0	1
	Cerrito Lindo (Proyecto)	0.39	Baja	0	42
			Media	0	0
	Copen	0.26	Baja	0	18
			Media	0	16
			Alta	0	17
	Cristo Viene	0.14	Baja	0	0
			Media	0	100
	El Chorizo	0.02	Baja	0	87
			Media	0	13
			Alta	0	0
	El Edén	0.05	Baja	0	0
	FESITRANH II	0.39	Baja	0	62
			Media	0	4
			Alta	0	0
	FESITRANH II 2da. Etapa	0.27	Baja	0	54
			Media	0	29
			Alta	0	1
	Guanacaste	0.08	Baja	0	80
			Media	0	0
	Haciendas	10.72	Baja	0	1
			Media	0	2
			Alta	0	4
	INDUNA	0.19	Baja	0	53
			Media	0	40
			Alta	0	4
	Jose IV. Arreaga I	0.03	Baja	0	7
			Media	0	10
			Alta	0	3
	Jose IV. Arreaga II	0.06	Baja	0	10
			Media	0	3
	La Cuchilla	0.08	Baja	0	66
			Media	0	0
	La Pedrosa	0.09	Baja	0	2
			Media	0	1
			Alta	0	0
	La Solita	0.24	Baja	0	96

Sector	Nombre de barrio o colonia [a]	Área total barrio[a] km²	Amenaza a inundación[b]	Área expuesta barrio [b] km²	% de exposición del barrio
			Media	0	1
	Llanos de Sula I	0.07	Baja	0	3
	Llanos de Sula II	0.08	Baja	0	37
			Media	0	37
			Alta	0	3
	Llanos de Sula IV	0.06	Baja	0	4
			Media	0	96
	Luke	0.04	Baja	0	11
			Media	0	86
			Alta	0	4
	Montanita	0.14	Baja	0	80
			Media	0	12
	Monte Verde	0.03	Baja	0	70
			Media	0	30
	Nueva Esperanza	0.02	Baja	0	3
			Media	0	96
			Alta	0	2
	Puerto Escondido	0.07	Baja	0	5
			Media	0	37
			Alta	0	44
	Reyes Martínez	0.04	Baja	0	25
	Roberth Larios Silva	0.09	Baja	0	13
			Media	0	2
	Ruiz	0.01	Baja	0	97
			Media	0	3
	Sandoval Soto	0.19	Baja	0	0
	Santa Martha	0.09	Baja	0	64
	Santa Venecia	0.06	Baja	0	23
			Media	0	77
	Aeropuerto-Bordo	6.95	Baja	0	3
			Media	1	8
			Alta	3	39
	Central-Santa Martha	0.14	Baja	0	43
	Rivera Hdez.-Lim. La Lima	1.38	Baja	0	0
			Media	0	0
	Villa Ernestina-Miguel Ángel Pavón	0.16	Baja	0	7
	Venecia	0.02	Baja	0	0
	Villas Kitur I	0.06	Baja	0	96

Sector	Nombre de barrio o colonia [a]	Área total barrio[a] km²	Amenaza a inundación[b]	Área expuesta barrio [b] km²	% de exposición del barrio
			Media	0	4
			Alta	0	0
	Villas Kitur III	0.01	Baja	0	96
			Media	0	4
Sub Urbano Noreste	Ángeles del Carmen	0.07	Baja	0	16
			Media	0	16
			Alta	0	2
	El Carmen	0.35	Baja	0	4
			Media	0	5
			Alta	0	18
	J.N.B.S.	0.09	Baja	0	3
			Media	0	3
			Alta	0	0
	San Martin	0.08	Baja	0	1
	2do. Anillo-El Limonar	1.25	Baja	0	2
			Media	0	3
			Alta	0	11
	Carr. La Lima-Lomas del Carmen	0.28	Baja	0	3
			Media	0	4
			Alta	0	21
	Limonar-Lomas del Carmen	0.10	Baja	0	13
			Media	0	16
			Alta	0	41
	Villas del Carmen-El Carmen	1.38	Baja	0	9
			Media	0	9
			Alta	1	42
	Hcda. El Rincón - Aldea El Carmen	3.72	Baja	0	2
			Media	0	1
			Alta	0	0
Sub Urbano Sur Este	Berman Hernández	0.33	Baja	0	0
			Media	0	1
			Alta	0	20
	Chamelecón	0.38	Baja	0	0
			Media	0	0
			Alta	0	4
	Chotepe	2.77	Baja	0	10
			Media	0	5
			Alta	0	16
	Fe y Esperanza	0.04	Baja	0	1

Sector	Nombre de barrio o colonia [a]	Área total barrio[a] km²	Amenaza a inundación[b]	Área expuesta barrio [b] km²	% de exposición del barrio
			Media	0	1
			Alta	0	2
	La Bolsa	0.47	Baja	0	1
			Media	0	1
			Alta	0	21
	Lempira No. 1	0.07	Baja	0	3
			Media	0	9
			Alta	0	21
	Monte Bello	0.44	Baja	0	52
			Media	0	1
	Palmira	0.03	Baja	0	1
			Media	0	1
			Alta	0	0
	Providencia II Etapa	0.19	Baja	0	4
	Reyes Leiva	0.21	Baja	0	32
			Media	0	9
	Sabillón Cruz	0.43	Baja	0	1
			Media	0	1
			Alta	0	4
	San Antonio II Etapa	0.29	Baja	0	1
	San Jorge	0.09	Baja	0	1
			Media	0	1
			Alta	0	13
	San José	0.06	Baja	0	1
			Media	0	1
			Alta	0	0
	Berman Hdez. Col. 14 de Julio	3.01	Baja	0	2
			Media	0	2
			Alta	0	11
	Peaje Lempira No. 2	0.11	Baja	0	0

Fuente: Elaboración con base en: (a) Alcaldía Municipal de San Pedro Sula (2015); (b) Informe de Hidrología (Rojas, Ayala, 2016).

A continuación, se presentan los elementos expuestos por barrios y colonias y según el nivel de amenaza.

Tabla 34. Exposición de elementos por barrio o colonia y nivel de amenaza a inundaciones, centro urbano de San Pedro Sula

Sector	Barrio o colonia [a]	Centros Educativos[b]	Centros de Salud[b]	Red Vial Pavimentada[b]	Red Vial No Pavimentada[b]
Noreste	Bordo Universal-Las Vegas	-	-	0.51	0.02
	Esquipulas No. 2	-	-	0.18	-
	Odilón Ayestas	-	-	0.14	-
	. Bogran-2do. Anillo	-	-	0.00	-
	. Guadalupe-2do. Anillo	-	-	0.06	-
Noroeste	Armenta	-	-	-	0.23
Sureste	El Paraíso	-	-	0.02	-
	Mi Única Esperanza	-	-	0.00	-
	Segundo Anillo-Desvió a El Limonar	-	-	0.04	-
	Villa Ernestina	-	-	0.13	-
	Villeda Morales	-	-	0.02	-
Sub Urbano Este	6 de Mayo (Asentamiento)	-	-	0.54	-
	Alfonso Lacayo	-	-	0.28	-
	Brisas del Aeropuerto	-	-	0.12	0.01
	Cablotales	-	-	-	0.01
	Cristo Viene	-	-	0.26	-
	Induna	-	-	-	0.15
	Llanos de Sula II	-	-	0.10	-
	Llanos de Sula IV	-	-	1.34	-
	Puerto Escondido	-	-	0.01	-
Suburbano Noreste	El Carmen	-	-	0.80	-
	Limonar-Lomas del Carmen	-	-	0.04	-
	Villas del Carmen-El Carmen	-	-	1.68	-
Sub Urbano Sureste	Berman Hdez. Col. 14 de Julio	-	-	0.06	0.08
Noreste	Andalucía	-	-	0.04	-
	Bordo Universal-Las Vegas	-	-	0.39	0.01
	Esquipulas No.2	-	-	0.28	-
	Odilón Ayestas	-	-	0.19	-
	Bogran-2do. Anillo	-	-	0.01	-
	Guadalupe-2do. Anillo	-	-	0.01	-
Noroeste	Armenta	-	-	0.04	0.02
	Pena Blanca	-	-	0.01	-
Sureste	El Paraíso	-	-	0.04	-
	La Sabana	-	-	0.01	-
	Las Palmas	-	-	0.14	-
	Mi Única Esperanza	-	-	0.08	-
	Monte Fresco	-	-	0.04	-
	Monte Fresco Centro	-	-	0.07	-
	Monte Fresco Este	-	-	0.08	-

Sector	Barrio o colonia [a]	Centros Educativos[b]	Centros de Salud[b]	Red Vial Pavimentada[b]	Red Vial No Pavimentada[b]
	San José de Sula	-	-	0.00	-
	Segundo Anillo-Desvió a El Limonar	-	-	0.09	-
	Valle de Sula	-	-	0.07	-
	Villa Ernestina	-	-	0.13	-
	Villeda Morales	-	-	0.01	-
Sub Urbano Este	6 de Mayo (Asentamiento)	-	-	4.01	-
	Alfonso Lacayo	-	-	1.75	-
	Altamisales	-	-	0.09	0.03
	Bordo 6 de Mayo	-	-	0.19	-
	Brisas del Aeropuerto	-	-	0.56	0.04
	Cablotales	-	-	0.09	0.70
	FESITRANH II	-	-	0.73	-
	FESITRANH II 2da Etapa	-	-	0.96	0.41
	Induna	-	-	0.86	1.49
	Llanos de Sula II	-	-	0.83	-
	Llanos de Sula IV	-	-	0.00	-
	Luke	-	-	1.02	-
	Montanita	-	-	0.49	-
	Monte Verde	-	-	-	0.21
	Nueva Esperanza	-	-	-	0.71
	Puerto Escondido	-	-	0.16	0.22
	Roberth Larios Silva	-	-	0.00	-
	Ruiz	-	-	0.00	-
	Santa Venecia	-	-	0.66	-
	Villas Kitur I	-	-	0.01	-
Sub Urbano Noreste	Ángeles del Carmen	-	-	0.07	-
	El Carmen	-	-	0.30	-
	Limonar-Lomas del Carmen	-	-	0.02	-
Sureste	Berman Hdez. Col. 14 de Julio	-	-	0.03	0.02
Noreste	Andalucía	-	-	0.62	-
	Bordo Universal-Las Vegas	-	-	0.21	0.00
	Esquipulas No.2	-	-	0.21	-
	Florida	-	-	0.07	-
	Las Vegas	-	-	0.89	-
	Modelo	-	-	0.09	-
	Odilón Ayestas	-	-	0.40	-
	Bográn-2do. Anillo	-	-	0.00	-
	Guadalupe-2do. Anillo	-	-	0.01	-
Noroeste	Agua Caliente	-	-	0.01	-
	Armenta	-	-	0.07	0.02
	Bosques del Merendón	-	-	0.10	-
	ETAHSA	-	-	0.05	-

Sector	Barrio o colonia [a]	Centros Educativos[b]	Centros de Salud[b]	Red Vial Pavimentada[b]	Red Vial No Pavimentada[b]
	Nova	-	-	0.11	-
	Pena Blanca	-	-	0.01	-
	Zerón	-	-	0.01	-
Sureste	Buena Vista	-	-	0.21	-
	El Paraíso	-	-	0.06	-
	Islas del Progreso	-	-	0.35	-
	La Sabana	-	-	1.10	-
	La Unión	-	-	0.33	-
	Las Palmas	-	-	4.10	-
	Los Ángeles	-	-	0.35	-
	Mi Única Esperanza	-	-	0.11	-
	Monte Fresco	-	-	1.63	-
	Monte Fresco o Centro	-	-	2.16	-
	Monte Fresco Este	-	-	2.11	-
	San Jorge de Sula	-	-	0.07	-
	San José de Sula	-	-	1.21	-
	Saturno	-	-	0.02	-
	Segundo Anillo-Desvió a El Limonar	-	-	0.68	-
	Valle de Sula	-	-	0.46	-
	Villa Ernestina	-	-	0.12	-
	Villa Olímpica	-	-	0.74	-
	Villeda Morales	-	-	0.02	-
	Zona Ind. Contiguo Col. Paz	-	-	0.26	-
Sur Urbano Este	6 de Mayo	-	-	0.06	0.04
	6 de Mayo (Asentamiento)	-	-	4.74	-
	Alfonso Lacayo	-	-	2.30	-
	Altamisales	-	-	1.06	0.14
	Bordo 6 de Mayo	-	-	0.25	-
	Cablotales	-	-	1.16	0.47
	Campo Alegre	-	-	0.07	0.79
	Central	-	-	0.60	0.76
	Centralita	-	-	-	0.01
	Cerrito Lindo (Proyecto)	-	-	1.57	3.89
	El Chorizo	-	-	0.02	-
	El Eden	-	-	0.00	-
	FESITRANH II	-	-	5.64	-
	FESITRANH II 2da Etapa	-	-	1.09	1.95
	Guanacaste	-	-	-	1.83
	Haciendas	-	-	-	0.16
	INDUNA	-	-	0.56	2.24
	José IV Arreaga I	-	-	0.08	-
	José IV Arreaga II	-	-	0.18	-

Sector	Barrio o colonia [a]	Centros Educativos[b]	Centros de Salud[b]	Red Vial Pavimentada[b]	Red Vial No Pavimentada[b]
	La Cuchilla	-	-	1.13	-
	La Solita	-	-	1.54	0.29
	Llanos de Sula I	-	-	0.01	-
	Llanos de Sula II	-	-	0.96	-
	Luke	-	-	0.13	-
	Montanita	-	-	2.96	-
	Monte Verde	-	-	-	0.73
	Nueva Esperanza	-	-	-	0.00
	Puerto Escondido	-	-	0.01	0.02
	Reyes Martínez	-	-	0.16	0.18
	Roberth Larios Silva	-	-	0.19	-
	Ruiz	-	-	0.48	-
	Sandoval Soto	-	-	0.00	-
	Santa Martha	-	-	1.20	-
	Santa Venecia	-	-	0.24	-
	Central-Santa Martha	-	-	0.71	0.03
	Villas Kitur I	-	-	1.80	-
	Villas Kitur III	-	-	0.25	-
Sur Urbano Noreste	Ángeles del Carmen	-	-	0.34	-
	El Carmen	-	-	0.33	-
	San Martin	-	-	0.01	-
	2do. Anillo-El Limonar	-	-	0.21	-
	Limonar-Lomas del Carmen	-	-	0.03	-
	Hcda. El Rincón - Aldea El Carmen	-	-	0.01	-
Sureste	Monte Bello	-	-	1.71	-
	Berman Hdez. Col. 14 de Julio	-	-	0.03	0.01

Fuente: Elaborado con base en(a) Alcaldía Municipal de San Pedro Sula (2015); (b) levantamiento de infraestructura crítica, 2015; e, Informe de Hidrología (Rojas, Ayala, 2016).

Los elementos expuestos a la amenaza a inundaciones en el centro urbano San Pedro Sula son los siguientes:

- Dos (2) comercios en amenaza baja;
- 73.66 km de red vial pavimentada (6.33 km en amenaza alta, 14.56 km en amenaza media y 52.77 km en amenaza baja); y,
- 17.92 km de red vial no pavimentada (0.5 km en amenaza alta, 3.86 km en amenaza media y 13.56 km en amenaza baja).

A continuación, se presentan los mapas de población y elementos expuestos para el centro urbano de San Pedro Sula, a la amenaza a inundación alta, media y baja.

Ilustración 16. Población expuesta a inundaciones, centro urbano de San Pedro Sula

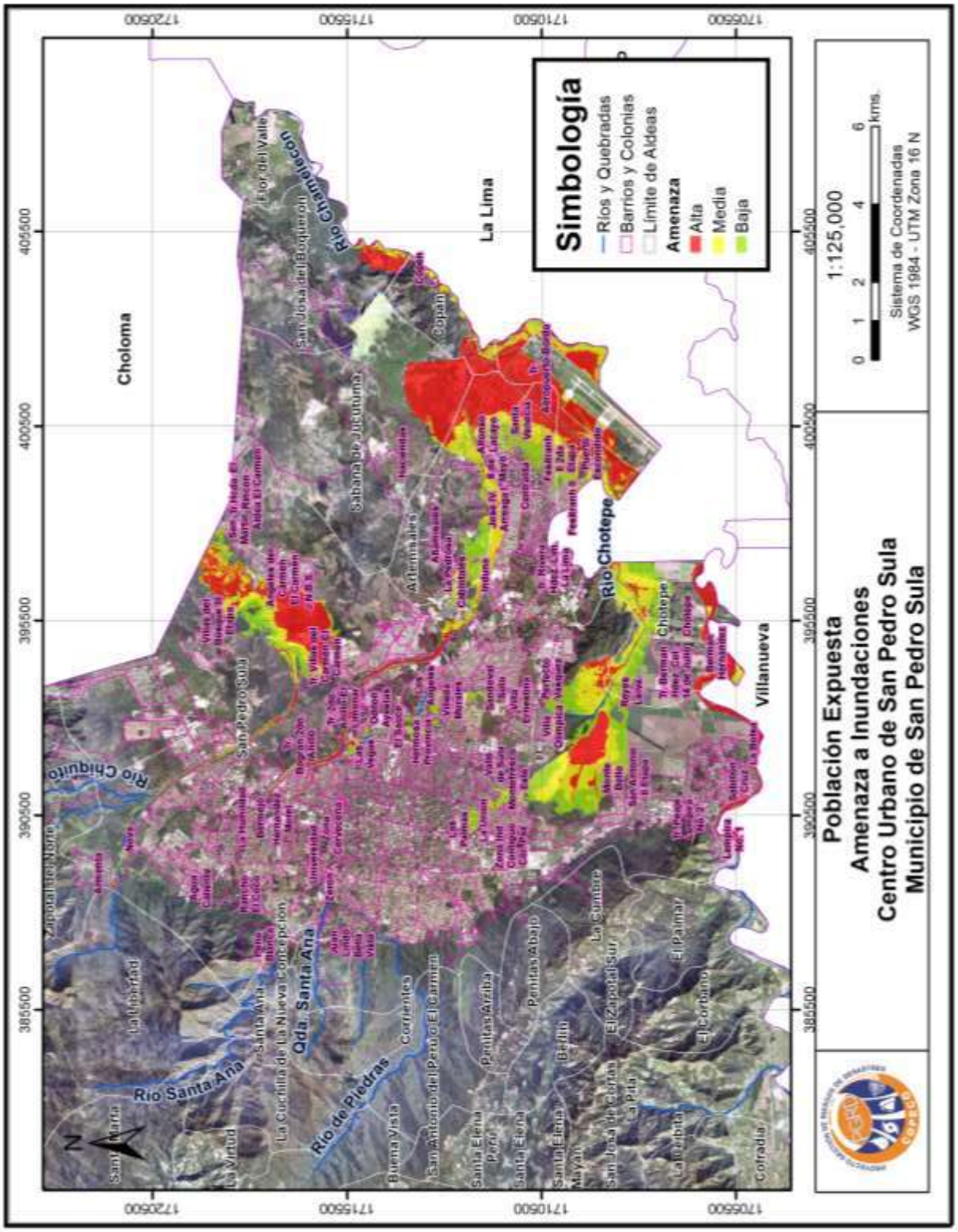
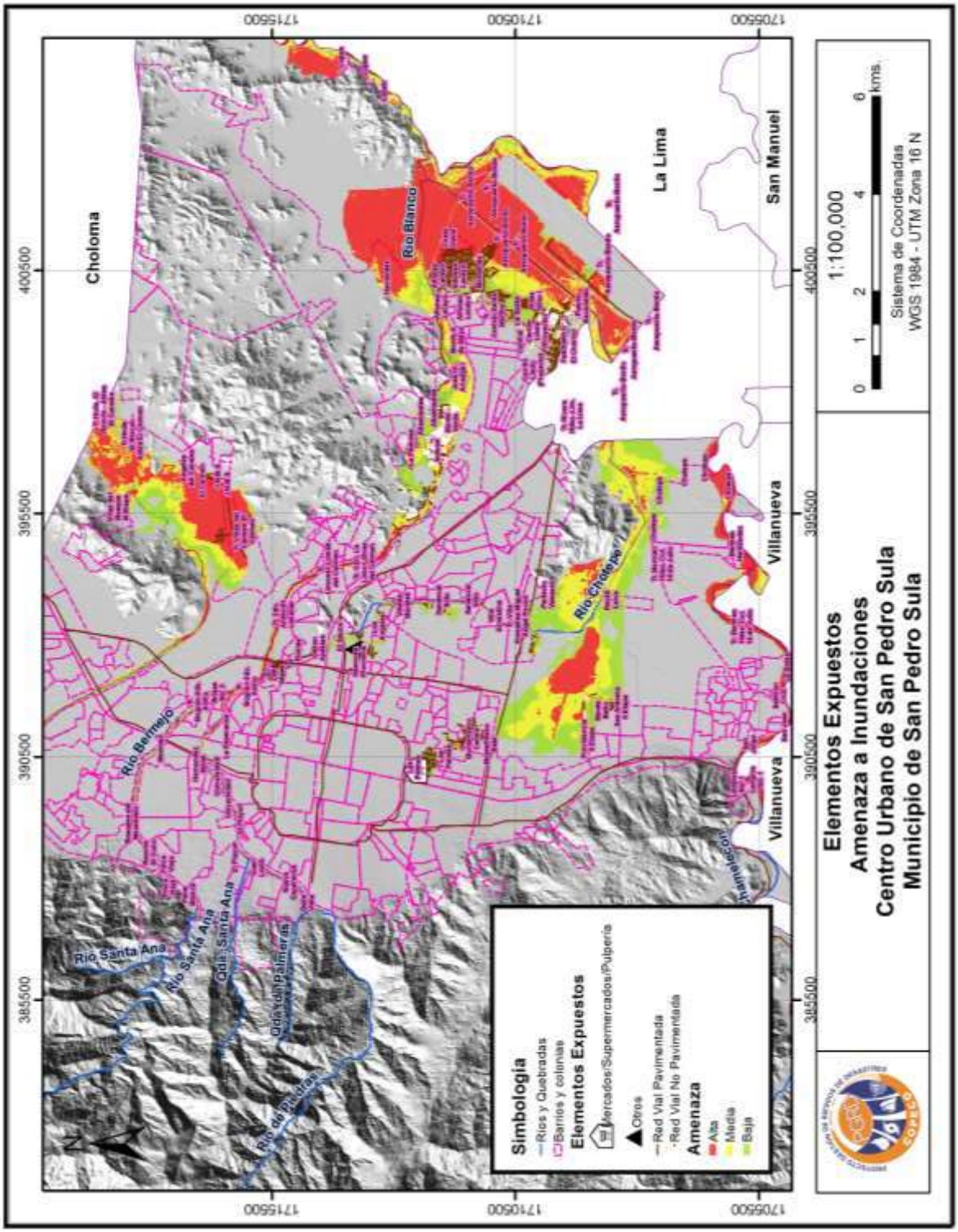

Simbología
Ríos y Quebradas
Barrios y Colonias
Límite de Aldeas
Amenaza
Alta
Media
Baja
1:125,000
0 1 2 4 6 kms
Sistema de Coordenadas
WGS 1984 - UTM Zona 16 N
Población Expuesta
Amenaza a Inundaciones
Centro Urbano de San Pedro Sula
Municipio de San Pedro Sula
Choloma
La Lima
Villanueva
Río Chotepe
Río Santa Ana
Río de Piedras
Río Chiquito
Río Chamelecón
Qda. Santa Ana
San Pedro Sula
Chotepe
Cofradía
Buena Vista
Corrientes
Pedregal
Cofradía
Villanueva
La Lima
Choloma
Zapotal del Norte
La Cuchilla de La Nueva Concepción
San Antonio del Peruo
El Carmen
Santa Elena
Santa Elena
Pedregal
Pedregal
Pedregal

Ilustración 17. Elementos expuestos a inundaciones, centro urbano San Pedro Sula



Fuente: Elaborado con base en datos de Sinit, 2006; Alcaldía Municipal de San Pedro Sula (2015); levantamiento de infraestructura crítica, 2015; e Informe de Hidrología (Salinas et al., 2016)

4.3. SITIOS CRÍTICOS POR AMENAZA A INUNDACIONES, CENTRO URBANO SAN PEDRO SULA

Los sitios críticos a nivel urbano son barrios o colonias en donde se han presentado condiciones y problemáticas identificadas en los análisis técnicos científicos, análisis histórico y los resultados de procesos participativos, por lo que se han priorizado acciones inmediatas. Ello no excluye que otros sitios no tengan problemáticas que, aunque no se mencionen en este estudio, eventualmente deberán ser atendidas por las instituciones, organizaciones y otros actores trabajando en GR.

El cálculo de sitios críticos por inundaciones a nivel de los centros urbanos seleccionados (barrios y colonias) se determinó considerando como críticas las planicies no ocupadas identificadas con amenaza alta, media y baja a inundaciones. De lo expuesto ocupado, se resaltan los barrios con una combinación de mayor área y mayor cantidad de infraestructura crítica y redes expuestas, que además coinciden con eventos históricos y recurrentes (Taller de Eventos Extremos y DesInventar) o que son mencionados en los informes de técnicos (planes anteriores o informes de geomorfología o hidrología)

Además, se consideran críticos las obras de infraestructura hídrica (por ejemplo, represas) y de mitigación como canales y bordos que potencialmente podrían fallar, afectando lugares ocupados (sedimentación, represamientos, daños por sismos, etc.); sitios críticos mencionados resultado del análisis geomorfológico e hidrológico (2016); y, las zonas de expansión urbana condicionadas por la presencia de susceptibilidad alta y media a inundaciones.

Finalmente se seleccionaron 3 sitios críticos por inundaciones a nivel del centro urbano de San Pedro Sula, para los cuales se recomiendan estudios a detalle, así como proyectos estructurales y no estructurales para la GR.

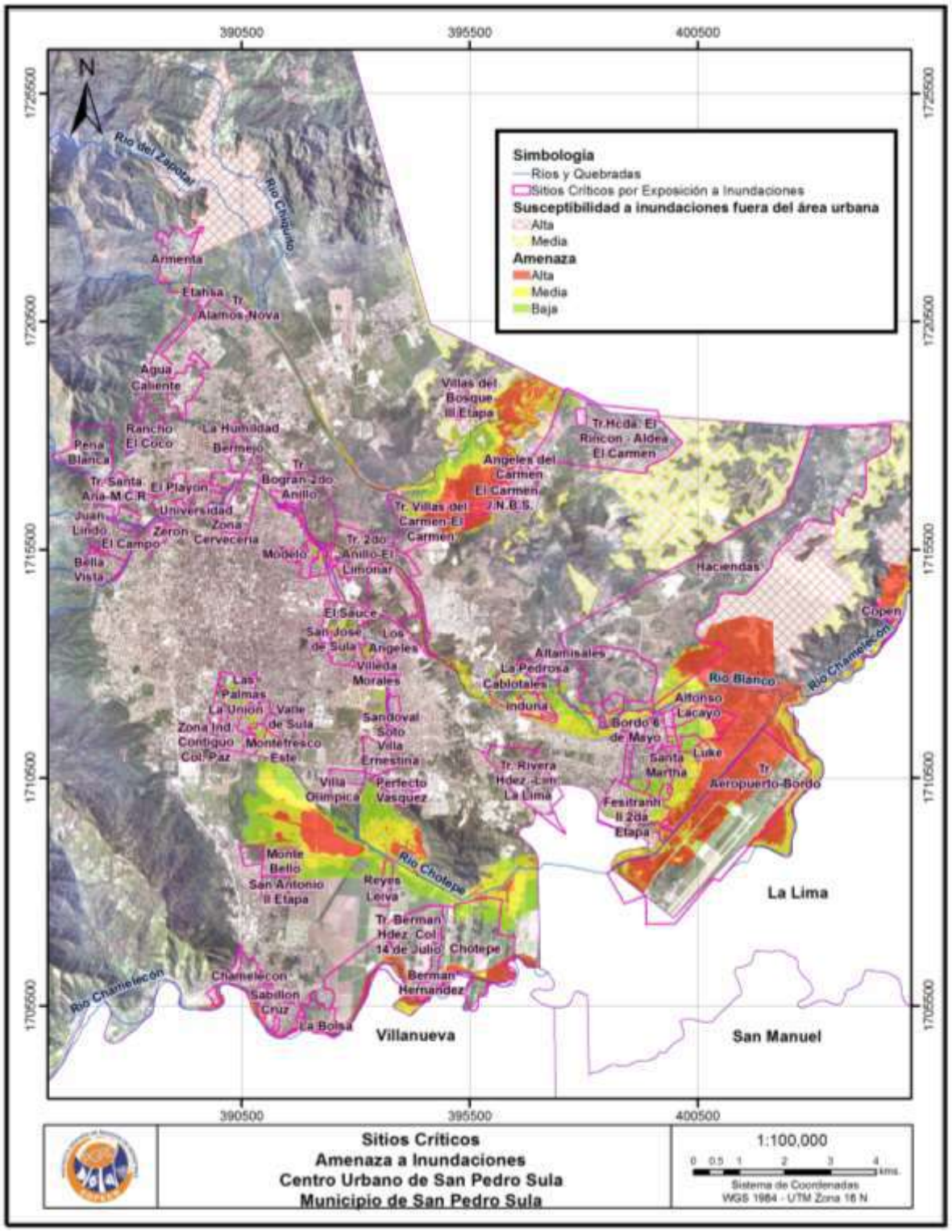
Tabla 35. Sitios críticos por susceptibilidad a inundaciones, centro urbano San Pedro Sula

SITIOS CRÍTICOS	*CRITERIOS*
Sitios críticos 1: planicies de inundaciones no ocupadas con alta, media y baja amenaza a inundación.	**Áreas no ocupadas que presentan amenaza alta, media o baja a inundaciones.** Encontramos en dos puntos: A. Los cauces de los principales ríos, quebradas y canales que atraviesan la ciudad. Incluye la Zona de Protección Hídrica definida por la Ley Forestal, Áreas Protegidas y Vida Silvestre Decreto No. 98-2007. B. Zonas alrededor del aeropuerto y las fincas al sur del sector de Chamelecón en las aldeas
Sitios Críticos 2: Barrios con amenaza alta media o baja a inundaciones.	Barrios y Colonias Expuestos: **Sector Sureste:** El Edén, Montefresco, Las Palmas, Saturno, Villeda Morales, San Jorge de Sula, San Jose de Sula, Villa Ernestina, Villa Olímpica, Islas del Progreso II, Montefresco Este, Montefresco Centro, Islas del Progreso, La Unión, Zona Ind. Contiguo Col. Paz, Valle de Sula, Hermosa Provincia, El Paraíso, Buena Vista, La Sabana, Los Ángeles, Mi Única Esperanza, Segundo Anillo-Desvió a El Limonar **Sector Noroeste:** Cementos de Honduras, Alamos-Nova,Nova, Etahsa, Agua Caliente, Armenta Juan Lindo, El Campo, Santa Ana-M.C.R., Peña Blanca, Zona Cervecería, Zeron, Universidad, El Playón, Hernández Morel, Bermejo, Finca Vieja, Bosques del Merendón, La Humildad, Rancho, El Coco, Nueva Esperanza, Bella Vista **Sector Nor-Este:** Guadalupe-2do. Anillo, La Esperanza, Bogran-2do. Anillo, Florida, Andalucía Las Vegas, Modelo, Odilón Ayestas, Brisas No. 3, Esquipulas No.2, El Sauce, Bordo Universal-Las Vegas, Villas del Carmen-El Carmen, 2do. Anillo-El Limonar

SITIOS CRÍTICOS	*CRITERIOS*
	Sector El Carmen: Odilón Ayestas, Cablotales, Limonar-Lomas del Carmen, La Lima-Lomas del Carmen, Villas del Carmen-El Carmen, JNBS El Carmen, Ángeles del Carmen y 2do. Anillo-El Limonar **Sector: Chamelecón**: Reyes Leiva, Monte Bello, Providencia II Etapa, San Antonio II Etapa Lempira No. 1, Peaje Lempira No. 2, Chamelecón, San Jorge, San José, Fe y Esperanza Sabillón Cruz, Palmira, Berman Hdez. Col. 14 de Julio, Berman Hernández, Chotepe, La Bolsa **Sector Rivera Hernández**: Aeropuerto-Bordo, El Chorizo, Cablotales, La Pedrosa, Sandoval Soto, El Edén, La Cuchilla, Santa Martha, Llanos de Sula IV, Cristo Viene, Santa Venecia, Luke, Montanita, 6 de Mayo (Asentamiento), Reyes Martínez, Alfonso Lacayo, Llanos de Sula I Venecia, 6 de Mayo, Central, Ruiz, La Solita, Villas Kitur I, FESITRANH II 2da Etapa, Brisas del Aeropuerto, Puerto Escondido, Cerrito Lindo (Proyecto), FESITRANH II, José IV. Arriaga I, Nueva Esperanza, Monte Verde, Guanacaste, Induna, Villa Ernestina-Miguel Ángel Pavón, Perfecto Vásquez, Villas Kitur III, Llanos de Sula II, Bordo 6 de Mayo, Campo Alegre, Central-Santa Martha Centralita, Carr. La Lima-Lomas del Carmen, Los Ángeles y Mi Única Esperanza ▪ La cantidad de **red vial pavimentada expuesta a amenaza** Alta es 6.31 km, media= 14.5 km, Baja= 52.7 km ▪ La cantidad de **red vial no pavimentada expuesta** a amenaza alta es 0.5 km, Media=3.8 km, Baja =13.56 km **Histórico:** En Taller de Eventos Extremos se mencionan varias colonias y barrios dentro de los sectores de Rivera Hernández, Chamelecón y El Carmen. En DesInventar se encuentra la información siguiente ocurrida en 1979: Ciudad de SPS, Comunidad la Centralita, Comunidad Puerto Escondido, Comunidad Río Blanco, Colonia Rivera Hernández, Colonia Brisas del Sauce, Barrio el Centro, Colonia la Centralita, Colonia 6 de mayo, Comunidad la Montañita, Asentamiento campesino La Mesa Número uno, Col. Santa Martha, La Solita hubo 6 muertos, más de 32 000 damnificados, 2 000 afectados, 4 600 evacuados, 707 viviendas destruidas, 24 inundadas, 2 749 Ha de cultivos destruidos, 4 represas que proveen el 50% del agua de la zona se dañaron y 5 tanques de abastecimiento de agua colapsaron por acción de las lluvias **Técnico Científico:** Según el análisis de hidrología-hidráulico estos sectores están bajo amenaza de inundaciones.
Sitios Críticos 3: Barrios actualmente protegidos por bordos, pero con registros históricos de eventos importantes.	Potencial falla de bordos que actualmente protegen asentamientos humanos y áreas cultivadas. Esto se considera prioritario y mayores estudios se deben realizar para determinar la condición en la que se encuentran estos bordos, debido a que se podría producir una inundación repentina o evento súbito, que no permite reaccionar a tiempo. Algunos críticos a nivel urbano son: **(i) área bajo amenaza se encuentra cercana al Río Chamelecón y otros afluentes (Río Blanco, Chotepe, El Carmen, Amarillo**, **Histórico:** Han presentado daños a personas y bienes (DesInventar) **(ii) Bordos (Asentamientos humanos en zonas de Riesgos) dentro del casco urbano** **Histórico:** Problemática de años para el municipio. Estudios y acciones de emergencias. **Técnico Científico:** Considerado sitio crítico por ruptura de bordos en el Plan de Prevención y Mitigación de Amenazas por Inundaciones y Terrenos Inestables (2002).

Fuente: Elaboración con base en datos de PMGR, 2006; DesInventar, 2014; Alcaldía Municipal de San Pedro Sula (2015); Taller 02 Evento Extremos y Recurrentes, 2015; levantamiento de infraestructura crítica, 2015; Informe de Hidrología (Rojas, Ayala, 2016); e Informe Geomorfológico (Šebesta, 2016).

Ilustración 18. Sitios críticos por inundaciones, centro urbano San Pedro Sula



Fuente: Elaborado con base en datos de Sinit, 2006; Alcaldía de San Pedro Sula, 2015; levantamiento de infraestructura crítica, 2015; Informe de Hidrología (Salinas et al., 2016); e Informe Geomorfológico (Šebesta, 2016)).

ANNEX 2

ECA: Flood Analysis of San Pedro Sula 2020

Flood Analysis of San Pedro Sula (Honduras)

Final Report

December 2020

UNU-EHS

Editors

Alvaro Rojas

Maxime Souvignet

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Abbreviations

abbreviation	unit	explanation
FHIS	-	Manual de referencias Hidrologicas
IDF	-	Intensity-Duration-Frequency (precipitation)
n	$s/m^{1/3}$	Manning's n roughness coefficient
n_o	-	roughness value for channel material
n_1	-	roughness value for level of irregularity
n_2	-	roughness value for variation between cross sections
n_3	-	roughness value for the relative effect of obstacles
n_4	-	roughness value for vegetation
m_5	-	correction factor to account for meandering of the channel
SCS	-	Soil Conservation Service
TR25	-	return period of 20 years
TR50	-	return period of 50 years
TR100	-	return period of 100 years
BC	-	Boundary condition
XS	-	Cross sections
RCP8.5	-	Representative Concentration Pathway 8.5
RCP4.5	-	Representative Concentration Pathway 4.5

1 Introduction

In the past Honduras has been repeatedly affected by flood events, caused by heavy rainfalls. In agreement with the Intergovernmental Panel on Climate Change (IPCC), a changing climate is likely to result in increasingly extreme weather conditions. This leads to higher frequencies of heavy precipitation in many regions of the world and unprecedented disasters (Seneviratne et al. 2012). Thereby countries with a high vulnerability will be most at risk. According to Kreft et al. (2015), Honduras suffered the highest economic losses due to climate related disasters between 1994 and 2013 in whole Central America. Especially Hurricane Mitch resulted in long-term consequences for the economy, the environment and the livelihood of Honduras' inhabitants.

The city of San Pedro Sula, located in the Sula Valley and the Merendon mountain chain, is the second largest city of Honduras. One of the poorest countries in Latin America, more than half of the inhabitants of Honduras lives below the poverty line (Hernandez Ore et al. 2016). As a result, a part of the population (2.4 %) lives in informal settlements. These so-called bordos are located along the riverbanks, thus in those areas most frequented by floods. Consequently, the inhabitants of the bordos are especially exposed to floods. Specifically, this concerns about 18,000 families. According to the Permanent Committee for Contingency Management (COPECO), the city of San Pedro Sula has a population of 754,000 inhabitants, of which 32% live in areas with high risks for flooding. 29.6 % of the population that lives in areas of high risk for flooding is located in the low land of the city, like the surrounding areas of river Chamelecon. The great exposure due to natural climate conditions and the spatial structure of the cities, combined with a low resilience, leads to a great vulnerability of Honduras' population towards floods.

In order to manage and to minimize damages of flood events, it is of great importance to identify those areas which are prone to flooding and those which are of high risk for the present and future. Hydrodynamic models form a tool to conduct these sorts of assessments, while providing the possibility of including various scenarios. This study aims at updating an existing HEC-RAS flood model provided by COPECO for the municipality of San Pedro Sula. Using new data and a two-dimensional approach, flood areas are depicted for the three major rivers Chamelecón, Rio Chotepe and Rio Blanco, including their larger tributaries. Future scenarios were determined by Representative Concentration Pathways (RCPs) adopted by IPCC in 2014. Future scenarios include projections based on the "worst-case scenario" (RCP 8.5) and the "intermediate scenario" (RCP 4.5). In addition, possible effects of the construction of a multipurpose power plant (El Tablón) were taken into account.

2 Previous studies and available data

In the last years, several studies took place examining flood hazard in San Pedro Sula region. COPECO conducted a detailed investigation in 2016 with the objective to provide a tool to support the municipality of San Pedro Sula in the creation of land management plans. Thereby the purpose was to minimize the economic impact of flood events on both the infrastructure and the live of the inhabitants. Evaluating hydrometeorological information, flood extents for the return periods 25, 50 and 100 years were estimated, using a hydraulic 1D model (HEC-RAS). With the estimated flow, the topography of the site and the channel characteristics, flood levels were computed. The COPECO-project focused on the areas in proximity to the rivers Río Blanco, Río Bermejo (with Río Chotepe and Canal Sauce as tributaries) and Río Chamelecón, as well as Cofradía.

Carlos Roberto Abrego Suaréz conducted an additional study in 2019, which further investigated flooding in the catchment of Río Chamelecón in the Sula Valley. A region, which in the past, was exposed to the hurricane events Fifi and Mitch. These events caused heavy damages, especially in the city of La Lima. In order to update warning thresholds for the Chamelecón River, the hydraulic transit of the flood flows was considered, using HEC-RAS as a hydraulic model. The consideration of the channels Filopo and Maya played a crucial role, since their hydraulic capacity influenced flooding significantly.

The presented studies and their findings were carefully analyzed and the provided data was scanned in order to use the existing models and results for further development of the hydrologic and hydraulic

modelling approach. In Table 1 the existing data of the COPECO study (2016) and the study by Abrego Suaréz is listed, also displaying the data availability for this study, as not all data was accessible.

Table 1: Existing data on hydrologic and hydraulic modelling in San Pedro Sula region with annotation if data was available for the present study and for what purpose it was used

Title	Explanation	Source	Availability	Comment on usage
1D model of Río Blanco	HecRAS model	COPECO	yes	enhancement to 2D modelling
1D model of Río Chamelecón	HecRAS model	COPECO/ Abrego Suárez	yes	enhancement to 2D modelling
1D model of Río Chotepe and Tributaries	HecRAS model	COPECO	yes	enhancement to 2D modelling
Bridges crossing Río Blanco Bulevar del Norte Segundo Anillo Periférico	HEC RAS model	COPECO	yes	utilization for hydrologic modelling
computed inundation depths (TR20, TR50, TR100) via 1D model of Río Blanco	raster format	COPECO	yes	validation
computed inundation depths (TR20, TR50, TR100) via 1D model of Río Chotepe and tributaries	raster format	COPECO	yes	validation
computed inundation depths (TR20, TR50, TR100) via 1D model of Río Chamelecón	raster format	COPECO	yes	validation
computed inundation depths (TR20, TR50, TR100) via 1D model of Río Chamelecón	pdf	Abrego Suárez	yes	validation
Cross section data	No measured values	COPECO/ Abrego Suárez	yes	used for adapting DEM in hydraulic modellingy
DEM	DEM (SPS_DstrbFixF.img) with combined information out of the DEM5 and DEM1	COPECO	yes	used for hydrologic and hydraulic modelling (adapted)
El Tablon discharge Values	Discharge calculation for the planned hydroelectric power dam El Tablon	UNU	yes	
Hydrologic model of Río Blanco	HecHMS model	COPECO	no	-
Hydrologic model of Río Chamelecón	HecHMS model	Abrego Suárez	yes	utilization for hydrologic modelling
Hydrologic model of Río Chotepe and Tributaries	HecHMS model	COPECO	no	-
Hydrological soil group (SCS)		Abrego Suárez	yes	
information about legal/illegal settlement	Reubicacion_pob_en_bordos.shp	Municipality of San Pedro Sula	yes	utilization for hydrologic modelling (roughness)
information of buildings	Shapefile (CSPS_URB_2016.shp GIRO <> "SOLAR BLADIO"	Municipality of San Pedro Sula	yes	utilization for hydrologic modelling
Land use	USO_SUELO_VEGETAC_2017.shp	COPECO	yes	used to assign roughness parameters
MITCH data for validating models		UNU	No	-

Title	Explanation	Source	Availability	Comment on usage
precipitation data (annual)		SPS / COPECO	yes	Different sources have different values and different spatial distribution. SPS is used
precipitation data (statistical values / IDF)		FHIS (2002)	yes (pdf)	
RCA4 precipitation data	Daily maxima for the Scenarios RCP4.5 and RCP8.5	UNU	yes	Used for developing the future scenarios together with UNU
soil data		SPS / COPECO	yes	With HSG

3 Aims of the study: tasks & improvements

Main focus of this study is the improvement of flood hazard maps for the Region of San Pedro Sula. The objective was to identify areas especially at risk of flooding. The research conducted by COPECO (2016a, 2016b) and Abrego Suárez (2019) was used as a solid fundament for a first investigation of hydrologic and hydraulic approaches and was enhanced in this study.

The aspired improvements and tasks can be summarized in the following aspects:

1. Building up a hydrologic model with Hec-HMS for the catchments of Río Blanco and Río Chotepe (including the Canal Sauce), as well as further developing the existing model of Río Chamelecón.
2. Modelling of present and future boundary conditions using GCM projections for two scenarios (future high RCP 8.5 and future low 4.5)
3. Conversion from a 1D-hydraulic model-setup to a 2D model approach with Hec-Ras in three separate models for Río Chamelecón, Río Blanco, and Rio Chotepe. The model of Rio Chotepe further includes the rivers Bermejo, Piedras and the Canal Sauce.
4. Simulation of flood footprints for 25-, 50- and 100-year return periods for three scenarios (present, future high, future low)
5. Using unsteady flow hydrographs as boundary condition for hydraulic modelling instead of assuming a steady flow rate in order to improve representation of a natural flood hydrograph
6. Enhancement of the DEM through integrating and interpolating cross section data to remove artefacts, obstacles and unnatural elevations in the river bed
7. Inclusion of building structures of formal and informal settlements in the DEM

4 Methodology

4.1 Hydrologic model

Rainfall-runoff models are often used as a tool for a wide range of tasks, such as the modelling of flood events, analysis of climate change effects and man-made changes as well as the prediction of flood extents to reduce flood damages.

Within this study, the flood extents of the return periods 25, 50 and 100 years were calculated using a 2D-hydrodynamic approach. Basis for these calculations were hydrologically modelled discharge time-series, resulting from short heavy storms.

Gauged Catchments provide the opportunity to analyse precipitation or runoff measurements, to build up statistical models, to derive reliable discharge values for return periods and to validate hydrological models. All of the three catchments considered in this study are ungauged. Therefore, a rainfall-runoff simulation was used to analyse the behaviour of the catchments and to simulate concentration and transformation of water to the main river channel.

Applying a hydrological model for event-based analysis requires the description and parametrization of relevant components of the hydrological cycle. Some components, such as evapotranspiration, may be neglected, due to the short timescale of most storm events and the minor effect of these components. The description of the remaining components mainly covers total precipitation, the infiltration loss, the resulting direct surface runoff, the concentration of surface water (overland flow) as well as the routing of water within the channel.

The modelling approach may be physically oriented by describing the real physical behaviour of the single components. Thereby, the physical description of infiltration by the Richards-Equation may serve as an example. This approach in general requires data with high temporal and spatial resolution. A further modelling approach is given by conceptual models, which describe the relation between different conditions and impacts via parameters observed in field studies (e.g. soil moisture and infiltration rate). These models are often lumped or semi-distributed and have lower requirements concerning spatial and temporal resolution of data.

Semi-Distributed Models offer the opportunity to subdivide the entire catchment into sub-catchments and to build up relatively homogeneous areas for parameterization. Concerning the requirements to spatial and temporal resolution this approach lines up in the middle between distributed/physical and lumped models.

Figure 1 shows the general differences between the model approaches.

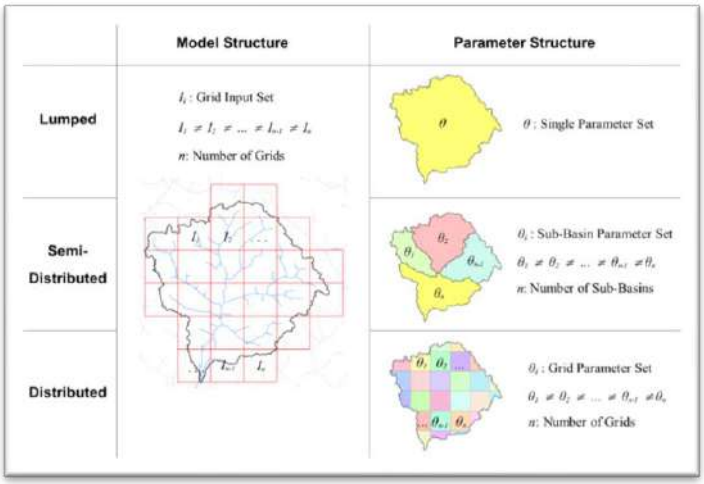


Figure 1: hydrological Modell approaches (source: S. Wi et al, 2015)

Based on the given data (temporal and spatial resolution), it was decided to model using a semi-distributed approach. The main driving factors in distributed modelling, that affect the resulting hydrograph are:

Drainage characteristics:

- Basin (Area, shape and slope)
- Soil type
- Landuse
- Drainage density
- Drainage topology

Rainfall characteristics:

- Intensity
- Duration
- Spatial & temporal distribution
- Storm motion

All of these factors have to be analysed to derive the parametrization of processes, they are involved in.

4.1.1 HecHMS model structure

The HecHMS model structure concentrates on the event-based, semi-distributed modelling, neglecting evapotranspiration and groundwater effects. Components of the water cycle that have to be parameterized are:

- precipitation input
- infiltration loss (function of soil, precipitation, and slope)
- overland flow / surface runoff (function of slope, landuse an surface runoff volume)
- river channel routing (function of river characteristics as width, depth, slope and discharge volume

As described in the chapter before, the semi-distributed approach allows the subdivision of the Catchment into sub-catchments, as shown in Figure 2. Later on, all of these processes have to be parameterized. The general workflow is shown in

Figure 3.

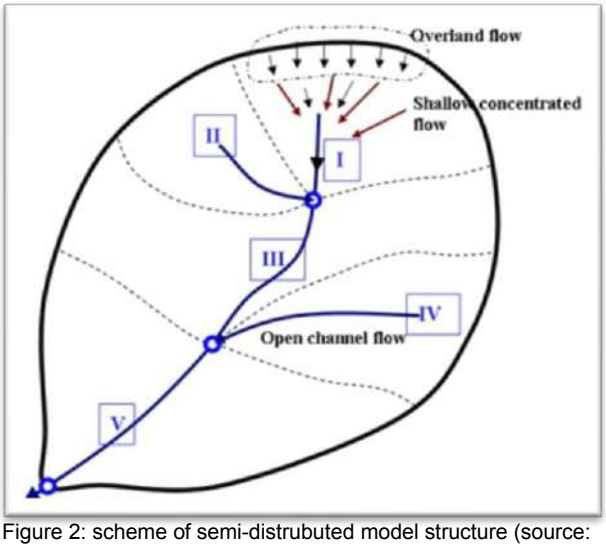


Figure 2: scheme of semi-distrubuted model structure (source: Lecture Notes Prof. Ke-Sheng Cheng)

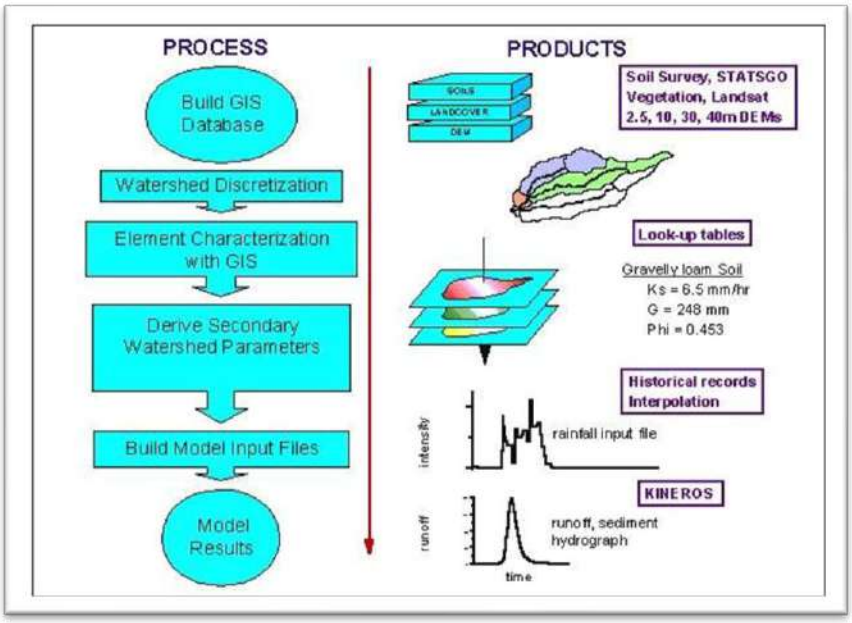


Figure 3: Schematic workflow of model generation (source: MILLER, S.N., and D.P. GUERTIN)

The internal structure of the HecHMS software requires building up an individual submodel for each considered topographical element (subbasin and river reaches as well as additional hydrological features as the El Tablon dam) and for each considered water cycle component (see Figure 4). Within the basin model, topographical elements had to be defined (subwatersheds and corresponding river reaches as well as the El Tablon-Dam discharges). Within the meteorological model, the modelling approach for precipitation was defined. The meteorological model is based on the definition of precipitation gauges as time series, that will be applied to each subwatershed individually. The entry control specification is used

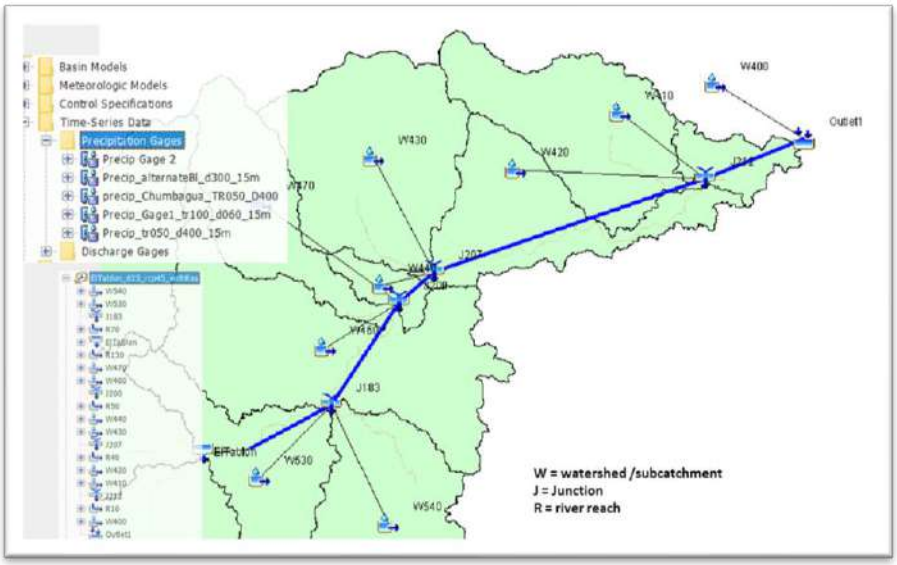


Figure 4: HecHMS relevant components of the software User Interface

to define the temporal resolution of the Simulation.

For the Rio Chamelecón the existing model was used and updated for the short-term storm duration. Basin elements and parameters were adopted without change for the present state simulations. For the future scenarios, the basin elements were adopted to simulate the effects of the El Tablon hydropower dam. Prior to the preparation of the input data, a decision regarding the submodels had to be made for the simulation of subprocesses. The following table gives an overview on the applied modelling approaches. The parameterization was done for each subwatershed and each river reach section.

Table 2: Components and Methods applied in HecHMS

SUBMODELL	PARAMETER METHOD	PARAMETER	VALIDATION POSSIBLE
PRECIPITATION	Depth-Duration-Frequency Alternate Block Method IDW	Total precipitation depth Storm duration Spatial distribution	no
INFILTRATION LOSS	SCS-CN	CN value LU Classes Hydrological soil group antecedent moisture Steepness Initial abstraction	no
SURFACE RUNOFF	CN Lag	Lag Time / Time of concentration	no
CHANNEL ROUTING	Muskingum-Cunge	Reach length & slope Channel roughness Channel shape (Slope / width)	no

4.1.2 Input parameters

A main part of the set-up of the HecHMS-Model, as well as of the parameter estimation, is the preparation of precipitation data and the analysis of the DEM. This first step is conducted with the objective to derive most of the above-mentioned parameters using the GIS Systems ArcGIS, QGIS and the extensions ArcHydro ans Hec-GeoHMS

4.1.2.1 DEM / Characterization of subwatersheds and river reaches:

The available DEM was used to derive flow accumulation and to define the sub-catchments. The analysis was carried out with different resolutions of the raw DEM (1m resolution) to rebuild the given river network with the main characteristics. For the flow accumulation spatial resolutions of 5, 10, 25, 50 and 100m were utilized. It was found that for the Rio Blanco, the best resolution was the 10 m resolution, whereas the best resolution for Rio Bermejo was the 25 m resolution. For both of the rivers, the DEM was modified to derive the correct river network and to assign adequate subcatchments. For the Rio Blanco, the inflow to San Pedro Sula was redirected into a culvert to reach Rio Blanco. Concerning the Rio Bermejo, one important change had to be implemented into the DEM to rebuild the correct river network and to consider a bypass around the settlement (Black arrows in Figure 5).

Based on the hydrological DEM, the subdivision of catchments was refined, taking into account changes in altitude and differences in the amount of settlements.

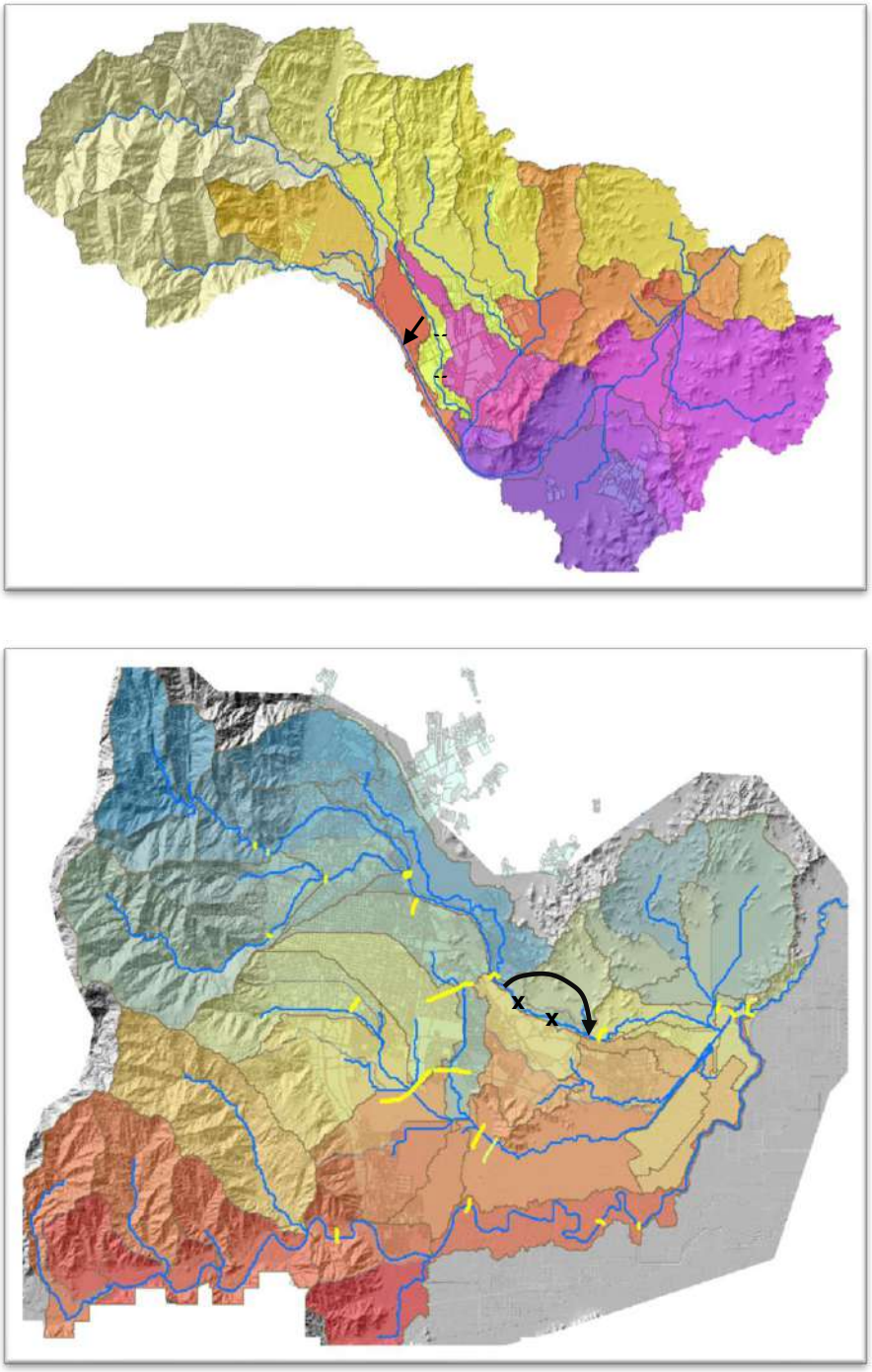


Figure 5: Subcatchments of Rio Blanco (above) and Rio Chotepe (below), as well as the integrated DEM changes (black arrow)

Figure 6 shows the final division of subcatchments for Rio Blanco and Rio Chotepe. Based on that final determination, the topographical characteristic, such as area, slope, river length and drainage density were calculated for each watershed.

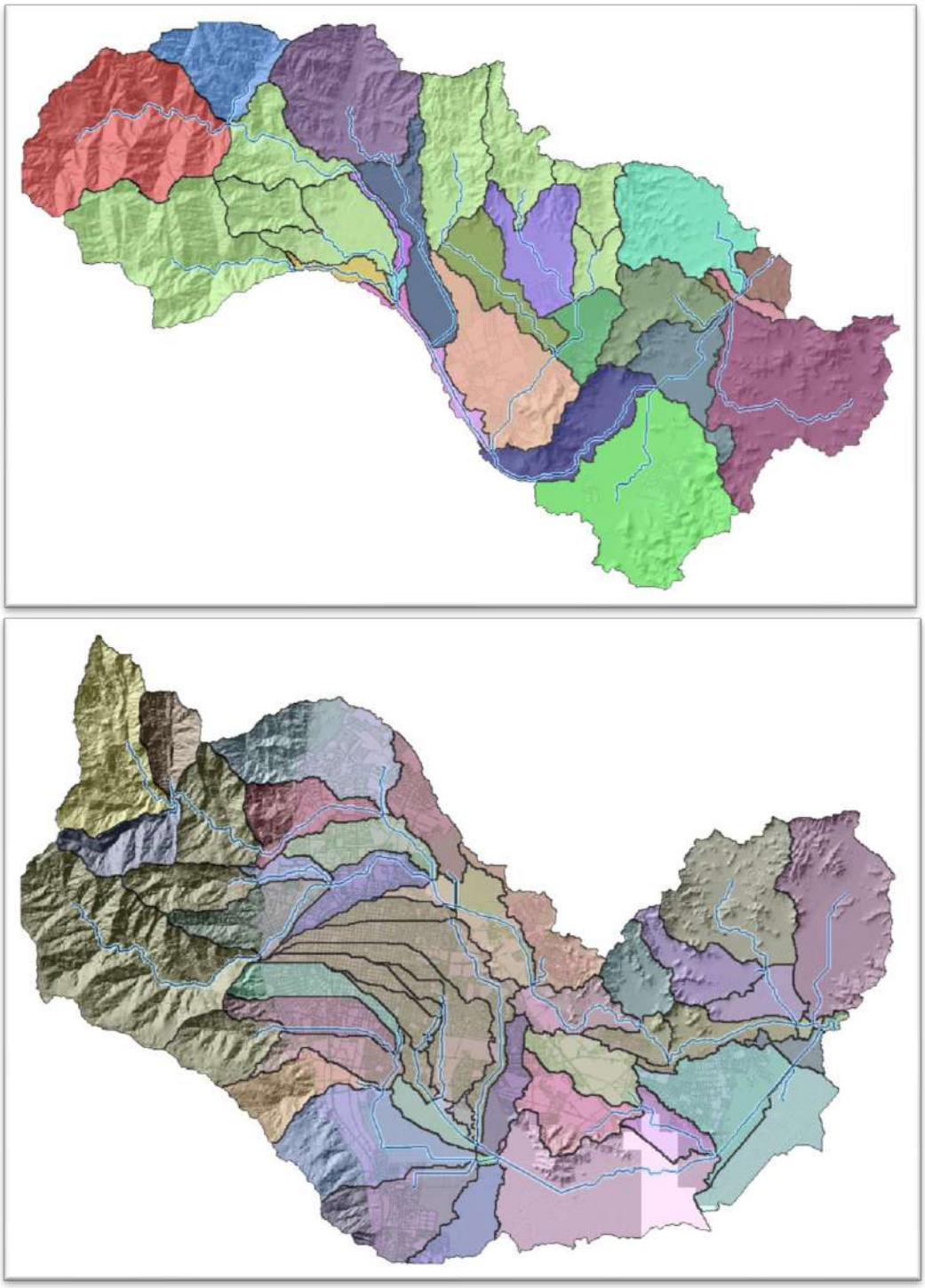


Figure 6: final definition of subcatchments for Rio Blanco and Rio Chotepe (see Annex)

4.1.2.2 Precipitation:

Precipitation is one of the most critical input data sets, defining the amount of water that is given into the simulated water cylce. Unfortunately, precipitation data with high temporal resolutions (higher than daily) was hardly available for the study region. Several Data sources were evaluated, but the FHIS (2002) provides the best information in terms of temporal resolution.

Based on the FHIS (2002), precipitation stations with existing statistical analyses were located, allowing to determine precipitation depth for short durations. Figure 7 gives an overview on the relevant precipitation stations.

The applied storm characteristics were based on the following assumptions: The storm will be applied equally to the whole subcatchment with the same duration and the same precipitation depth over time.

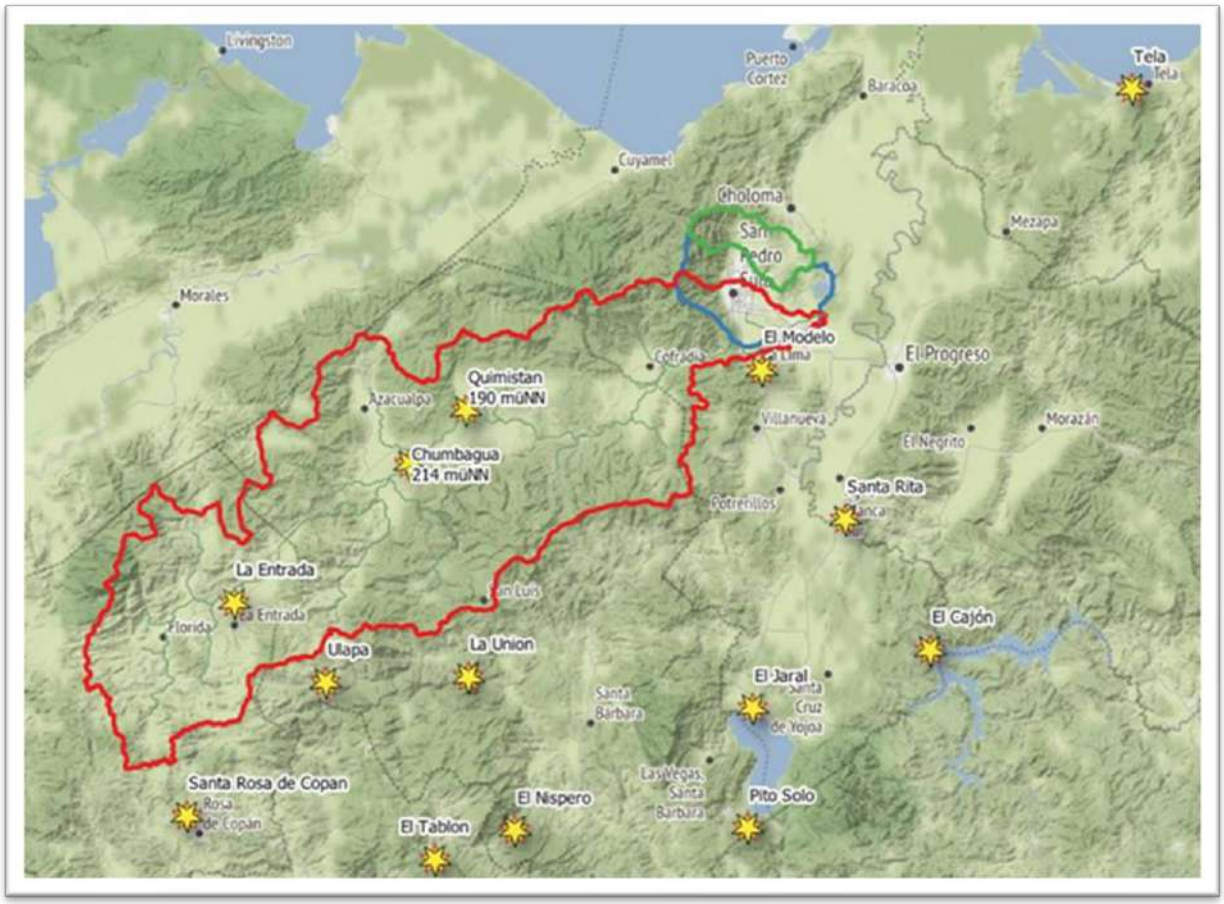
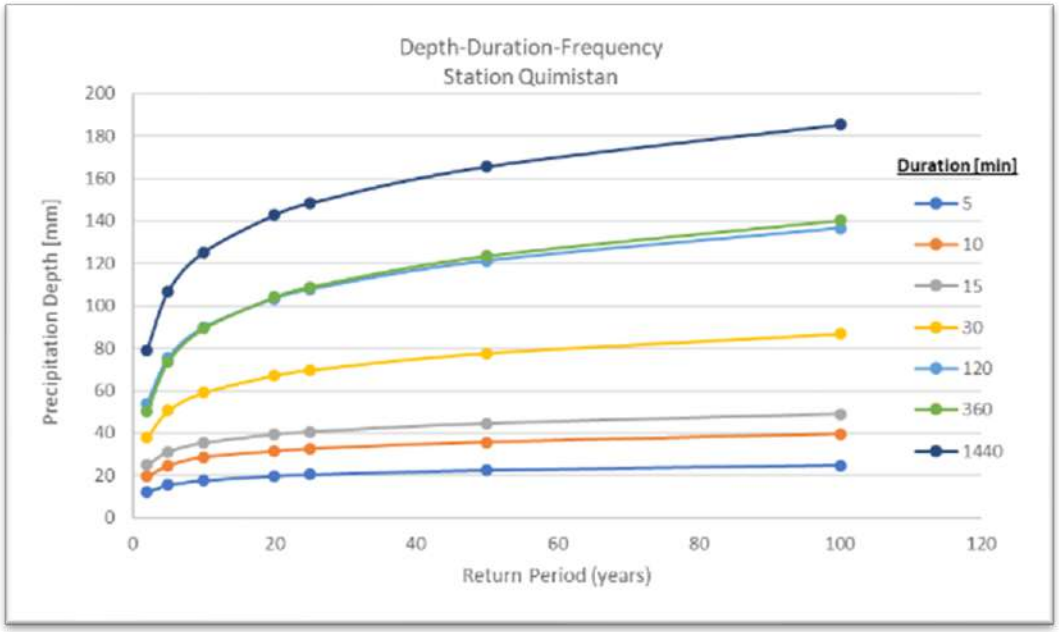


Figure 7: Overview relevant precipitation station of FHIS (2002)



Return Period	2	5	10	20	25	50	100
Duration	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
5	12.21	15.5	17.67	19.76	20.42	22.46	24.81
10	19.61	24.76	28.71	31.44	32.59	35.68	39.48
15	24.96	31.21	35.34	39.31	40.56	44.44	48.89
30	37.87	50.64	59.1	67.21	69.77	77.72	86.82
360	50.12	73.69	89.29	104.26	108.99	123.65	140.43
120	53.86	75.45	89.75	103.47	107.80	121.24	136.62
1440	79.24	106.95	125.3	142.91	148.47	165.71	185.45

Figure 8: Depth-Duration-Frequency curve (RP 25 and 100 interpolated)

Focusing on a short storm duration is an essential point, as short duration storms generally show a higher precipitation intensity, compared to long duration storms. Additionally catchment characteristics (shape, slope, landuse, etc.) define the concentration of surface runoff to the outlet in the main channel – superposition of surface runoff and channel discharge from subcatchments has to point out the “worst” (highest) superposition and peak discharge. Therefore, it is recommended that the selected storm duration is close to the time of concentration of each subcatchment. Because of later on discussed results and availability of data, the storm duration was defined as T = 320 min and T = 400 min. This decision was based mainly on the time of concentration and subcatchment analysis.

Precipitation depth for these storm durations were calculated on the base of the FHIS (2002) values and depth-duration statistics. Distribution over time was done with the alternate Block method. The return periods 25 and 100 years were interpolated from exiting values. The following figure (Figure 9)**Fehler! V erweisquelle konnte nicht gefunden werden.** provides an example for the station Quimistan.

The Method was applied to each precipitation station separately. The results were spatially interpolated via Inverse Distance Weighting (IDW). With the help of a regional analysis, the mean precipitation value was calculated for each subwatershed individually

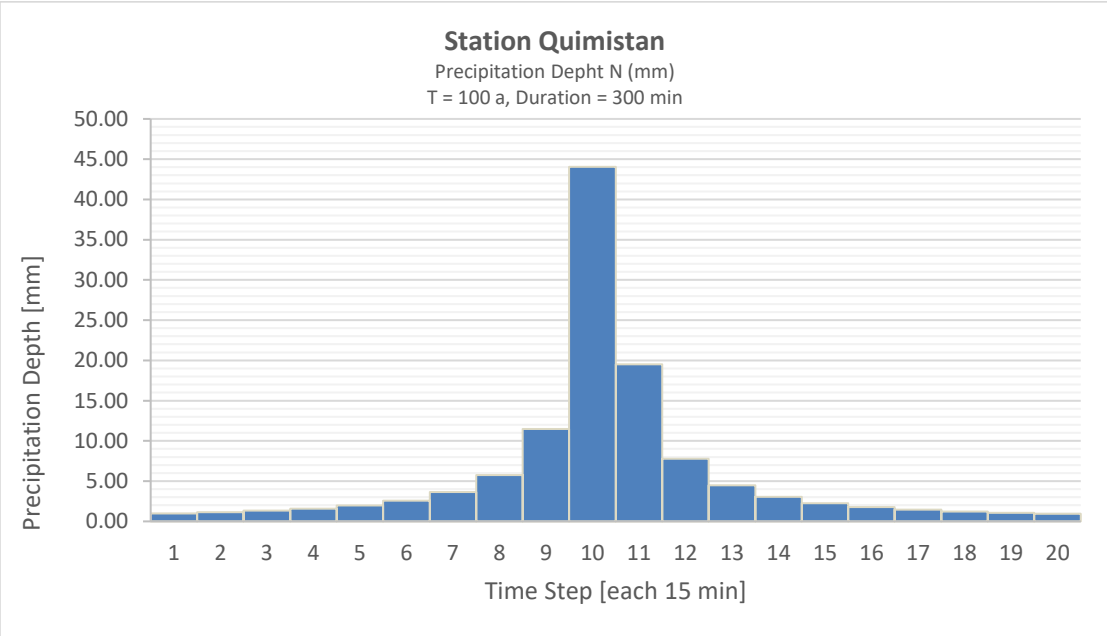


Figure 9: Application of Alternate Block Method / Precipitation Station Quimistan T=100 a, D=300 min

4.1.2.3 Infiltration / CN-Values

Infiltration was considered via the runoff Curve Number method (CN) developed by the *Soil Conservation Service (SCS).* The method generally requires soil and landuse information to set up a conceptual relation between infiltration, storage and infiltration excess. The initial abstraction was set to 0.2. The initial abstraction accounts all possible losses prior to runoff (e.g. interception, surface depression storage) Soil information was classified in Hydrological Soil Groups (HSG), defined by their hydraulic infiltration capacity.

$$Q = \frac{(R - 0.2\,S\,)^2}{R + 0.8\,S} \qquad [mm]$$

$$S = \frac{1000}{CN} - 10 \qquad [mm]$$

A polygon-shape was provided with a relatively coarse resolution of soil types and the already existing classification to HSG (Table 3 and Figure 10).

Table 3. Soil types available in the catchment Rio Blanco and Rio Chotepe

SOIL TYPE	***TAX***	***HSG PROVIDED***	***HSG ASSIGNED***
ALIVIAL BIEN DRENADO TEXTURA GRUESA	*AG*	*A*	*A*
ALUVIAL BIEN DRENADO TEXTURA FINA	*AF*	*A*	*A*
TOMALA	*Ta*	*B*	*B*
ALUVIAL MAL DRENADO TEXTURA FINA	*AM*	*D*	*D*
SUELO DE VALLES	*SV*	-	*C*

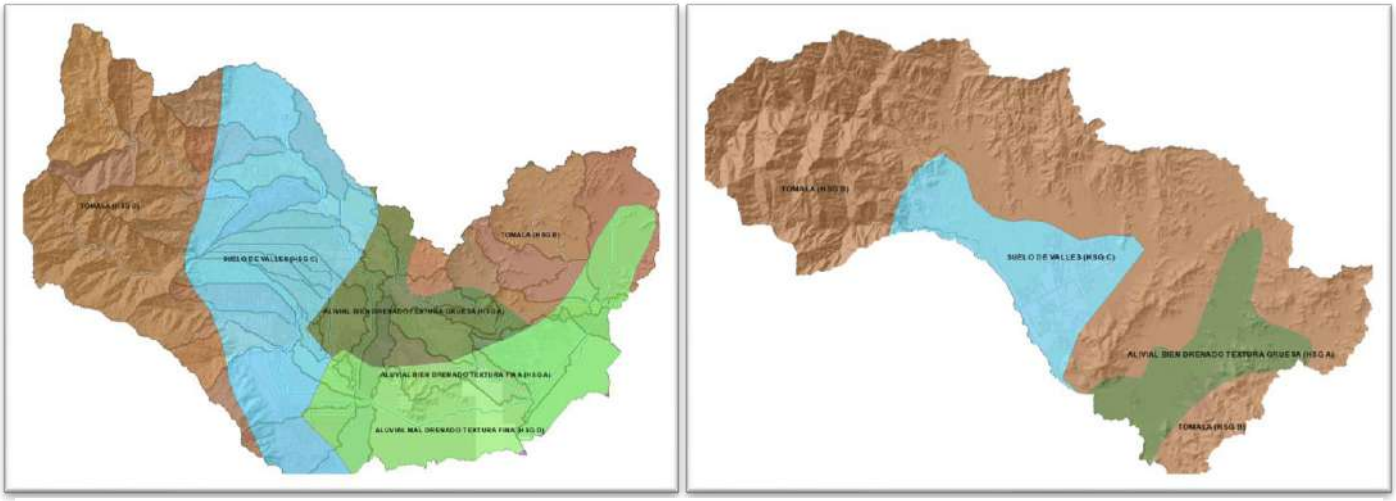


Figure 10: soil map Rio Chotepe (left) and Rio Blanco (right)

For the landuse, the same dataset as described in chapter 4.2.5 was used. Landuse classes were assigned to the CN-Values provided by the FHIS (2002) and complemented with the following literature: Ward (2004) and Hawkins et al (2002). Table 4 shows the resulting lookup-Table.

Table 4: Landuse Classification to CN II - Values

CN_ID	USO DE SUELO 2014_ENG	USO DE SUELO 2014_ESP	A	B	C	D
1	Agriculture	Agricultura Tecnificada	72	81	88	91
2	Deciduous Forest	Bosque Latifoliado Deciduo	45	66	77	83
3	Evergreen deciduous forest	Bosque Latifoliado Humedo	25	55	70	77
4	Mixed Forest	Bosque Mixto	25	55	70	77
5	Coniferous forest (dense)	Bosque de Conifera Denso	45	66	77	83
6	Coniferous forest (light)	Bosque de Coniferea Ralo	36	60	70	77
7	Coffee plantations	Cafetales	48	68	79	83
8	Artificial water bodies	Cuerpos de Agua Artificial	100	100	100	100
9	Natural lakes and lagoons	Lagos y Lagunas Naturales	100	100	100	100
10	African palms	Palma Africana	71	80	87	90
11	Pasture/Crops	Pasto/Cultivos	30	58	71	78
12	Continuous Urban area	Zona Urbana Continua	89	92	94	95
13	Single tree groups	Arboles Dispersos Fuera de Bosque	43	65	76	82
14	Non-vegetated area (continental)	Suelo Desnudo Continental	77	86	91	94
15	Secondary deciduous forest	Vegetacion Secundaria Decidua	40	40	51	58
16	Secondary evergreen deciduous forest	Vegetacion Secundaria Humeda	40	65	80	87

The Antecedent Moisture Class (AMC) for heavy, short-duration storms is usually set to AMCIII, this class assumes a high soil moisture and infiltration excess. Concerning the high relief energy in the catchments Rio Blanco and Rio Chamelecón, the classification into AMC-classes was replaced by the modification of CN-values via the terrain slope. The involvement of terrain slopes modifies the CN values and is guided by the SWAT-approach, described by Williams (1995) and Bieger et al. (2015).

$$\mathrm{CN}_2 = \frac{\mathrm{CN}_3 - \mathrm{CN}_2}{3} * \left[1 - 2 * \exp(-13.86 * s)\right] + CN_2$$

4.1.2.4 The resulting CN values tend to be higher as the calculated CN_3 values. For each watershed, the required SCS-CN parameters were calculated individually and transferred to the HecHMS-Model.Time of Concentration and Lag-Time

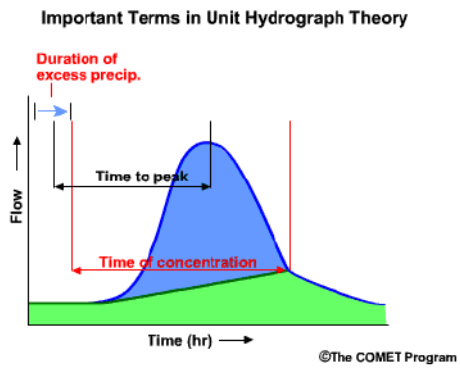
Concentration times were calculated according to the FHIS (2002) manual and further common approaches. Different approaches were taken into account to compare the outcomes and to have an idea about the reliability of the resulting timescales. Because of the restricted time frame of the project, it was not possible to extend this sensitivity analysis into modelling. This would have helped to analyze effects on hydrographs or simulated flood extents. The time of concentration and lag time are defined as following:

Time of concentration T_C

Longest travel time for a drop of water to reach the watershed outlet in time of the end of rainfall excess ti, the infection point of the hydrograph's recession curve.

Lagtime T_L

Time from the rainfall center of mass to the hydrograph peak



Citing the FHIS (2002), following terms are defined:

Time of concentration T_c, Kirpich:

$$T_c = 0.01947 \left(\frac{L^{0.77}}{S^{0.385}}\right) \qquad [min]$$

L = Flow Length [m]

l = Flow Length [km]

S = [m/m]

Time of concentration T_c, Rziha:

$$T_c = \frac{l}{72\, S^{0.6}} \qquad [h]$$

For the Lag-Time, the following relation is defined:

Lag-time T_L:

$$T_L = 0.6 * T_C \qquad [all\ in\ h]$$

Both times were first calculated within GIS and transferred to the HecHMS Modell.

4.1.2.5 Channel Routing

Channel routing for Rio Blanco and Rio Chamelecón was implemented via the Muskingum-Cunge Method. The necessary parameters for the Muskingum method were estimated via the DEM analysis and the assumptions of river channel characteristics. Reach length and reach slope were derived by the definition of subwatersheds and the analysis of the DEM. Channel roughness was set according to the description in chapter 4.2.5. The shape of the river cross sections for the Rio Chamelecón were set to a trapezoidal shape with 8 m bottom width and a side slope of 1:2. For the Rio Blanco, the channel shape was set rectangular varying from 5 m width (upstream) up do 50 m width upstream. Initial values were taken from aerial photos and adopted in the plausibility check. These parameters are clearly tuning parameters, because of the missing measurements and validation data. The channel routing of Rio Chamelecón was done based on the Muskingum Method.

4.1.2.6 Precipitation for future scenario

For the design of the future scenarios, the above mentioned HecHMS-Models were used. The future precipitation change was examined using the regional climate model RCA4 and the scenarios RCP4.5 and RCP8.5. The regional climate Model RCA4 provides daily precipitation with a spatial resolution of about 0.44° (approximately 50 km). The dataset was separated into a past and a future time period (past: 1950 – 2005; future 2006 – 2100) for a statistical analysis done in corporation with the UNU to obtain statistical precipitation depths for the return periods 25, 50 and 100 years.

Involving an additional data set for future scenarios raises the following tasks:

a) Comparability of return periods and their precipitation depth for the past (1950 - 2005) with different spatial and temporal resolutions
b) Connection of future precipitation, derived from the climate model, and the statistical precipitation depth derived from the weather stations
c) Filling the gaps in spatial resolution between short storm durations of 300 min and 420 min with the daily data

The comparison between the station data and the data given by the RCA4 model, showed a general overestimation of the daily data from the model. As an example, the analysis of the station Quimistan is given below (Table 5 and Figure 11). The overestimation rises with increasing return period.

Table 5: Comparison of precipitation Data FHIS (2002)/ RCA4

Station Quimistan	**Return Period**	**2**	**5**	**10**	**20**	**25**	**50**	**100**
Scenario	**Duration [min]**	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
Present, station (...)	**1440**	**79.2**	**107**	**125.3**	**142.9**	**148.47**	**165.7**	**185.45**
Present, RCA4 (1950 - 2005)	**1400**	107.79	157.60	193.93	232.92	246.5	293.38	351.4
RCA4 rcp4.5 (2006 - 2100)	1440	114.0	167.6	206.5	247.8	262.1	310.8	369.6
RCA4 rcp8.5 (2006 - 2100)	1440	115.9	174.1	219.6	271.9	291.1	363.0	468.4
CHIRPS (1981 - 2020)	1440	103.6	148.1	174.9	199.0	206.3	227.9	248.2

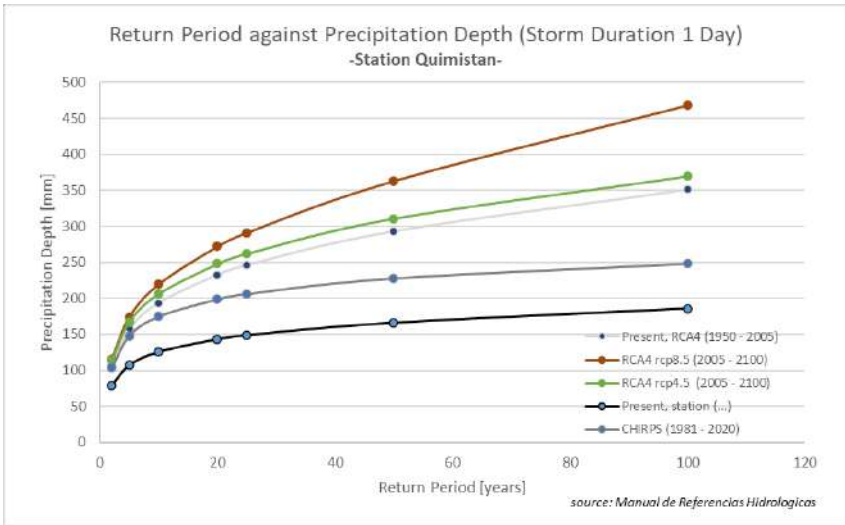


Figure 11: Comparison of Return Period / Precipitation depth of RCA4 and station analysis

To bridge the gap, the above-mentioned tasks were addressed by introducing a precipitation factor. The precipitation factor was derived by analysing the RAC4 statistical analysis for the past period on base of the corresponding scenario (e.g. RCP4.5) to express the future increase or decrease of precipitation. Derived factors ranged from 0.74 (meaning a decrease) to 1.68 (meaning an increase). The mean increase factor for all analysed stations measured about 1.19. The factor was applied to the present precipitation depth for each station and return period, to derive future precipitation. The factor was spatially interpolated, as explained in Chapter 4.1.2 for the precipitation values and applied to each watershed.

4.1.2.7 El Tablon hydropower Dam

The El Tablon dam was considered as an additional future scenario. Information about the El Tablon dam was limited to the following table shown in Figure 12, providing planned discharge values. Information on storage-discharge, elevation-discharge or elevation-storage was not available. The exact location of the dam was estimated on the base of the available maps (Figure 12).

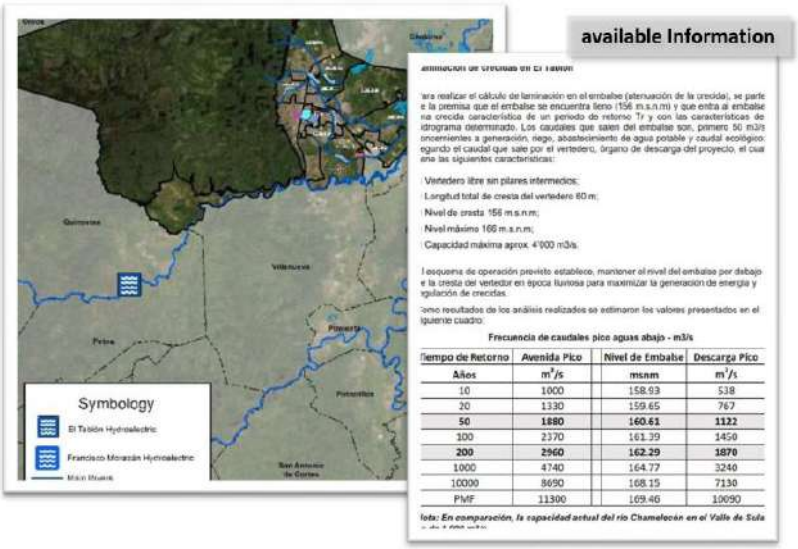


Figure 12: available Information about El Tablon hydropower Project

Given the fact, that the hydrological Model of the Rio Chamelecón already exists and no background data was available, the Reservoir was included with the following assumptions and workflow:

1) Shifting of Dam location upstream inflow the corresponding watershed

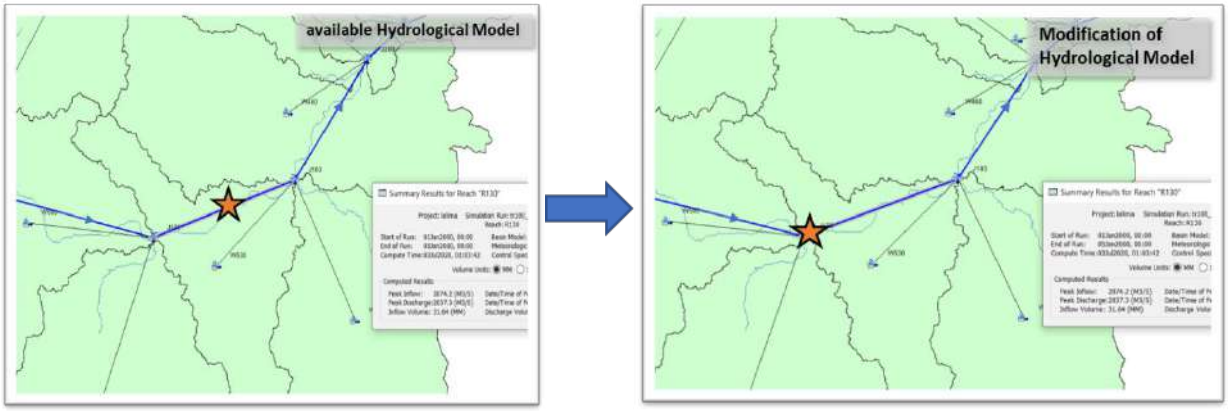


Figure 13: Location of El Tablon dam within the HecHMS-Model

2) Calculation of the contributing area to the model location of El-Tablon

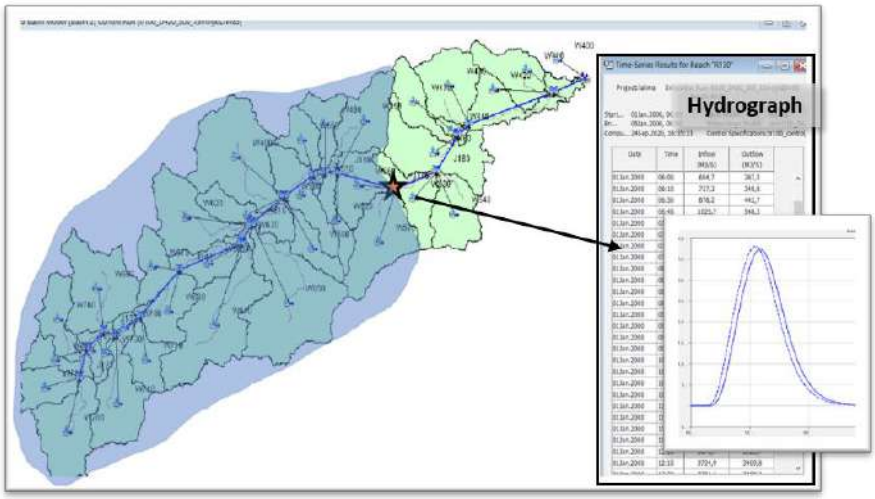


Figure 14: Calulation of “El Tablon catchment”

3) Locating the discharge Peak of the contributing area to the given discharge Table for El Tablon reservoir and cutting off the peak discharge by the influence of the reservoir.

Tiempo de Retorn	Avenida Pico	Nivel de Embalse	Descarga Pico
Años	m3/s	msn	m3/s
10	1000	158.93	538
20	1330	159.65	767
25	**1422**	**160**	**826**
50	**1880**	**160.61**	**1122**
100	**2370**	**161.39**	**1450**
200	2960	162.29	1870
1000	4740	164.77	3240
3200	6177	166	4656
10000	8690	168.15	7130
20000	11300	169.46	10090

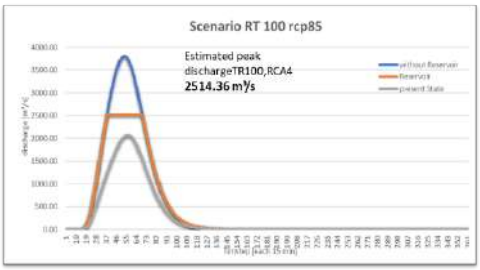


Figure 15: Calculation of El Tablon influence

4) Application of modified discharge Hydrograph as outflow from El Tablon as input for the downstream hydrological Model

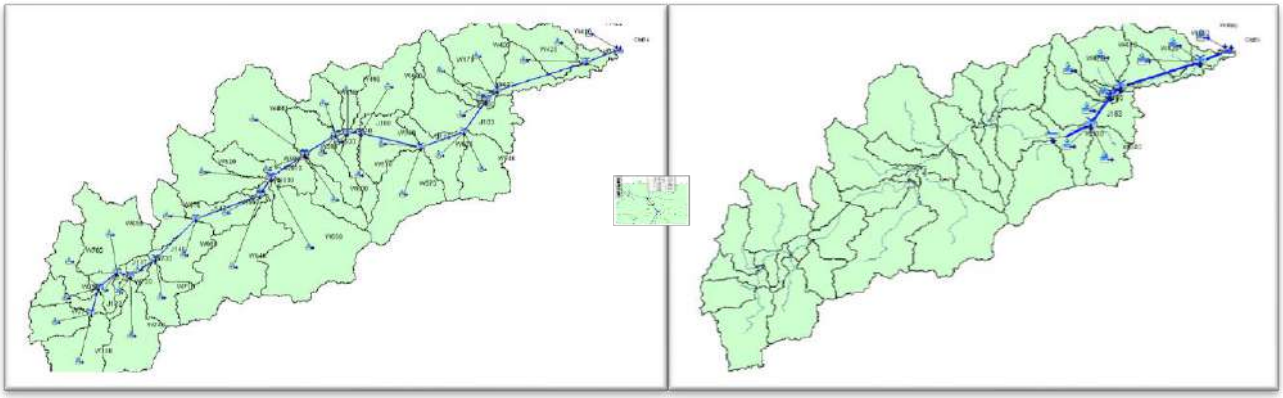


Figure 16: application of El Tablon outflow Hydrograph as boundary condition for downstream simulation

4.1.3 Computation of probabilities/return periods

As described above, the modelling was carried out for the return periods of 25, 50 and 100 years, combining two future scenarios. The El Tablon reservoir was included in the future scenario of the Rio Chamelecón model. The following tables provides an overview about the results.

Table 6: simulation results Rio Blanco

Rio Blanco	RP 25	RP 50	RP 100
Q Present state	1'110.5 m³/s	1'331.4 m³/s	1'425.0 m³/s
Q Future Scenario RCP4.5	1'229.4 m³/s	1'514.5 m³/s	1'854.4 m³/s
Q Future Scenario RCP8.5	1'446.1 m³/s	1'869.0 m³/s	2'392.9 m³/s

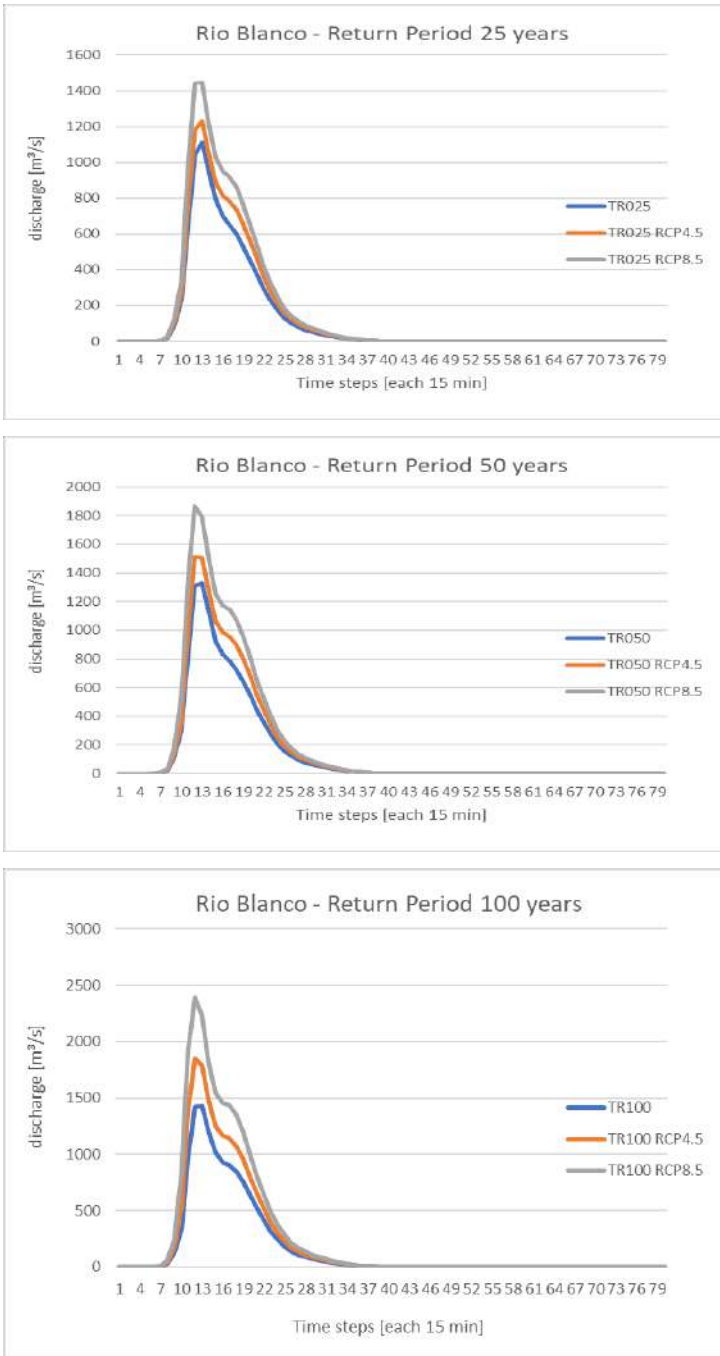


Figure 17: Hydrograph simulation results Rio Blanco

Table 7: simulation results Rio Chamelecón

Rio Chamelecón	RP 25	RP 50	RP 100
Q Present state	1‘210.0 m³/s	1’792.0 m³/s	2’108.0 m³/s
Q Future Scenario RCP4.5	1‘282.5 m³/s	1‘685.4 m³/s	2‘213.0 m³/s
Q Future Scenario RCP8.5	1‘707.5 m³/s	2‘398.8 m³/s	3‘470.1 m³/s

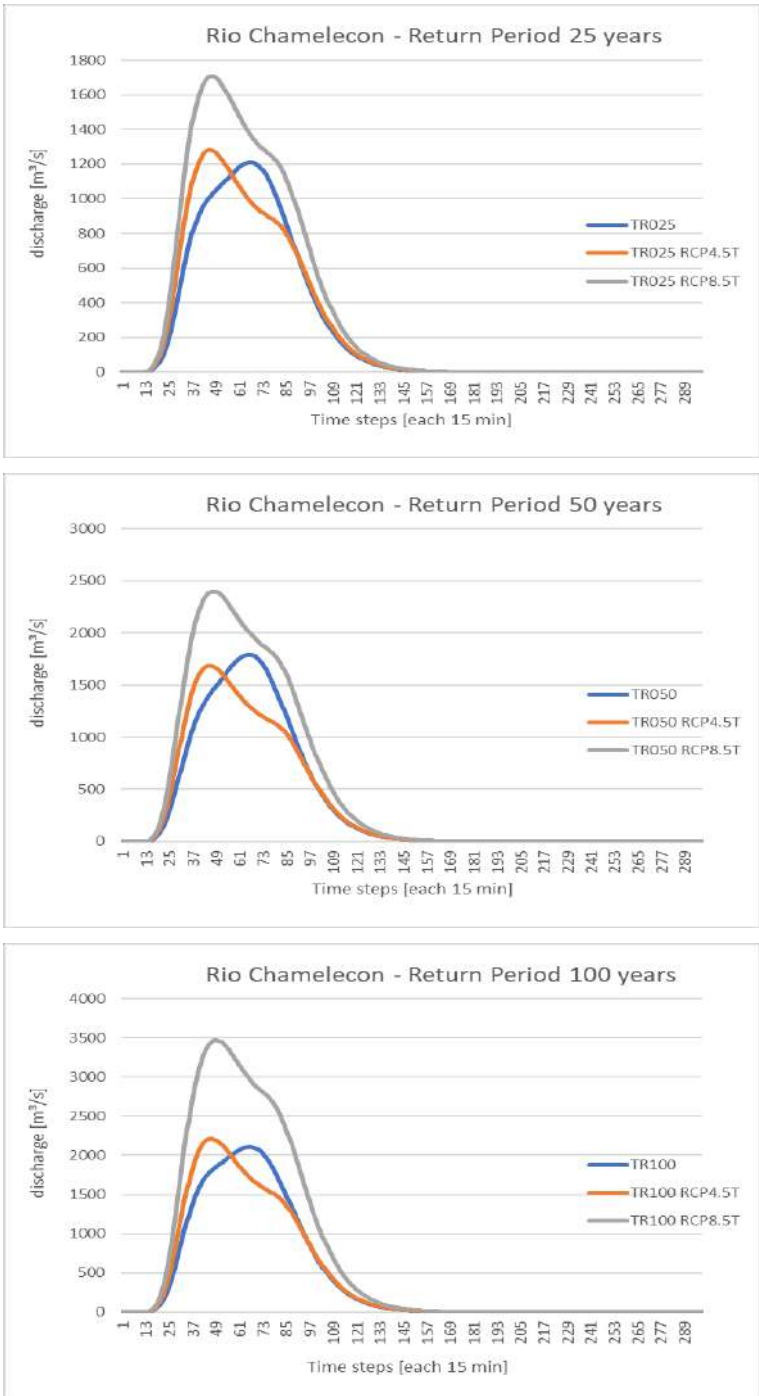


Figure 18: Hydrograph simulation results Rio Chamelecón

Table 8: simulation results Rio Chotepe

Rio Chotepe	RP 25	RP 50	RP 100
Q Present state	999 m³/s	1'229.1 m³/s	1'493.2 m³/s
Q Future Scenario RCP4.5	1'294.5 m³/s	1'585.5 m³/s	1'883.6 m³/s
Q Future Scenario RCP8.5	1'513.1 m³/s	1'917.7 m³/s	2'396.0 m³/s

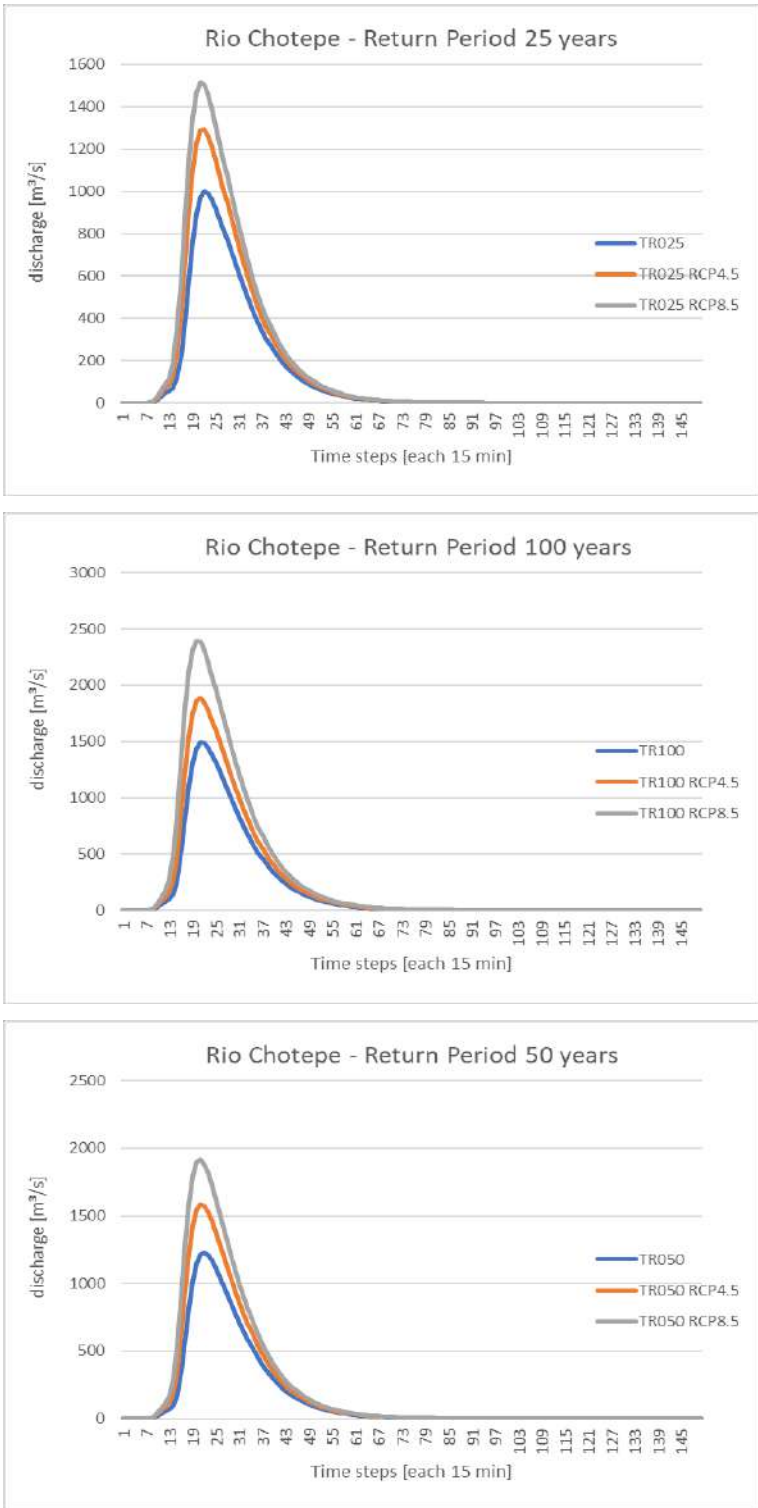


Figure 19: Hydrograph simulation results Rio Chotepe

4.1.4 Validation

Because of the data availability and the general lack of measurement data (e.g. precipitation, runoff, infiltration), the validation of the results was based on the knowledge of local authorities, a plausibility check with literature (USGS, 2002), the Creager envelope curves for extreme floods as well as the results out of the hydrodynamic modelling. The results of the hydrodynamic modelling will be discussed later on. Rio Chamelecón is the most noted catchment, addressed by the USGS Paper (2002). Validation was therefore possible with restriction against the Creager-Equation (HQ50) and the USGS Paper, analysing the storm event Mitch (USGS 2002). Referenced values are highly different and strongly varying over available studies. The USGS study examined the station Chamelecón el Puente and defined the station as not reliable and deals with the corresponding values carefully. They also carried out a Drainage area relation for the peak flow estimation, calculating a Q_{HQ50} = 2400 m³/s whereas based on the statistical analysis Q_{HQ50} measures 1070 - 2060 m³/s. The often-referenced gauge "Chamelecón en puente" is located around 20 km upstream of the analysed model output of this study.

Rio Chamelecón	***Model results (J212)***	***Creager (HQ50) Gauge "Chamelecón en Puente"***	***USGS (2000)***
RT= 50	*1'792 m³/s*	*1'475 m³/s*	*2'206.26 m³/s (Table 10, p 29)* *1'070 - 2'400 m³/s (statistical analysis)* *2'400 m³/s (drainage area relation)*
RT = 100	*2'108 m³/s*	-	*1210 – 2460 m³/s*

Rio Blanco	***Model results***	***Creager (HQ50)*** (108 km², C=80)	
RT = 50	*1'331.4 m³/s*	*1,691.40 m³/s*	-

Rio Chotepe	***Model results***	***Creager (HQ50)*** (228.41 km², C=80)	
RT = 50	*1'229.1 m³/s*	*2,630.70 m³/s*	-

4.2 Hydraulic model

In the following chapter the model structures of the three hydrodynamic models will be presented. Necessary steps towards model enhancement, such as terrain modifications, consideration of 3D structures and the creation of a roughness (manning's n) layer will be explained. Finally, the outcome of the model validation will be outlined.

4.2.1 HecRAS 2D model structure

The major rivers, which have led to flooding events in the past, posing a risk to San Pedro Sula and its outskirts, are the rivers Río Blanco, Río Bermejo, Río Piedras, Río Chotepe and Río Chamelecón. In order to efficiently model the effects of flooding for certain events, it was necessary to distribute the rivers of interest into several models. The achievement of results with a high spatial resolution, for a region of interest of this extent, was only possible by the division of the area into three separate models. Río Blanco being a separate river system was easily distinguishable. The model "Río Blanco" is identified as the yellow region in Figure 20. The "Model Río Chotepe" consists of the rivers Río Chotepe, Piedras and Bermejo and is indicated in red in the figure below. Finally, it was decided to model Río Chamelecón separately (blue area in Figure 20), despite river Bermejo, forming an inflow to the former. This decision was based on the different catchment extents and the locations of the areas of interests, as well as total number of cells and the resulting computational costs of each model.

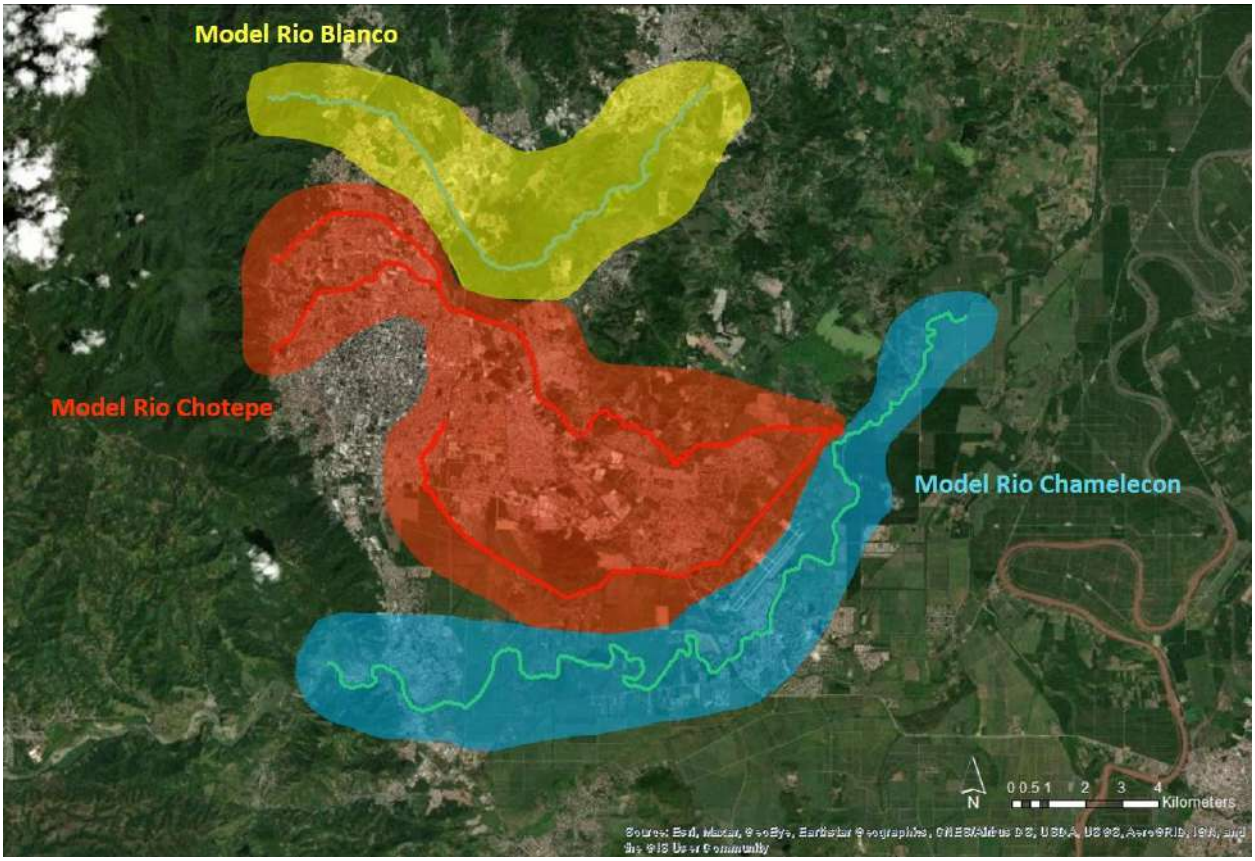


Figure 20: Overview on the Hec-RAS models in San Pedro Sula region: a.) model of Río Blanco, b.) model of Río Chotepe, Río Bermejo, Río Piedras and Canal Sauce, c.) model of Río Chamelecón.

4.2.2 Terrain modification and amelioration

The base for the set-up of the 2D model formed the 1D models created by COPECO in 2016 (COPECO 2016a). These models included a DEM (DEM), which was used for the 2D hydrodynamic, unsteady modelling process. Before creating the model terrain in HECRAS the DEM was analyzed and some impurities and artifacts were identified. Especially the profiles of the rivers seemed staggered, partially not declining consistently, posing obstacles for the flow of water. It was found that the DEM did not solely represent the terrain, but that anthropogenically sourcing objects, such as bridges were still included in some parts (e.g. compare Figure 26). In addition, within the river channel the water surface was not subtracted from the terrain in most parts.

As measured cross-section (XS) profiles were not available, except for a partial section of canal sauce of approximately 2 km, it was decided the use the XS profiles from the 1D COPECO model, which had been extracted from the DEM, to create a plausible, smooth river profile. Before doing so, the centerlines of the rivers were readjusted. This was done manually based on satellite data and the available DEM. Subsequently, the bank-stations of the remaining XS stations were adapted accordingly. Having created a consistent channel (the width was also selected based on satellite imagery), it was possible to burn these channels into the DEM. This process was done iteratively for each river, until a plausible channel profile was obtained.

The XS profiles, kindly provided by the municipality of Honduras, for the urban part of canal sauce were adapted during the process of creating a plausible river channel for the model of Rio Chotepe. Unfortunately, not all XS profiles were viable. Therefore, the profiles were sorted to create a tenable channel. Further, it was decided to move the starting point of the channel to the point where the channel becomes visible on satellite data (compare Fig. 2). Canal sauce forms an extension of the old 1D model, which did not have the channel included. As mentioned, XS Profiles from the 1D COPECO model were used to create the channels of the other rivers. For the river section between Canal Sauce and Rio Chotepe no information on channel width or shape was available. To fill the gap the last XS profile of Canal Sauce and the first XS profile of Rio Chotepe was used, to interpolate between the former and the latter.

Figure 21: Starting Point Canal Sauce

The processed DEM was further implemented as model terrain for the three hydrodynamic models. Some results from this particular work step are presented in the figures below (Figure 22, Figure 23, Figure 24: it shows that river center line was successfully adjusted to a continuous slope, resulting in an improved model stability and representing a sloping river channel.

As shown in Figure 3 additional adjustments concerning the DTM were implemented for the Chamelecón model: The DTM showed some obstacles in the elevation data, especially regarding the inflow into the channels Canal de Filopo and Canal Maya. Therefore, some passages were opened to allow the water to access the present channels. All alterations were made in consultation with a local correspondent.

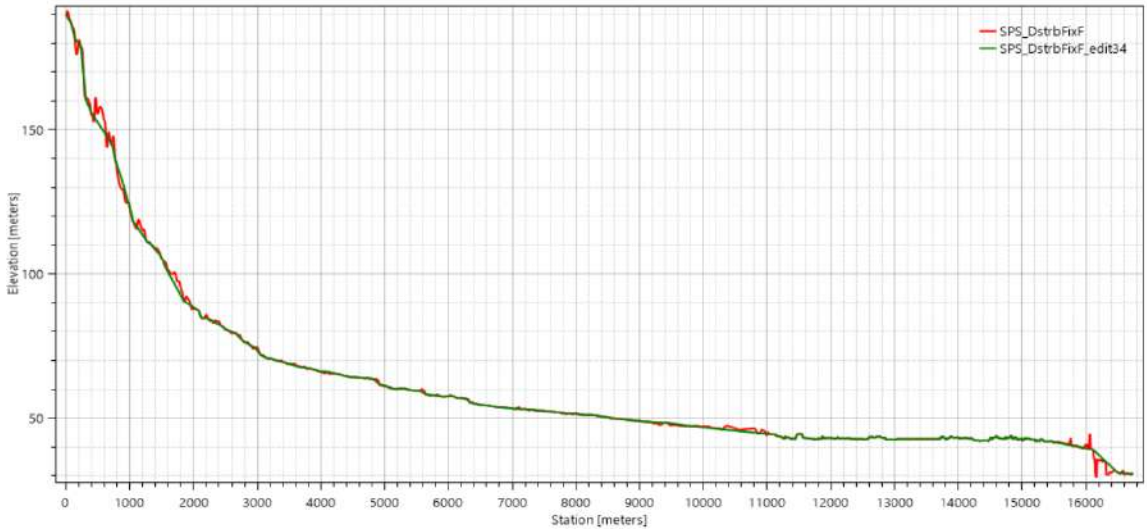


Figure 22: Edited Terrain profile of Model Río Blanco

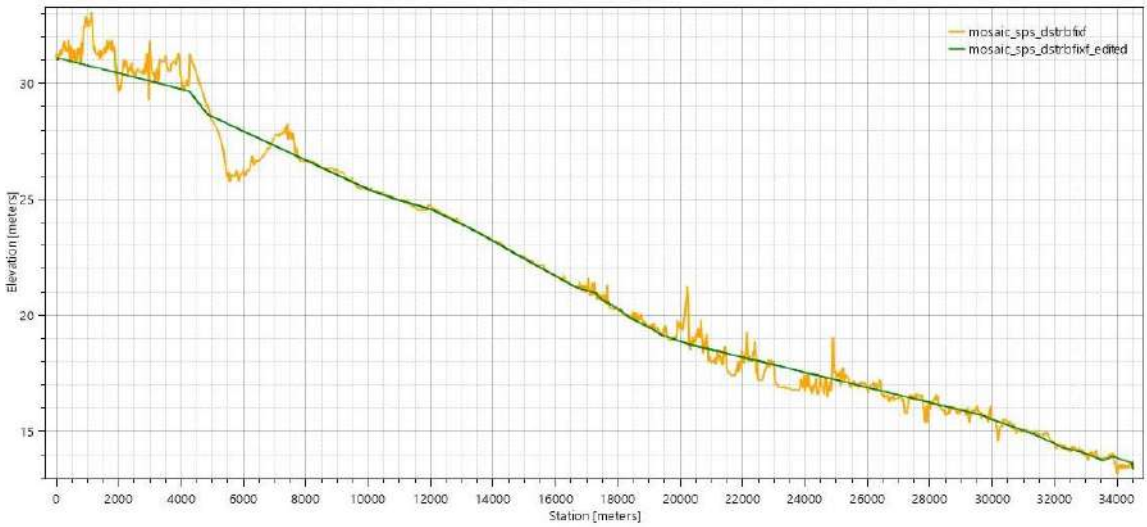


Figure 23: Edited Terrain profile of Model Río Chamelecón

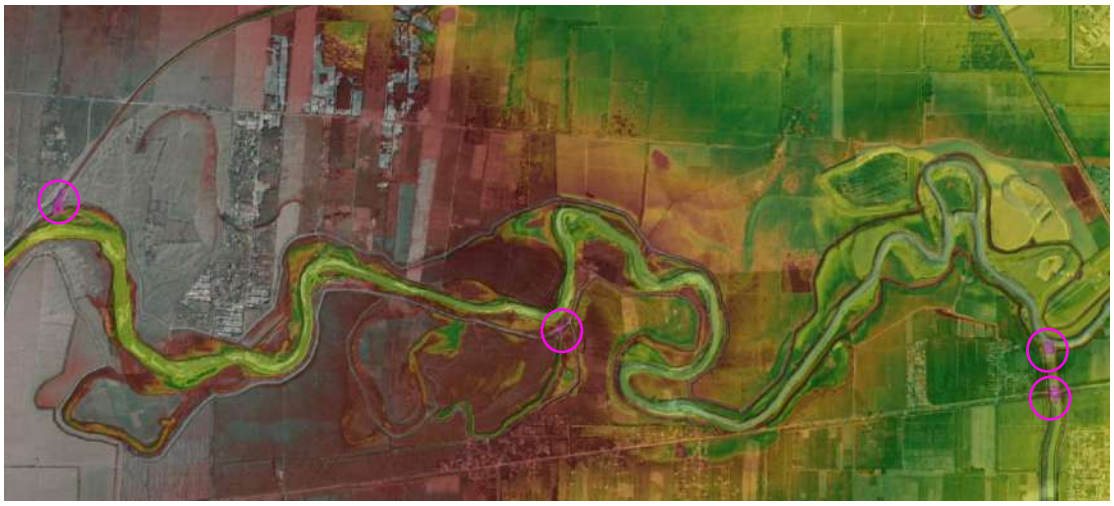


Figure 24: Terrain modification (marked in pink) in the Chamelecón model in order to integrate canal passages (in accordance with local consultant) to facilitate water flow to Canal de Filopo (north-west) and Canal Maya (south-east)

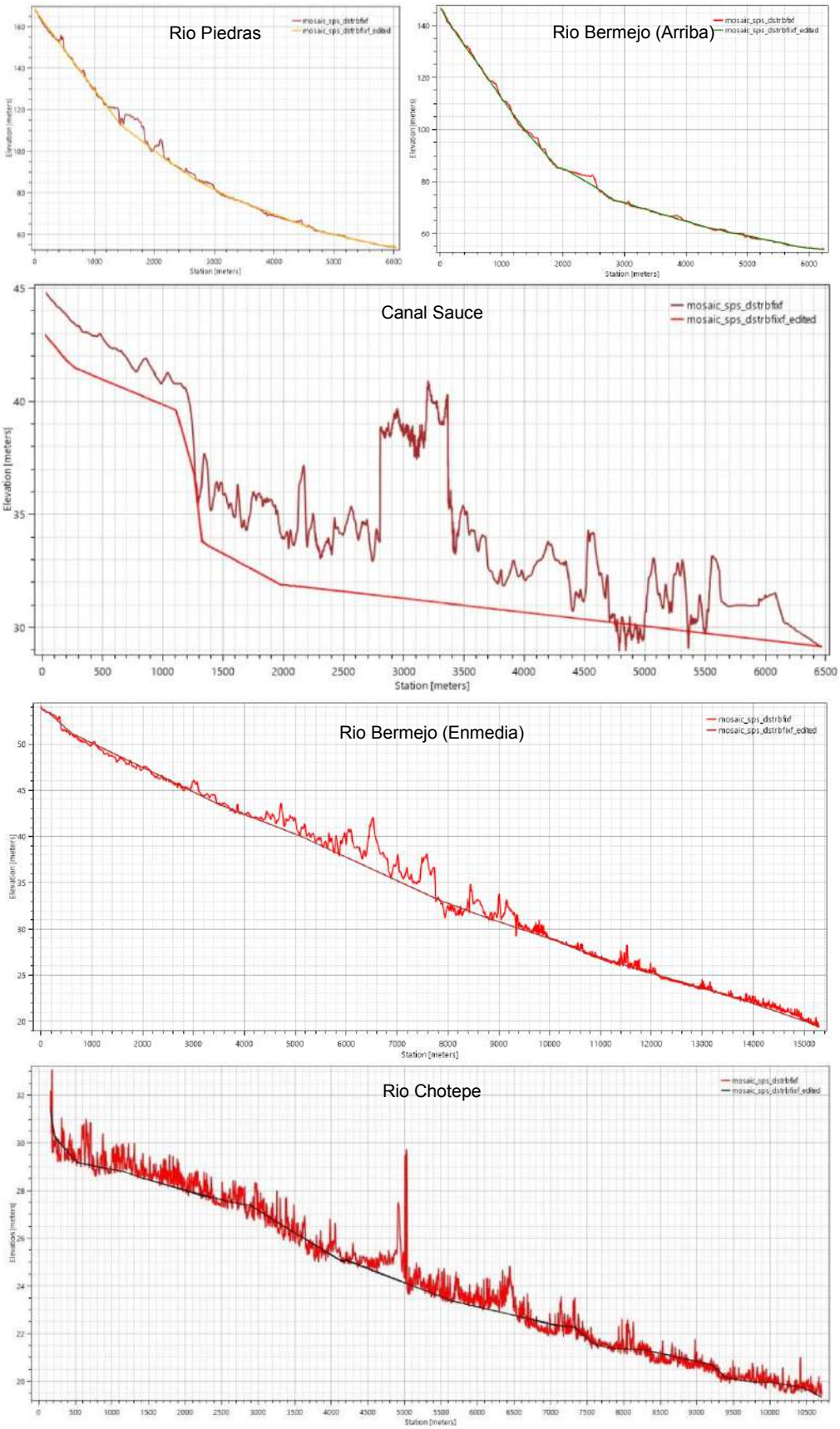


Figure 25: Edited Terrain profiles of Model Río Chotepe

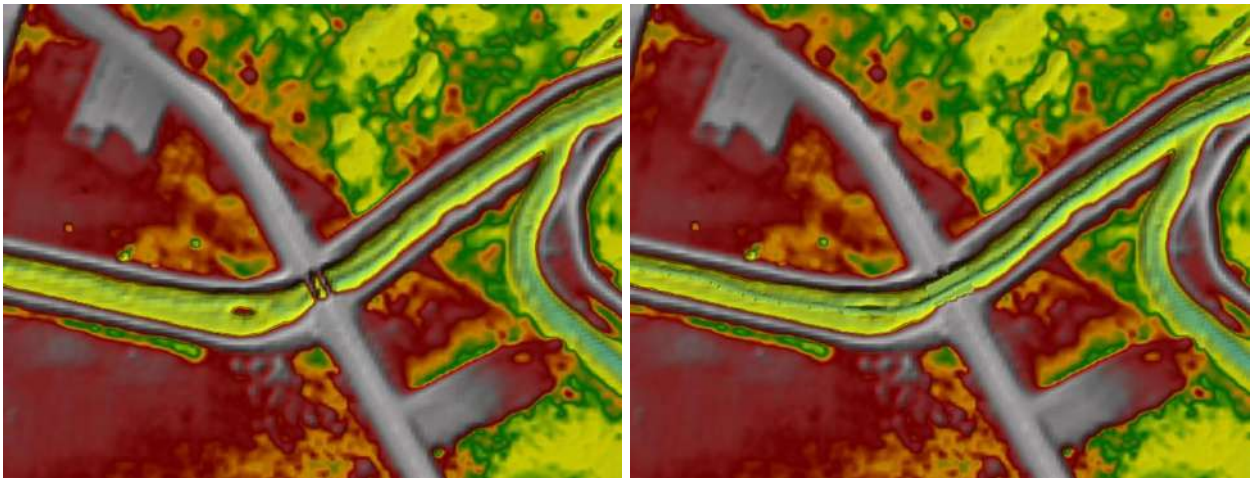


Figure 26: An example of a burned river channel at Río Chotepe (before and after)

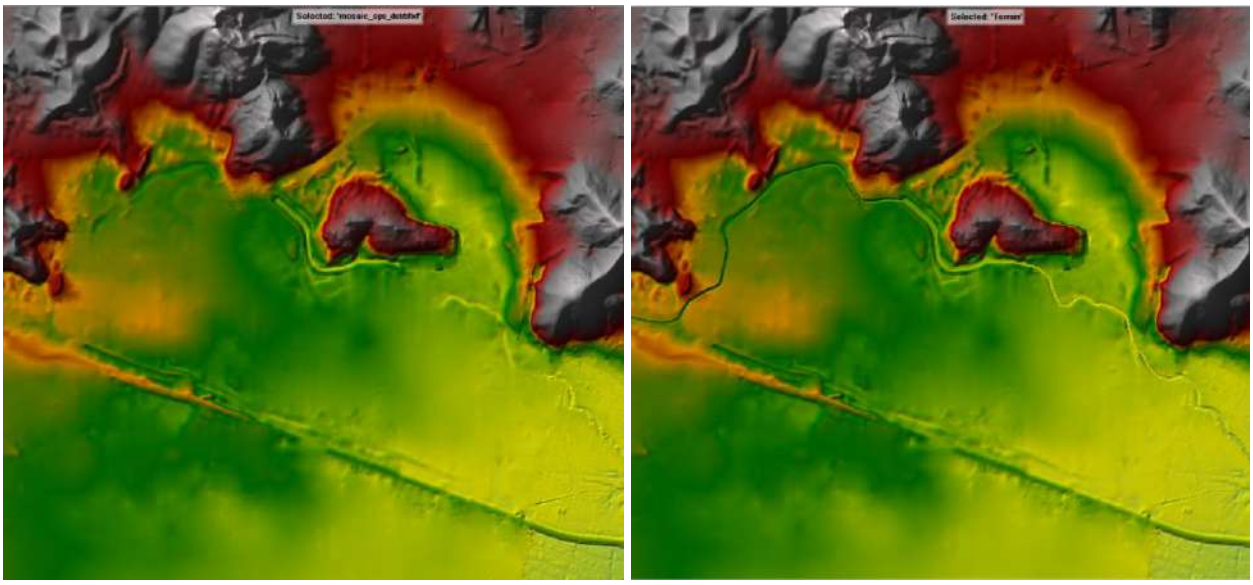


Figure 27: An example of a burned river channel at Río Bermejo (before and after)

4.2.3 Model setup

The computational mesh for all models was implemented with a grid size of 10 m. Certain areas, such as informal settlements (“bordos”) and some districts, were of special interest. These areas were refined with a grid size of 5 m, thus the resolution of the DEM and therefore the finest grid size possible.

As the floodplain in the model of Río Chamelecón was found to have a large extent, it was necessary to coarsen the grid in some selected areas, mainly flat areas without settlements or infrastructure, to a size of 20 m. Breaklines were implemented for each model along walls, dikes and any kind of structure forming an obvious obstacle towards flow.

The region of San Pedro Sula is characterized by rather steep slopes in the mountainous areas and large, flat areas in the valleys. In addition, due to extensive infrastructure and settlements in the flood plain and in proximity to the river, rapid changes in flow velocity may be expected. For these reasons it was decided to use the Full Momentum equation set for calculation, as these are able to conserve local advective impulses e.g. resulting from changes in flow velocities. Even though this method requires higher

computational costs, it will provide more accurate results for areas with rapid velocities (USGS 2016). With the goal to increase the model's stability a warm up phase was implemented. phase. Detailed values are presented in the following chapters for each model.

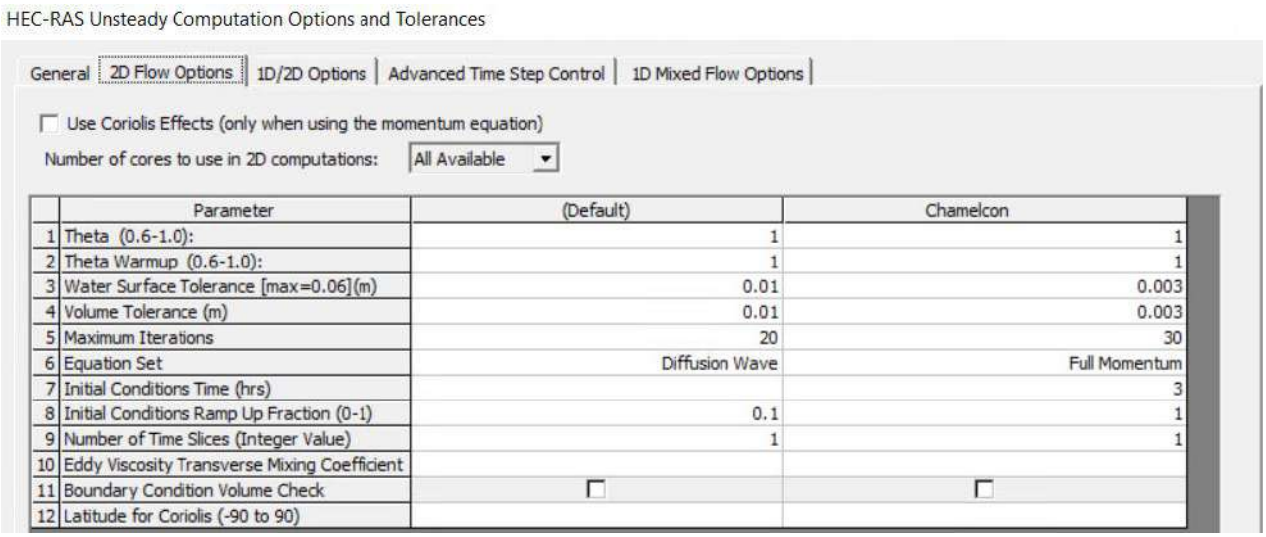
The computational time step was determined using the advanced time step control, in which the time step is automatically adjusted during the computation. The basic time step was selected based on the Courant Criteria (<1), where t is the fraction of the average cell size and the velocity.

$$\Delta T \leq \frac{\Delta X}{v}$$

Once again, the detailed parameters for each model are presented in the following.

Table 9: Computational Settings HEC-RAS

	Río Blanco	**Río Chotepe**	**Río Chamelecón**
Time Step Control			
Fixed Time Step	3 s	5 s	15 s
Maximum Courant	2	2	1
Minimum Courant	0.55	0.55	0.6
Number of steps below Minimum before doubling	7	7	4
Maximum number of doubling base time step	1 (= 5 s)	1 (= 10 s)	1 (= 30 s)
Maximum number of halving base time step	1 (= 1.5 s)	1 (= 2.5 s)	1 (= 07.5 s)
Mapping Output Interval	15 min	1 h	1 h
Hydrograph Output Interval	15 min	1h	1 h
Detailed Output Interval	1 h	1 h	1 h



	Parameter	(Default)	Chamelcon
1	Theta (0.6-1.0):	1	1
2	Theta Warmup (0.6-1.0):	1	1
3	Water Surface Tolerance [max=0.06](m)	0.01	0.003
4	Volume Tolerance (m)	0.01	0.003
5	Maximum Iterations	20	30
6	Equation Set	Diffusion Wave	Full Momentum
7	Initial Conditions Time (hrs)		3
8	Initial Conditions Ramp Up Fraction (0-1)	0.1	1
9	Number of Time Slices (Integer Value)	1	1
10	Eddy Viscosity Transverse Mixing Coefficient		
11	Boundary Condition Volume Check	☐	☐
12	Latitude for Coriolis (-90 to 90)		

Figure 28: 2D Flow options used in HEC-Ras

4.2.3.1 Río Blanco

Model setup for Río Blanco (Figure 29) includes a spacious 2D area especially regarding the Laguna del Carmen – which is due to lack of data concerning storage capacity etc. not included as storage area itself. In the area of Laguna del Carmen also no channel was burned into the DTM. Numerous breaklines (indicated in red in the figure below) were drawn, giving consideration to dams and dikes in the model region, as well as outlining building blocks. Río Blanco includes in total five boundary conditions: an inflow boundary condition and three intermediate inlet taking into account the tributaries as well as the outflow boundary condition as normal depth to ensure outflow.

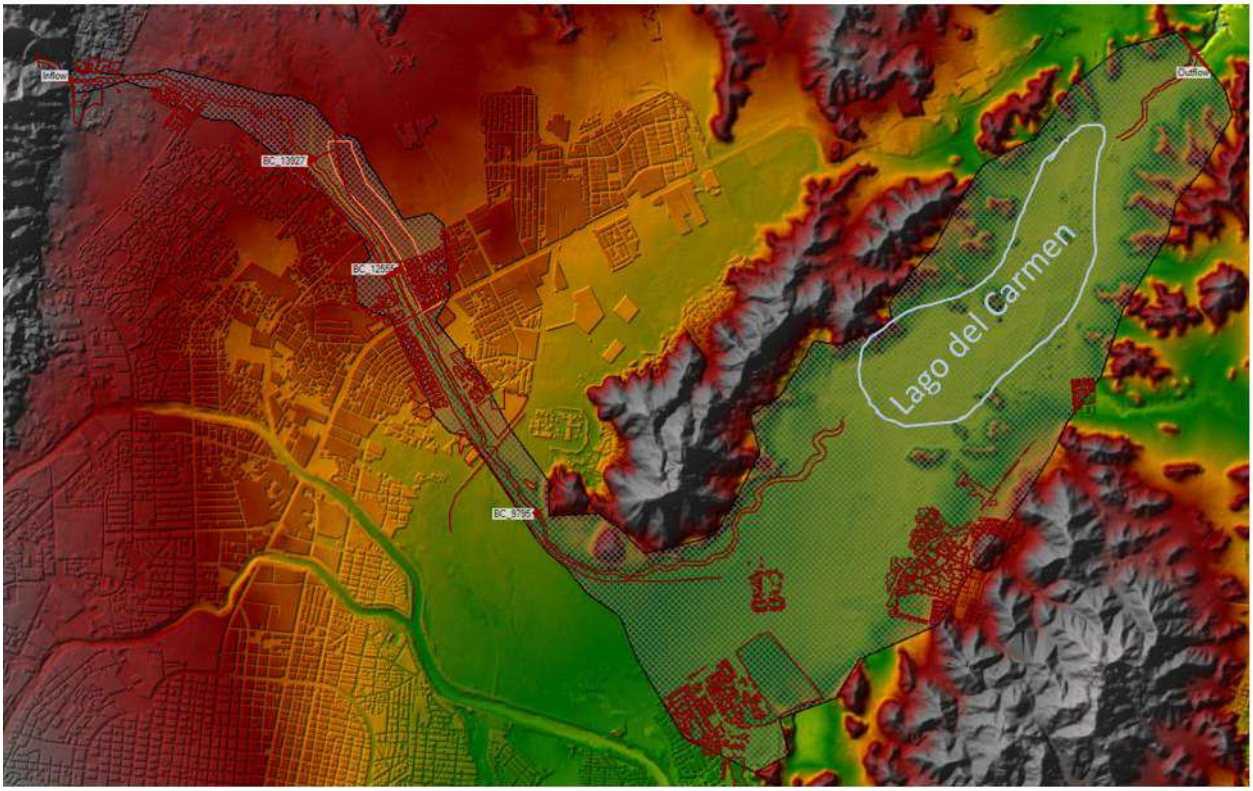


Figure 29: Model setup for model Río Blanco including breaklines (red), refinement regions (orange) and boundary conditions (green).

4.2.3.2 Río Chotepe

Model setup for Rio Chotepe (Figure 30) includes a spacious 2D area, having numerous breaklines (drawn in red) giving consideration to dams and dikes in the model region, as well as outlining building blocks. Informal settlements are included as refinement regions (indicated as orange) with a resolution of 5 m × 5 m, large areas without buildings were considered with a wider cell with 20 m × 20 m (also indicated as orange polygons). In addition, the original extent of the 1D COPECO model was extended by including the Canal Sauce. Rio Chotepe includes in total 10 boundary conditions: 3 inflow boundary condition and 6 intermediate inlets taking into account the tributaries as well as the outflow boundary condition as normal depth to ensure outflow.

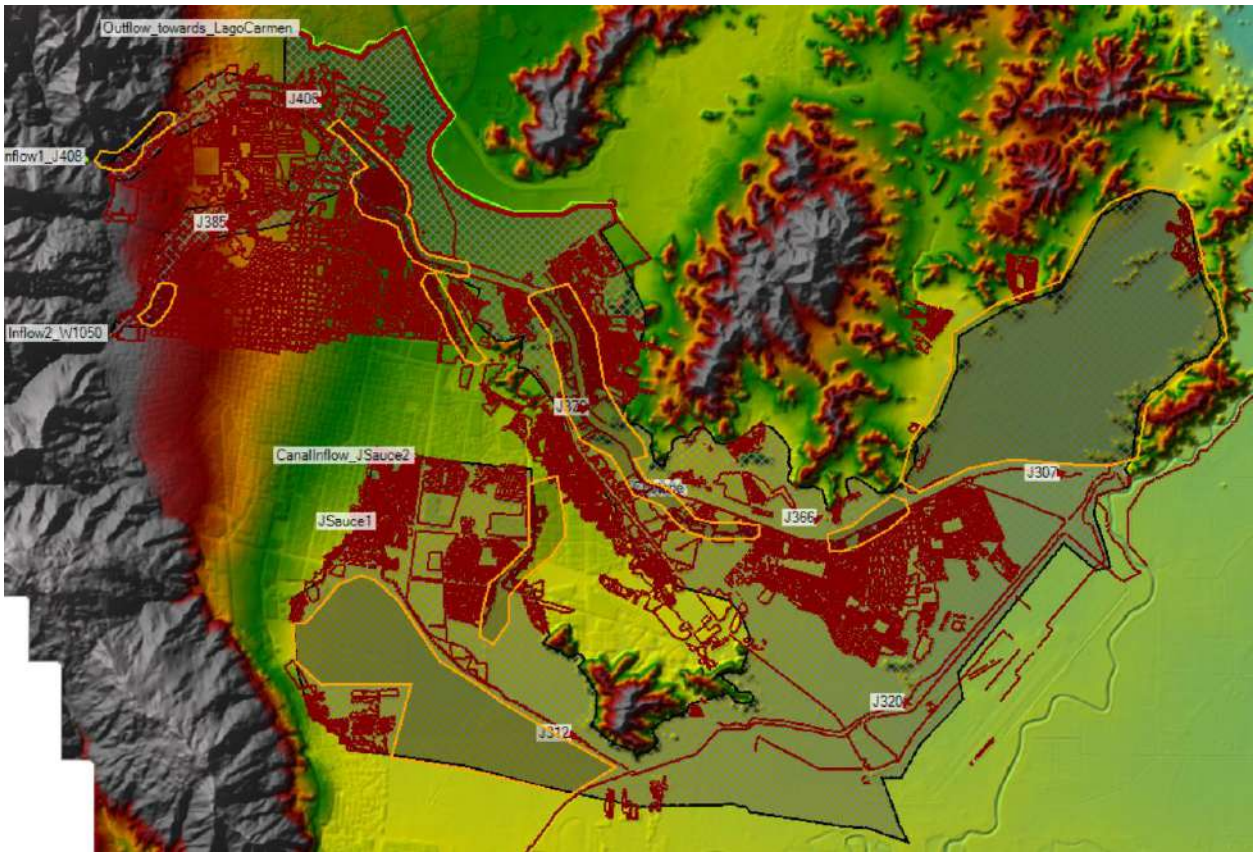


Figure 30: Model setup for model Río Chotepe including breaklines (red), refinement regions (orange) and boundary conditions (green).

4.2.3.3 Río Chamelecón

Model setup for Río Chamelecón (Figure 31) includes a spacious 2D area. Numerous breaklines were drawn, giving consideration to dams and dikes in the model region, as well as outlining building blocks. Various test-runs confirmed a very large extent of the flood plain in this region. This results from the flat topography and lack of any obstacles towards flow. As it was not possible, to cover the entire floodplain with the grid, due to overlapping with the other models and sub catchments, as well as for computational regions, the model extent was delimited along the perimeters of the 2D area in some regions. In detail, the model extent was delimited in the southwest of the 2D area due to errors in the DTM, using Quebrada El Calan as boundary (normal depth boundary condition). As well as in the northern region. The exact boundaries are indicated in green in the figure below. In the north the Canal Filopo acts as outflow, in the south the canal Maya (see Figure 14 on page 19). The outflows in both channels were validated based on the results of Suárez (2019), confirming the plausibility of the model.

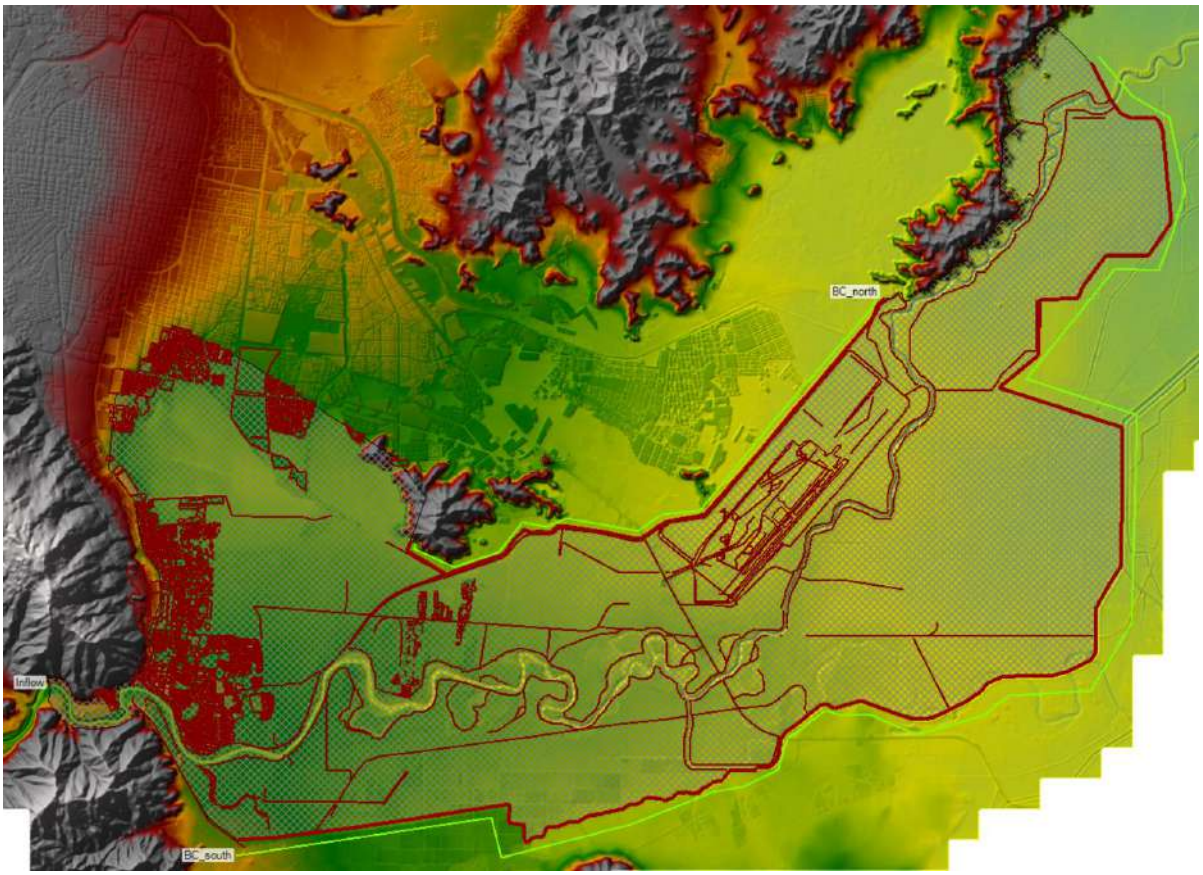


Figure 31: Model setup for model Río Chamelecón including Breaklines (red) and boundary conditions (green).

4.2.4 Consideration of 3D structures

4.2.4.1 Bridges and canals

As mentioned, linear structures, such as dikes, were implemented in the 2D model domain using break lines. In addition, information about two bridges within Río Blanco was available. To take into account backwater effects and resulting flooding, these bridges were included in the Río Blanco model, as shown below.

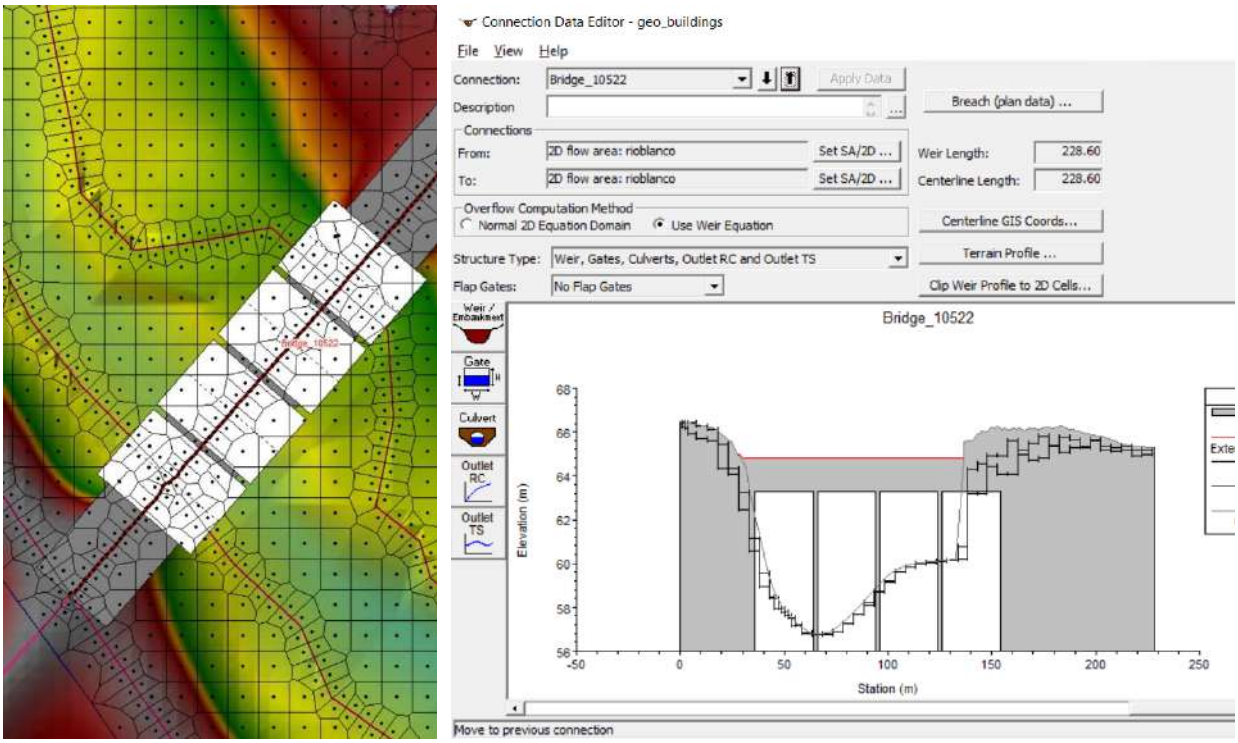


Figure 32: Considering the bridge of XS 10522 as a 2D flow area connection in the HEC-RAS model of Río Blanco.

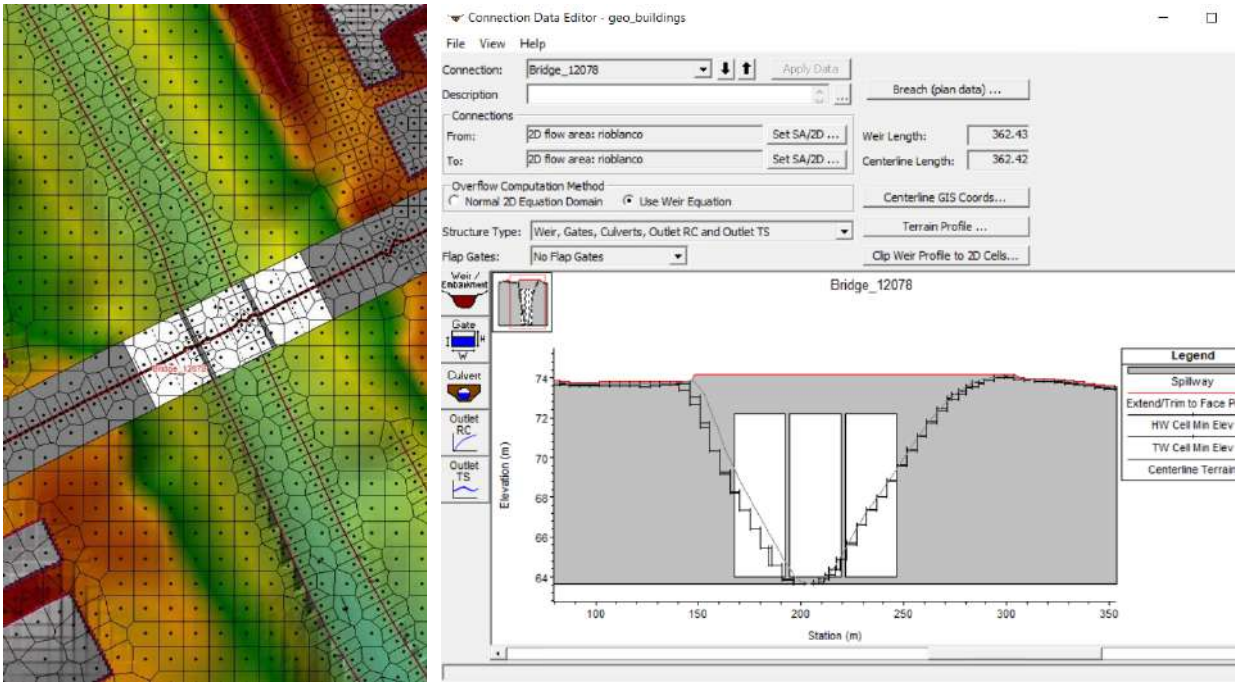


Figure 33: Considering the bridge of XS 12078 as a 2D flow area connection in HEC-RAS model of Río Blanco.

Even though plenty more bridges exist within San Pedro Sula, measurement information is scarce. Thus, all further bridges could not be implemented, forming a source of uncertainty within the modelling results. We advise to add this information in future, to reduce uncertainties in the modelling results.

Also, various artificial channels were constructed within the study area. Especially in the valley of Río Chamelecón two major channels were implemented: The Canal de Filopo and Canal Maya. Based on photographs, it was possible to depict, that the outflow of Río Chamelecón into these channels is not controlled by gates or other structures (Figure 15). Therefore, it was decided to consider them by including outflow boundary conditions at the two intersections of the channels and the perimeters of the 2D mesh.

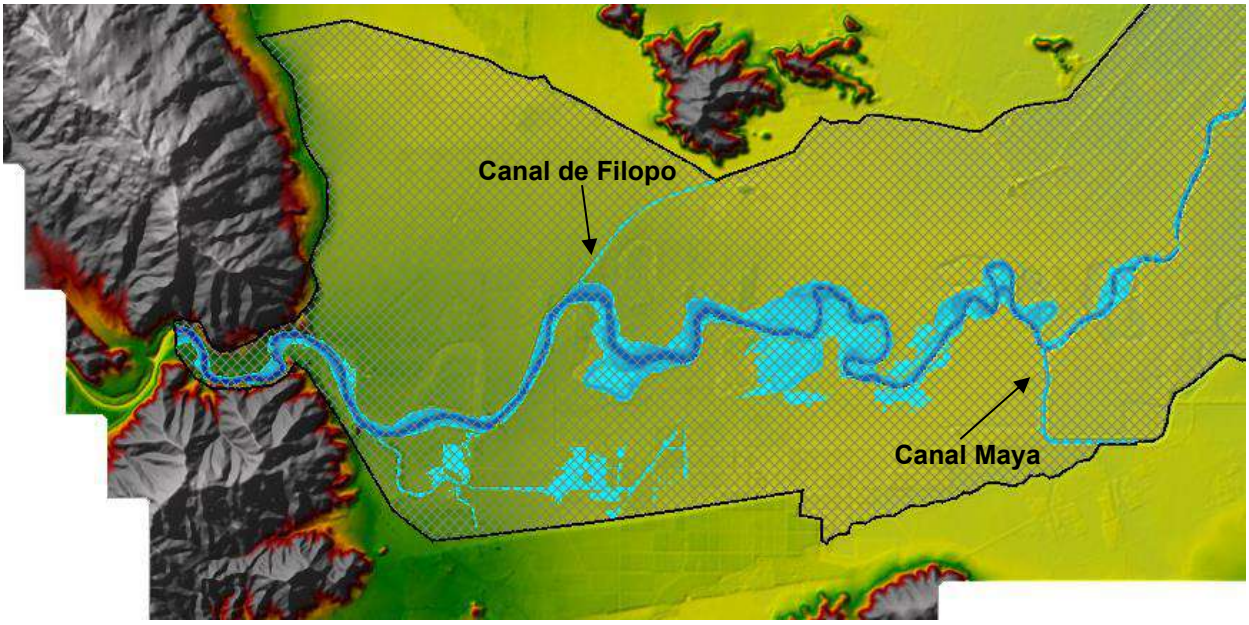


Figure 34: Canal de Filopo and Canal Maya as outflow from the Río Chamelecón

4.2.4.2 Buildings

Buildings, as one of the most important hydraulic structures, influence inundation depth in urban areas significantly. To include topography of buildings or urban areas in general, different approaches are commonly used (Beretta et al. 2019): Option 1 is to include buildings via an adequate roughness coefficient, allowing the water to flow through the area but with very slow flow velocity, taking into account the permeability of houses and at the same time the fact, that houses have a certain backwater effect to the flow. Option 2 is to consider buildings as a real obstacle in the terrain, including them as impervious blocks into the DTM, not allowing any flow through the houses and leading flow alongside building blocks.

In this study the more detailed Option 2 was chosen and building information out of the “CSPS_URB_2016.shp” dataset were filtered ([GIRO] <> “SOLAR BALDIO”) to extract the building information. After dissolving the polygons, the objects were used as a masked to lift up elevation for an estimated height of buildings to 5 m and included into the terrain. To embrace this level of detail into the hydraulic model, the building block outlines were inserted and enforced as breaklines to ensure as detailed consideration of the 2D structures. Figure 35 illustrates the explained work steps. Some of the polygons with large areas but no visible buildings in the orthophoto (e.g. near Canal Sauce or the airport) were excluded because they are assumed not to be real obstacles and would have influenced water flow direction immensely. Therefore, these polygons were not considered in order to not mislead flow.

The informal settlements “bordos” on the contrary are not captured in the referred cadaster dataset. In order to give consideration to these settlements anyhow, Option 2 was chosen to factor those areas (using the “REUBICACION_POB_EN_BORDOS.shp” dataset) via a high roughness coefficient (Beratta et al.

2019 recommends n=10). The adapted roughness can be seen in the next chapter 4.2.5 Roughness in Figure 36.

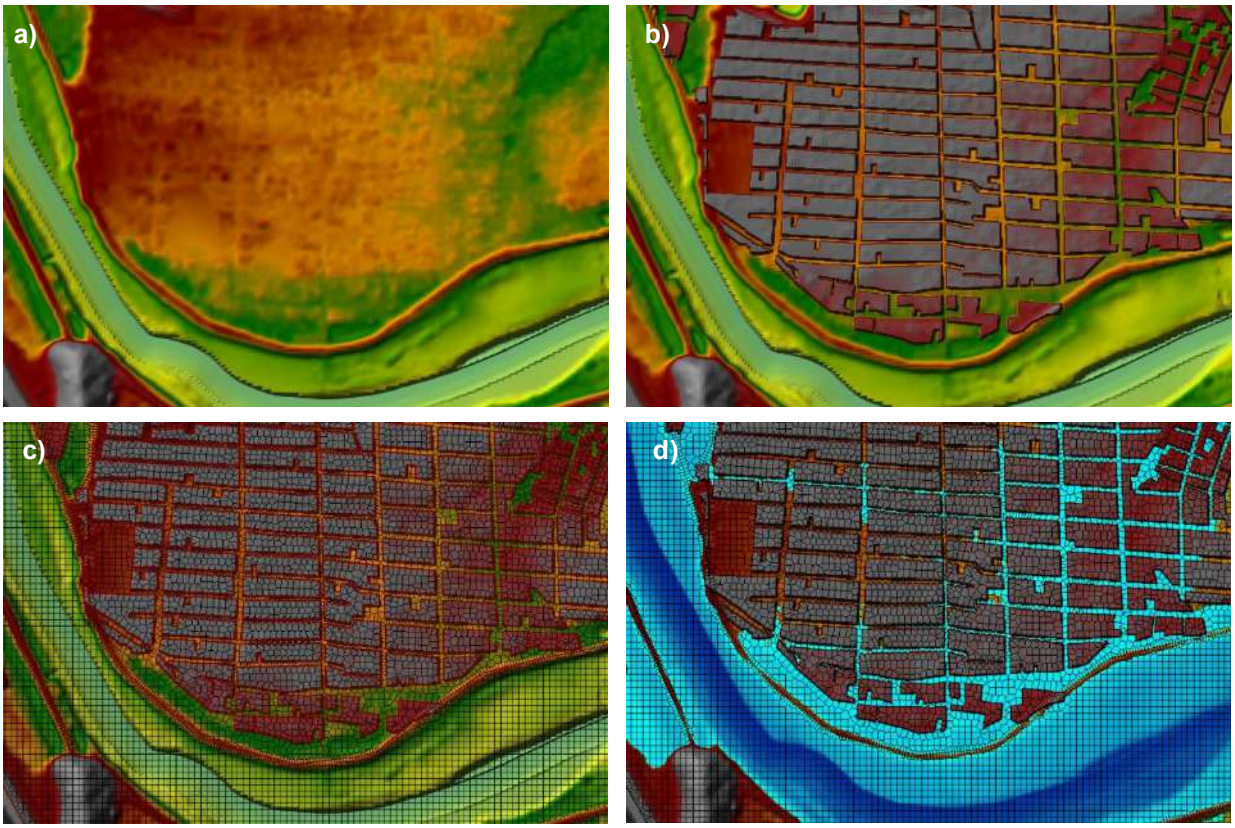


Figure 35: Example of including buildings: a) DTM without buildings, b) DTM with buildings included via lifting up the elevation up to 5m above ground, c) enforcing building (blocks) outline as Breaklines into the mesh, d) flooding into settlements using streets as flow path

4.2.5 Roughness

The Manning coefficient of roughness “n” is a parameter within the calculations of the hydraulic model and has a high impact on the results of the simulation. The coefficient represents characteristics of different land uses as well as for river channels and embankments.

Roughness values of different land use classes were obtained from the previous study of Copeco (2016a) and are represented in Table 10. As Canal Sauce was not included in the previous study the extension was created using the roughness values of Rio Chotepe (Aldea), namely a roughness value of 0.045 for the channel.

Table 10: Roughness coefficients of the considered land use classes (see Copeco (2016a)).

Rough_ID	Uso de suelo 2014_esp	Uso de suelo 2014_eng	n-Value
1	Agricultura Tecnificada	Agriculture	0.100
2	Bosque Latifoliado Deciduo	Deciduous forest	0.050
3	Bosque Latifoliado Humedo	Evergreen deciduous forest	0.075
4	Bosque Mixto	Mixed forest	0.060
5	Bosque de Conifera Denso	Coniferous forest (dense)	0.065
6	Bosque de Coniferea Ralo	Coniferous forest (light)	0.055
7	Cafetales	Coffee plantations	0.055
8	Cuerpos de Agua Artificial	Artificial water bodies	0.035
9	Lagos y Lagunas Naturales	Natural lakes and lagoons	0.033
10	Palma Africana	African palms	0.070
11	Pasto/Cultivos	Pasture/Crops	0.055
12	Zona Urbana Continua	Continuous Urban area	0.055
13	Arboles Dispersos Fuera de Bosque	Single tree groups	0.050
14	Suelo Desnudo Continental	Non-vegetated area (continental)	0.040
15	Vegetacion Secundaria Decidua	Secondary deciduous forest	0.055
16	Vegetacion Secundaria Humeda	Secondary evergreen deciduous forest	0.065

For the river channel Manning's values are also obtained from the previous study of Copeco (2016a) (see Table 11) and rely on a local analysis of river bed conditions like channel material, level of irregularity, variation between cross sections, relative effect of obstacles, vegetation and level of meandering summarized by Cowan's procedure (1956):

$$n = (n_0 + n_1 + n_2 + n_3 + n_4) \times m_5$$

Table 11: Roughness coefficients of the considered river channels (see Copeco (2016a)).

River bed condition			value	Río Chamelecon	Río Chotepe	Canal Sauce	Río Bermejo	Río Blanco
channel material	Soil	n_o	0.020					
	Rocks		0.025					
	Fine gravel		0.024					
	coarse gravel		0.028	0.024	0.02	0.02	0.028	0.024
level of irregularity	gentle	n_1	0.000					
	minor		0.050					
	moderate		0.010					
	severe		0.020	0	0	0	0	0
Variation between cross sections	graduate	n_2	0.000					
	occasionally alternating		0.005					
	frequently alternating		0.010-0.015	0	0	0	0	0
relative effect of obstacles	negligible	n_3	0.00					
	minor		0.010-0.015					
	significantly		0.020-0.030					
	severe		0.040-0.050	0	0.005	0	0.02	0
Vegetation	low	n_4	0.050-0.010					
	medium		0.010-0.025					
	high		0.025-0.050					
	very high		0.050-0.100	0.005	0.02	0.025	0.025	0.005
level of meandering	low	m_5	1.000					
	medium		1.150					
	high		1.300	1.3	1	1	1	1
			Sum n_i	0.029	0.045	0.045	0.073	0.029
			estimated roughness n	0.038	0.045	0.045	0.073	0.029

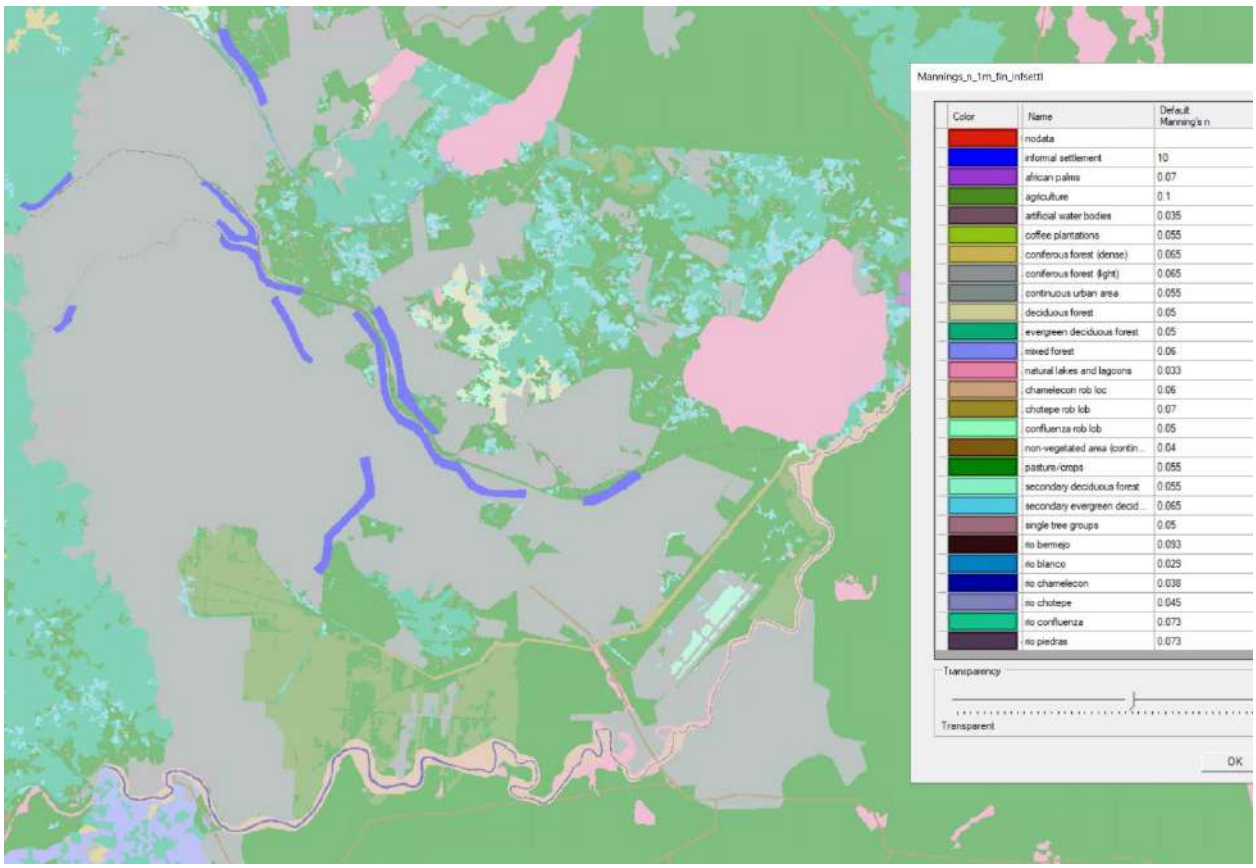


Figure 36: Manning's n roughness coefficients used for the hydraulic models.

4.2.6 Plausibility check and validation

Due to scarce data availability, a validation of the hydraulic model results was not practicable. A comparison of the results to the storm flood Mitch from the year 1998 failed, due to a lack of data of both discharge and recorded flood plains.

Model results were therefore compared with the previous studies from Copeco (2016a, 2016b) as well as with the thesis of Abrego Suárez (2019). The available 1D model results from these studies confirm the 2D results in this study quite well. In addition, Abrego Suárez supported this study with his local expert knowledge and could confirm most of the assumptions and results with his expertise.

In the Rio Chamelecón model the outflow through Canal de Filopo and Canal Maya agrees well with the estimated discharge values in the study of Abrego Suárez (2019).

5 Results

The model runs of the 2D hydraulic simulations result in maximum flood extents, flood depths as well as in water surface elevation. In order to display the flood plains, flood depths were mapped and presented in the following figures. The maps show the different food plains for the three return periods (TR25, TR50, TR100) and the different scenarios (present, future high and future low). Thus, various climate future scenarios and possible developments are considered.

For an easier understanding, inundation depths have been classified into three classes of severity of exposure:

- Water depth < 1 m = “low” severity of exposure
- Water depth 1 - 2 m = “medium” severity of exposure
- Water depth > 2 m = “high” severity of exposure

For Rio Chamelecón, an additional future scenario was considered, taking into account the planned construction of a dam called “El Tablón”. The dam retains Rio Chamelecón upstream of San Pedro Sula.

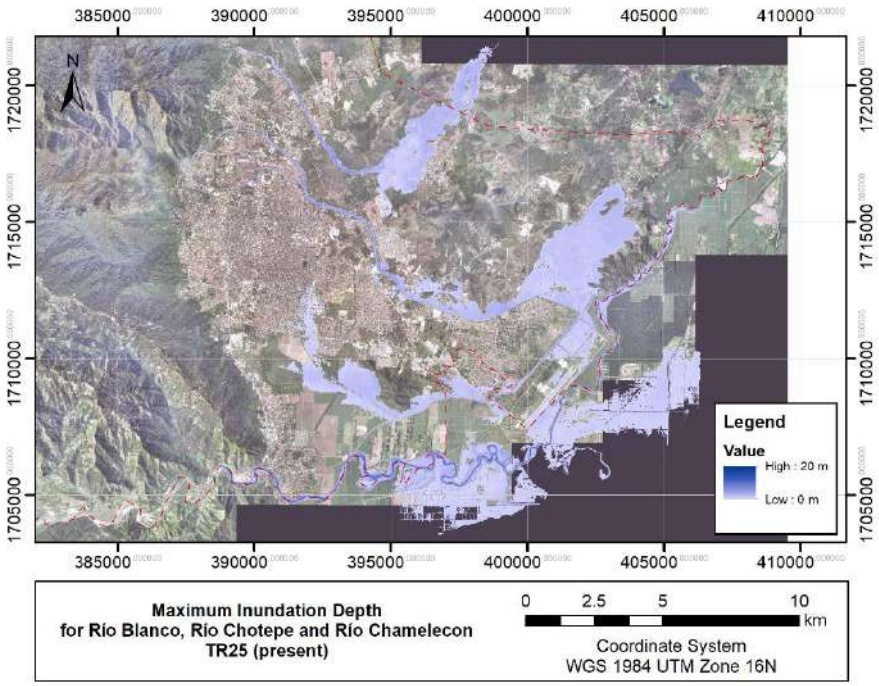


Figure 37: Maximum inundation depth for the return period of 25years (present)

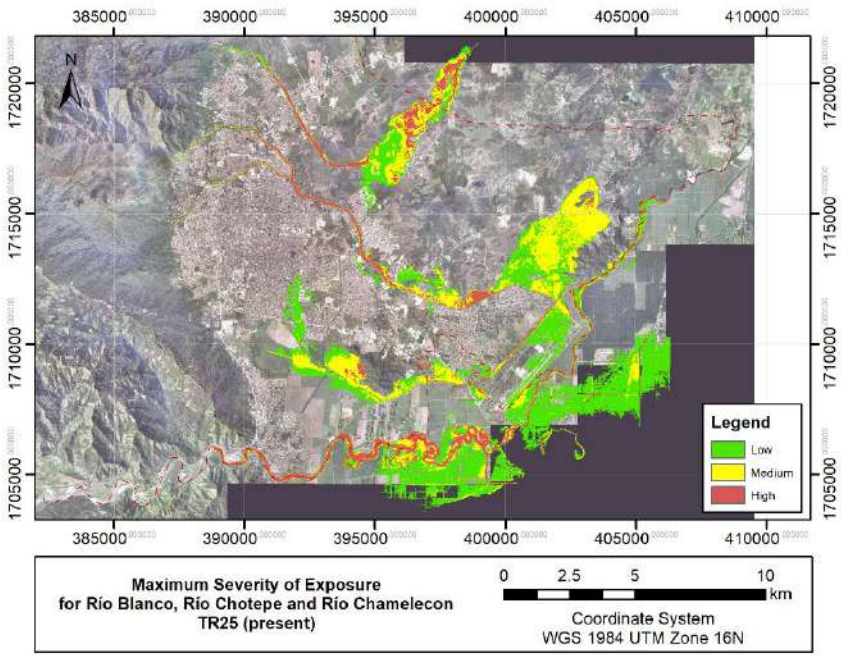


Figure 38: Maximum severity of flood exposure for the return period of 25 years (present)

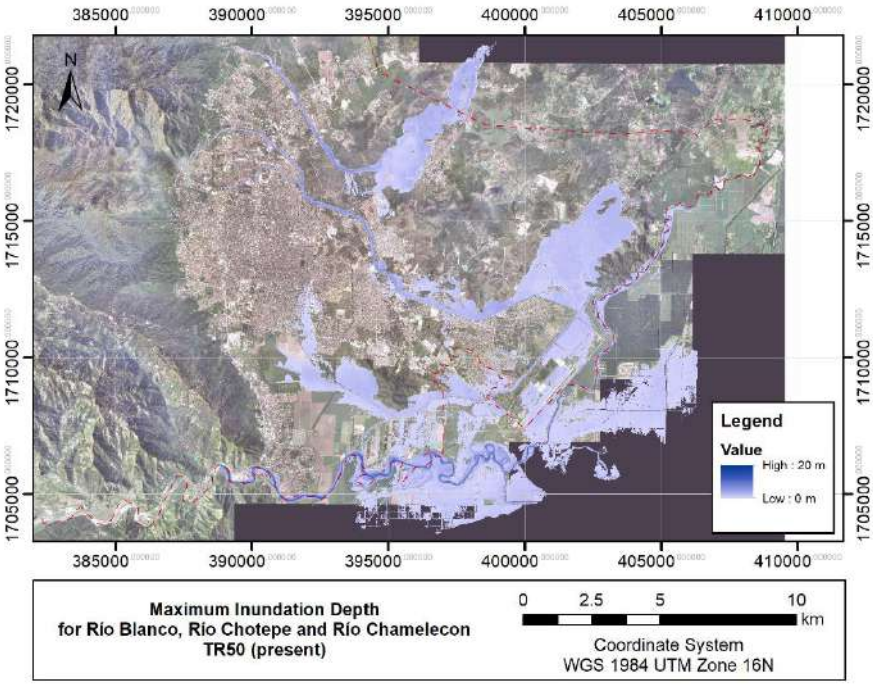


Figure 39: Maximum inundation depth for the return period of 50 years (present)

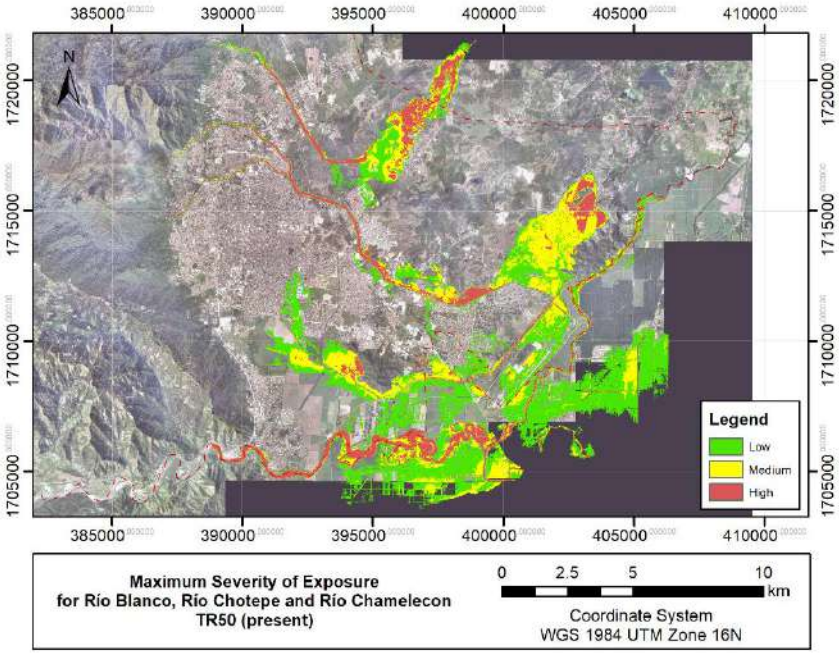


Figure 40: Maximum severity of flood exposure for the return period of 50 years (present)

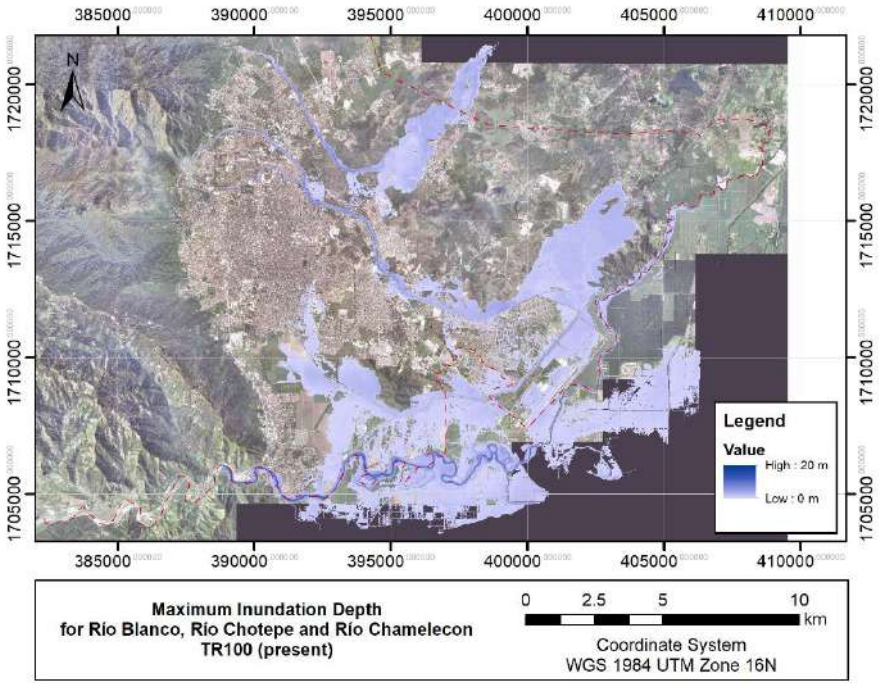


Figure 41: Maximum inundation depth for the return period of 100 years (present)

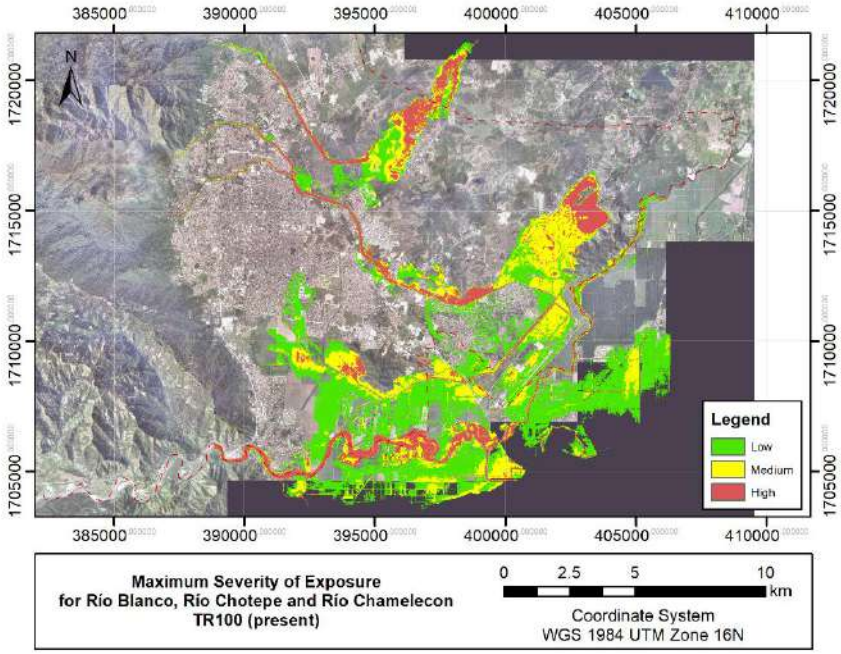


Figure 42: Maximum severity of flood exposure for the return period of 100 years (present)

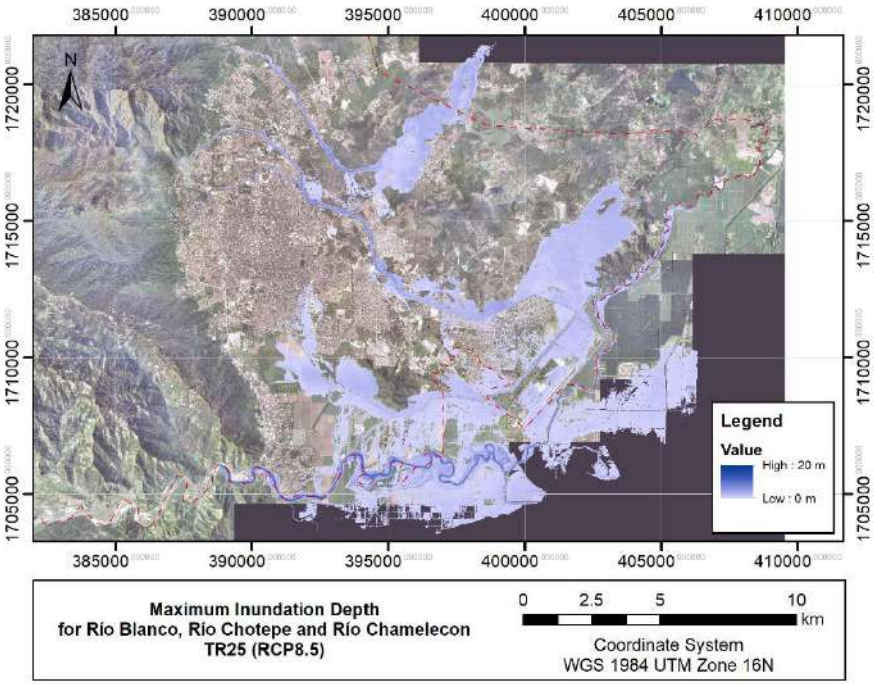


Figure 43: Maximum inundation depth for the return period of 25 years (future high RCP8.5)

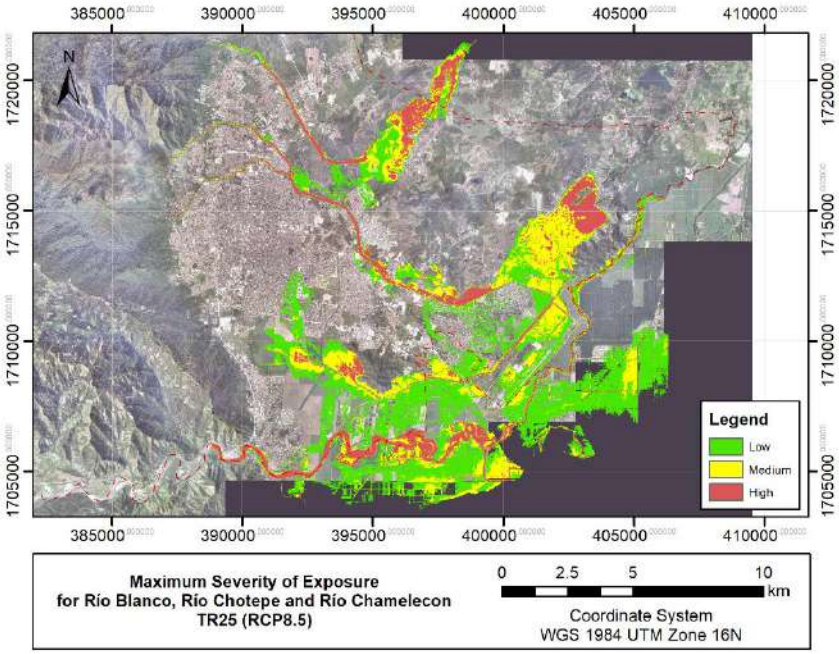


Figure 44: Maximum severity of flood exposure for the return period of 25 years (future high RCP8.5)

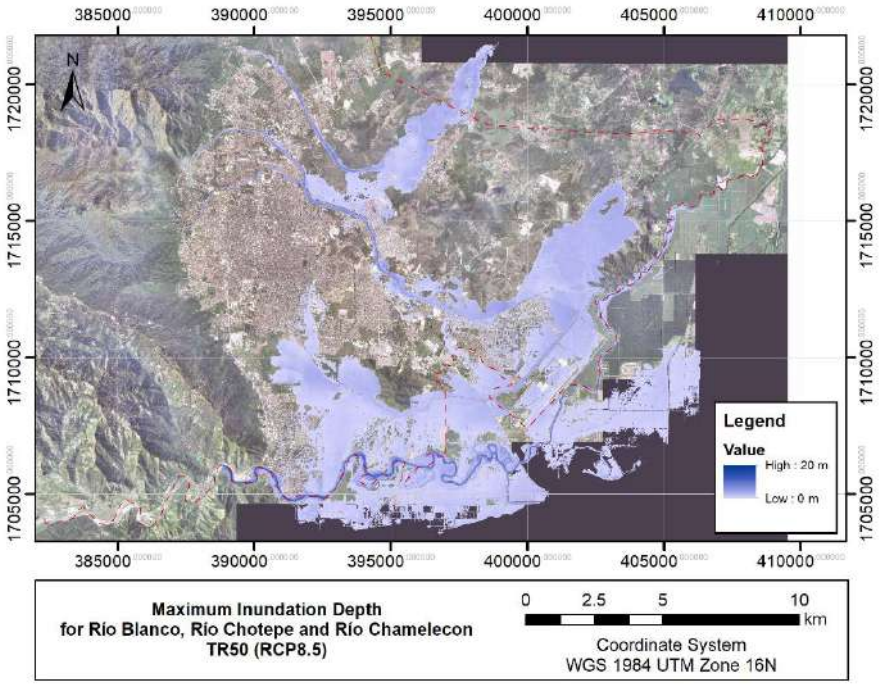


Figure 45: Maximum inundation depth for the return period of 50 years (future high RCP8.5)

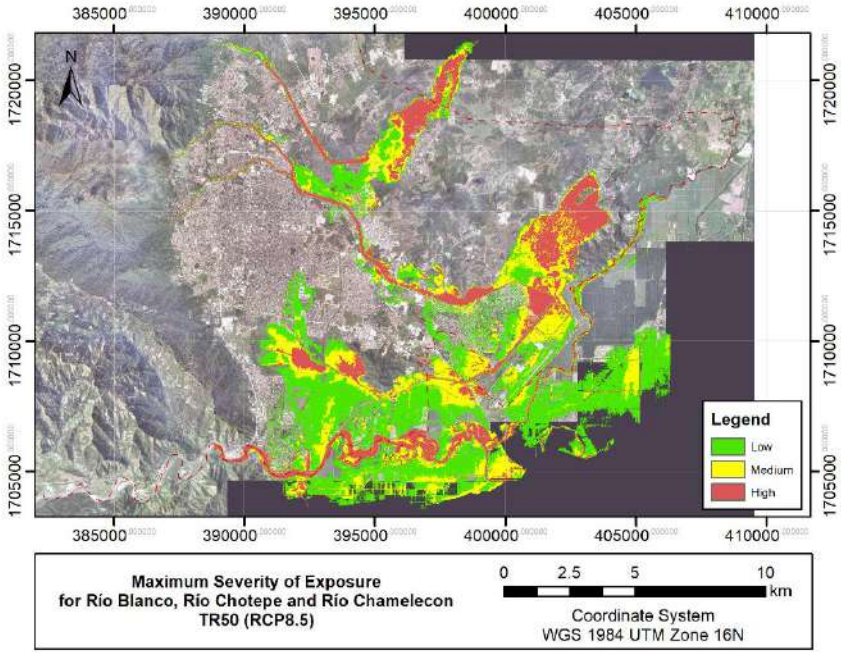


Figure 46: Maximum severity of flood exposure for the return period of 50 years (future high RCP8.5)

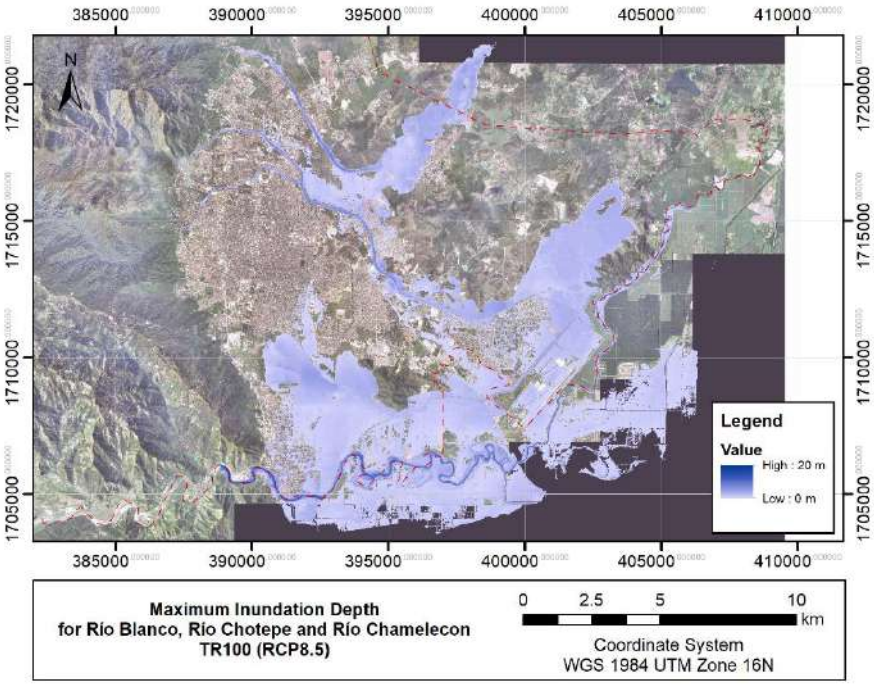


Figure 47: Maximum inundation depth for the return period of 100 years (future high RCP8.5)

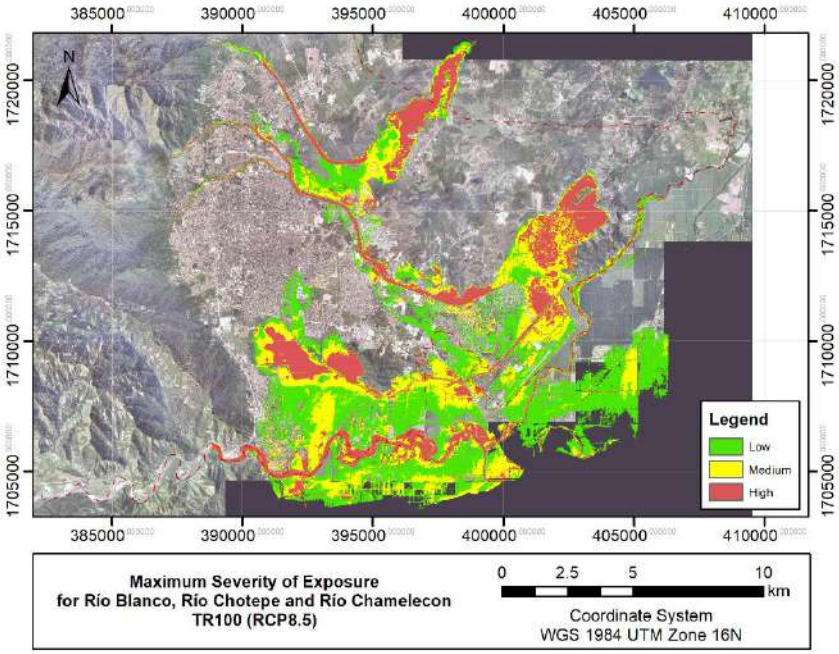


Figure 48: Maximum severity of flood exposure for the return period of 100 years (future high RCP8.5)

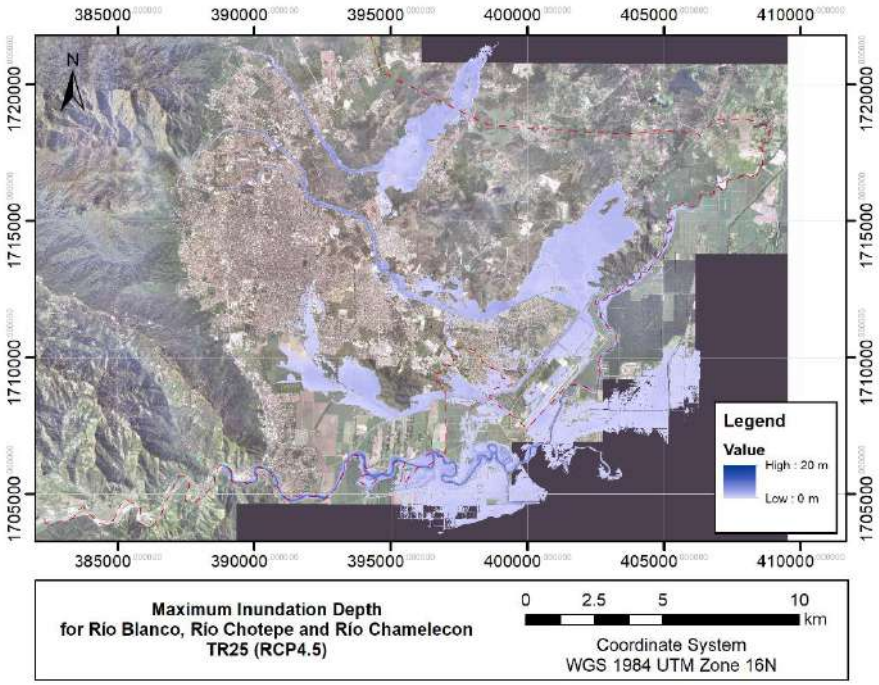


Figure 49: Maximum inundation depth for the return period of 25 years (future low RCP4.5)

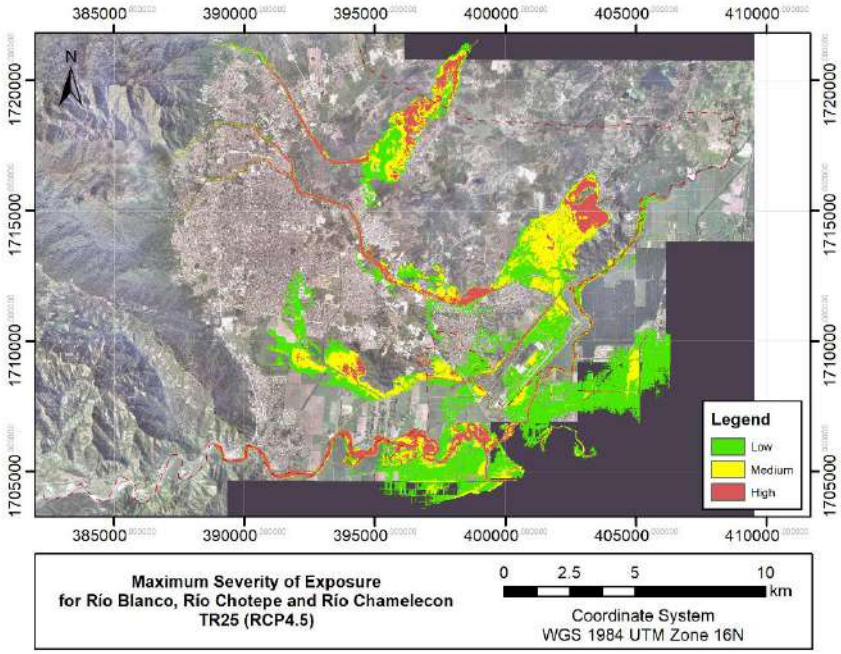


Figure 50: Maximum severity of flood exposure for the return period of 25 years (future low RCP4.5)

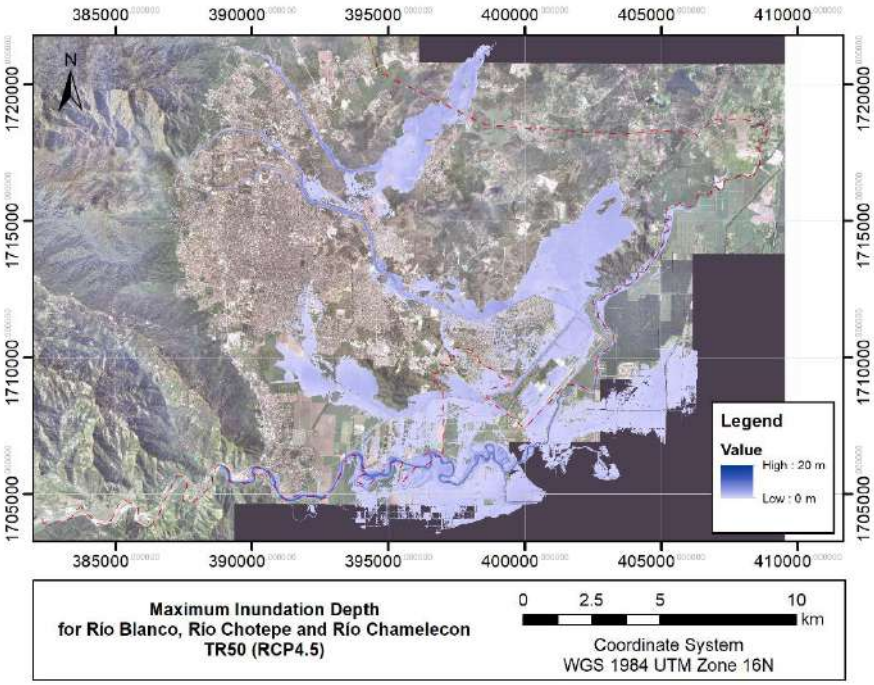


Figure 51: Maximum inundation depth for the return period of 50 years (future low RCP4.5)

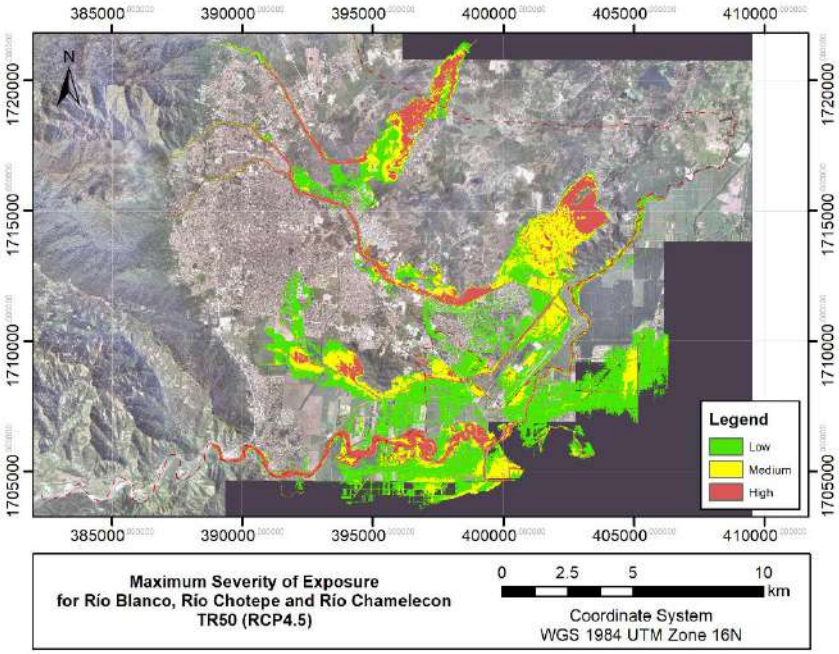


Figure 52: Maximum severity of flood exposure for the return period of 50 years (future low RCP4.5)

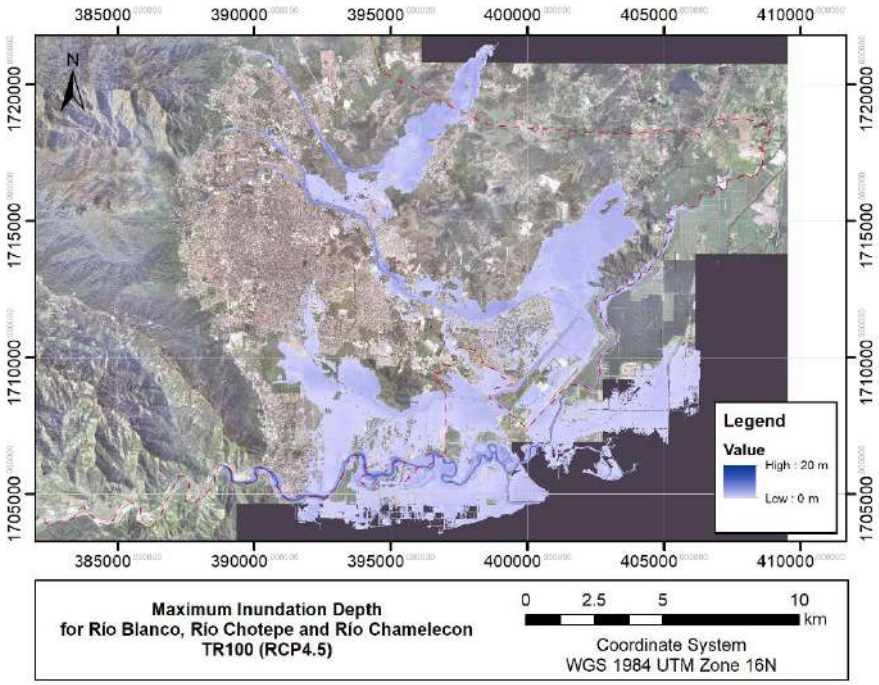


Figure 53: Maximum inundation depth for the return period of 100 years (future low RCP4.5)

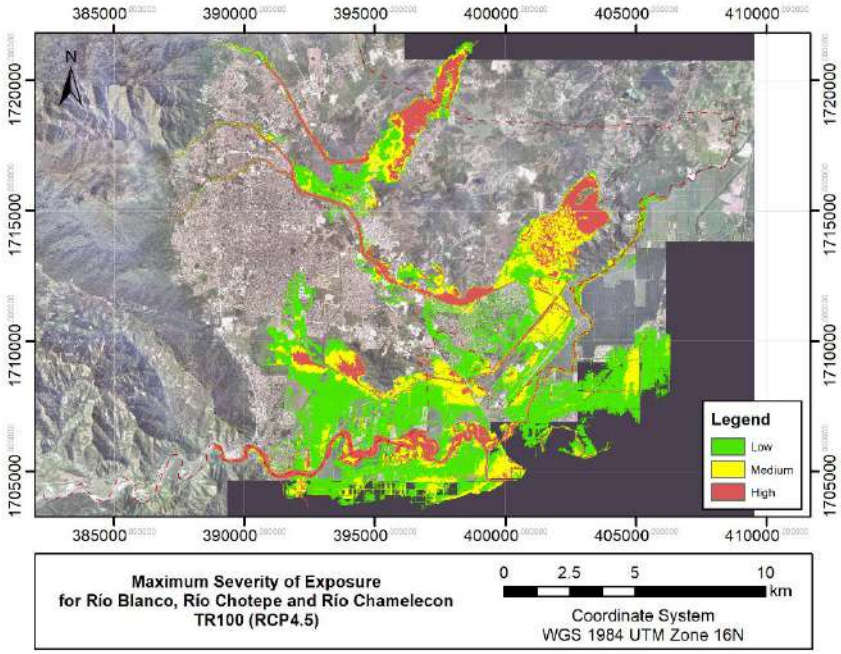


Figure 54: Maximum severity of flood exposure for the return period of 100 years (future low RCP4.5)

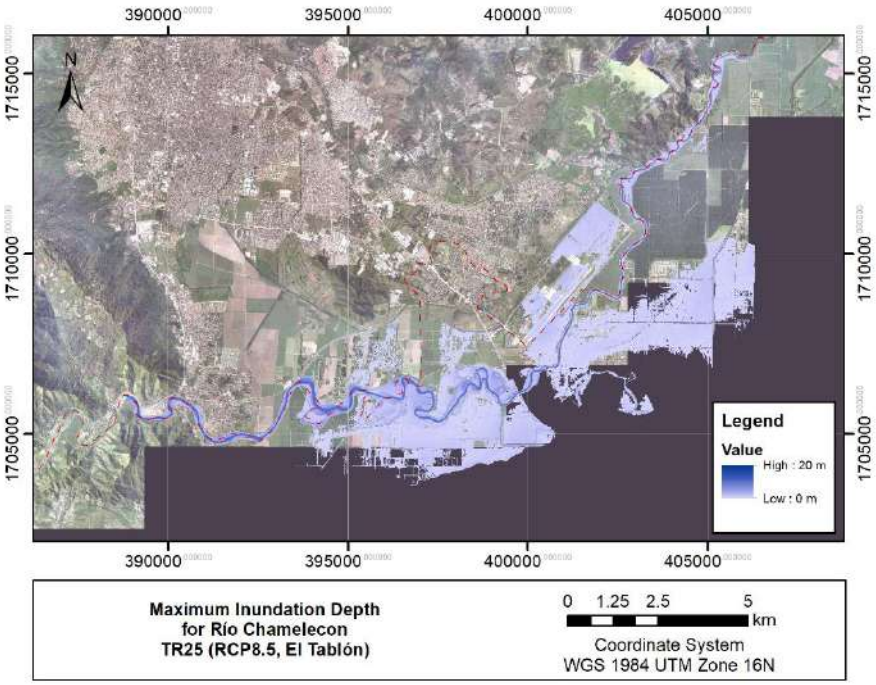


Figure 55: Maximum inundation depth for the return period of 25 years (future high RCP8.5 with consideration of El Tablón)

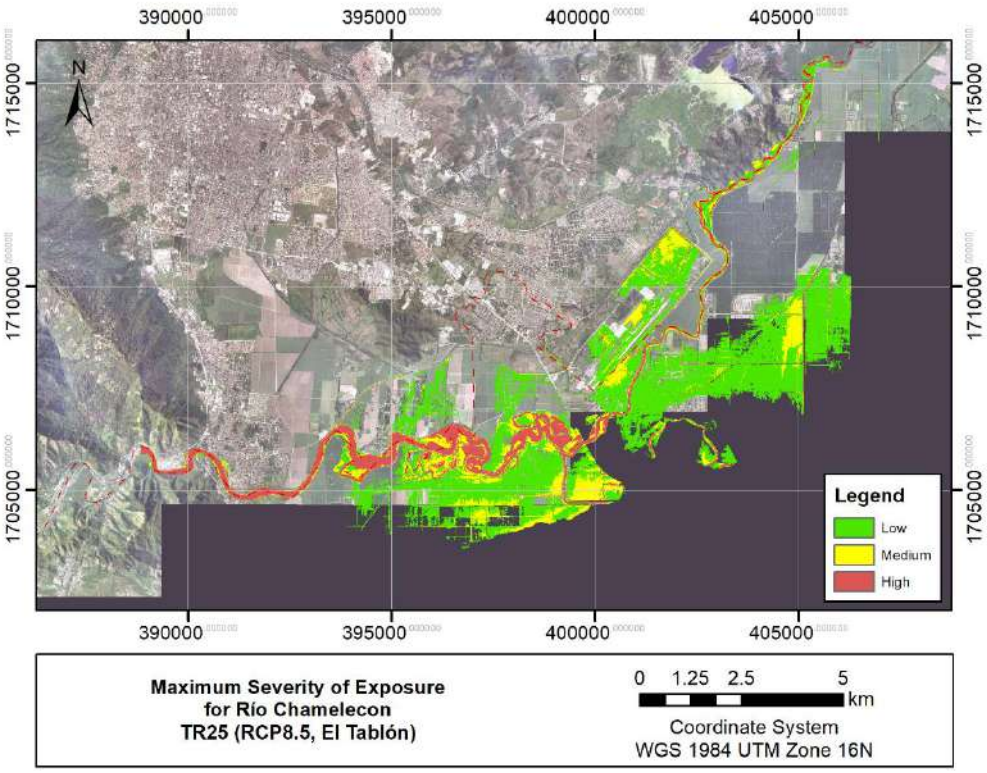


Figure 56: Maximum severity of flood exposure for the return period of 25 years (future high RCP8.5 with consideration of El Tablón)

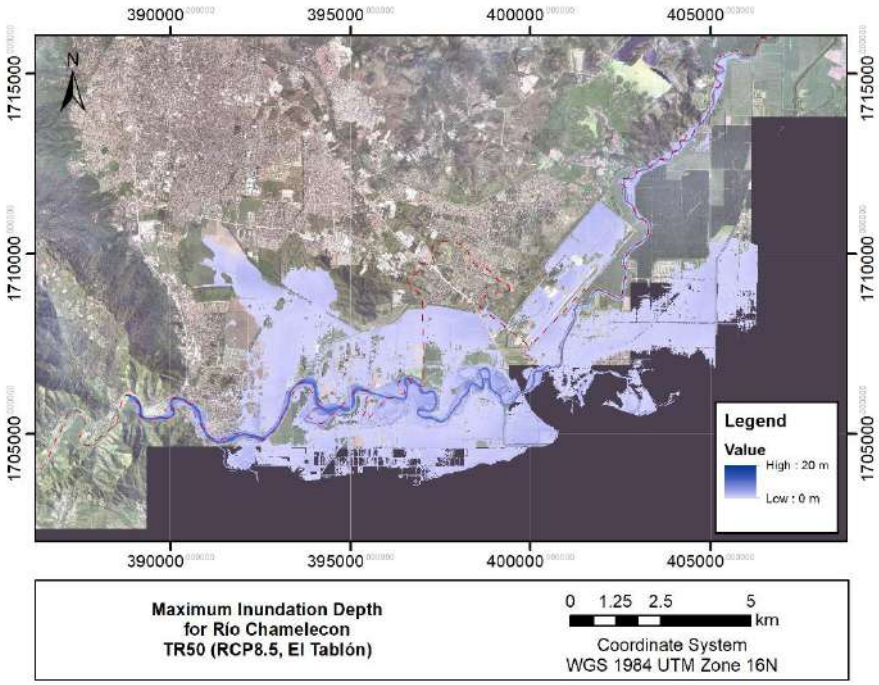


Figure 57: Maximum inundation depth for the return period of 50 years (future high RCP8.5 with consideration of El Tablón)

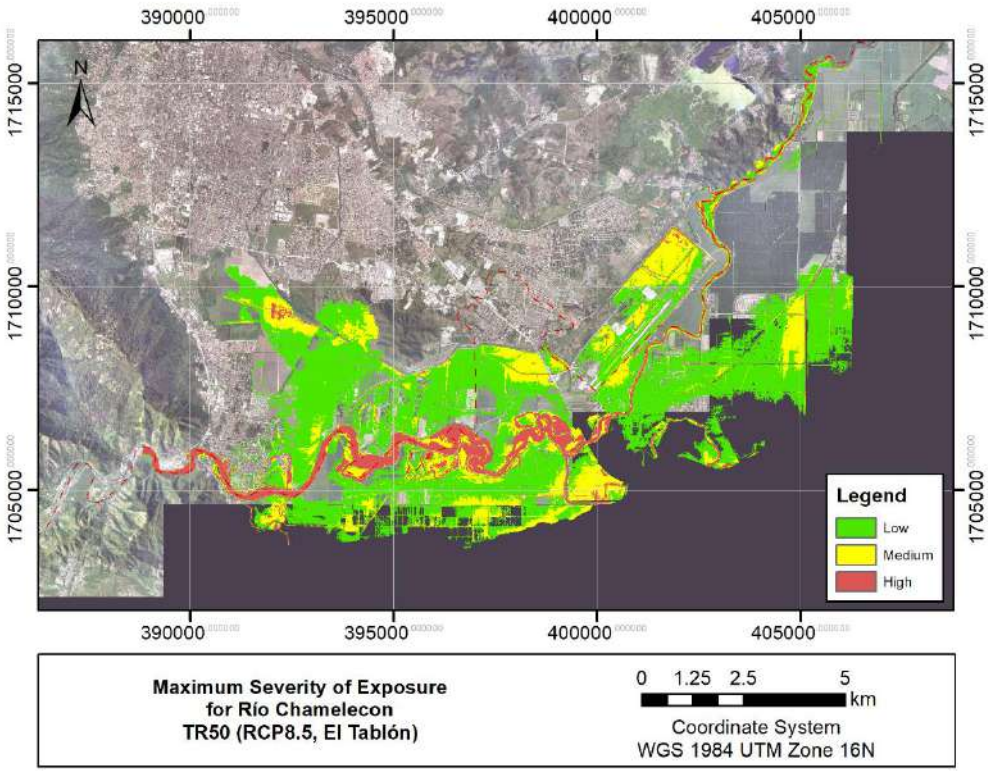


Figure 58: Maximum severity of flood exposure for the return period of 50 years (future high RCP8.5 with consideration of El Tablón)

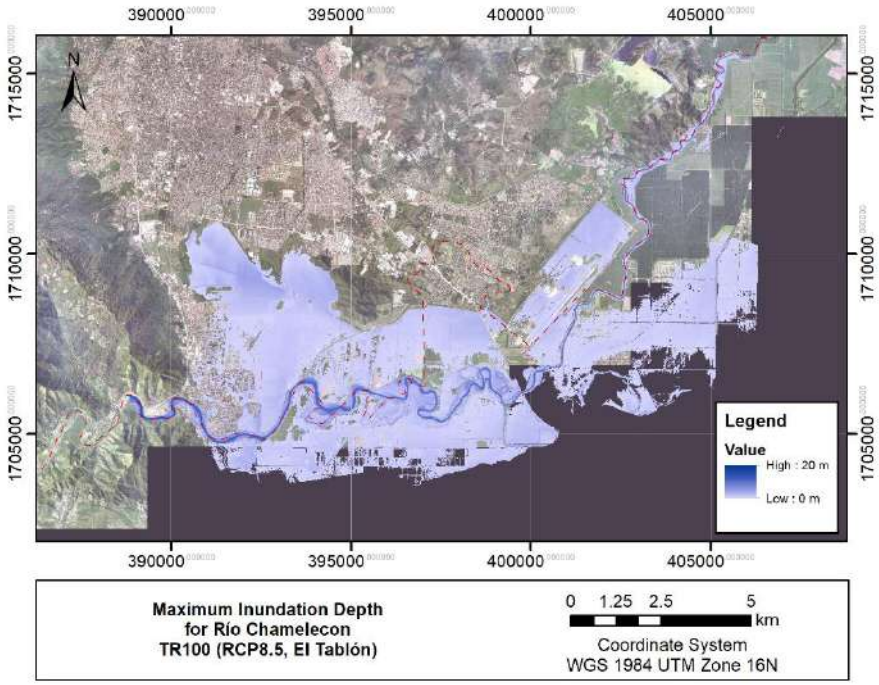


Figure 59: Maximum inundation depth for the return period of 100 years (future high RCP8.5 with consideration of El Tablón)

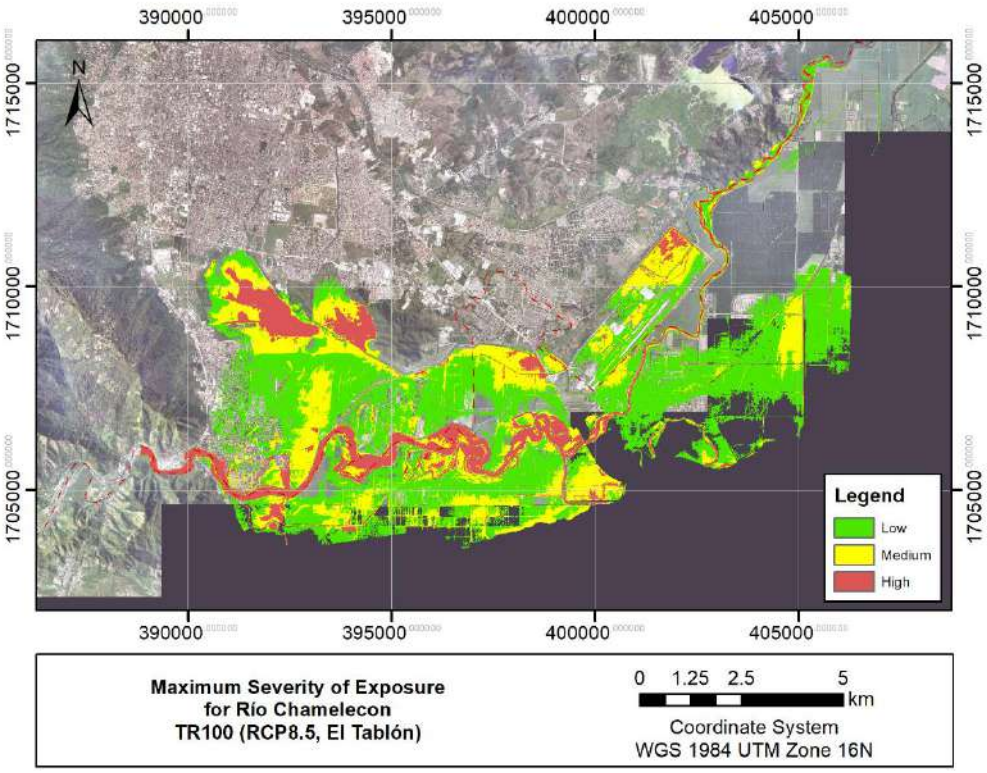


Figure 60: Maximum severity of flood exposure for the return period of 100 years (future high RCP8.5 with consideration of El Tablón)

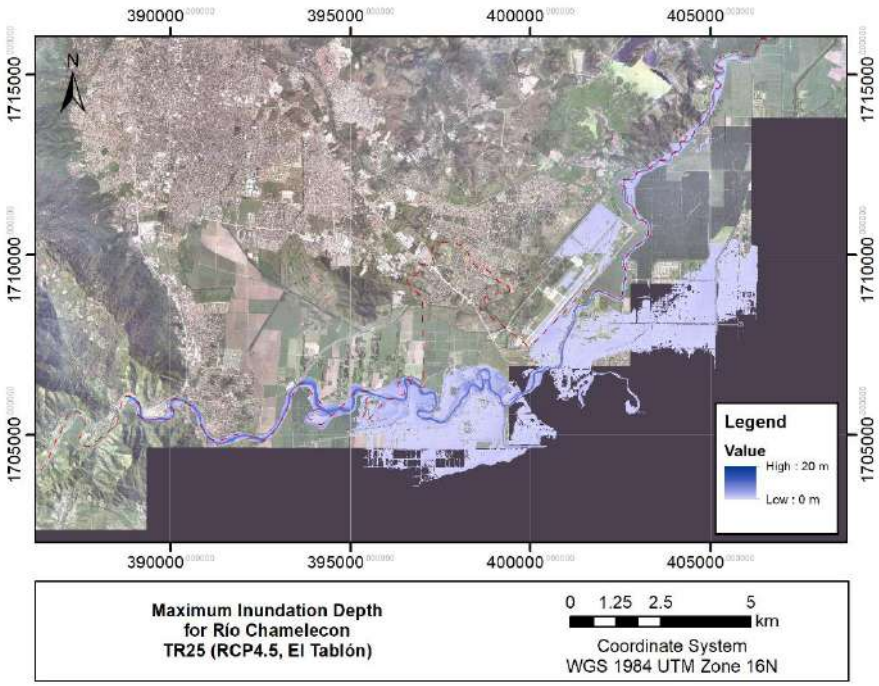


Figure 61: Maximum inundation depth for the return period of 25 years (future low RCP4.5 with consideration of El Tablón)

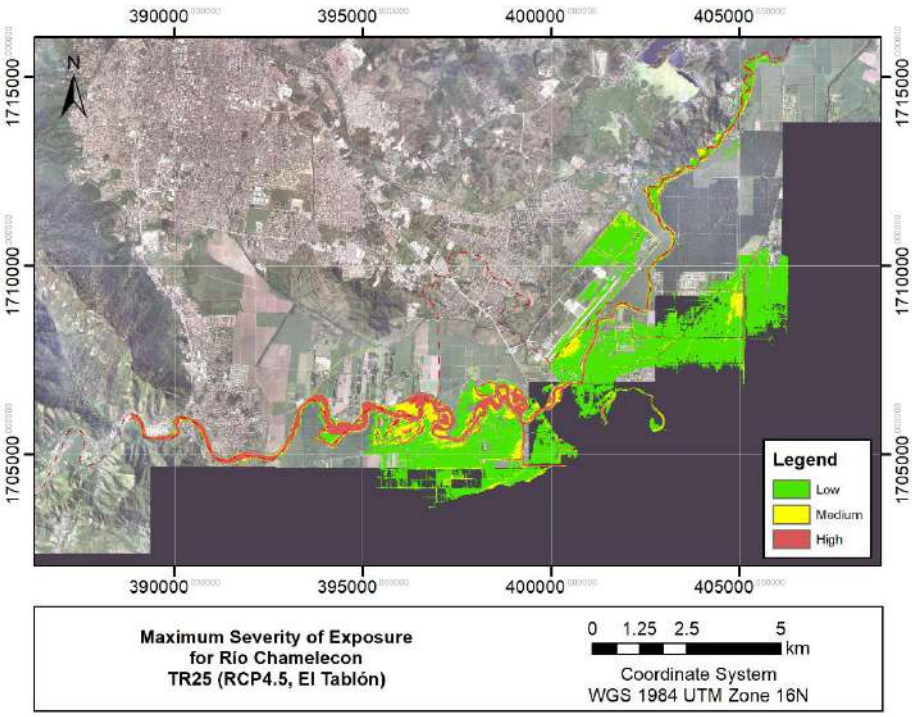


Figure 62: Maximum severity of flood exposure for the return period of 25 years (future low RCP4.5 with consideration of El Tablón)

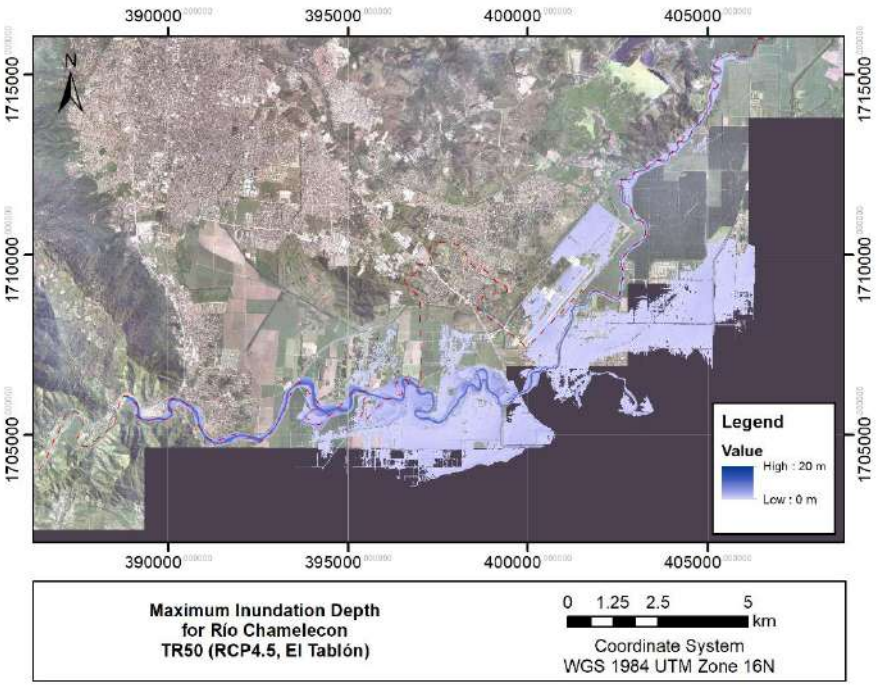


Figure 63: Maximum inundation depth for the return period of 50 years (future low RCP4.5 with consideration of El Tablón)

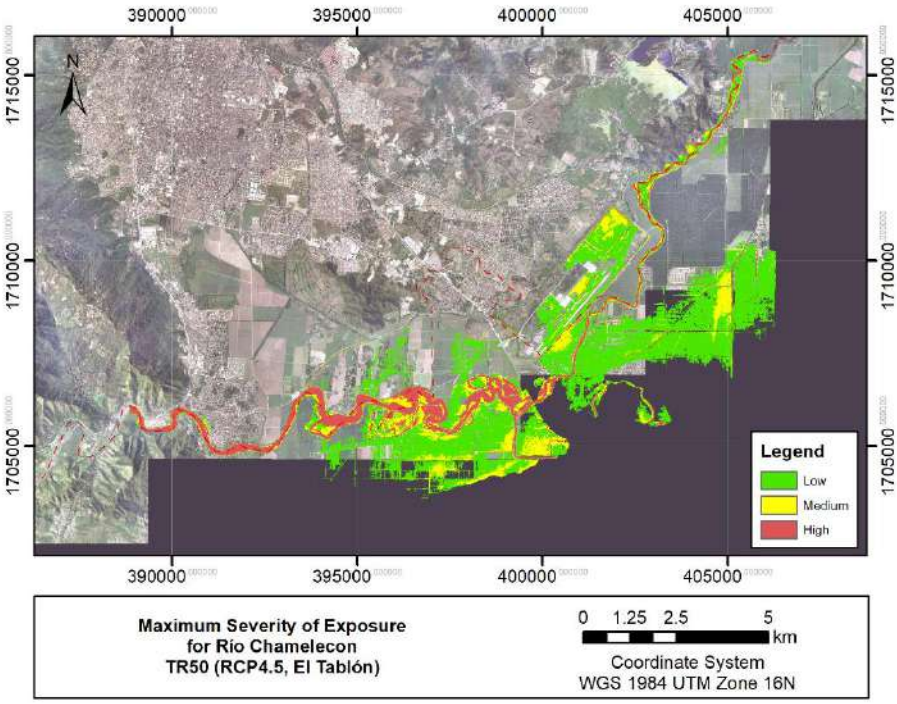


Figure 64: Maximum severity of flood exposure for the return period of 50 years (future low RCP4.5 with consideration of El Tablón)

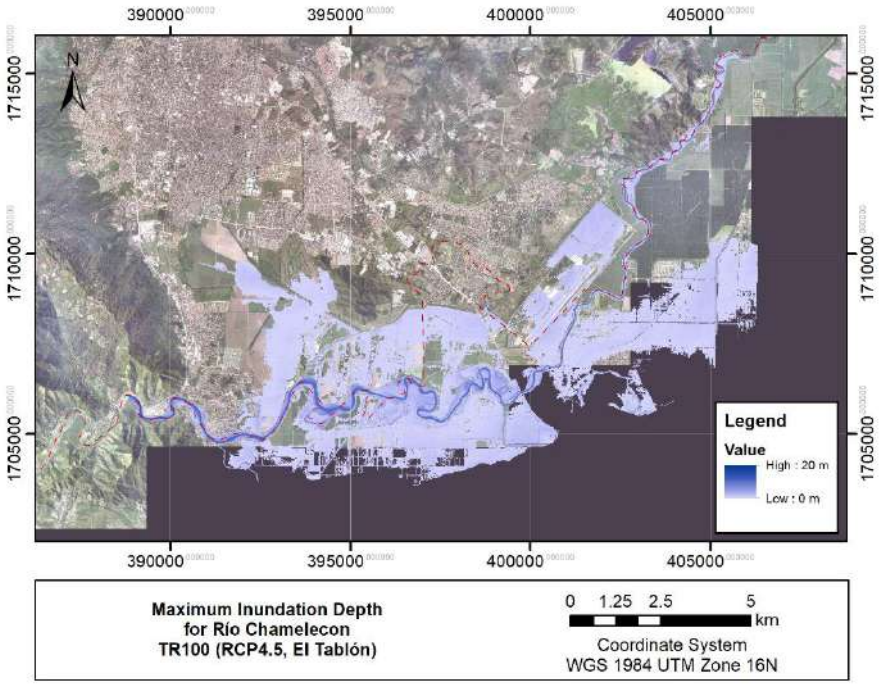


Figure 65: Maximum inundation depth for the return period of 100 years (future low RCP4.5 with consideration of El Tablón)

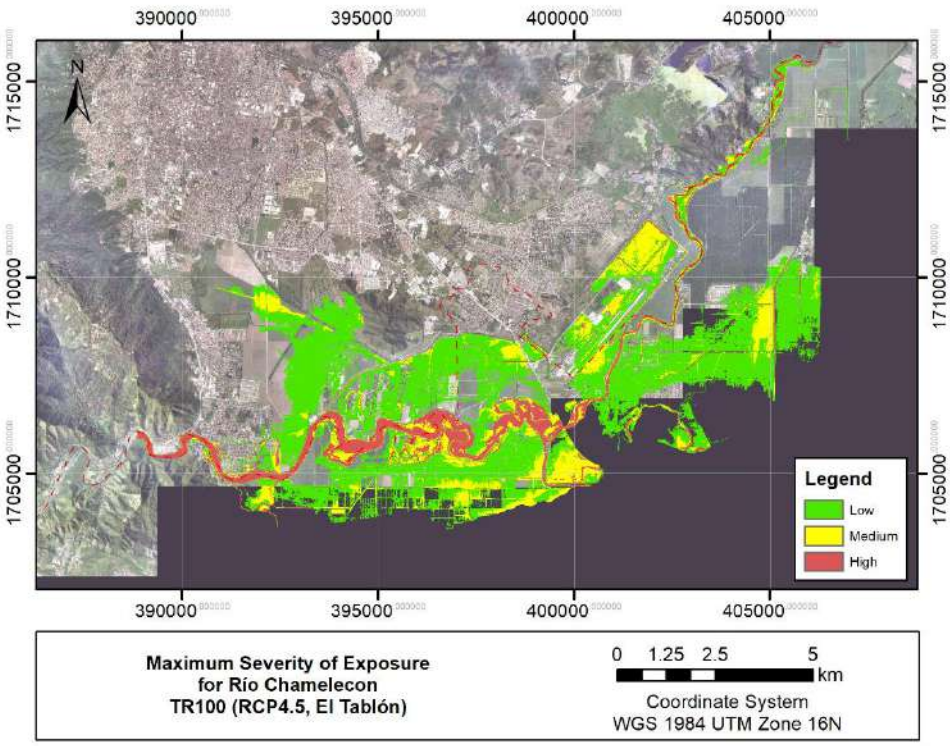


Figure 66: Maximum severity of flood exposure for the return period of 100 years (future low RCP4.5 with consideration of El Tablón)

6 Discussion & Uncertainties

6.1 Validation

Specific remarks on validation of hydrological analysis are described in Chapter 4.1.4 and are targeting similar problems as the validation of hydrodynamic models.

For a validation of hydrodynamic models generally measurement data is required. This measurement data may include parameters such as discharge (m^3/s), velocities (m/s) or water levels (m). Unfortunately, data for the validation of the obtained results for the hydrodynamic modelling of San Pedro Sula, was not available. However, local experts in Flood Modelling monitored this project, providing their advice and commenting on regional conditions. In this way feedback on DTM alterations and other work steps was given. In addition, results obtained were compared to the former results of the 1D Model made available by COPECO (2016a, 2016b).

6.2 Terrain data and bridges

Uncertainties will arise in hydrodynamic modelling, when data is incomplete or the quality is poor. Also, within this project the results should always be examined on the base of the provided data, as it was necessary to make assumptions throughout the modelling process.
E.g. the quality of the DEM was shown to be implausible in some regions. One example is a shift in height south of Río Chamelecón (see Figure 67), which was anticipated by setting up an outflow condition via normal depth into the hydraulic model in order to prevent backwatering effects through the shift. Other artefacts, presumably sourcing from vegetation, are also present throughout the whole project area (see Figure 68) without possibilities of improvements of the data.

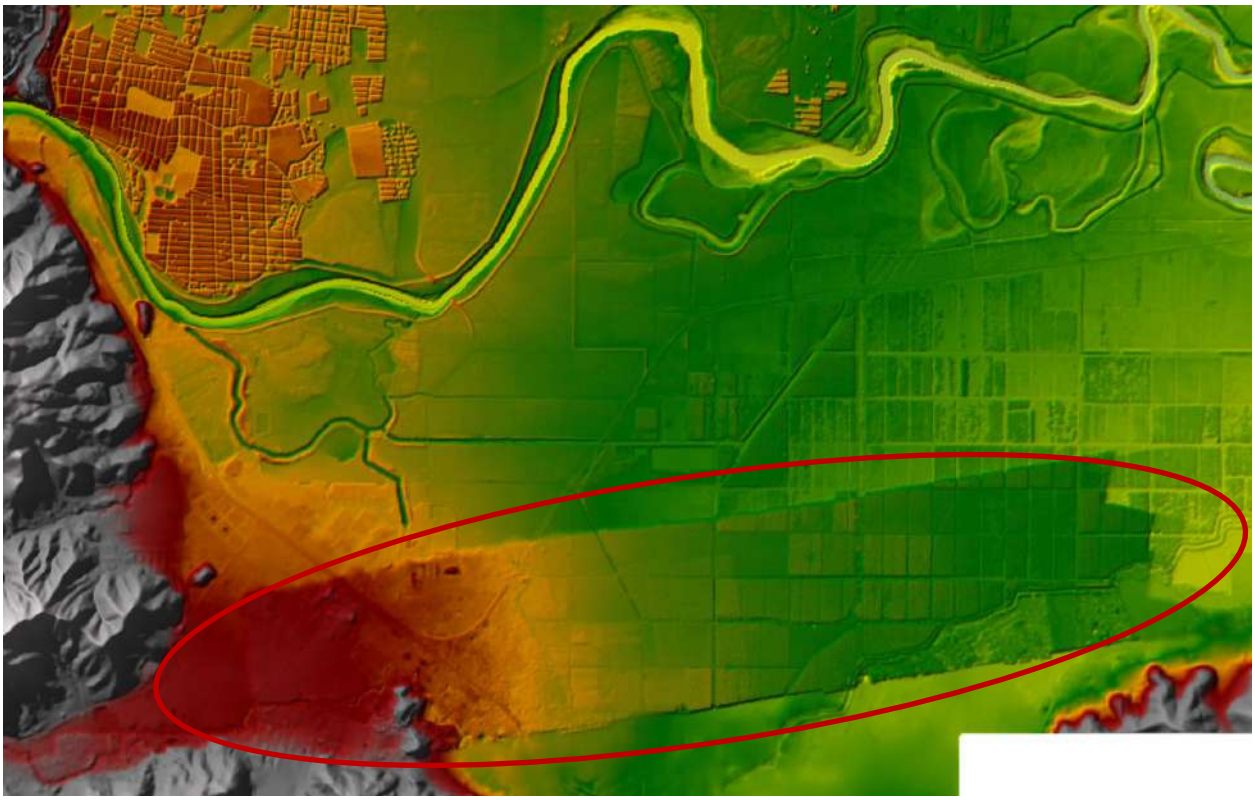


Figure 67: Error in the DTM showing a "stripe" in elevation south of Río Chamelecón, therefore this part was excluded from the model area to prevent unnatural backwatering effects

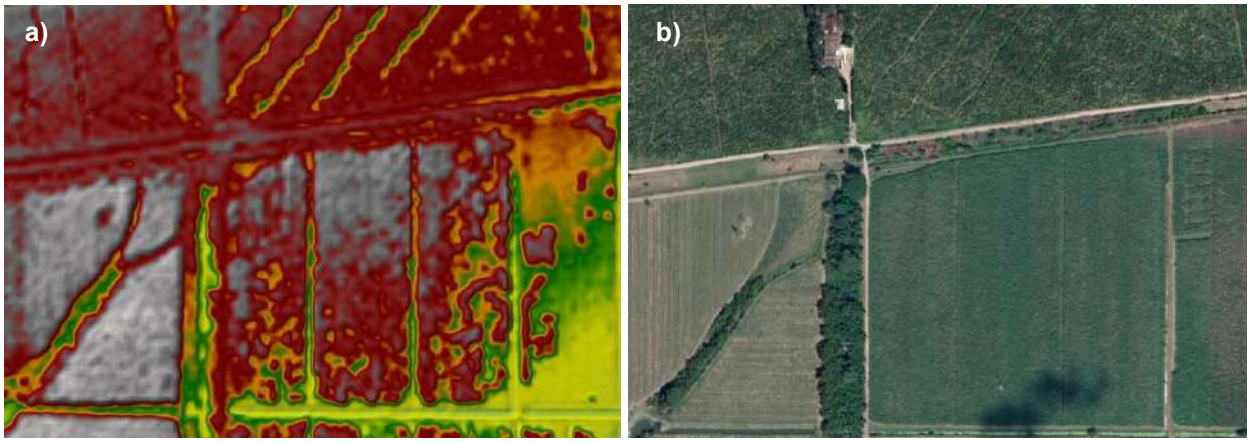


Figure 68: Artefacts by vegetation showed in the DTM when comparing elevation heights (a) with orthophoto (b)

During the implementation of the river channels in the hydraulic models, several assumptions were made, deflecting real conditions. As mentioned before, the utilized cross sections (expect those of Canal Sauce) were not measured, but extracted from the DEM. Therefore, they may not reflect real conditions. Especially when looking at the upstream area of Rio Blanco, difficulties occurred finding adequate cross sections from the DEM to interpolate the river channel. Since the DEM is not showing the river course very clearly, some shortcomings of this river sections may not be resolved (see Figure 69).

Figure 69: Constraint of the DTM in the upstream part of Río Blanco model not showing a clear picture of Río Blanco river channel

For the biggest of the examined rivers, namely Río Chamelecón, a medium depth of approximately 2 - 3 m was assumed by local expert knowledge and considered into the editing of the river channel. Due to the smaller size of the river bed and smaller extent of the catchments of Río Blanco and Río Chotepe, no further assumptions were made here. Also, the pathways of the rivers were not clearly visible in the DTM at some points. For the implementation of canal Sauce, XS profiles were provided only for a short, urban section of approximately 2 km. To connect this section with the old boundary of the former COPECO model it was necessary to interpolate the XS profiles along the river centerline. This river centerline was not clearly

visible in the DTM and thus was manually drawn based on satellite data. The results of this alteration are shown in Figure 70.

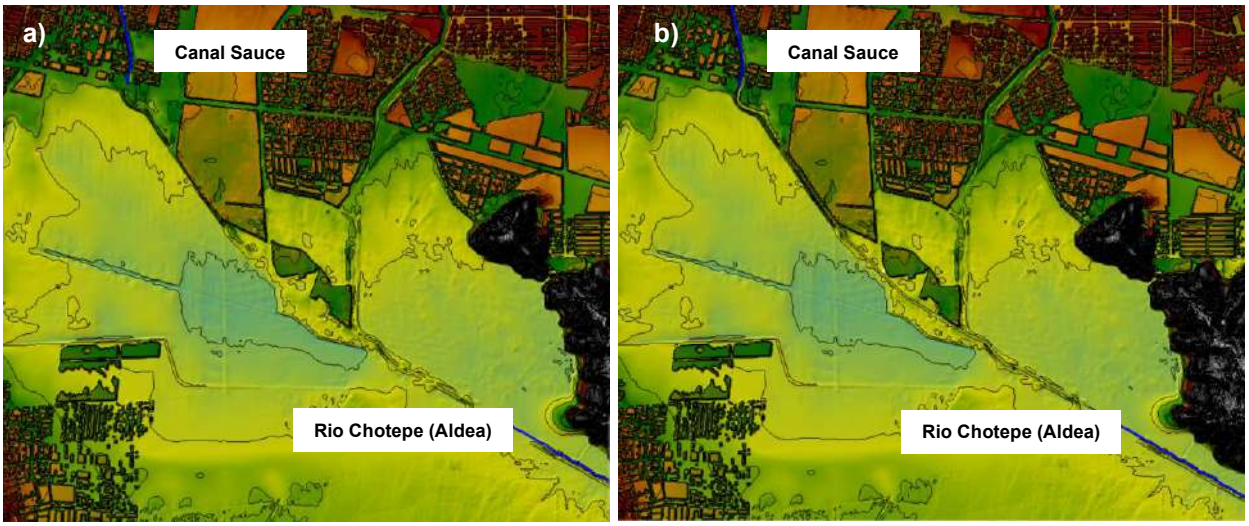


Figure 70: It was necessary to interpolate XS profiles in between Canal Sauce and Rio Chotepe (a). The river centerline was drawn based on satellite data, the resulting channel was burned into the DTM (b)

Concerning the consideration of bridges and outlets of the canals of Canal Maya and Canal de Filopo it can be said, that all available information was included. This includes the bridge of Bulevar del Norte and Segundo Anillo Periférico, as well as the outlets for Canal Maya and Canal de Filopo, however without exact measurements (see Figure 71 showing the inlets with top edges). As mentioned earlier, validation data was scarce. However, it was possible to compare the outflow of Canal Maya with information provided by the regional expert: Canal Maya was designed for discharges up to 650 – 700 m^3/s. This discharge was also reflected by the model results in this project.

Figure 71: Canal de Filopo (a) and Canal Maya (b)

Many other bridges are located in the region of San Pedro Sula. An analysis of all bridges present in the area was conducted based on satellite data. The results are shown in Figure 72, where bridges are indicated as blue points. The neglection of this high quantity of bridges may possibly cause backwatering effects.

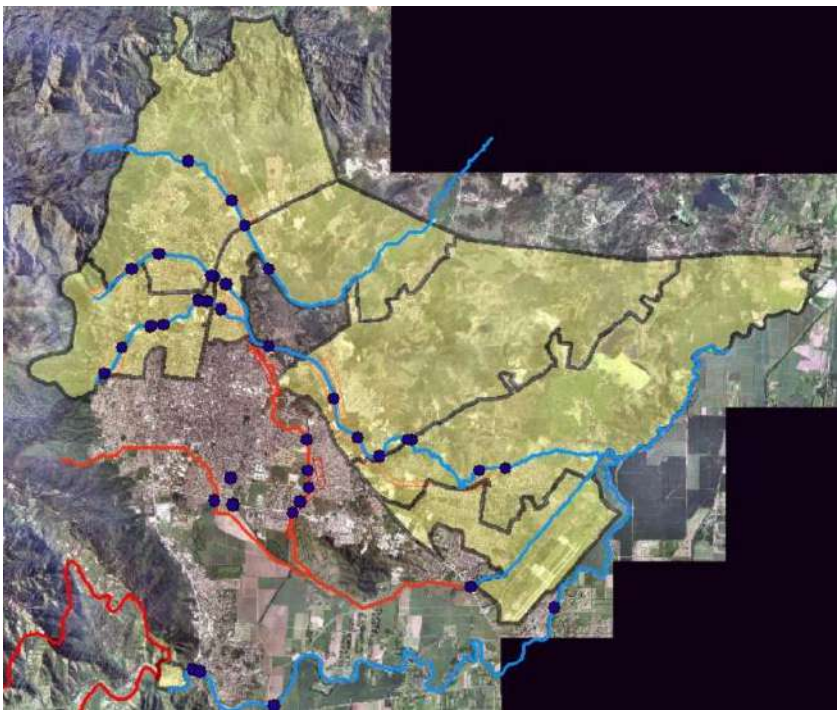


Figure 72: A large quantity of bridges (indicated as blue points) were not taken into account during the modelling process

Finally, in the Rio Blanco Model uncertainties may arise due to a lack of information on the lake storage area downstream of Rio Blanco, which is shown in Figure 29 in chapter 4.2.3.1. It would have been advisable to include the Lake as a storage area in the hydrodynamic model. However, the extent of the storage, the volume of the lake etc. were not available, which why an adequate consideration of the lake was not possible.

6.3 Land use and building information

Uncertainties also arise from the land use and building information. As shown in Figure 50, the available cadaster seemed unreasonable in some parts. While in some areas several houses were represented as larger blocks, in other areas houses which were shown on satellite data, are not represented in the cadaster. In addition, no information on dimensions, material or permeability was available. Therefore, a generic approach was chosen, in which the DTM was altered to represent the houses and infrastructure. In order to do so, all blocks were lifted by 5 meters. This is of course and all-encompassing approach, which might lead to diverse results, as the house-blocks are obstacles for flow. The cadaster was edited to the best possible manner and blocks, which seemed unrealistic were removed.

Figure 73: Uncertainties due the incompleteness of housing cadaster: region a) and b) show very big areas being considered as a block, c) and d) show that not all buildings in the orthophoto are included in the cadastre

7 Conclusions

The main focus of the study was the improvement of flood hazard maps for the region of San Pedro Sula, with the objective to analyze impacts of flooding on formal and informal settlements. On the base of the studies conducted by COPECO (2016a, 2016b) and Abrego Suárez (2019), hydrologic and hydraulic models were set-up, further developing and improving the existing ones.

The hydrologic modelling included the simulation of three return periods (25, 50 and 100 years) for the present and future. Projections were given by the RCP 4.5 and RCP 8.5 scenarios (on the basis of the regional RCA4 model). For Río Chamelecón, the planned hydropower reservoir “El Tablon” was implemented in the model by considering the resulting changes in discharge. Discharge values were calculated based on the framework of dam-planning provided by San Pedro Sula Municipality. This meant a new model set up with HecHMS for the catchments of Rio Blanco and Rio Bermejo as well as an enhancement of the existing model for Rio Chamelecon. Driven by data availability and data resolution, the hydrological model was set up as a semi-distributed model, dividing the whole basin into a number of smaller sub-watersheds with relatively homogeneous physical characteristics. These physical characteristics were determined on the base of available data (e.g. landuse, soil, altitude range/steepness) and a GIS-based analysis to derive the parameterization of the physically-based description of the hydrological cycle components.

Results from the hydrological modelling were successfully adopted as input for the hydrodynamic modelling. The hydrographs resulting from the HEC-HMS model, provided the input for the boundaries of the hydrodynamic HEC-RAS model. Because of the data availability and the general lack of measurement data (e.g. precipitation, runoff, infiltration), the validation of the results was based on the knowledge of local authorities, a plausibility check with literature (USGS, 2002), the Creager envelope curves for extreme floods as well as the results out of the hydrodynamic modelling.

The hydraulic modelling, as a key task of the study, successfully adopted and ameliorated the existing 1D HEC-RAS models to a 2D model approach. Main steps to adapt the models were the terrain processing, including the interpolation of cross sections for a continuous river channel, as well as the integration of buildings as hydraulic structures. The quality of the terrain was shown to be in need for improvement, since several artefacts appeared, forming a source for uncertainties for the hydraulic modelling results. Some short-comes were overcome by data processing. In addition, assumptions or neglections had to be made, deflecting real conditions. The construction of the river channels was based on the DEM (except for canal sauce), since measurements were not available. Measured crosssections would have provided a higher accuracy, leading to better results. Additionally, there are several bridges in the area of San Pedro Sula, of which only two were considered. Possible backwater effects could therefore not be taken into account.

Nevertheless, local expertise as well as a comparison to previous studies showed an overall agreement with the results. Concisely, the outputs of the study included inundation depths and flood extents for three return periods (25, 50 and 100 years) for the present and the future (RCP4.5 and RCP8.5). Comparing the results to those of the previous 1D study from COPECO (2016) and Abrego Suarez (2019), evident improvement took place. The level of detail concerning spatial resolution was enhanced and the number of possible scenarios considered augmented. The results of this study may serve as a planning basis for the further development of San Pedro Sula.

8 References

Abrego Suárez, C. R. (2019). *Actualización preliminar de los umbrales de alerta por inundación de Río Chamelecón en ciudad La Lima, Cortés, para el período de observaciones 2010-2018.* Tegucigalpa, Honduras.: Master Thesis.

Beretta, R., Ravazzani, G., Maiorano, C., & Mancini, M. (2018). Simulating the Influence of Buildings on Flood Inundation in Urban Areas. *Geosciences, 8, 77; doi:10.3390/geosciences8020077*.

COPECO: Comisión permanente de contingencias. (2016a). *Informe V- Hidrología, Producto 1. Análisis de Riesgo a nivel municipal y local, Estimación de Avenidas – Sistemas de cuencas del Municipio de San Pedro Sula Departamento de Cortés.* San Pedro Sula.

COPECO: Comisión permanente de contingencias. (2016b). *Informe Geomorfológico.* San Pedro Sula: Municipio de San Pedro Sula Departemento de Cortés.

Cowan, W. (1956). Estimating Hydraulic Roughness Coefficients. *Agricultural Engineering Vol. 37 No. 7*, pp. 473-475.

Hernandez Ore, M. A., D. Sousa, L. D., & Lopez, J. H. (2016). *Honduras: Unlocking Economic Potential for Greater Opportunities. Systematic Country Diagnostic.* Washington, D.C. : World Bank Group.

Kreft, S., Junghans, L., Eckstein, D., & Hagen, U. (2015). *Global Climate Risk Index 2015: Who Suffers Most from Extreme Weather Events? Weather Related Loss Events in 2013 and 1994 to 2013.* Bonn: Germanwatch Nord-Süd Initiative E.V.

Seneviratne, S., Nicholls, N., Easterling, D., Goodess, C., Kanae, S., Kossin, J., . . . Zhang, X. (2012). Changes in climate extremes and their impacts on the natural physical environment. In *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC)* (pp. 109-230). Cambridge, UK, and New York, NY, USA: Cambridge University Press.

The World Bank. (2018). *Guidelines for Flood Risk Modelling in the Sula Valley, Honduras.*

USGS: US Army Corps of Engineers - Hydrologic Engineering Center. (2016, February). *HEC-RAS River Analysis System - 2D Modeling User's Manual Version 5.0.* Davis: USGS.

USGS: US Arma Corps of Engineers - Hydrologic Engineering Center. (2020). *Hydrologica Modelling System. User's Manual Version 4.6.1.* Davis: USGS.

USGS: US Arma Corps of Engineers - Hydrologic Engineering Center. (2002): Flood-Hazard Mapping in Honduras in Response to Hurricane Mitch. Water-Resources Investigations Report 01-4277.

Ward, Andy D.; Trimble, Stanley W. (2004): Environmental Hydrology. Boca Raton, Florida 33431: CRC Press LLC.

Wi, s. et al, (2015): Calibration approaches for distributed hydrologic modelsin poorly gaged basins: implication for streamflowprojections under climate change. Hydrol. Earth Syst. Sci., 19, 857–876, 2015www.hydrol-earth-syst-sci.net/19/857/2015/doi:10.5194/hess-19-857-2015.

Williams, J.R., 1995. The EPIC model. In: V.P. Singh, ed,Computermodels of watershed hydrology. Highlands Ranch, CO: WaterResources Publications, 909–1000.

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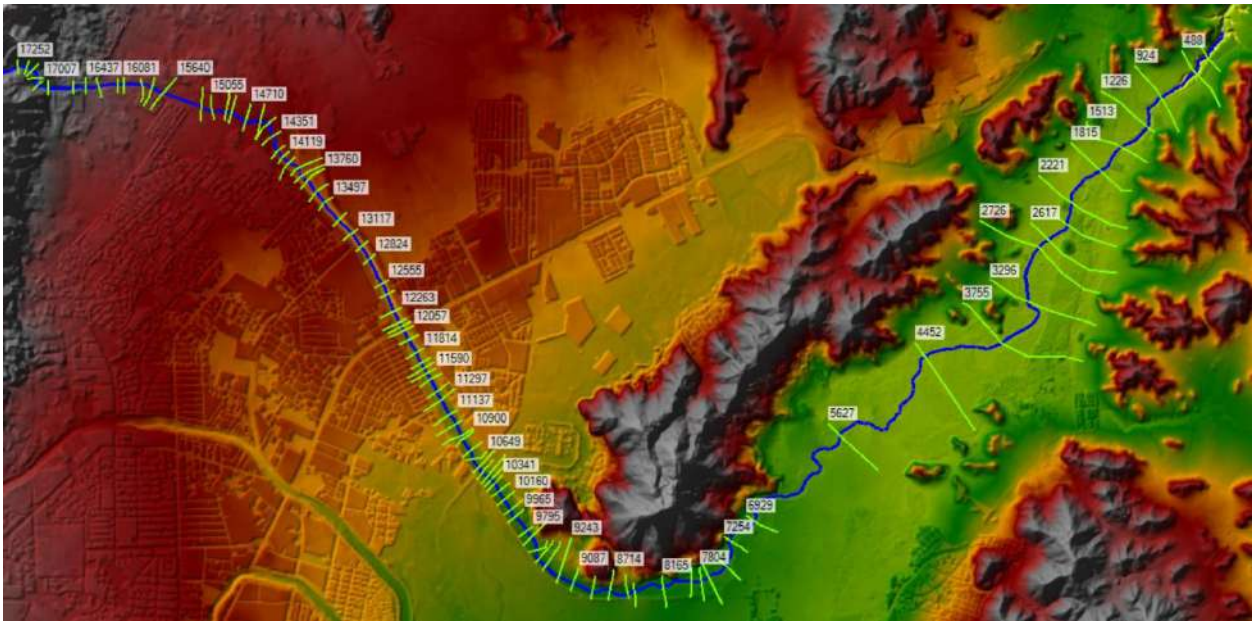
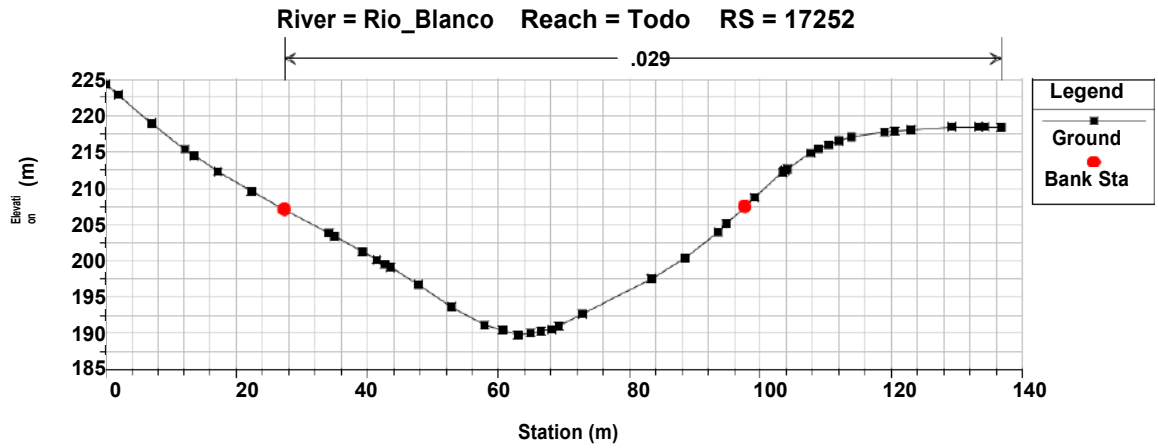
11 Annex

A1 Crosssections Model Río Blanco

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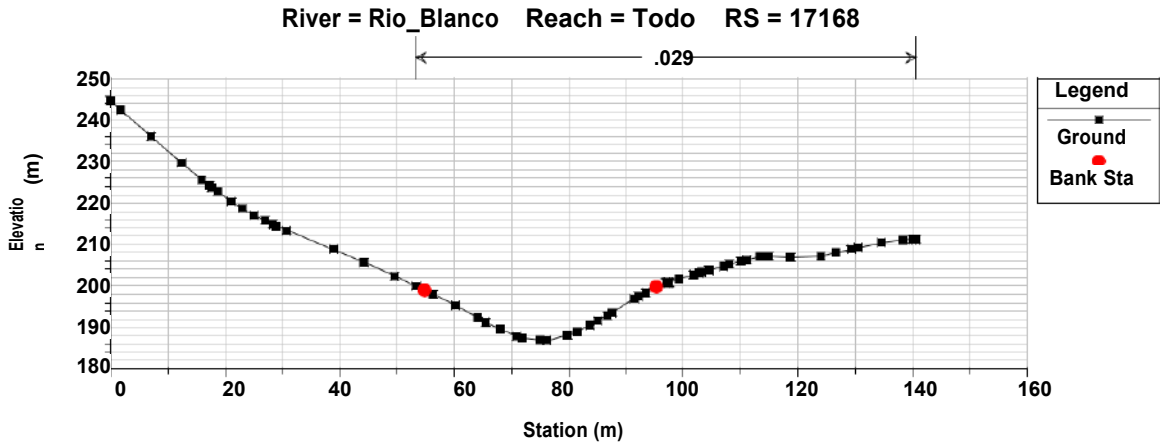
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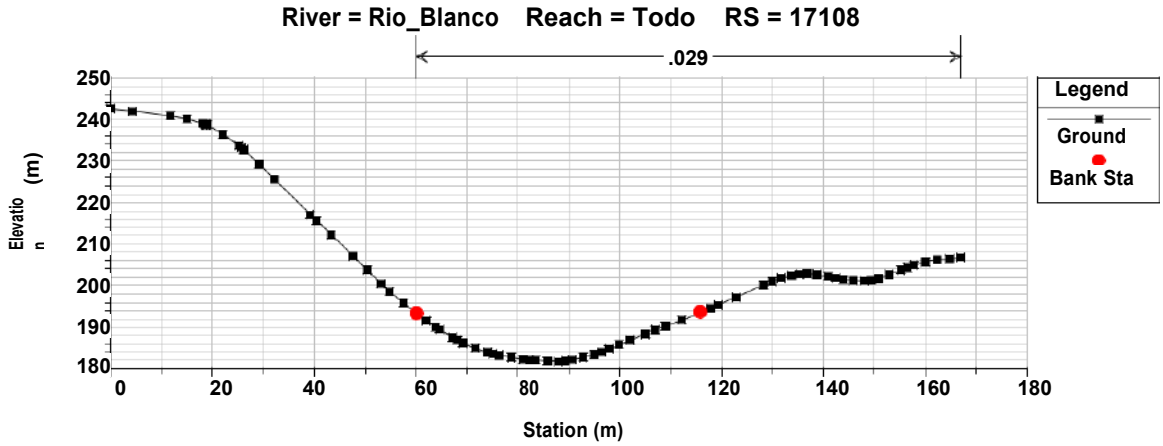
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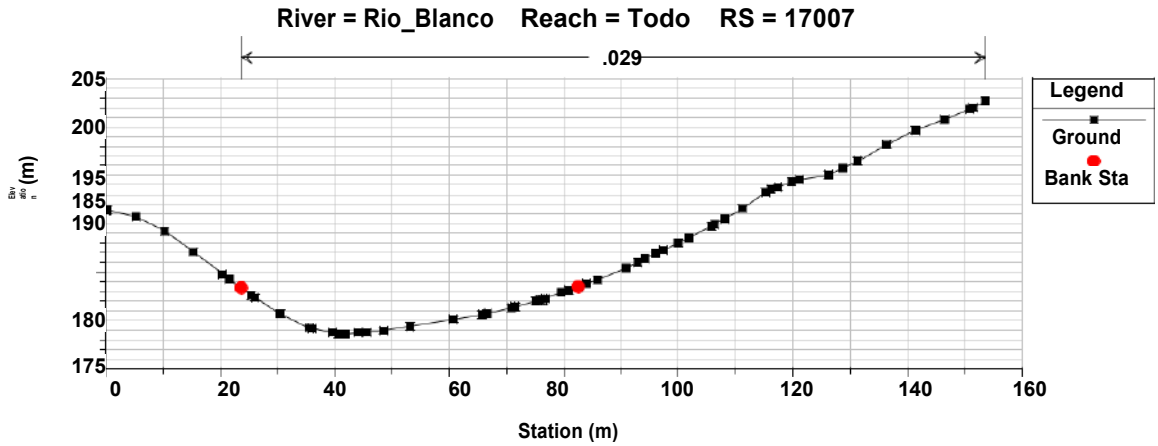
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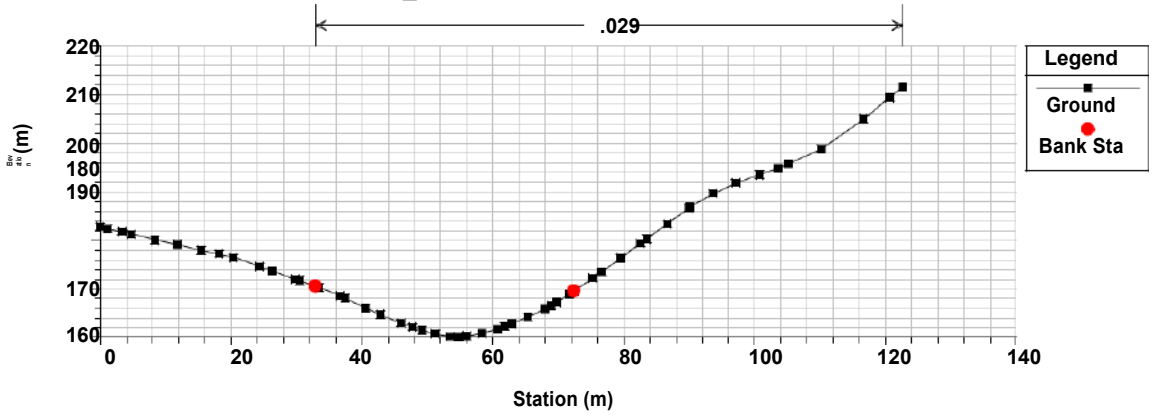

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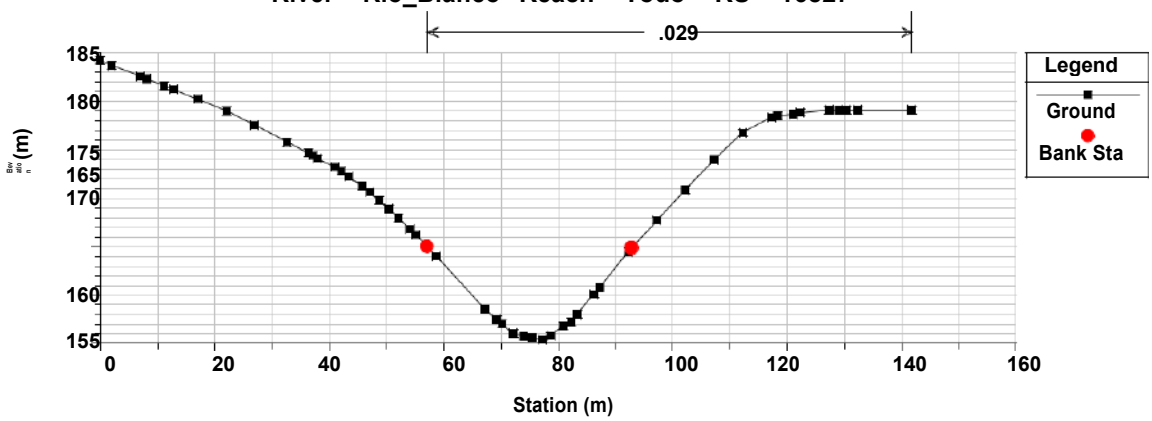

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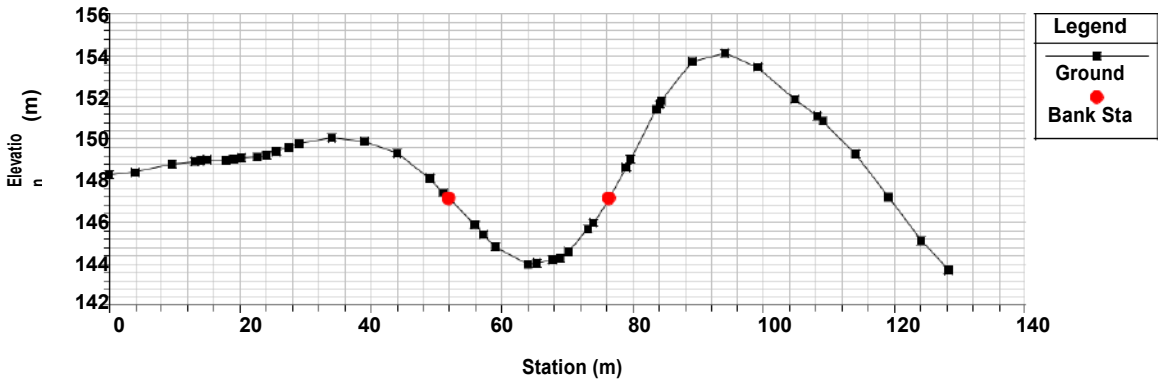

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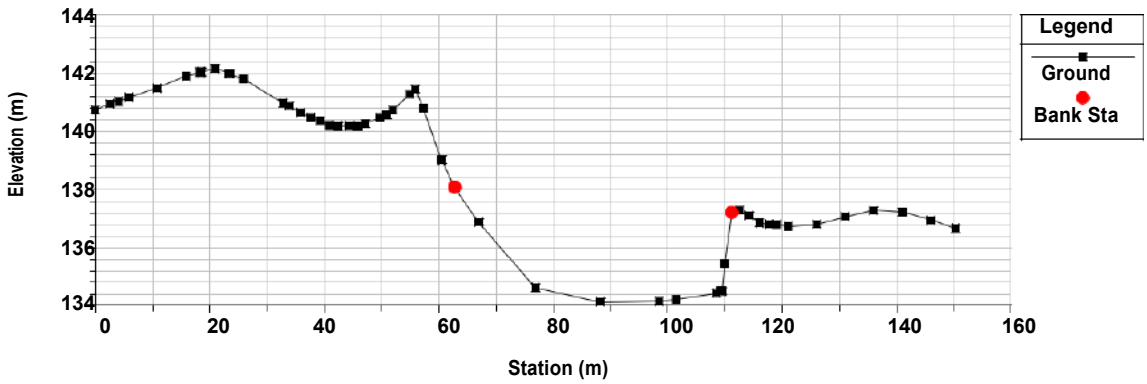

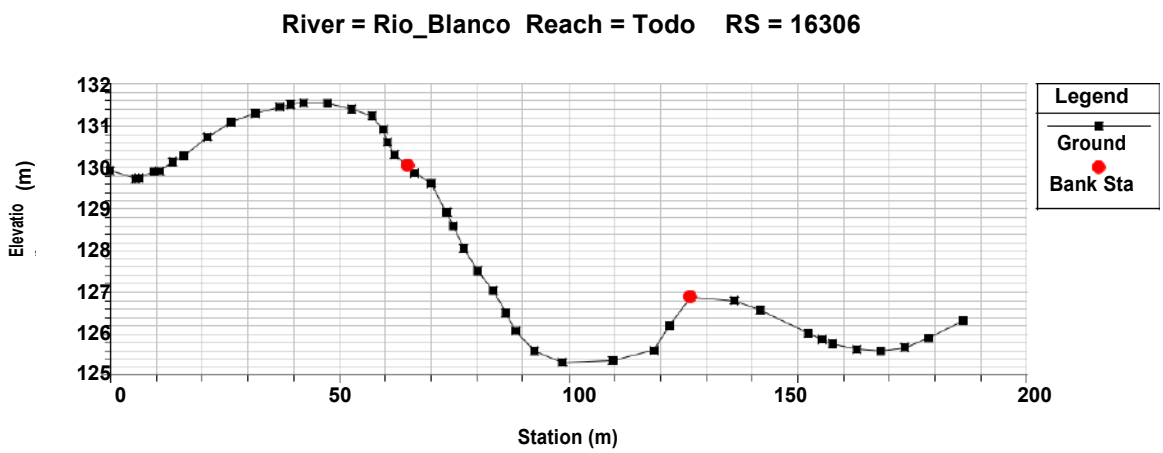
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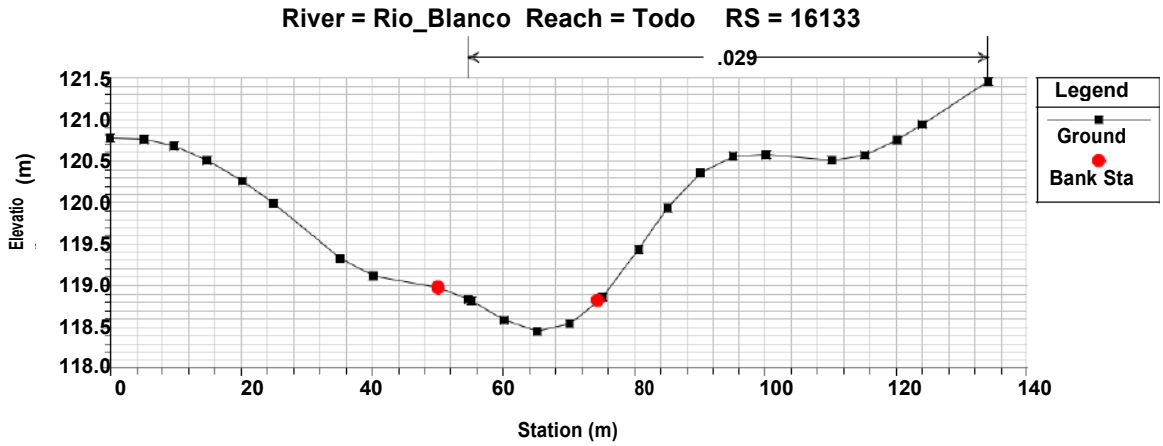
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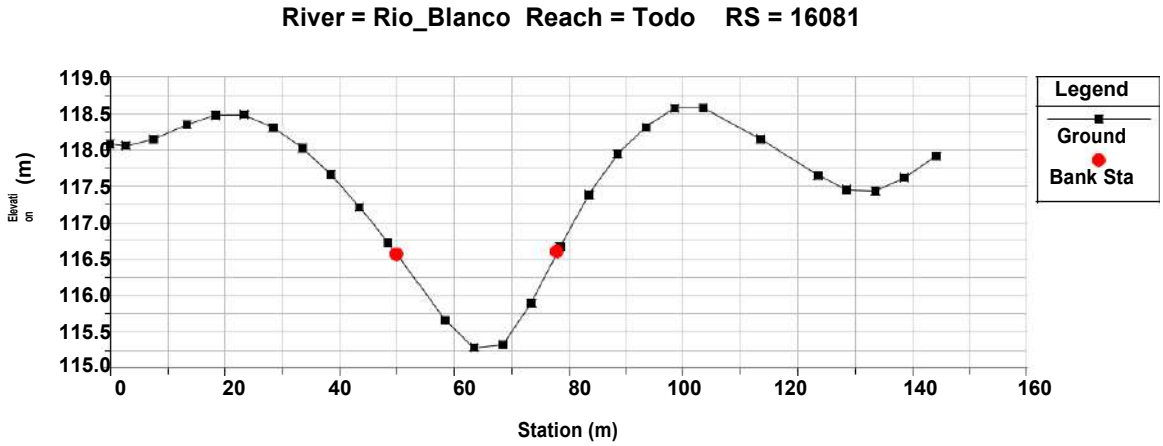
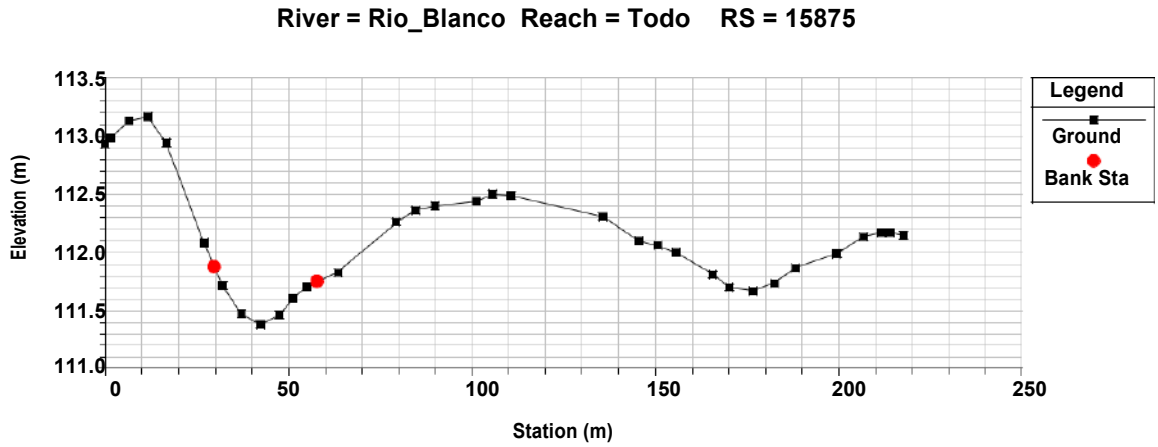
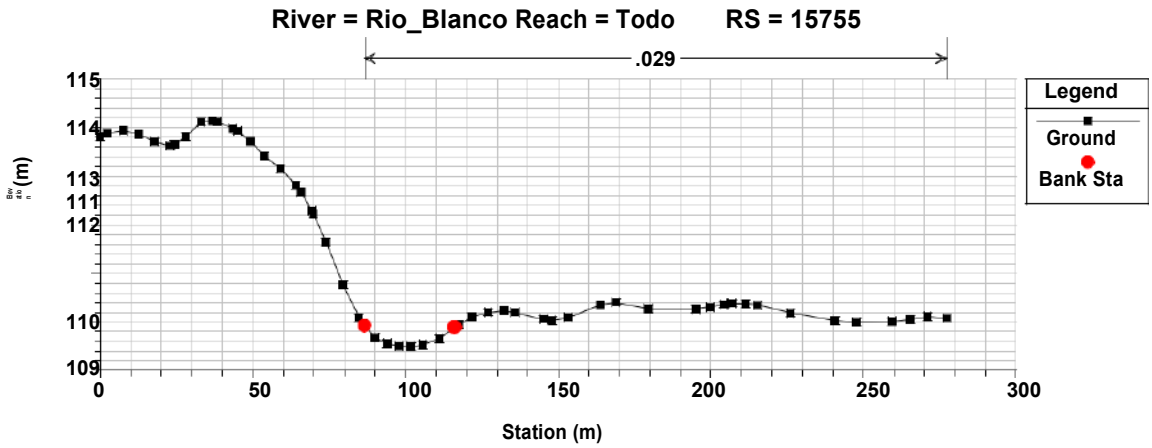
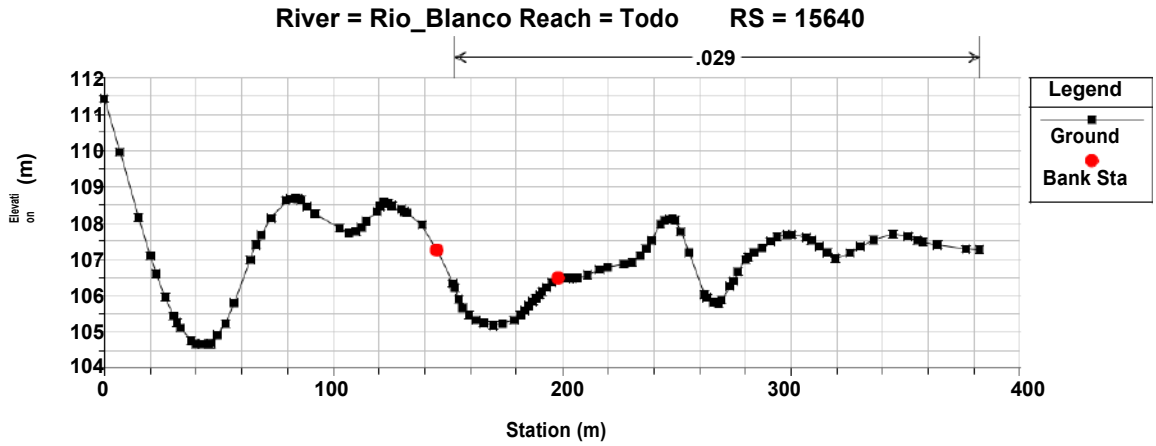
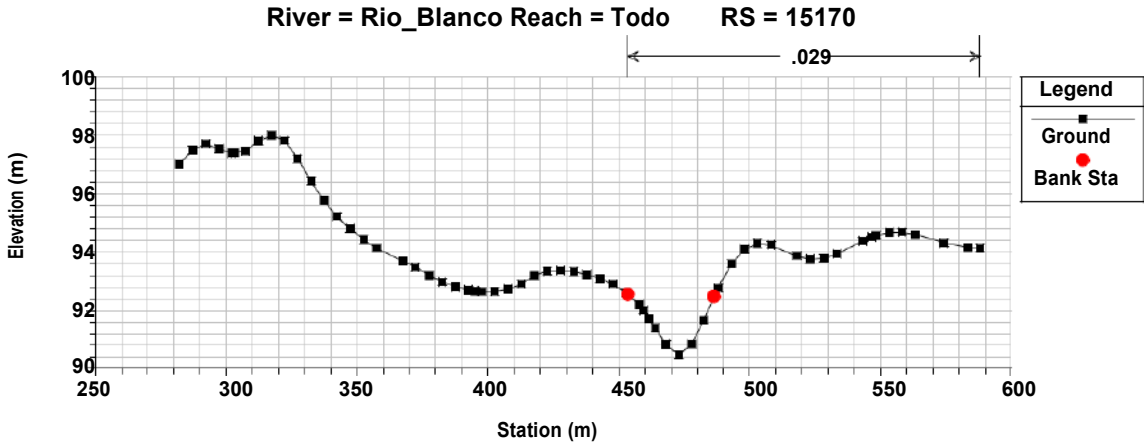
Ground
Bank Sta

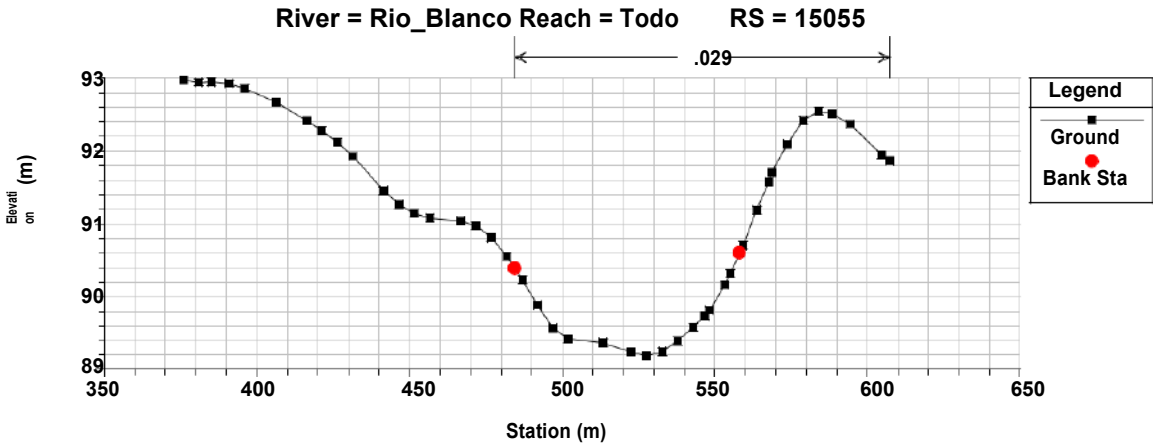

River = Rio_Blanco Reach = Todo RS = 16081
Elevati on (m)
Station (m)
Legend
Ground
Bank Sta

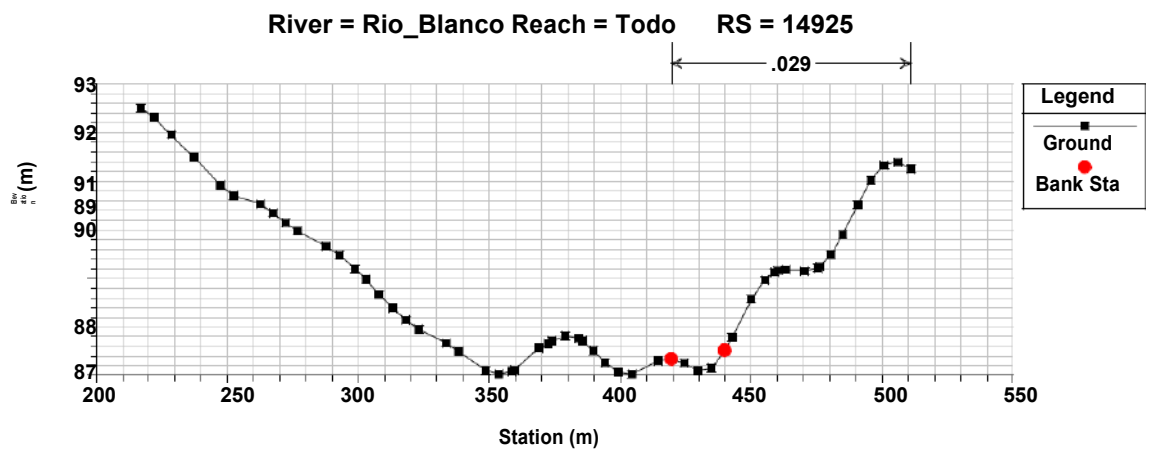

River = Rio_Blanco Reach = Todo RS = 15875
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

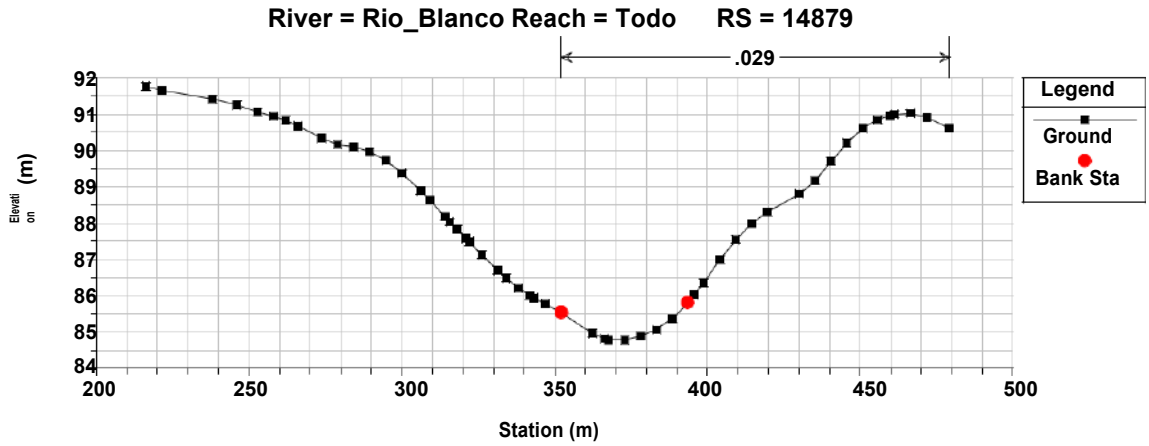

River = Rio_Blanco Reach = Todo RS = 15755
.029
Legend
Ground
Bank Sta
Station (m)

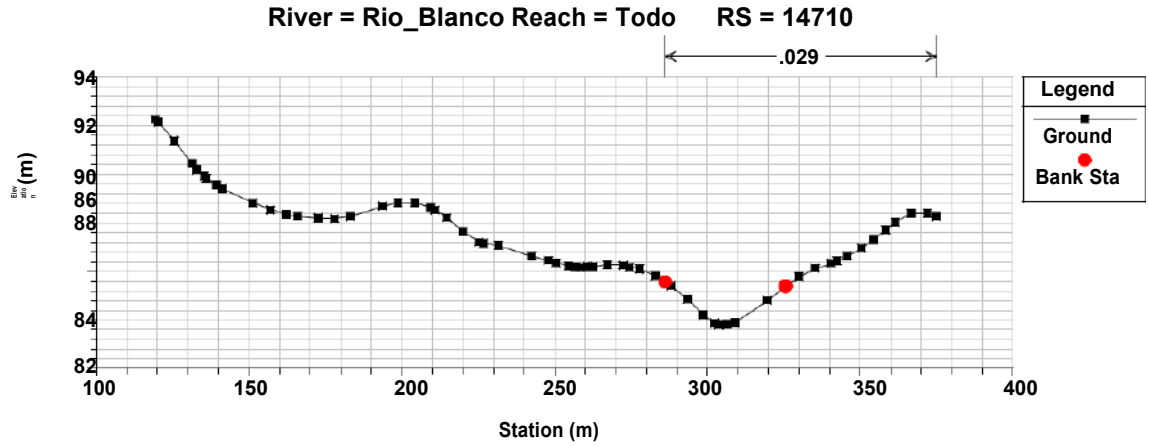

River = Rio_Blanco Reach = Todo RS = 15640
.029
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

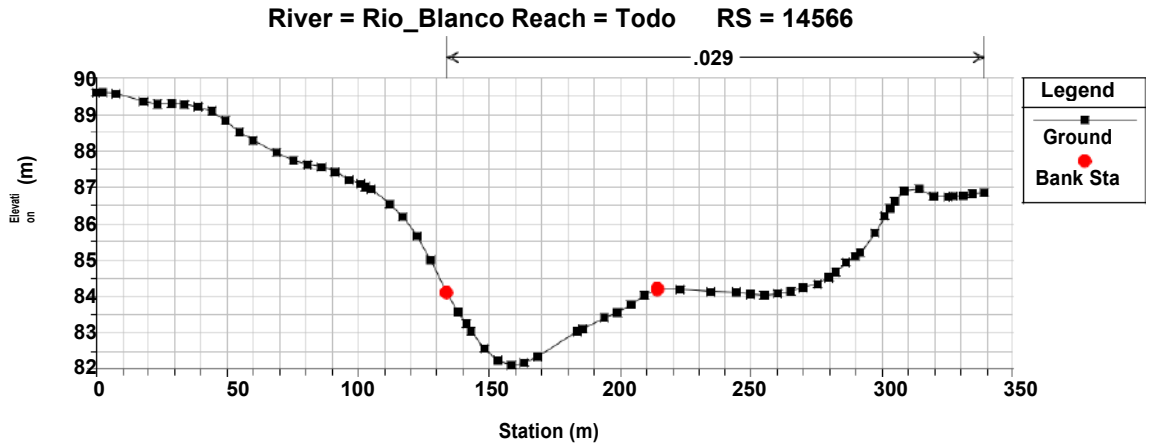

River = Rio_Blanco Reach = Todo RS = 15170
.029
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

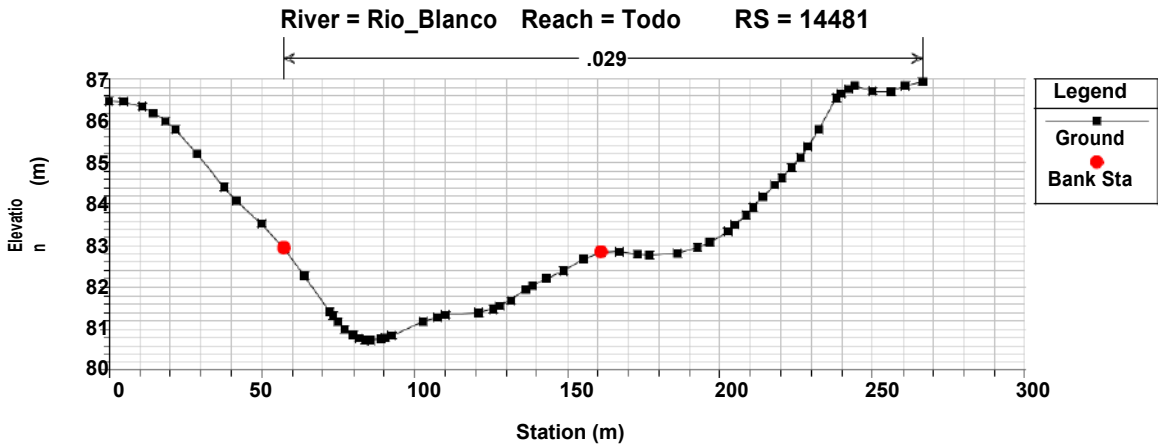

River = Rio_Blanco Reach = Todo RS = 15055
.029
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

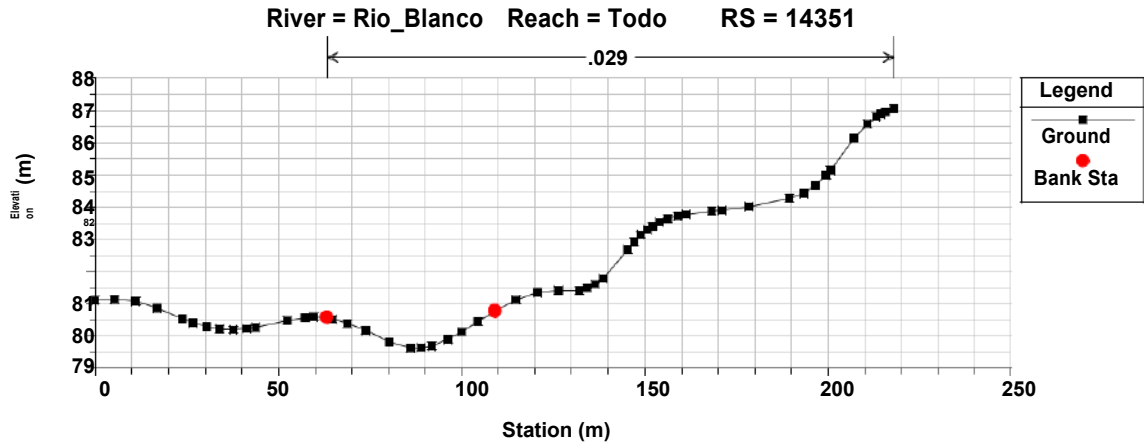

River = Rio_Blanco Reach = Todo RS = 14925
.029
Legend
Ground
Bank Sta
Station (m)

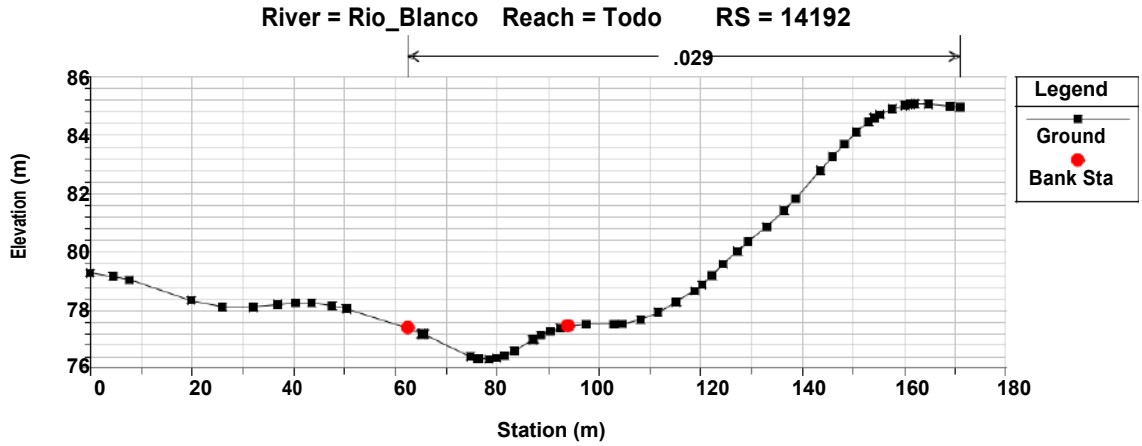

River = Rio_Blanco Reach = Todo RS = 14879
.029
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

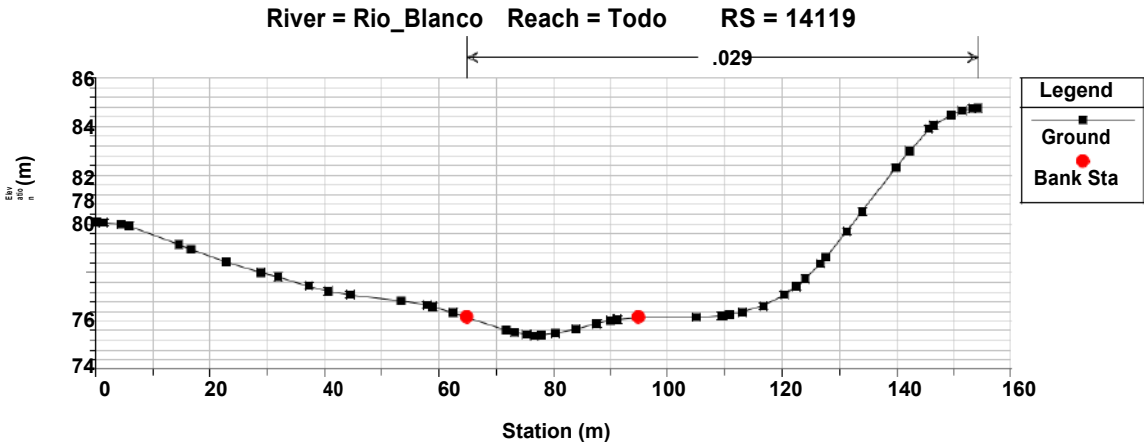

River = Rio_Blanco Reach = Todo RS = 14710
.029
Legend
Ground
Bank Sta
Station (m)

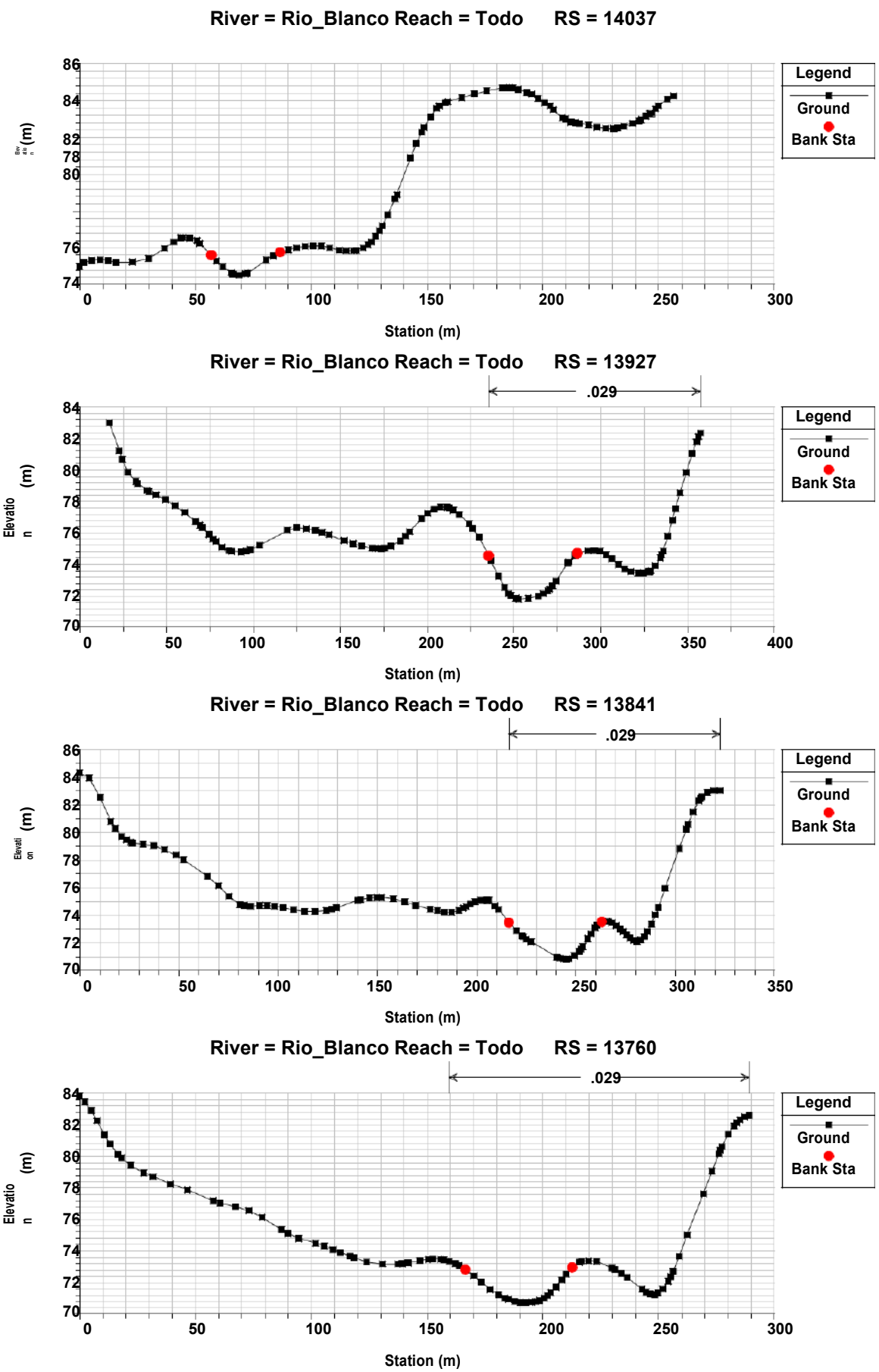

River = Rio_Blanco Reach = Todo RS = 14566
.029
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

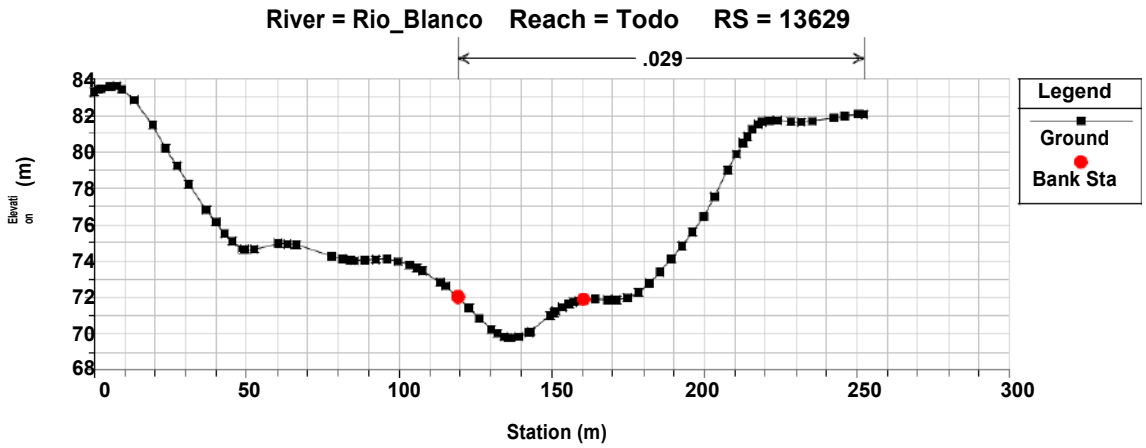

River = Rio_Blanco Reach = Todo RS = 14481
.029
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

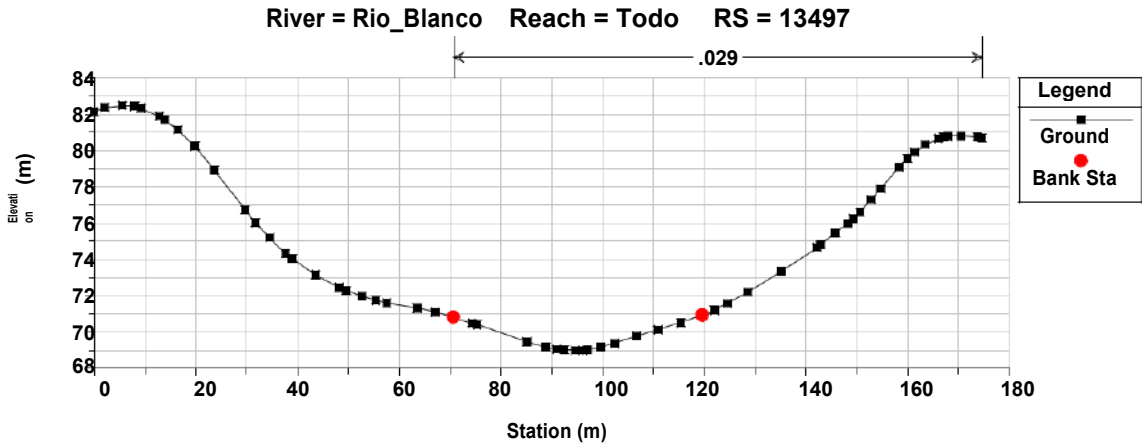

River = Rio_Blanco Reach = Todo RS = 14351
.029
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

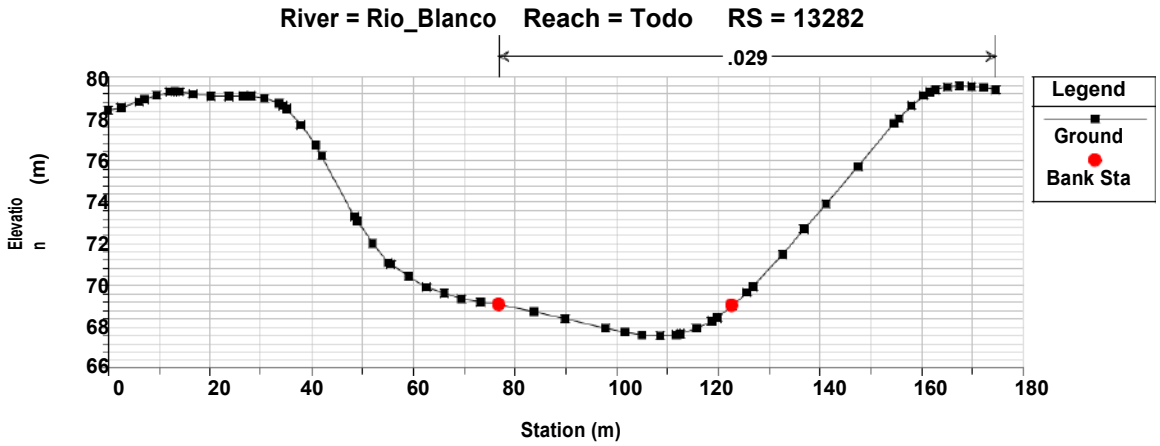

River = Rio_Blanco Reach = Todo RS = 14192
.029
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

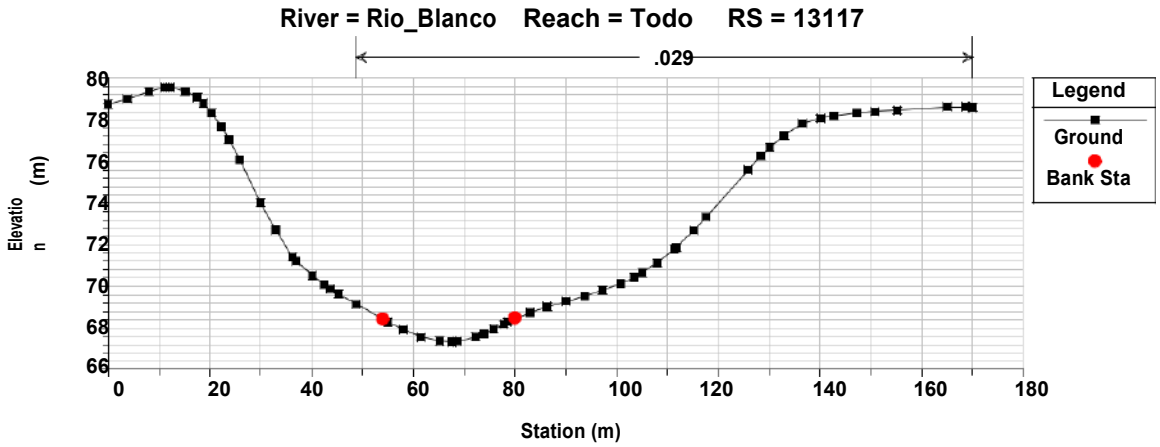

River = Rio_Blanco Reach = Todo RS = 14119
.029
Legend
Ground
Bank Sta
Station (m)

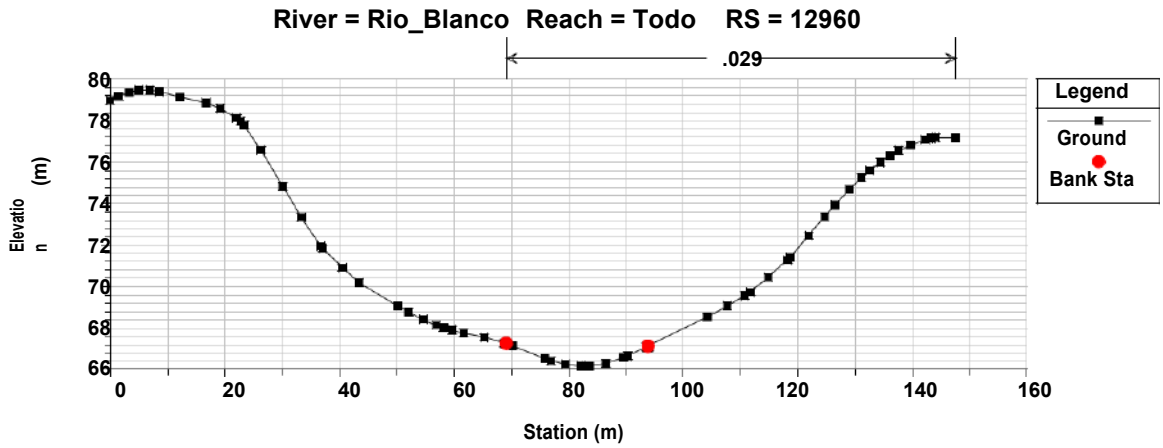

River = Rio_Blanco Reach = Todo RS = 14037
Legend
Ground
Bank Sta
Station (m)
River = Rio_Blanco Reach = Todo RS = 13927
.029
Elevation (m)
Station (m)
River = Rio_Blanco Reach = Todo RS = 13841
.029
Elevation (m)
Station (m)
River = Rio_Blanco Reach = Todo RS = 13760
.029
Elevation (m)
Station (m)

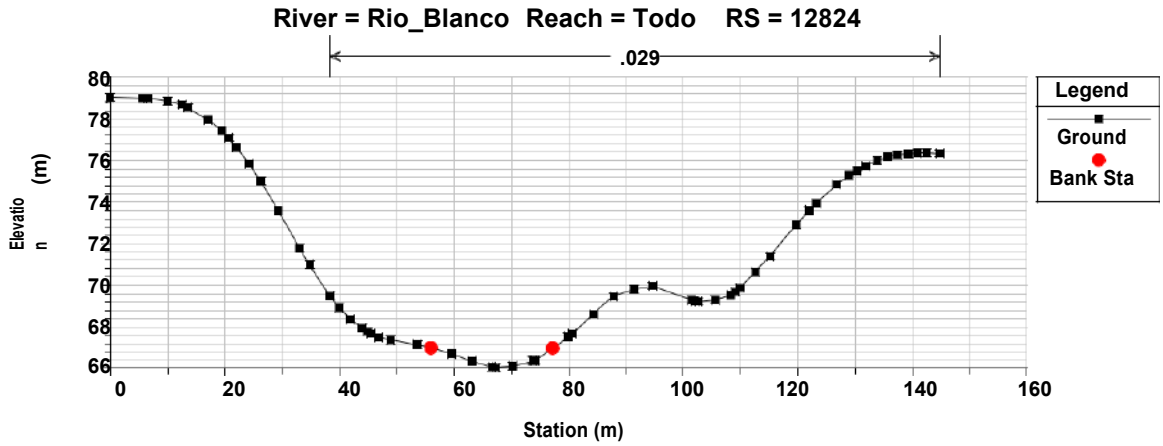

River = Rio_Blanco Reach = Todo RS = 13629
.029
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

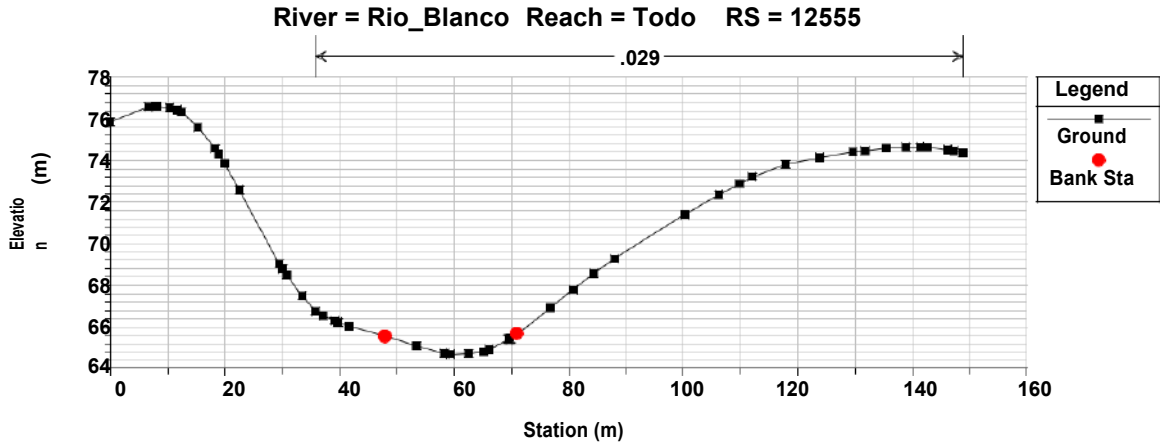

River = Rio_Blanco Reach = Todo RS = 13497
.029
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

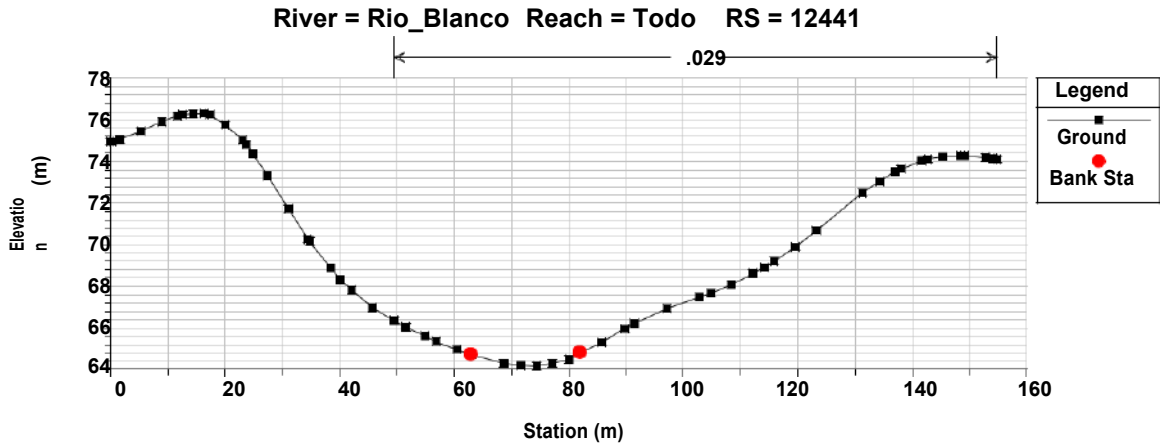

River = Rio_Blanco Reach = Todo RS = 13282
.029
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

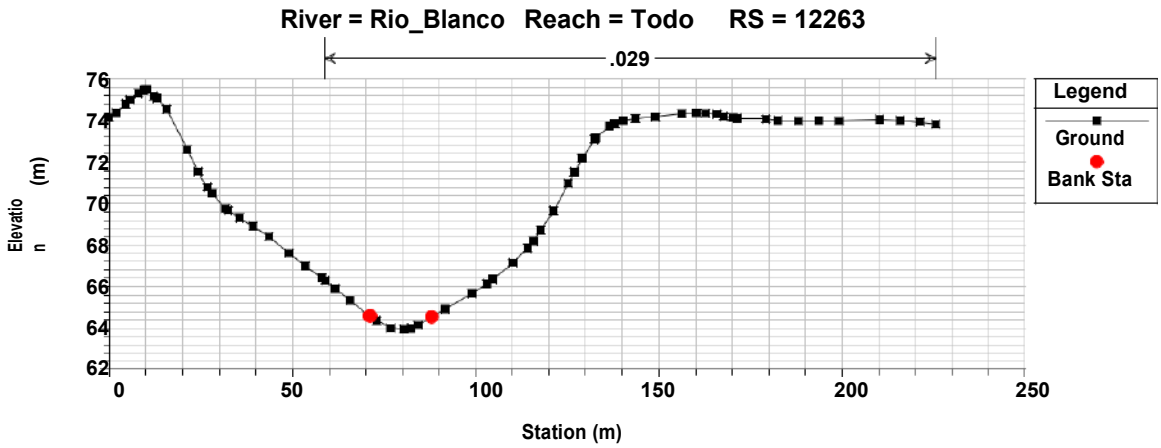

River = Rio_Blanco Reach = Todo RS = 13117
.029
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

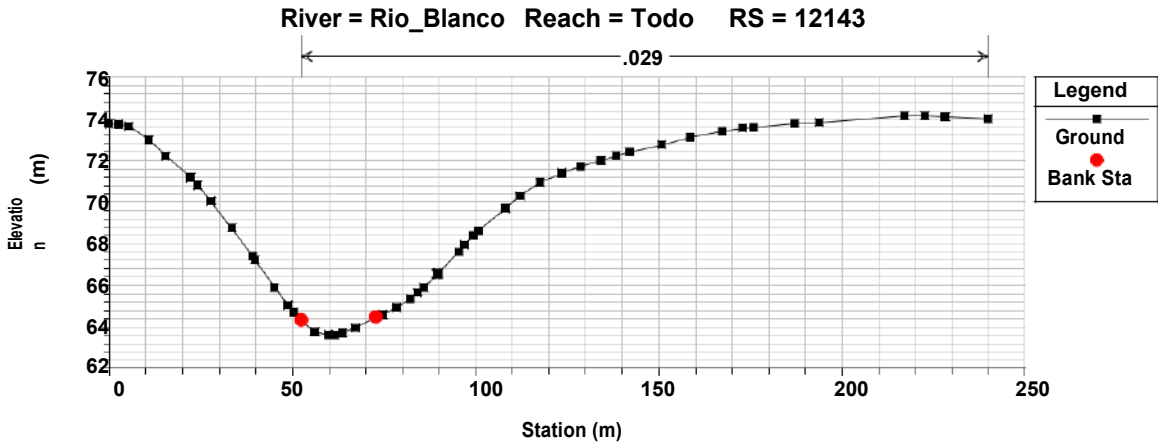

River = Rio_Blanco Reach = Todo RS = 12960
.029
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

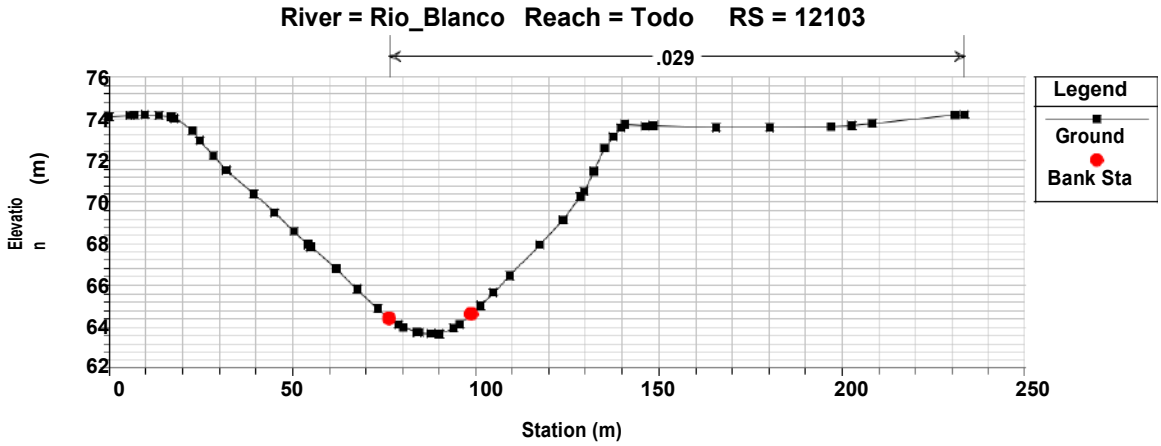

River = Rio_Blanco Reach = Todo RS = 12824
.029
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

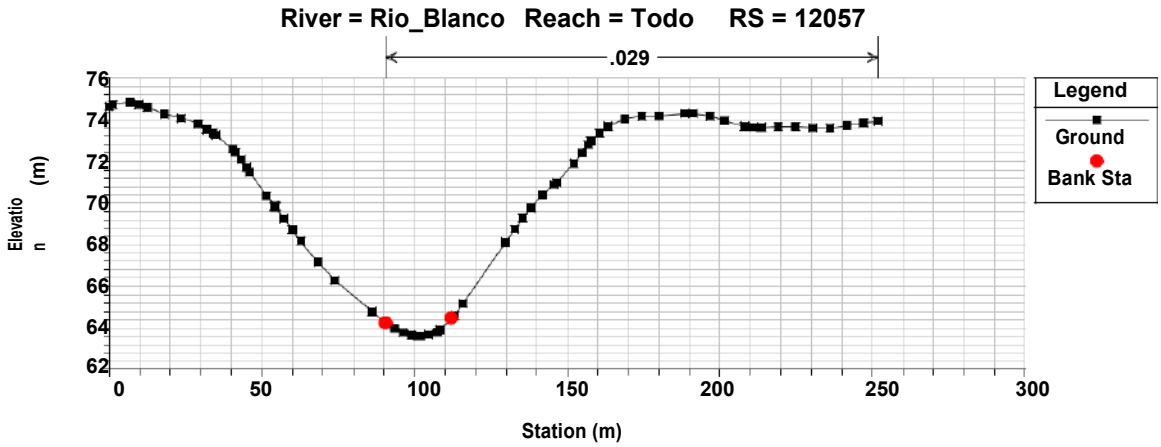

River = Rio_Blanco Reach = Todo RS = 12555
.029
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

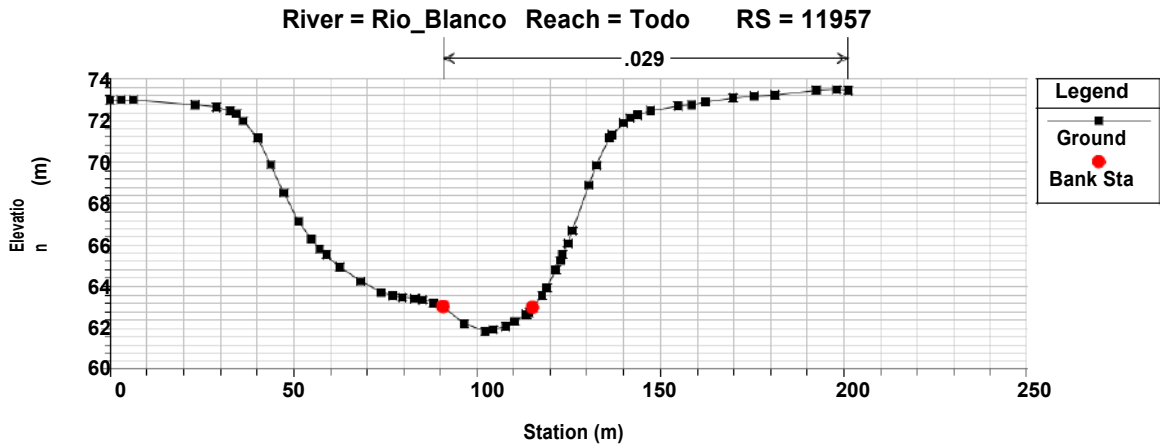

River = Rio_Blanco Reach = Todo RS = 12441
.029
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

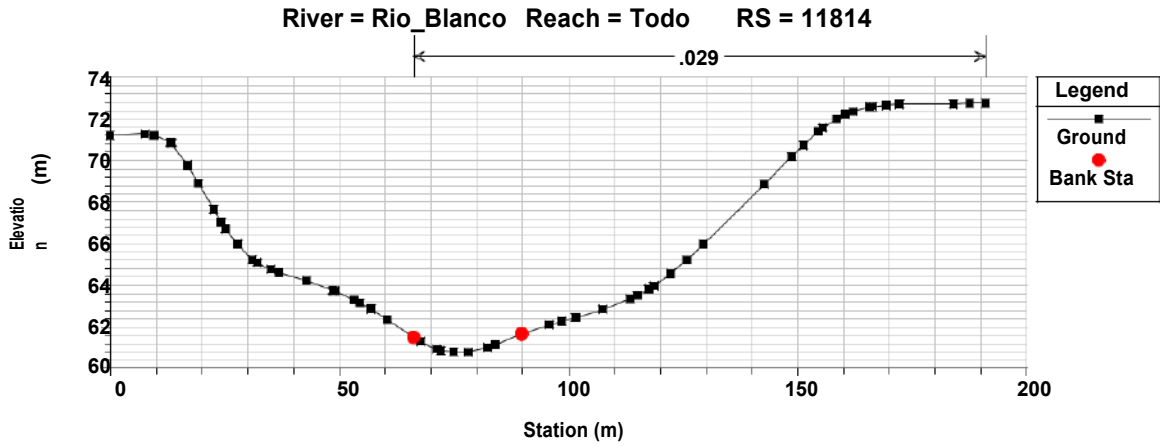

River = Rio_Blanco Reach = Todo RS = 12263
.029
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

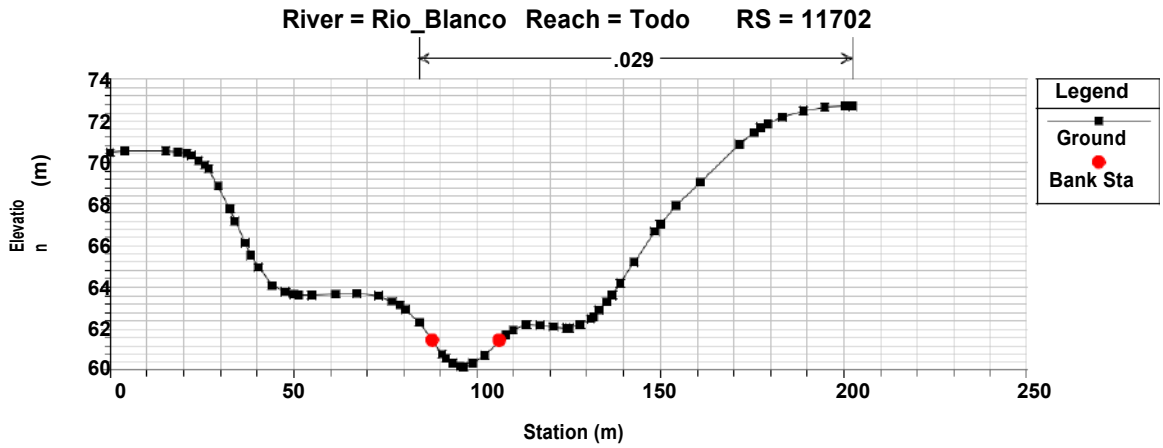

River = Rio_Blanco Reach = Todo RS = 12143
.029
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

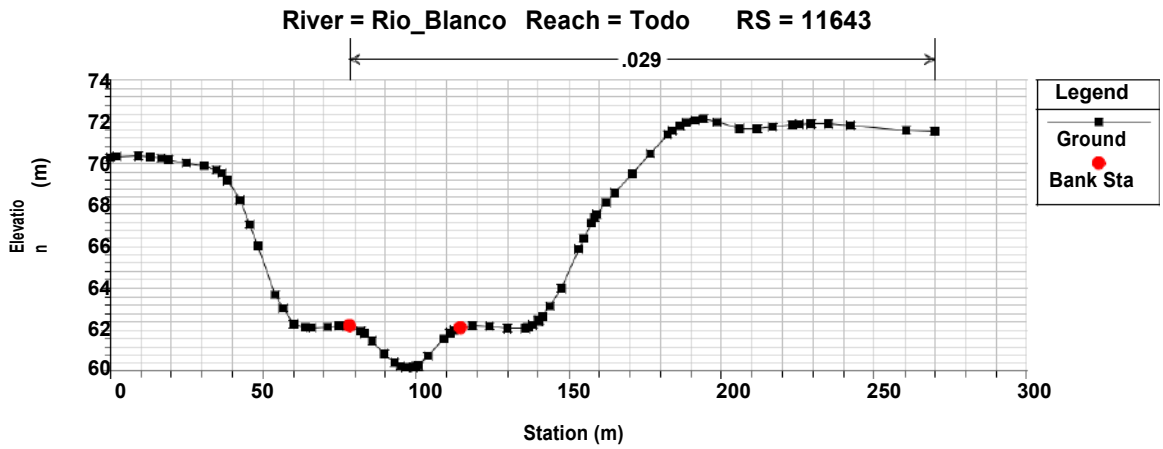

River = Rio_Blanco Reach = Todo RS = 12103
.029
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

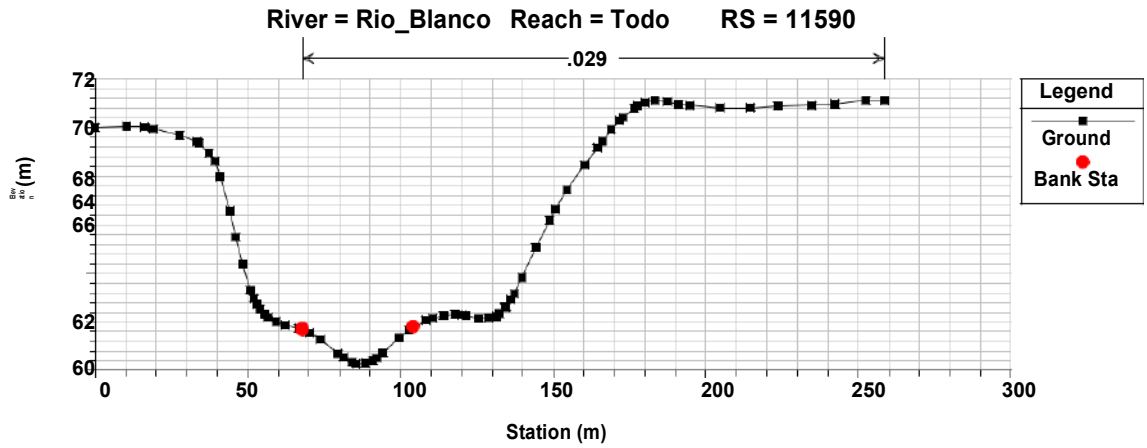

River = Rio_Blanco Reach = Todo RS = 12057
.029
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

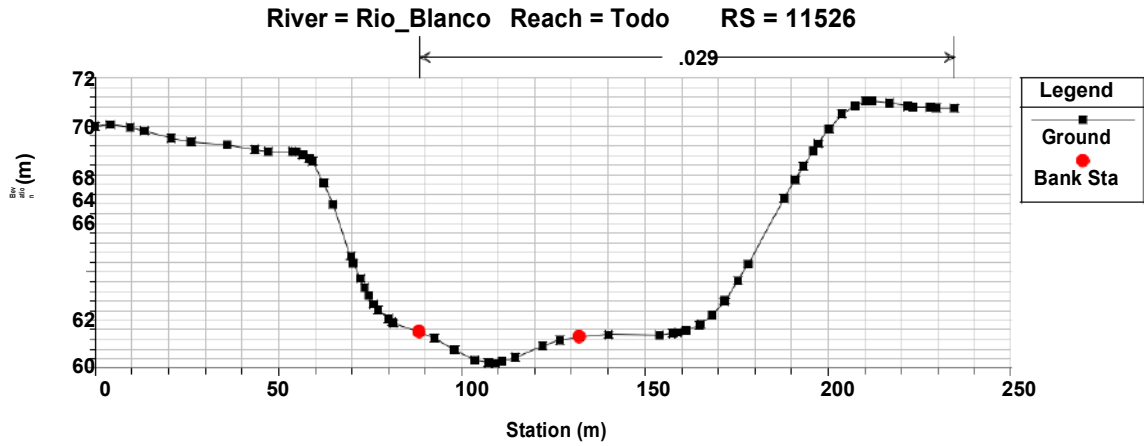

River = Rio_Blanco Reach = Todo RS = 11957
.029
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

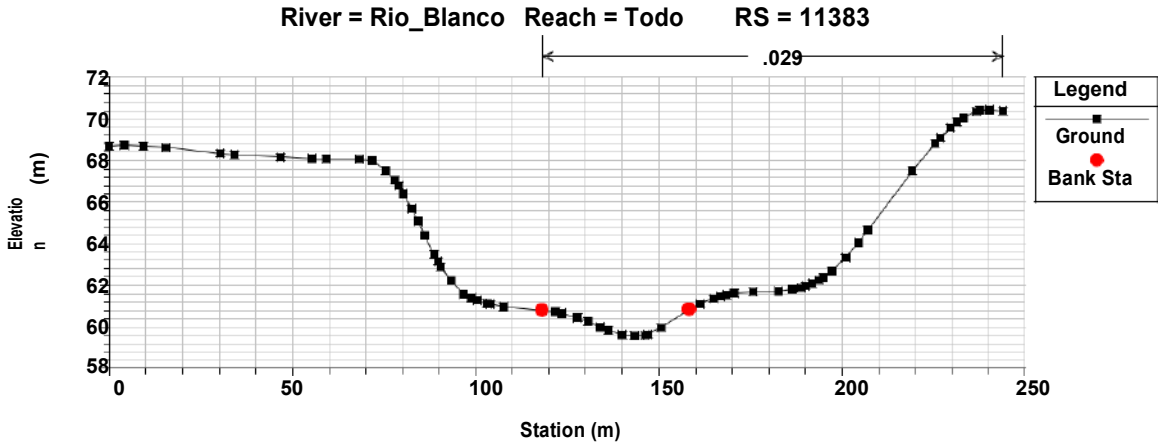

River = Rio_Blanco Reach = Todo RS = 11814
.029
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

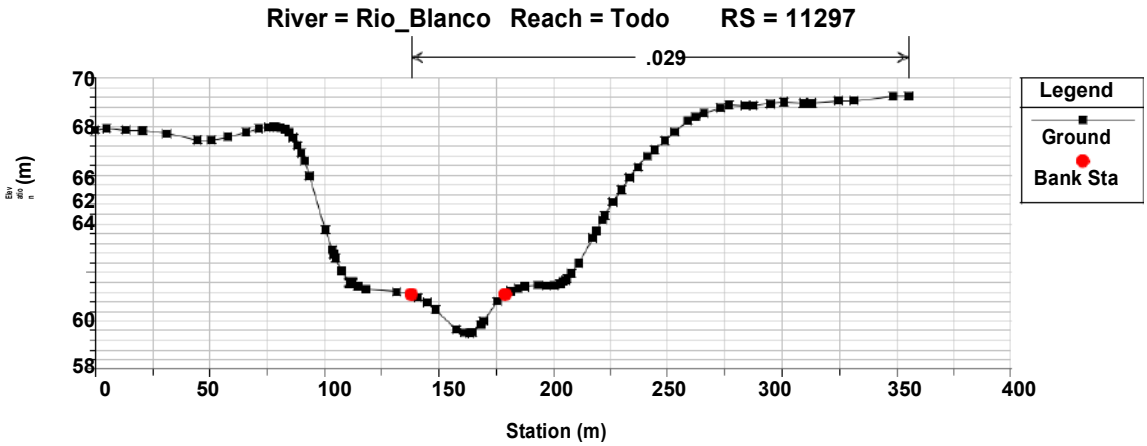

River = Rio_Blanco Reach = Todo RS = 11702
.029
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

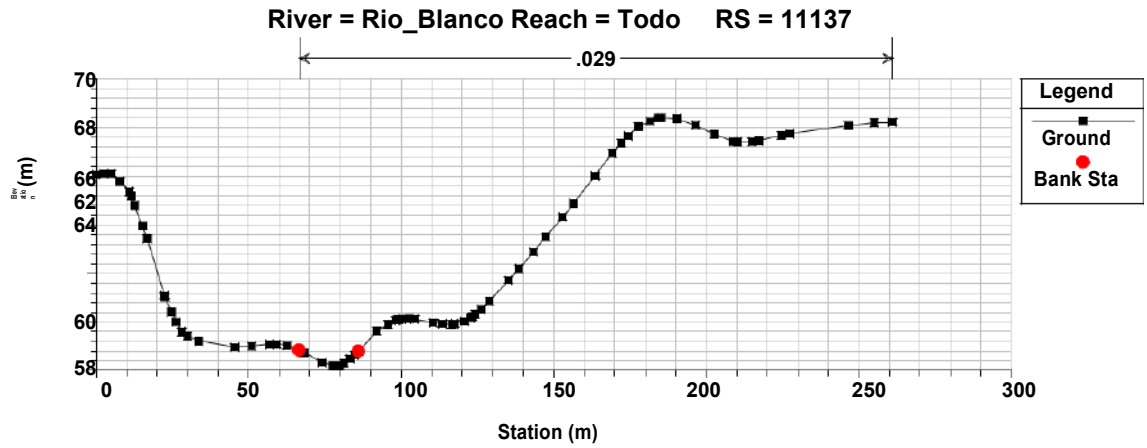

River = Rio_Blanco Reach = Todo RS = 11643
.029
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

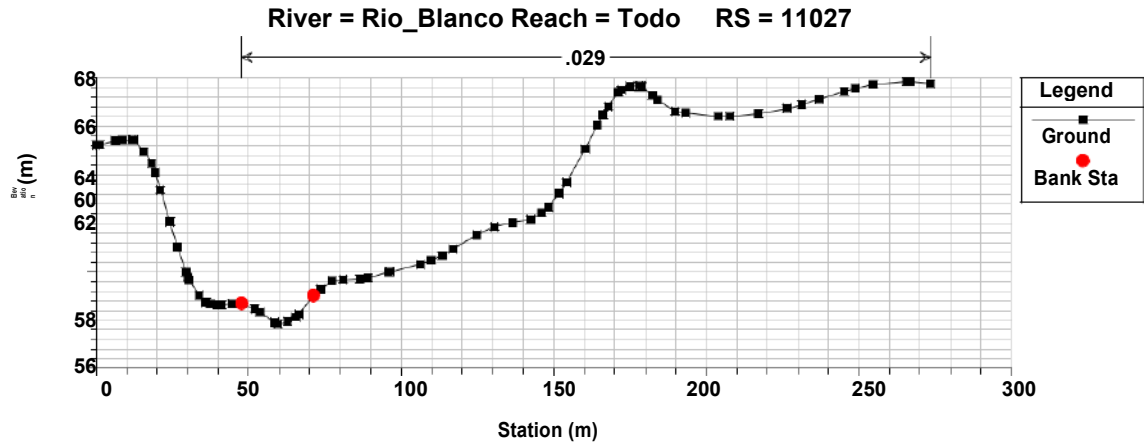

River = Rio_Blanco Reach = Todo RS = 11590
.029
Legend
Ground
Bank Sta
Station (m)

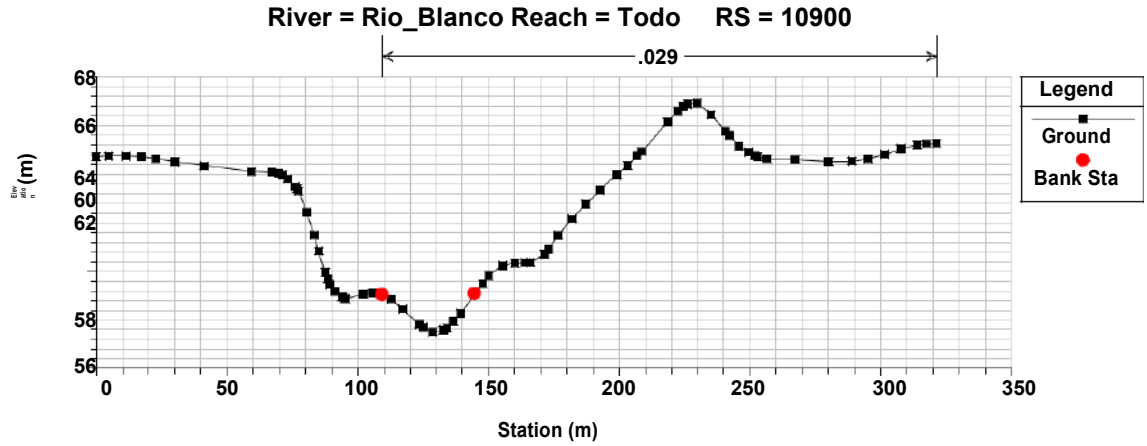

River = Rio_Blanco Reach = Todo RS = 11526
.029
Legend
Ground
Bank Sta
Station (m)

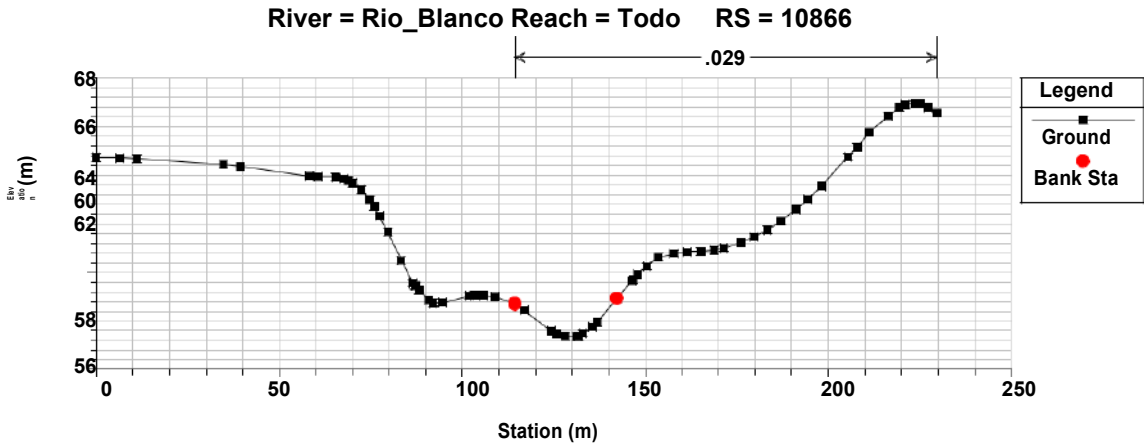

River = Rio_Blanco Reach = Todo RS = 11383
.029
Elevation (m)
Legend
Ground
Bank Sta
Station (m)

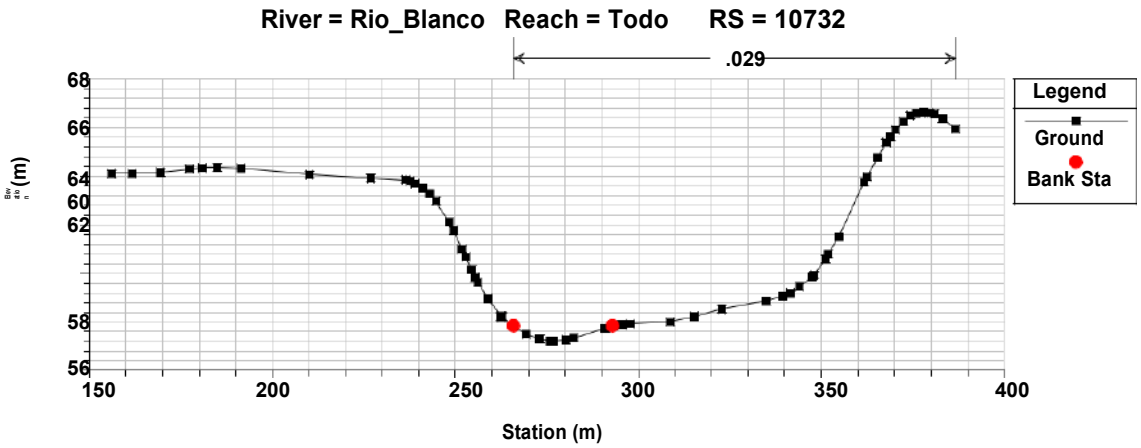

River = Rio_Blanco Reach = Todo RS = 11297
.029
Legend
Ground
Bank Sta
Station (m)

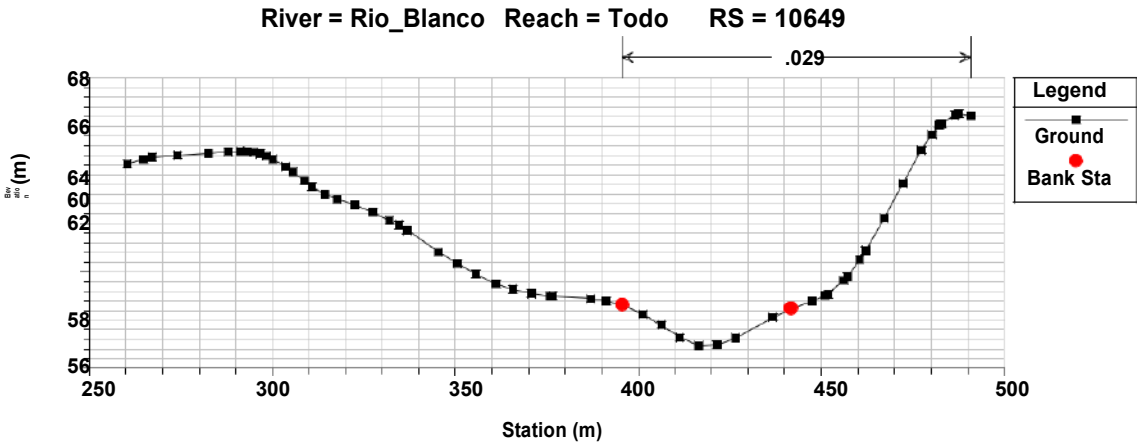

River = Rio_Blanco Reach = Todo RS = 11137
.029
Legend
Ground
Bank Sta
Station (m)

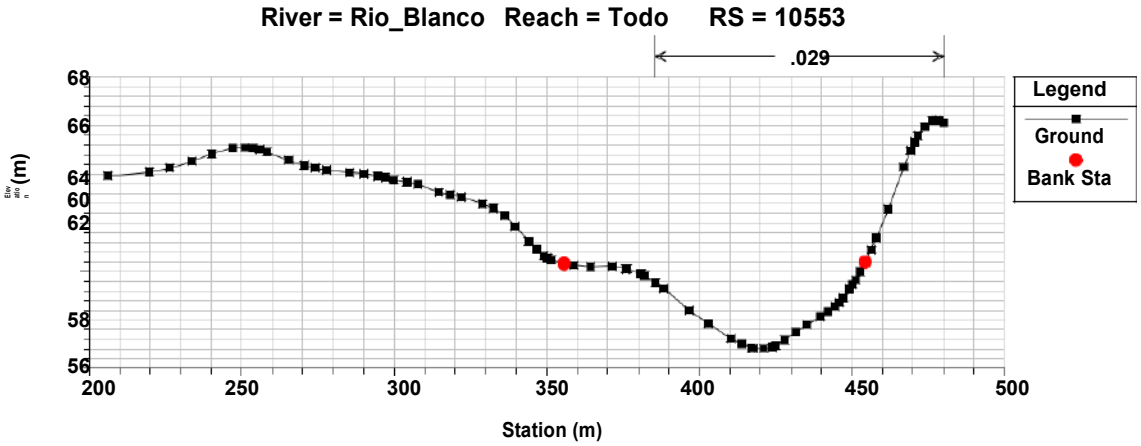

River = Rio_Blanco Reach = Todo RS = 11027
.029
Legend
Ground
Bank Sta
Station (m)

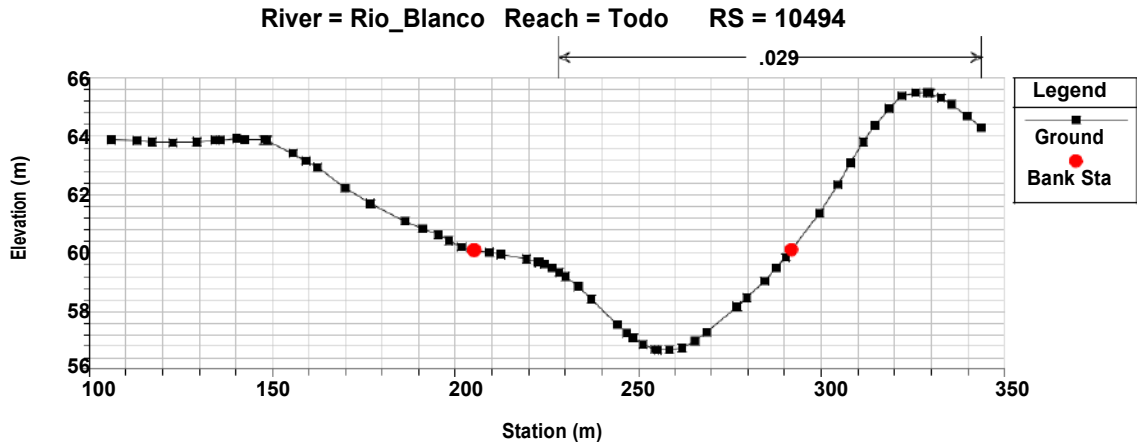

River = Rio_Blanco Reach = Todo RS = 10900
.029
Legend
Ground
Bank Sta
Station (m)

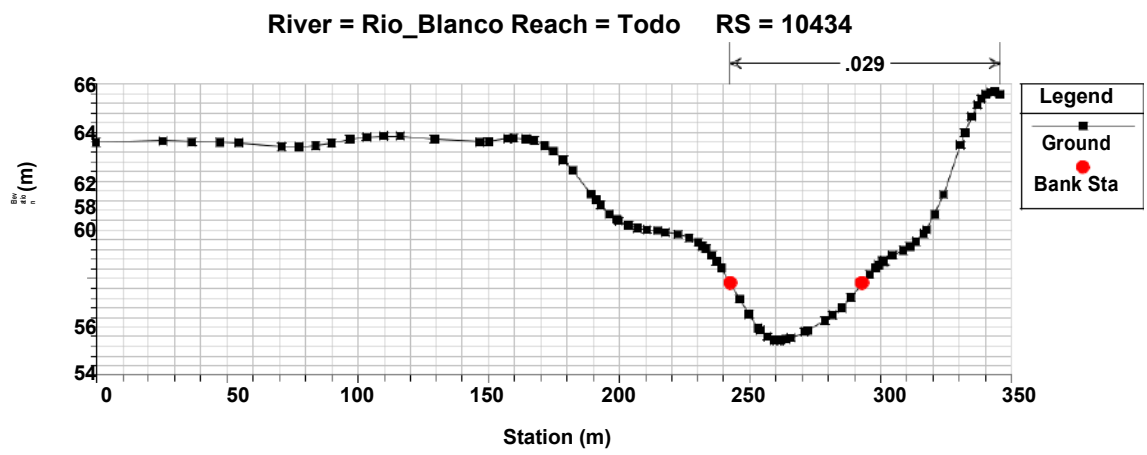

River = Rio_Blanco Reach = Todo RS = 10866
.029
Legend
Ground
Bank Sta
Station (m)

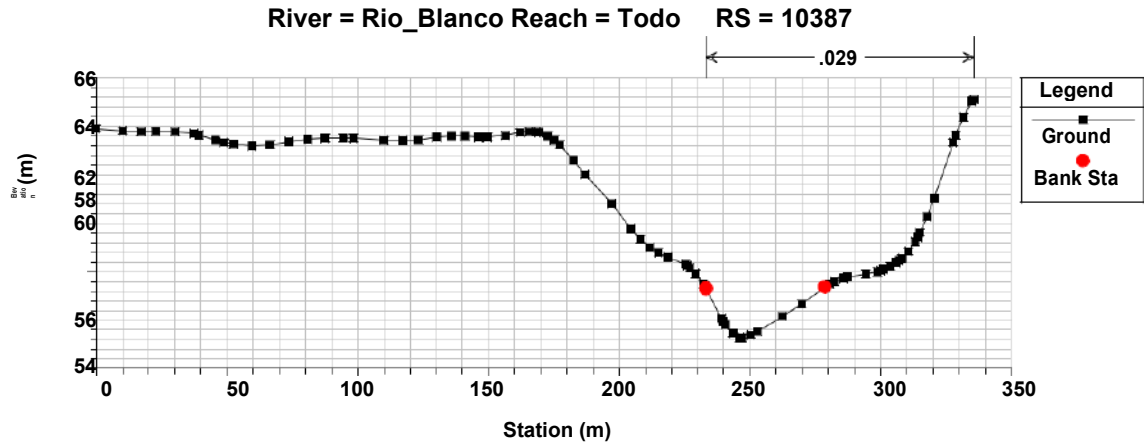

River = Rio_Blanco Reach = Todo RS = 10732
.029
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

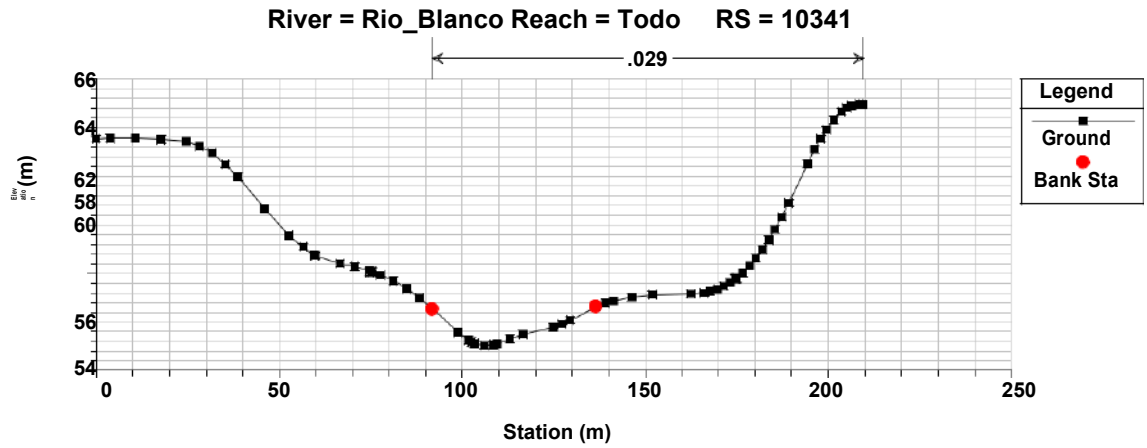

River = Rio_Blanco Reach = Todo RS = 10649
.029
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

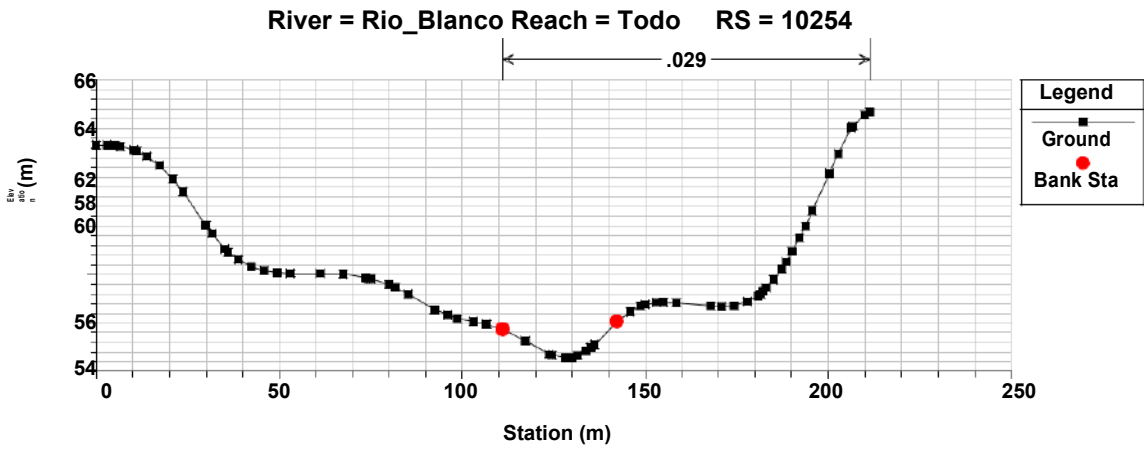

River = Rio_Blanco Reach = Todo RS = 10553
.029
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

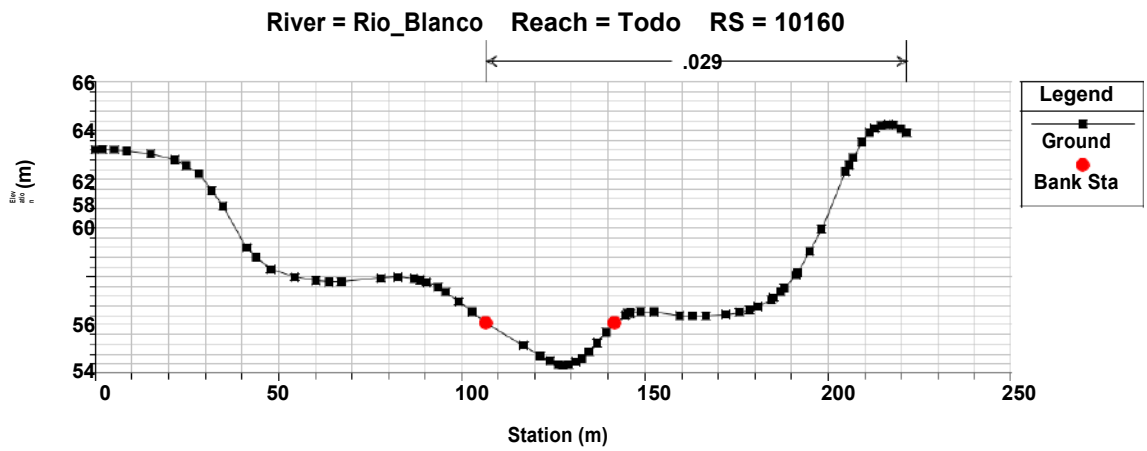

River = Rio_Blanco Reach = Todo RS = 10494
.029
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

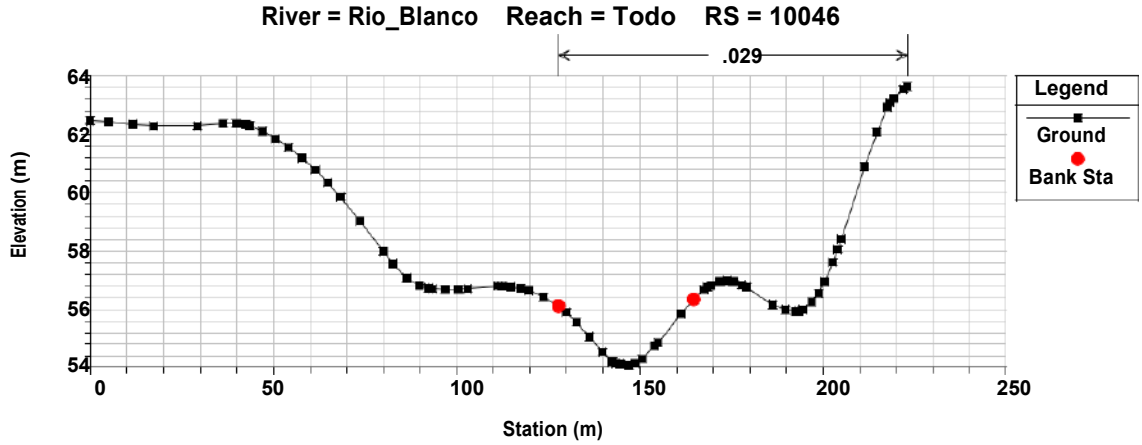

River = Rio_Blanco Reach = Todo RS = 10434
.029
Legend
Ground
Bank Sta
Station (m)

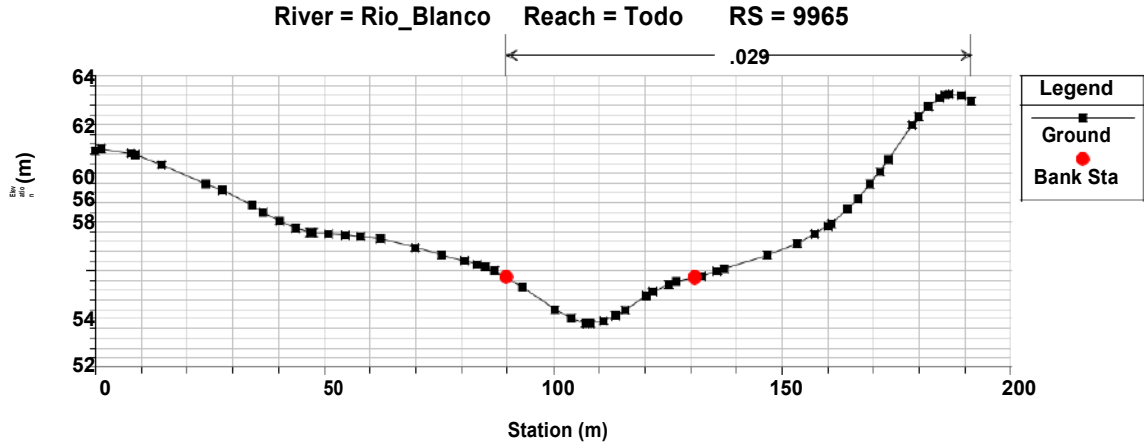

River = Rio_Blanco Reach = Todo RS = 10387
.029
Legend
Ground
Bank Sta
Station (m)

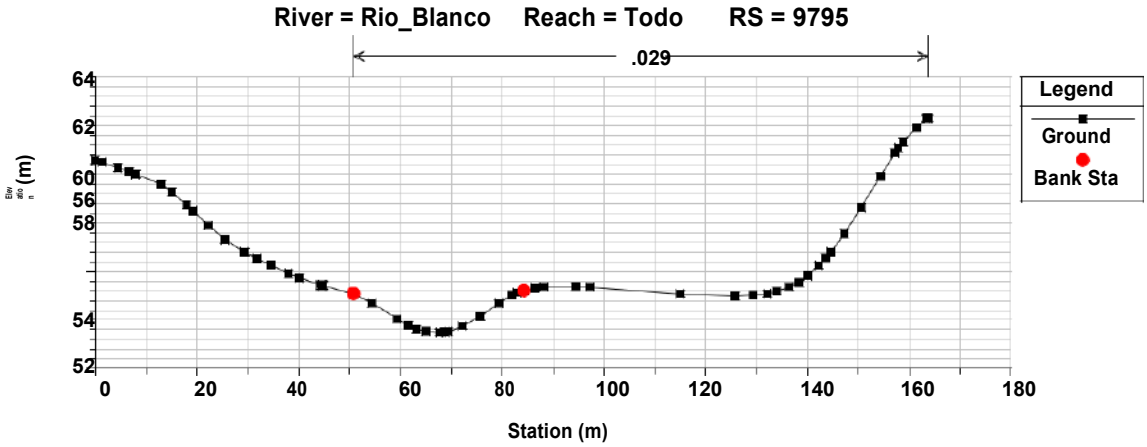

River = Rio_Blanco Reach = Todo RS = 10341
.029
Legend
Ground
Bank Sta
Station (m)

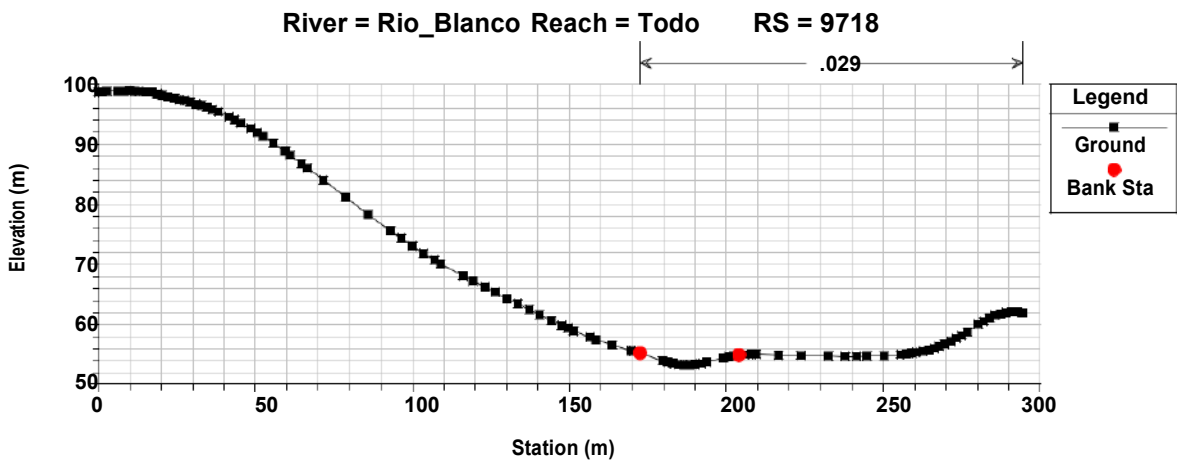

River = Rio_Blanco Reach = Todo RS = 10254
.029
Legend
Ground
Bank Sta
Station (m)

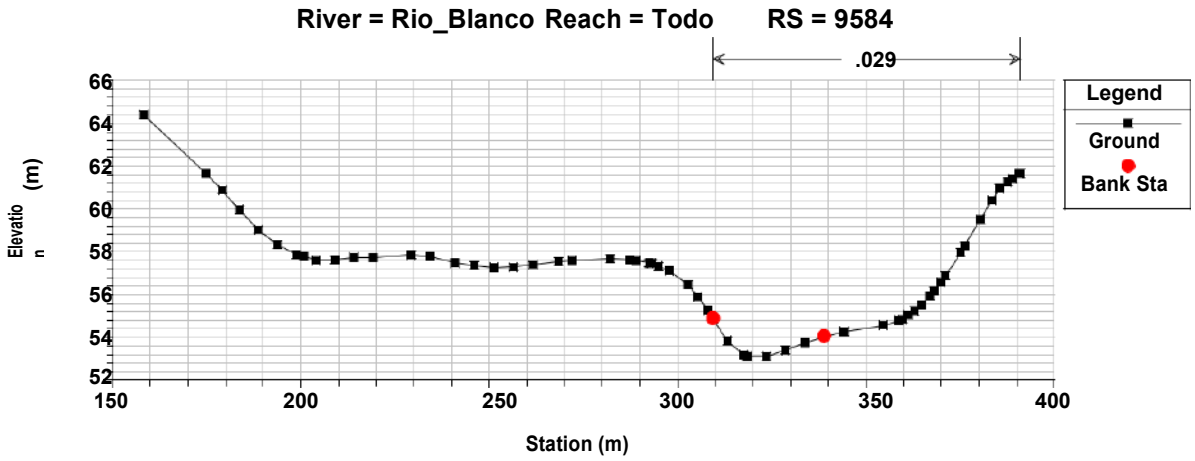

River = Rio_Blanco Reach = Todo RS = 10160
.029
Legend
Ground
Bank Sta
Station (m)

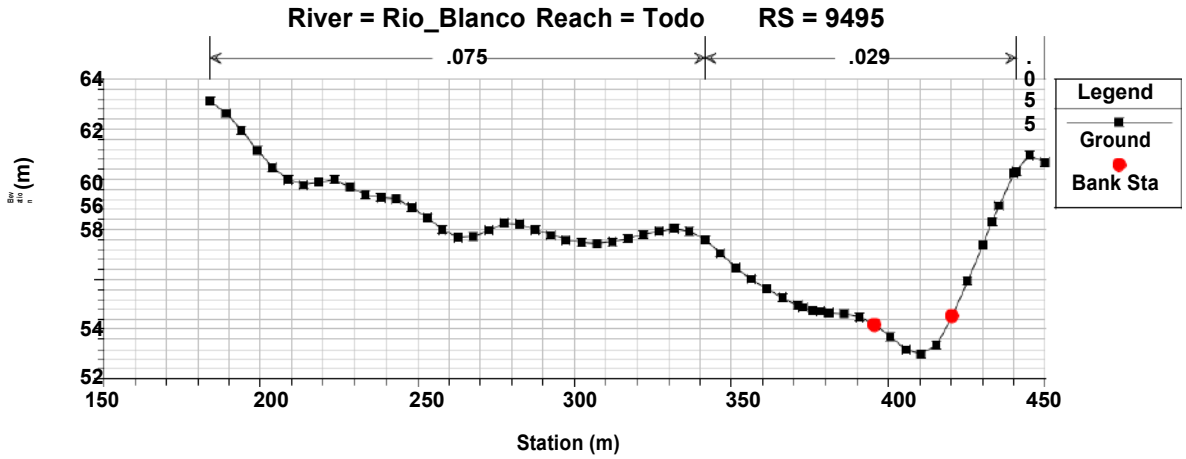

River = Rio_Blanco Reach = Todo RS = 10046
.029
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

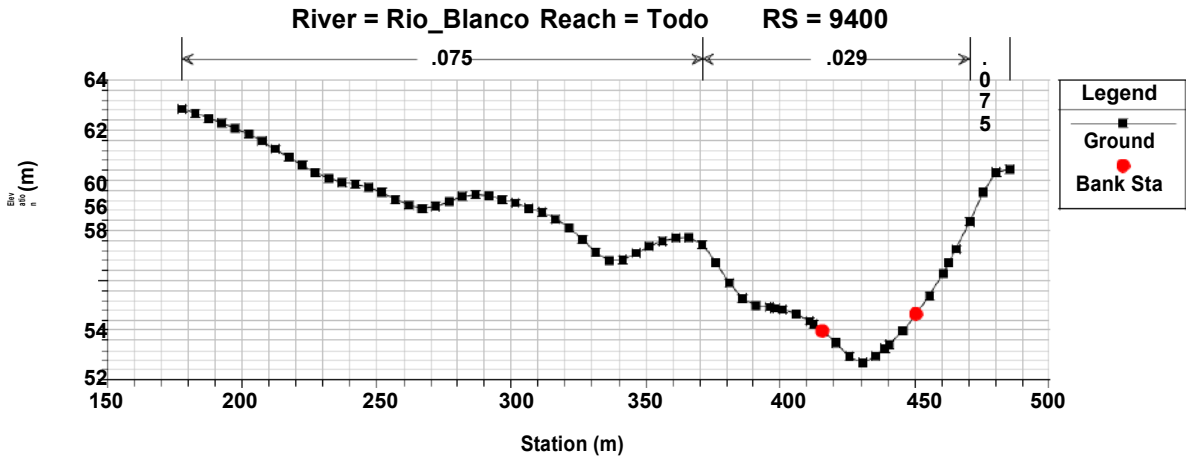

River = Rio_Blanco Reach = Todo RS = 9965
.029
Legend
Ground
Bank Sta
Station (m)

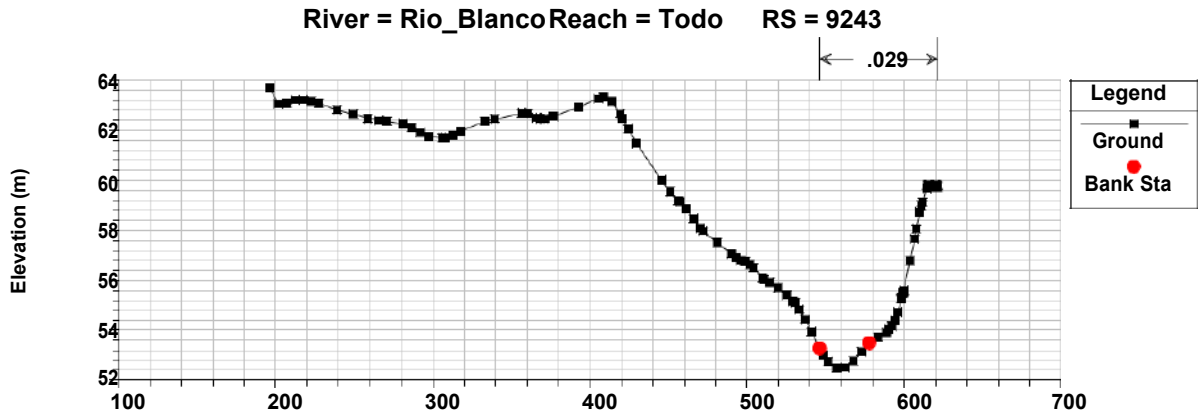

River = Rio_Blanco Reach = Todo RS = 9795
.029
Legend
Ground
Bank Sta
Station (m)

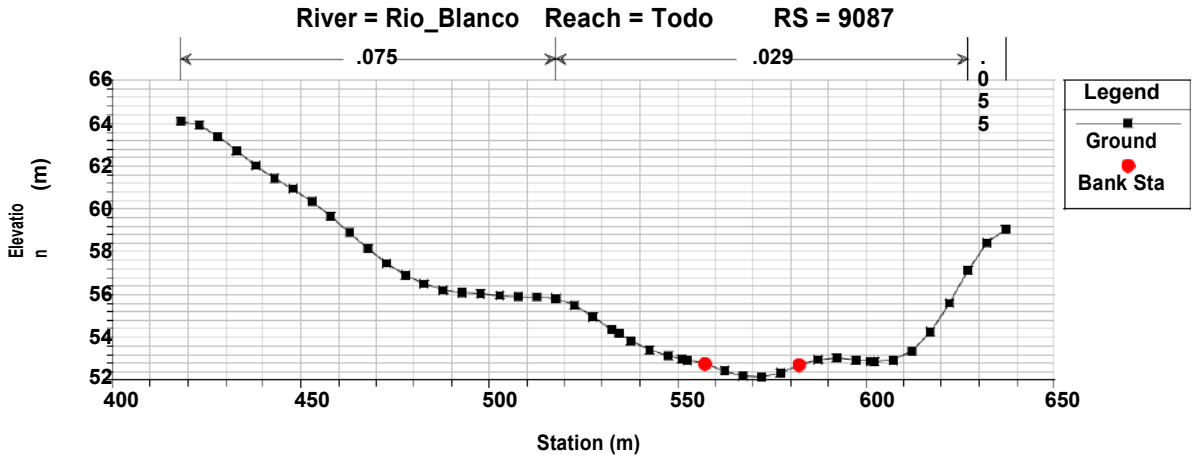

River = Rio_Blanco Reach = Todo RS = 9718
.029
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

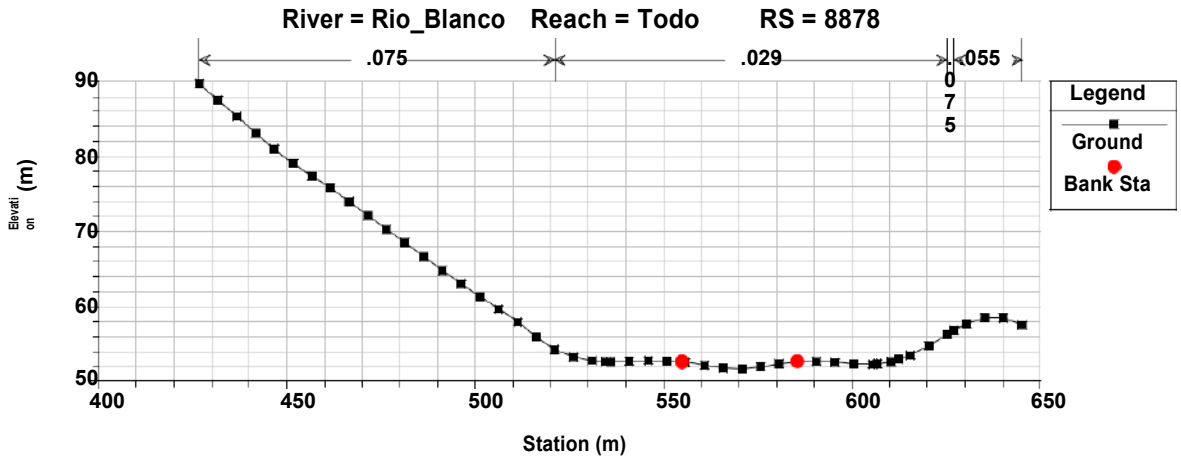

River = Rio_Blanco Reach = Todo RS = 9584
.029
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

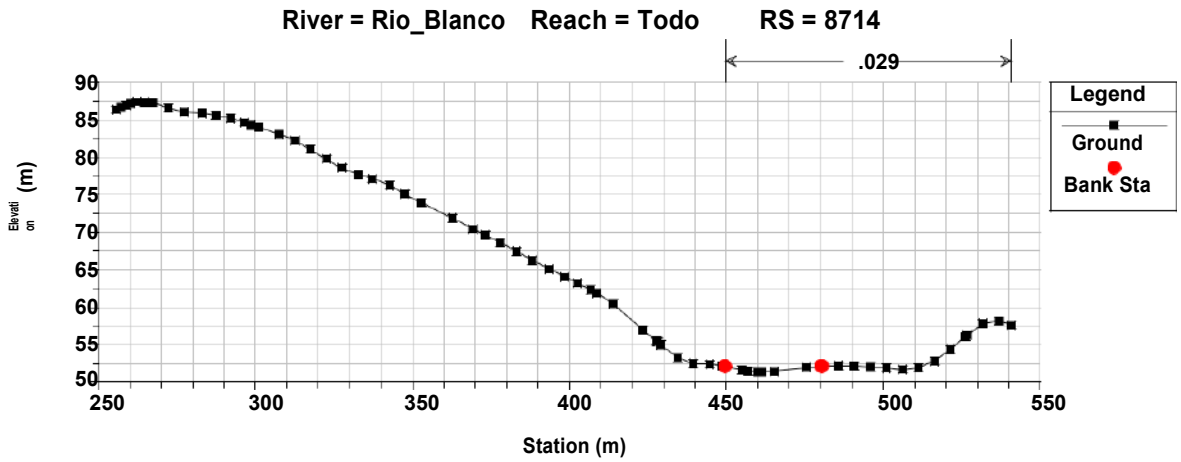

River = Rio_Blanco Reach = Todo RS = 9495
.075
.029
.055
Legend
Ground
Bank Sta
Station (m)

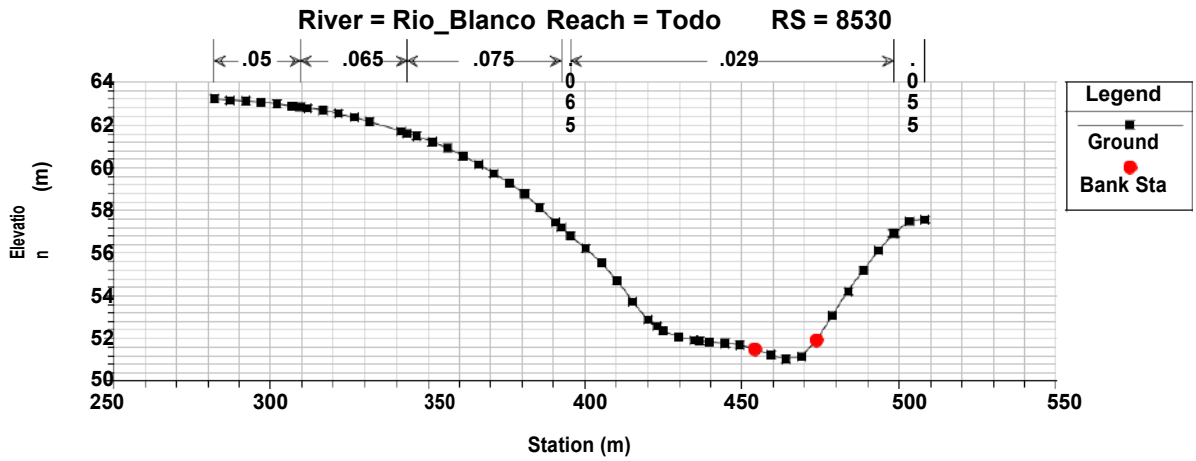

River = Rio_Blanco Reach = Todo RS = 9400
.075
.029
.075
Legend
Ground
Bank Sta
Station (m)

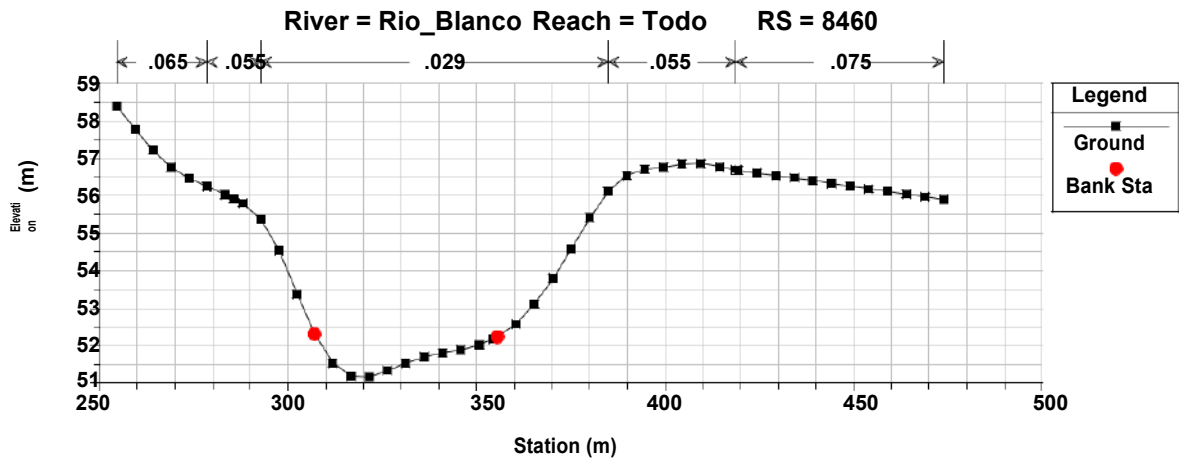

River = Rio_Blanco Reach = Todo RS = 9243
.029
Legend
Ground
Bank Sta
Elevation (m)
64
62
60
58
56
54
52
100
200
300
400
500
600
700

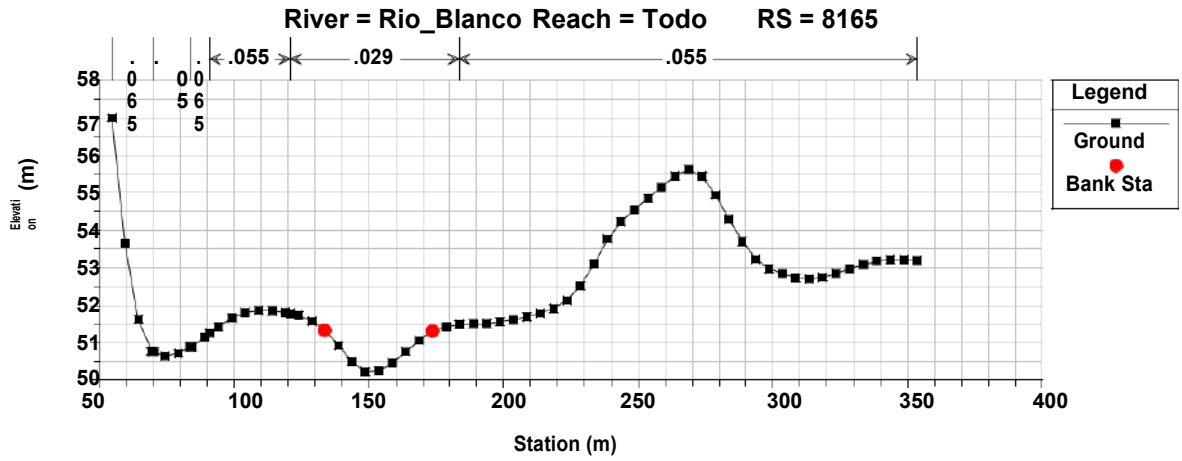

River = Rio_Blanco Reach = Todo RS = 9087
.075
.029
.055
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

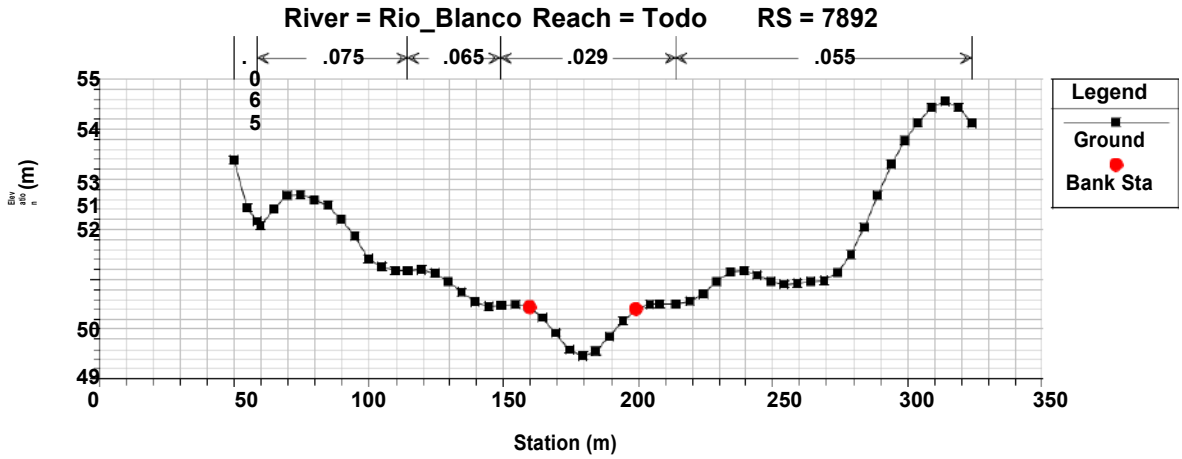

River = Rio_Blanco Reach = Todo RS = 8878
.075
.029
.055
Legend
Ground
Bank Sta
Elevation (m)
Station (m)


River = Rio_Blanco Reach = Todo RS = 8714
.029
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

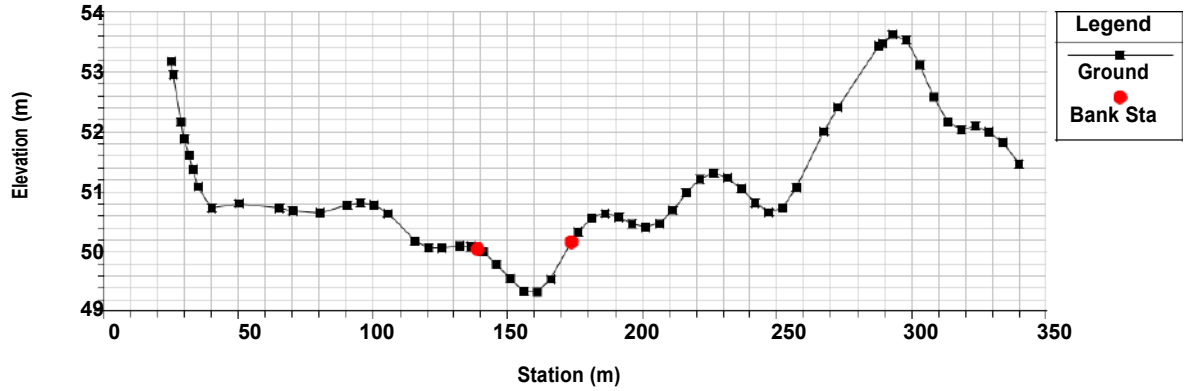

River = Rio_Blanco Reach = Todo RS = 8530
.05
.065
.075
.029
.065
.055
Elevation (m)
Station (m)
Legend
Ground
Bank Sta


River = Rio_Blanco Reach = Todo RS = 8460
.065
.055
.029
.055
.075
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

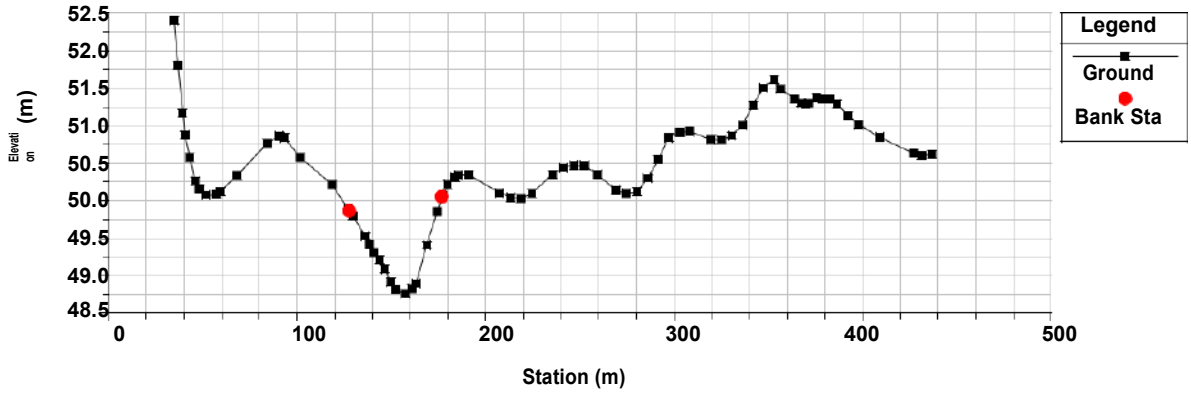

River = Rio_Blanco Reach = Todo RS = 8165
.065
.055
.065
.055
.029
.055
Elevation (m)
Station (m)
Legend
Ground
Bank Sta


River = Rio_Blanco Reach = Todo RS = 7892
.065
.075
.065
.029
.055
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

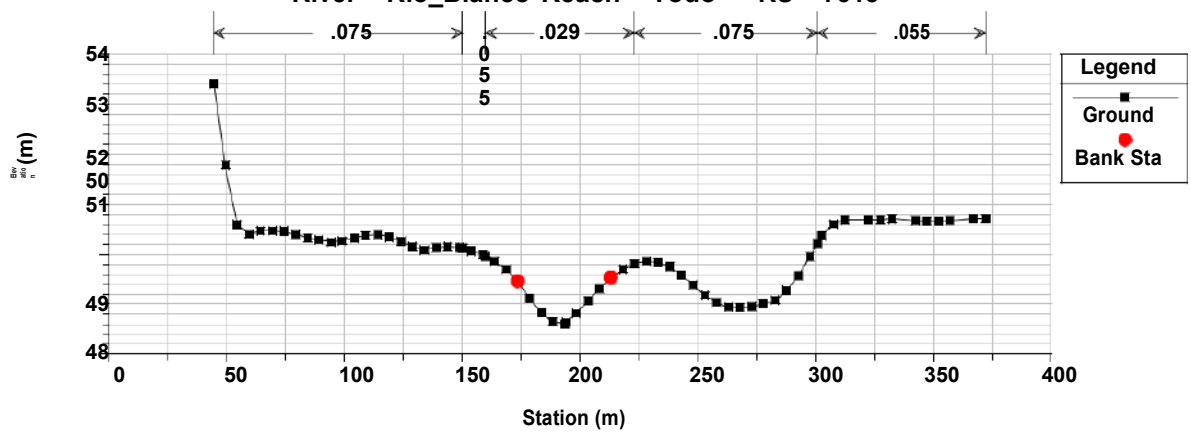
River = Rio_Blanco Reach = Todo RS = 7804



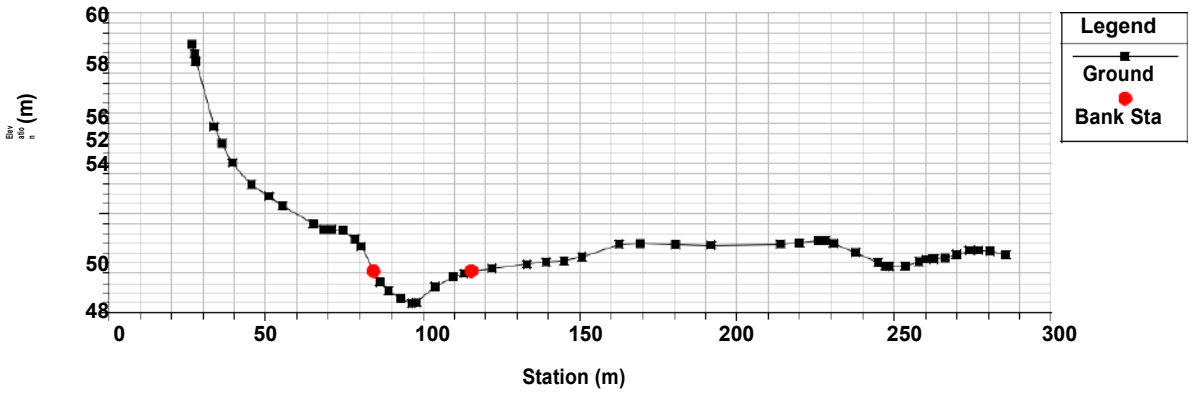
River = Rio_Blanco Reach = Todo RS = 7719



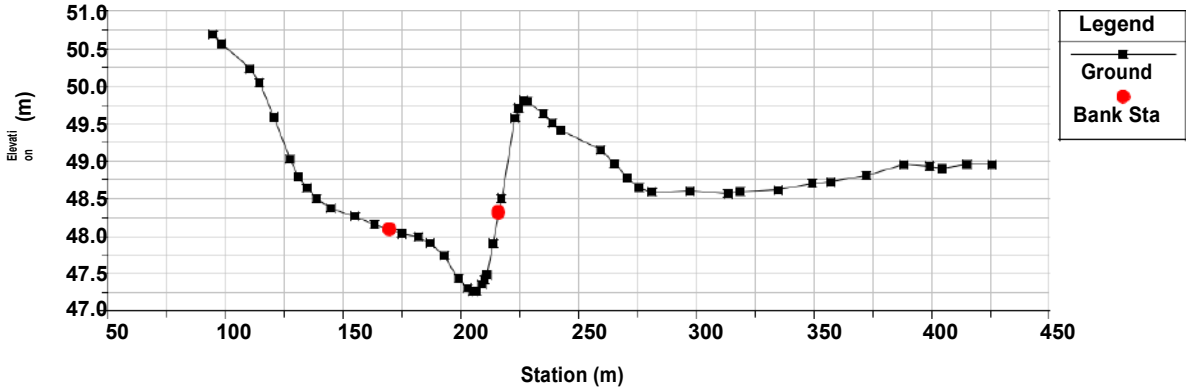
River = Rio_Blanco Reach = Todo RS = 7518



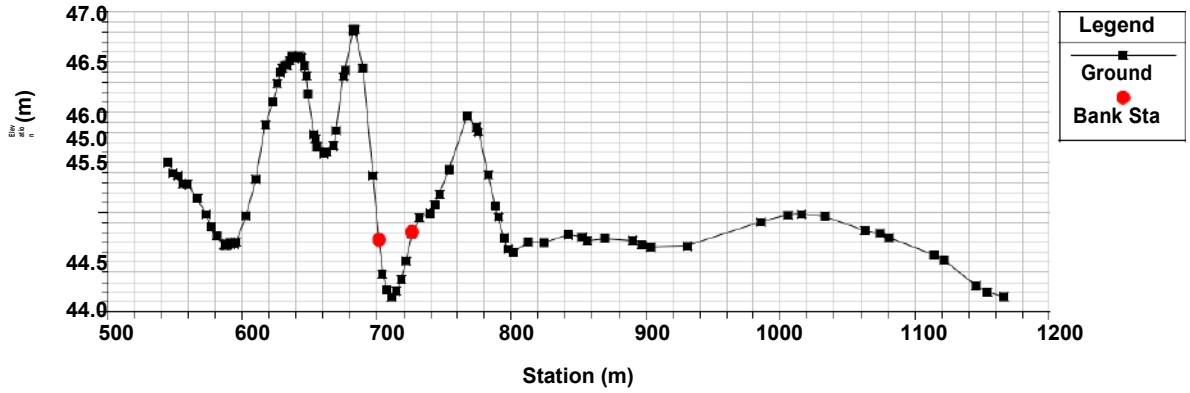
River = Rio_Blanco Reach = Todo RS = 7254



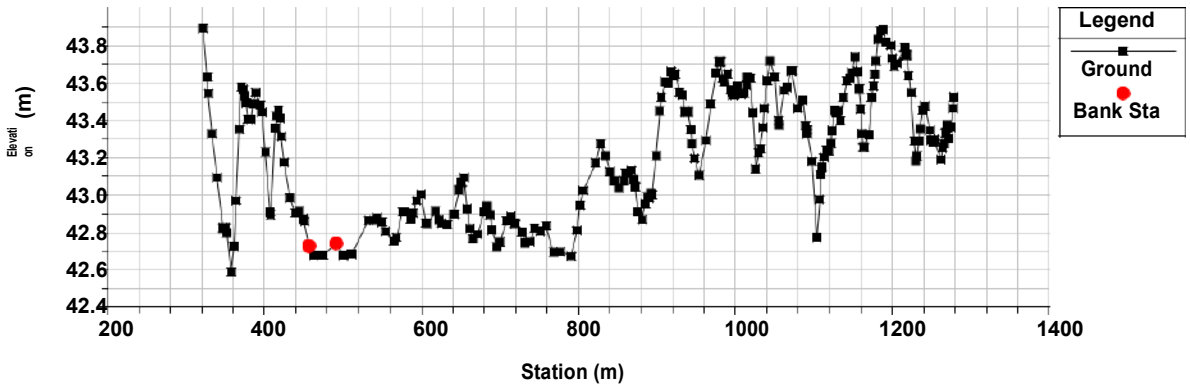
River = Rio_Blanco Reach = Todo RS = 6929



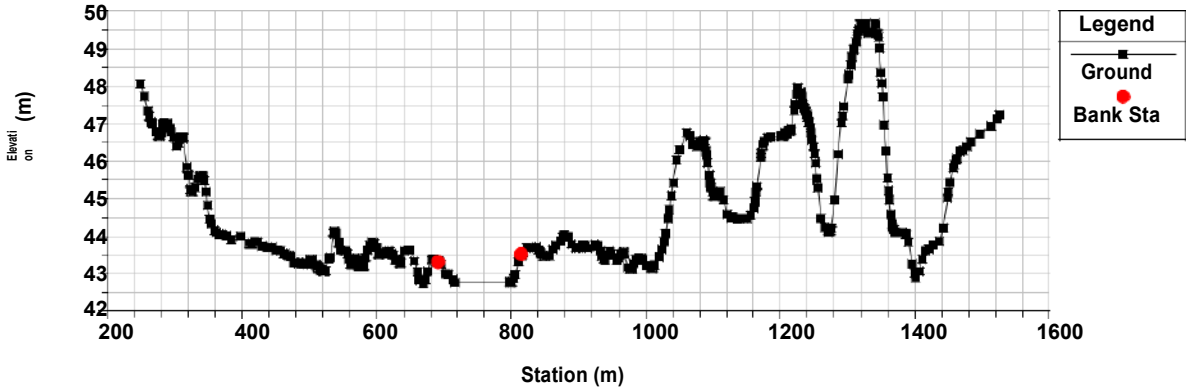
River = Rio_Blanco Reach = Todo RS = 5627



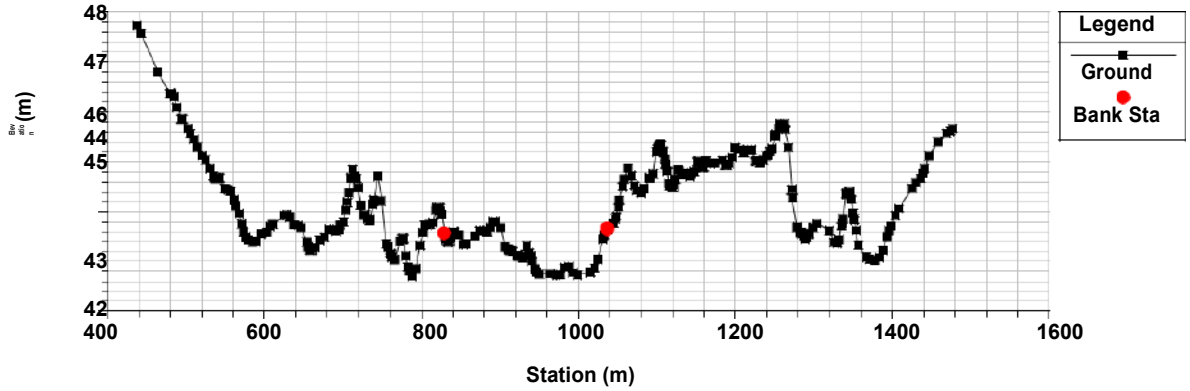
River = Rio_Blanco Reach = Todo RS = 4452



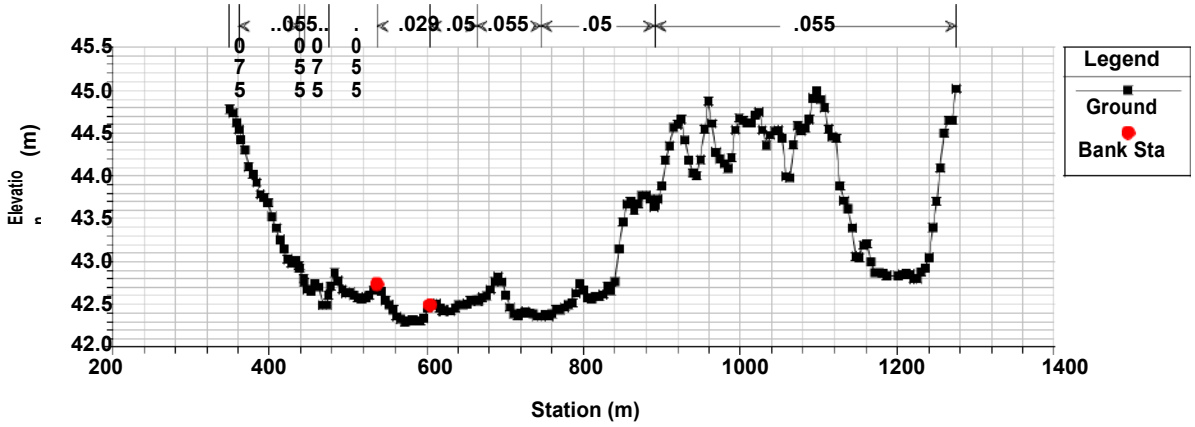
River = Rio_Blanco Reach = Todo RS = 3755



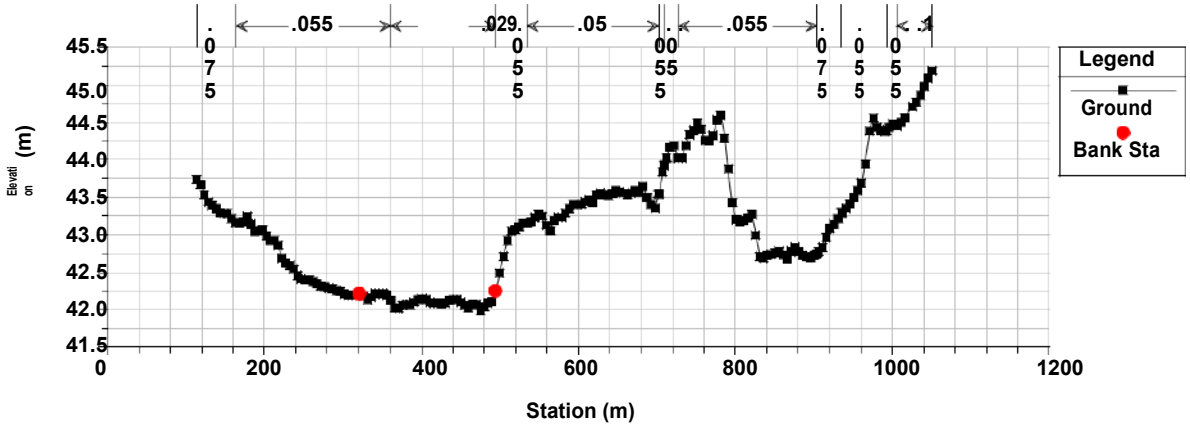
River = Rio_Blanco Reach = Todo RS = 3296



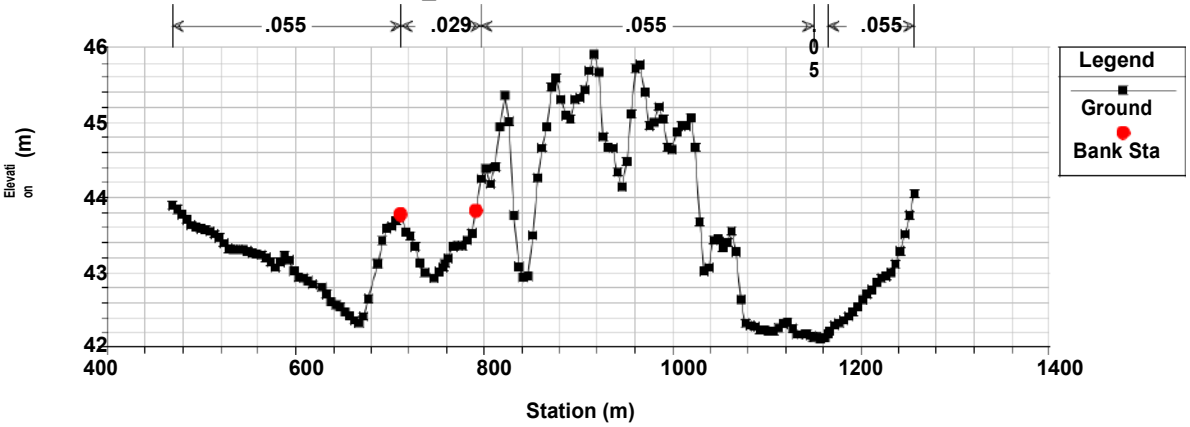
River = Rio_Blanco Reach = Todo RS = 2726

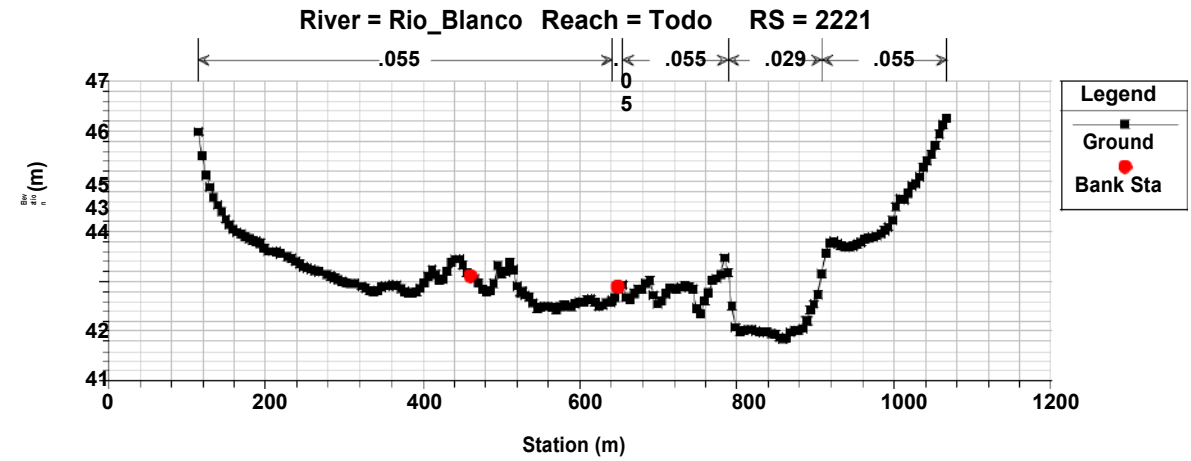


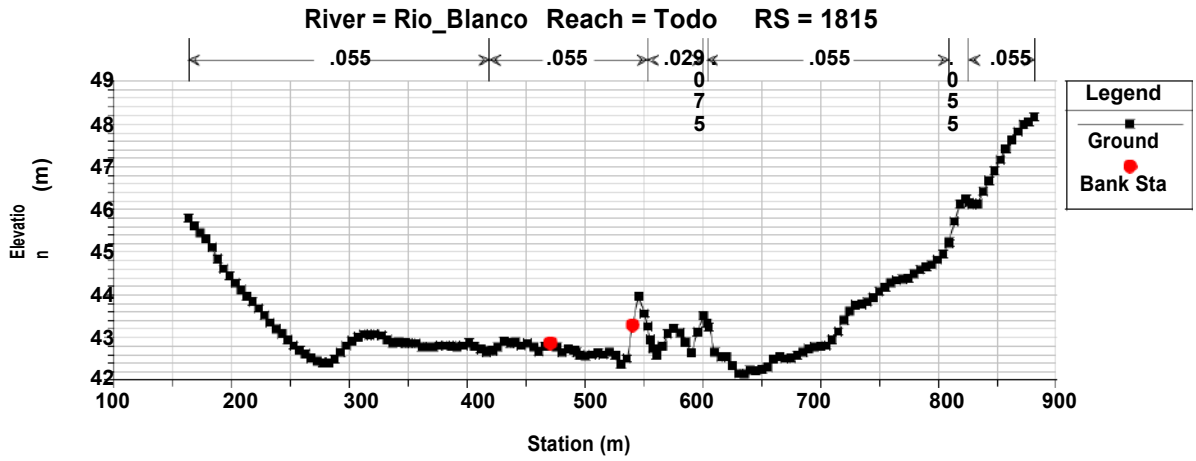
River = Rio_Blanco Reach = Todo RS = 2617

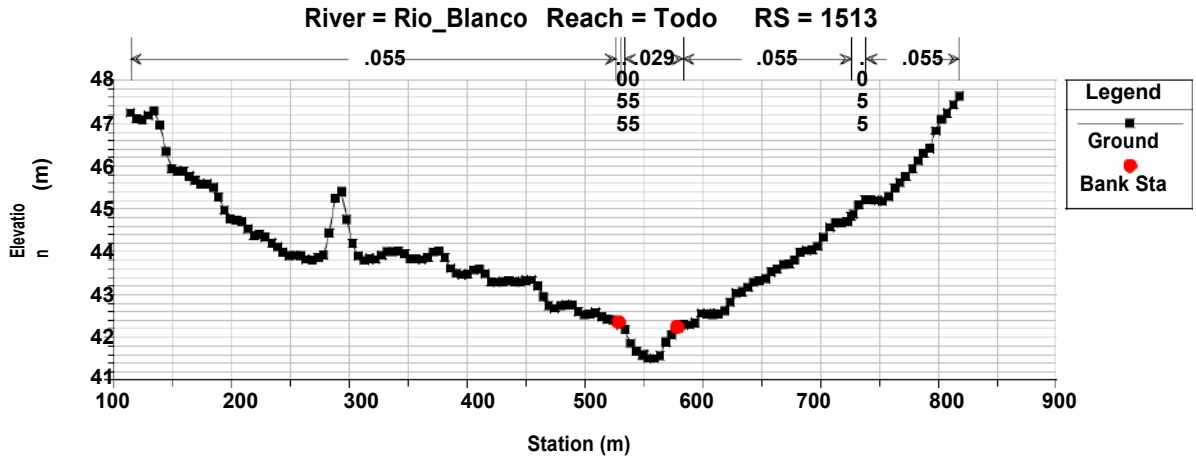


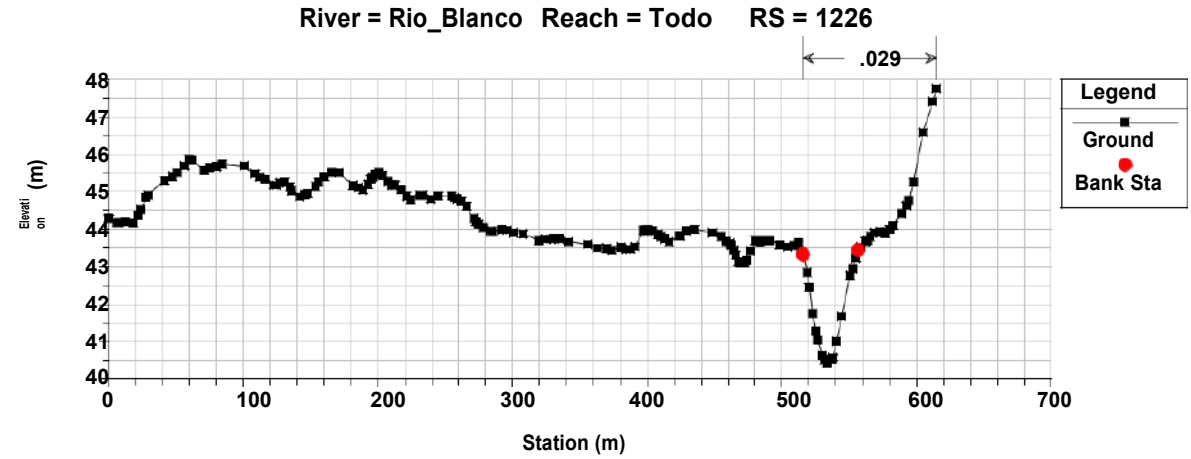
River = Rio_Blanco Reach = Todo RS = 2414

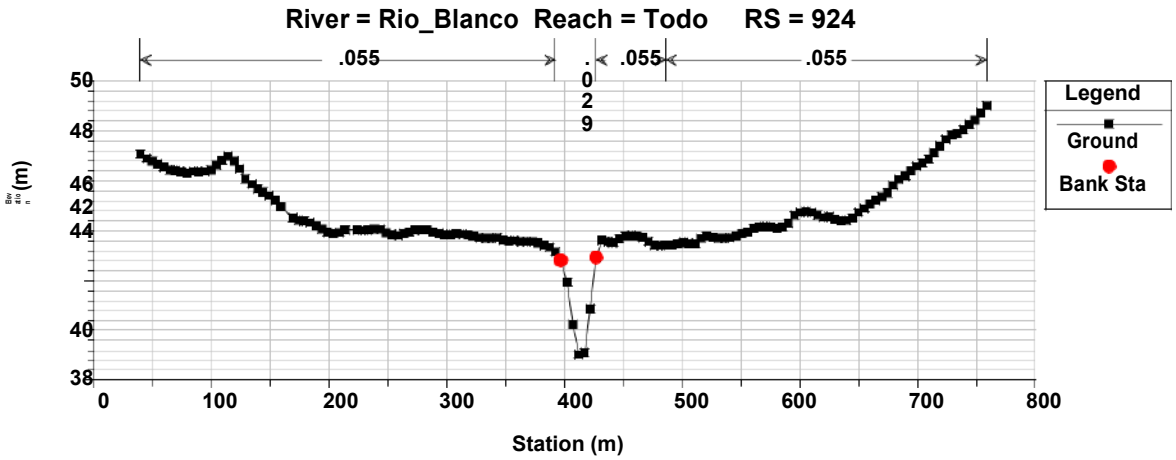


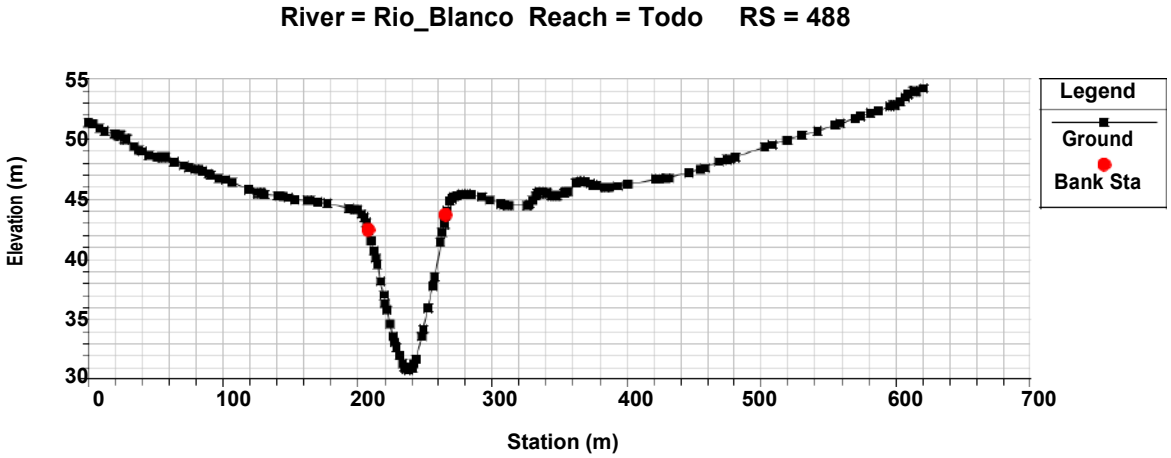

River = Rio_Blanco Reach = Todo RS = 2221
.055
.055
.029
.055
Legend
Ground
Bank Sta
Station (m)

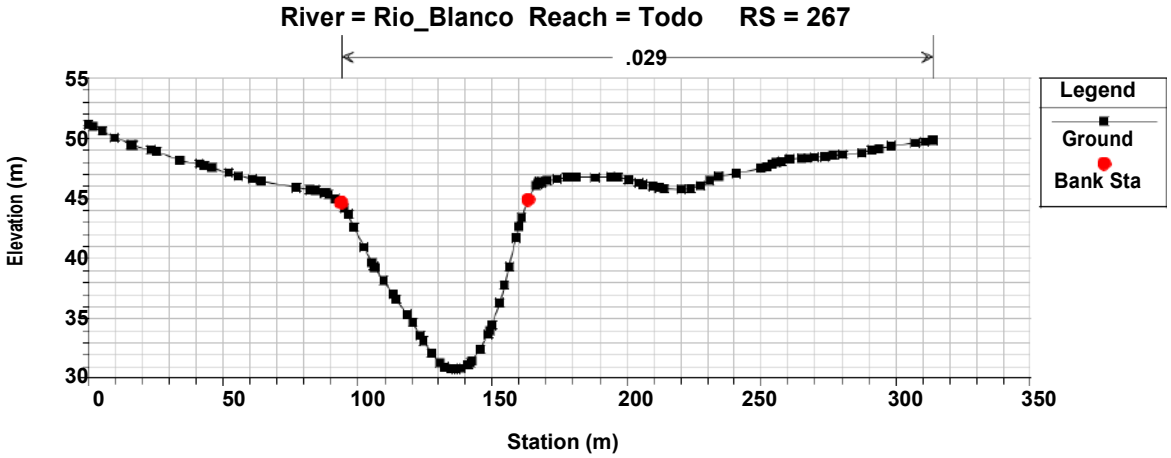

River = Rio_Blanco Reach = Todo RS = 1815
.055
.055
.029
.055
.055
Legend
Ground
Bank Sta
Elevation (m)
Station (m)


River = Rio_Blanco Reach = Todo RS = 1513
.055
.029
.055
.055
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

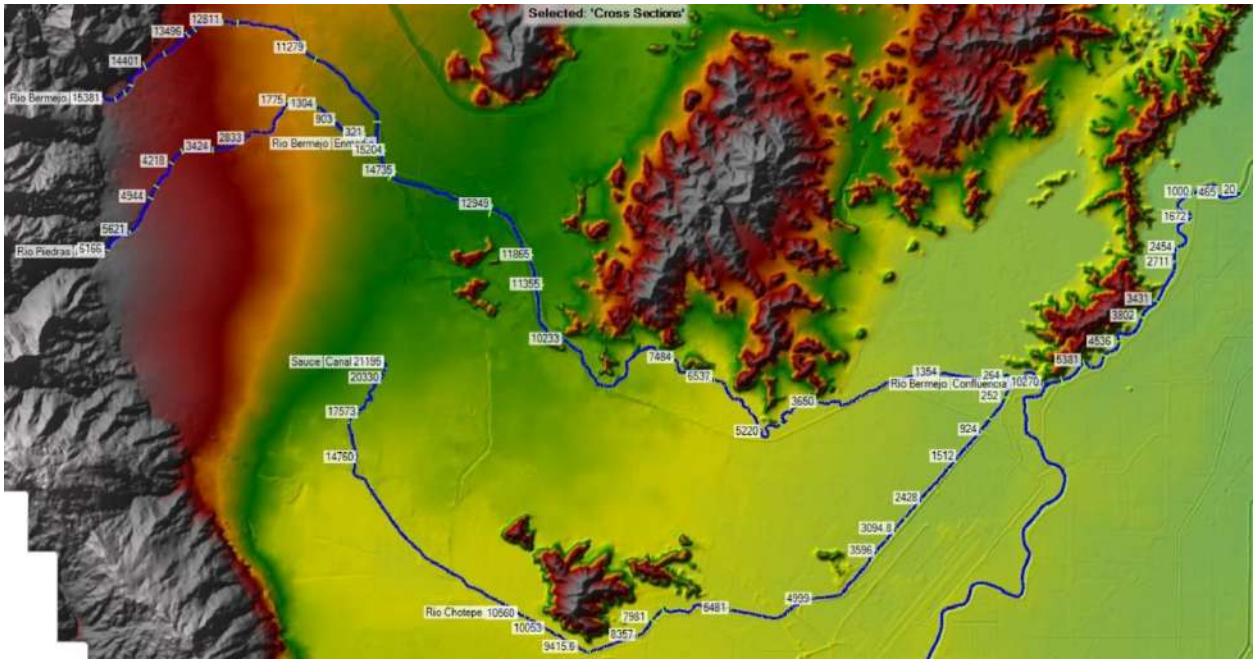

River = Rio_Blanco Reach = Todo RS = 1226
.029
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

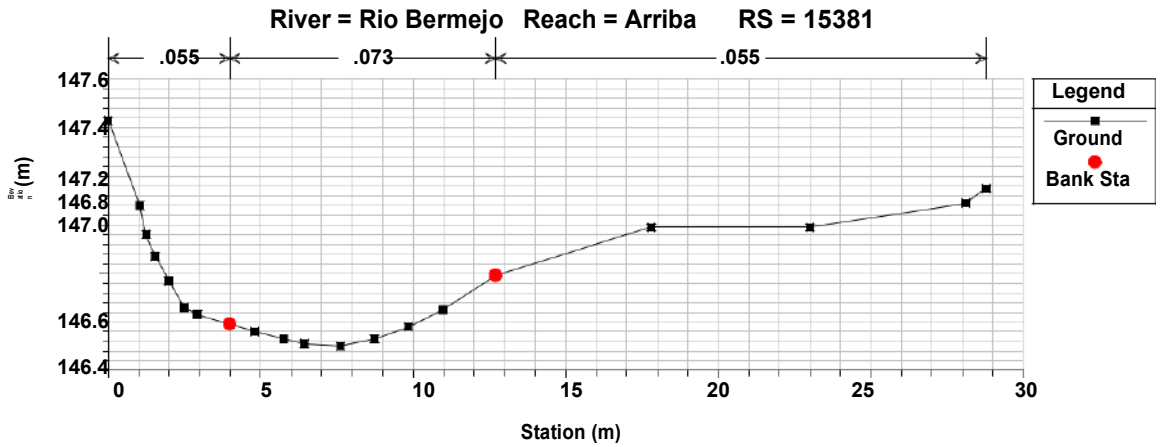

River = Rio_Blanco Reach = Todo RS = 924
.055
.029
.055
.055
Legend
Ground
Bank Sta
Station (m)

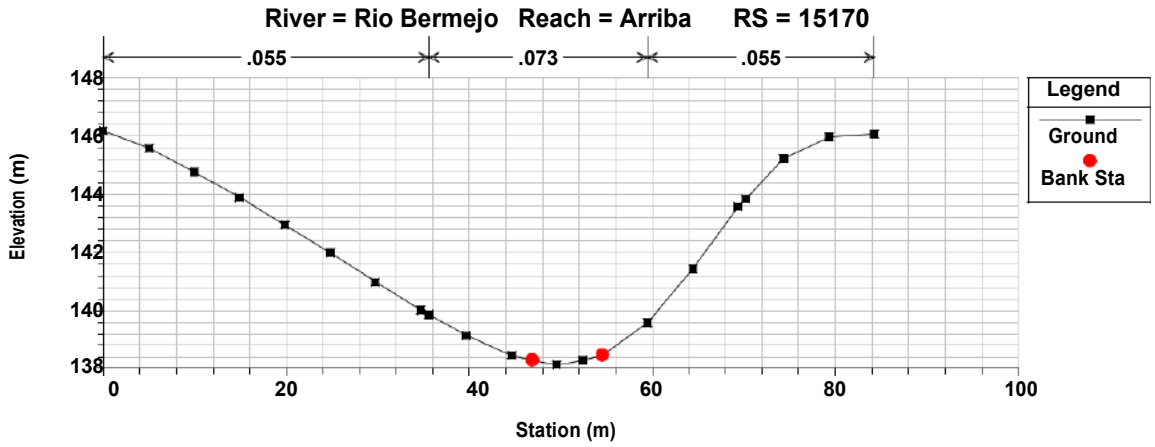

River = Rio_Blanco Reach = Todo RS = 488
Elevation (m)
Legend
Ground
Bank Sta
Station (m)

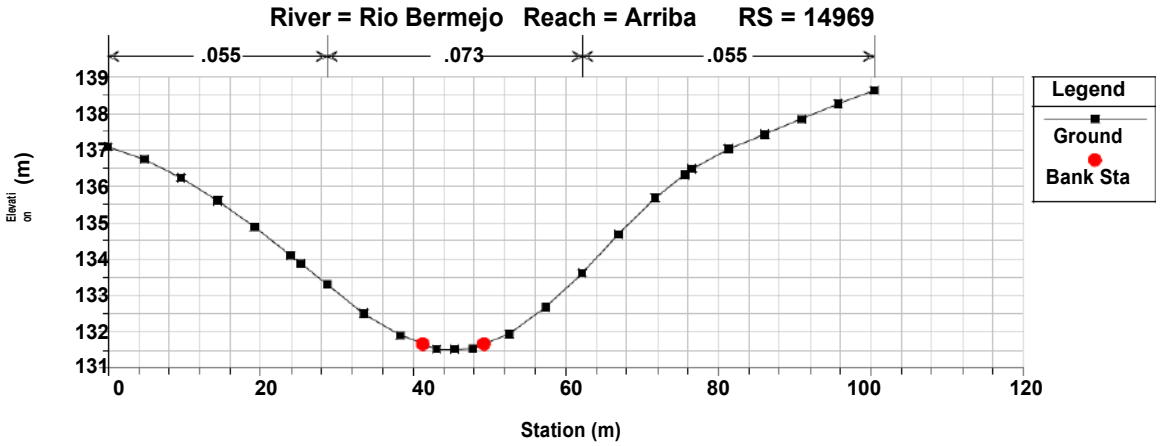

River = Rio_Blanco Reach = Todo RS = 267
.029
Elevation (m)
Legend
Ground
Bank Sta
Station (m)

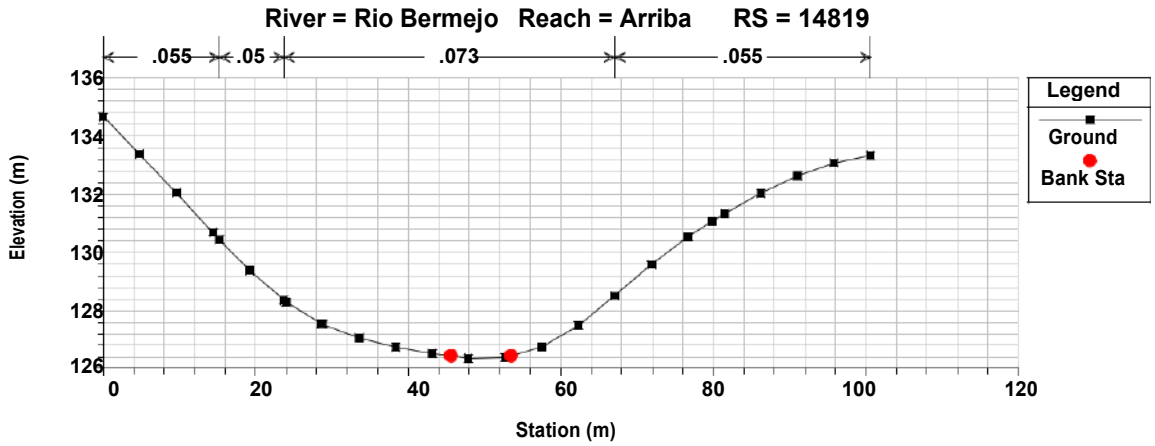
A2 Crosssections Model Río Chotepe

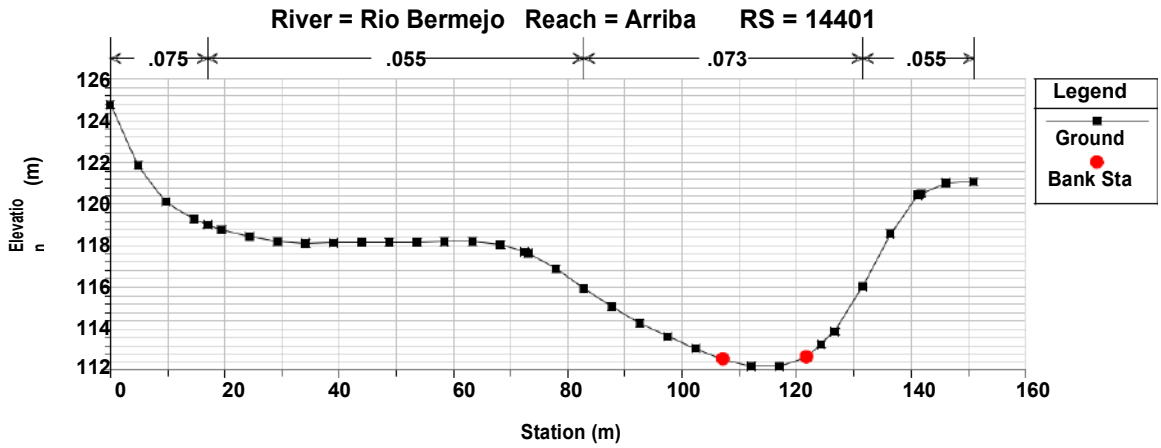


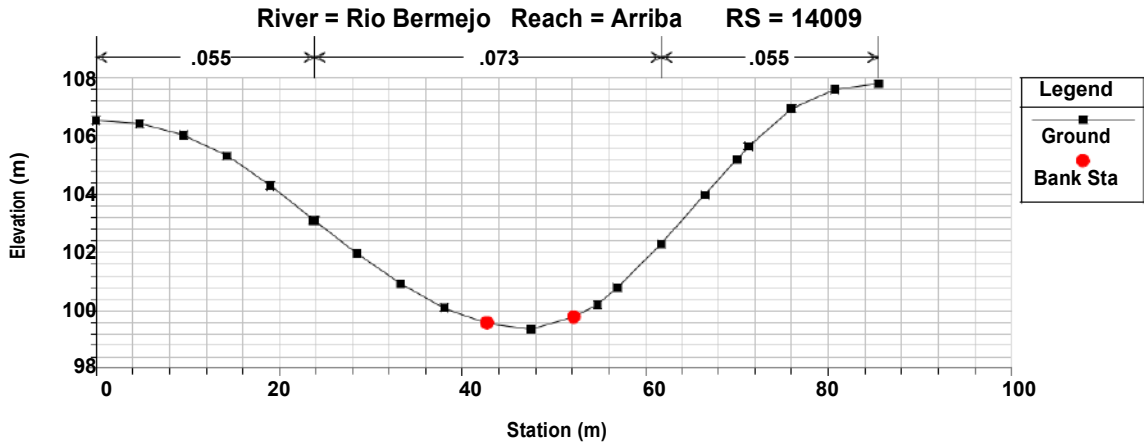

River = Rio Bermejo Reach = Arriba RS = 15381
.055
.073
.055
Legend
Ground
Bank Sta
Station (m)

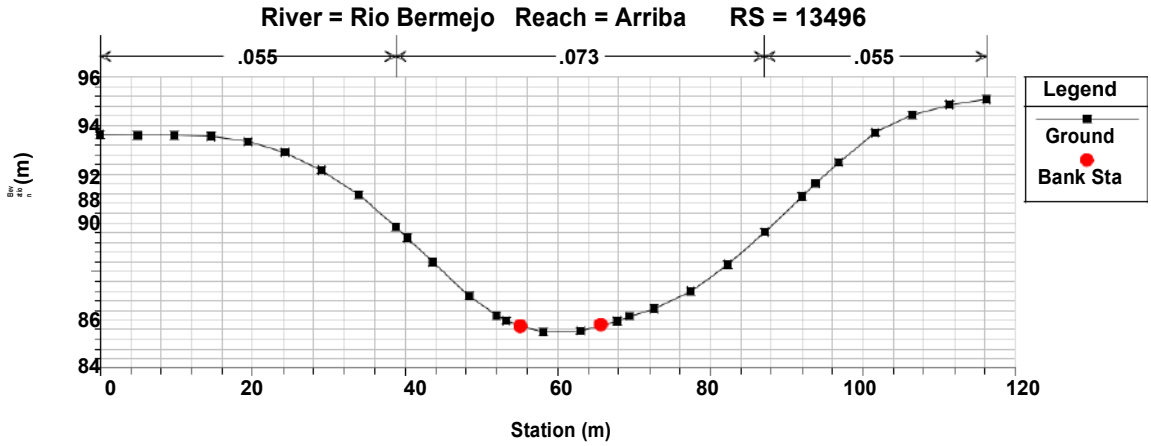

River = Rio Bermejo Reach = Arriba RS = 15170
.055
.073
.055
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

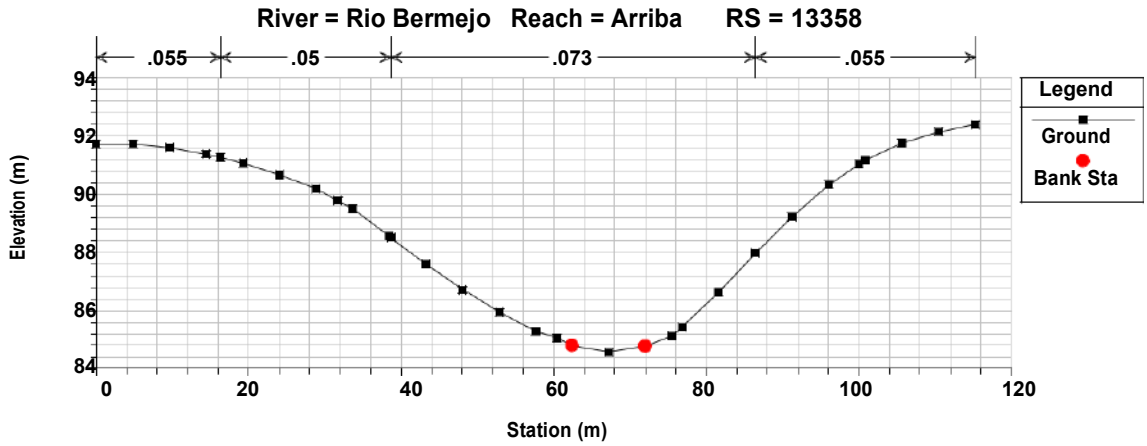

River = Rio Bermejo Reach = Arriba RS = 14969
.055
.073
.055
Legend
Ground
Bank Sta
Station (m)

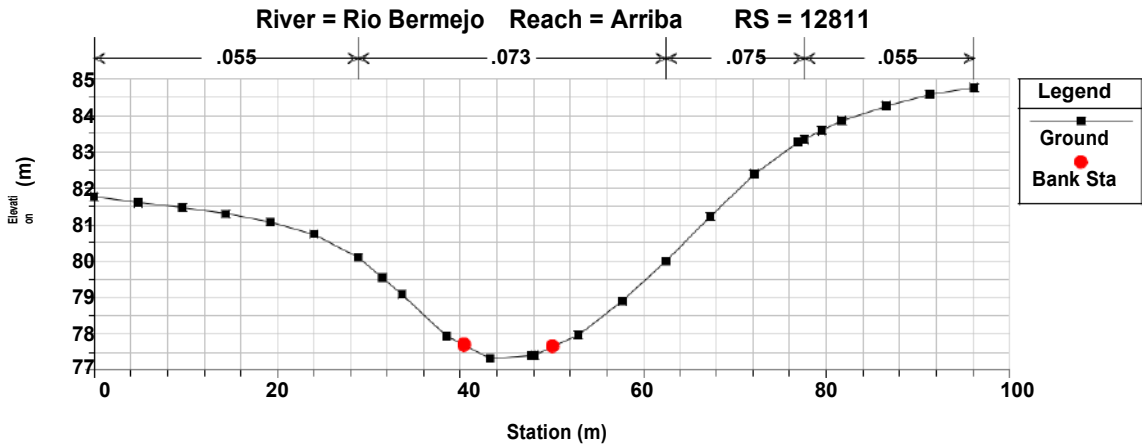

River = Rio Bermejo Reach = Arriba RS = 14819
.055
.05
.073
.055
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

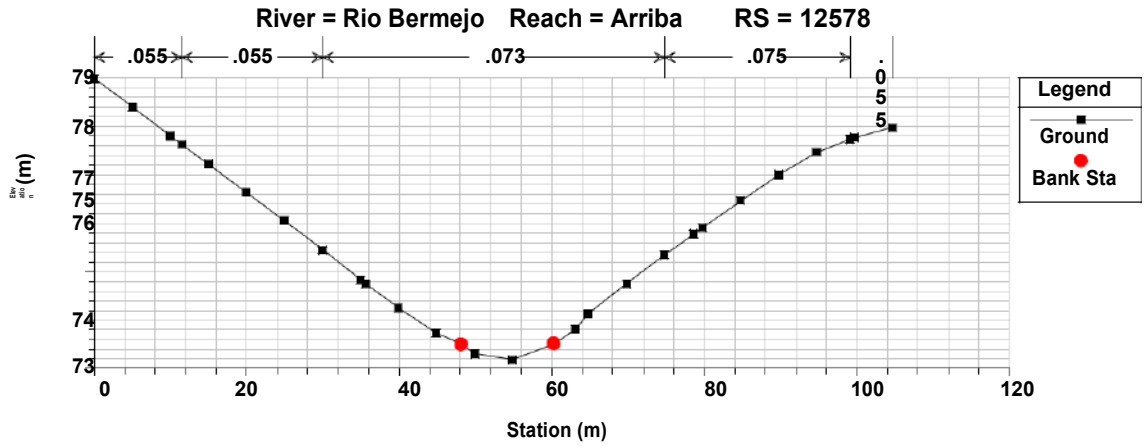

River = Rio Bermejo Reach = Arriba RS = 14401
.075
.055
.073
.055
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

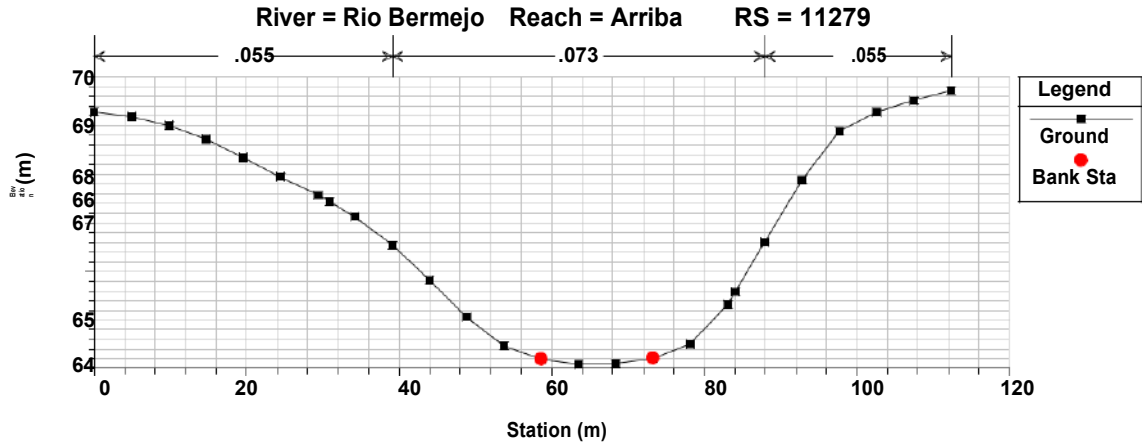

River = Rio Bermejo Reach = Arriba RS = 14009
.055
.073
.055
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

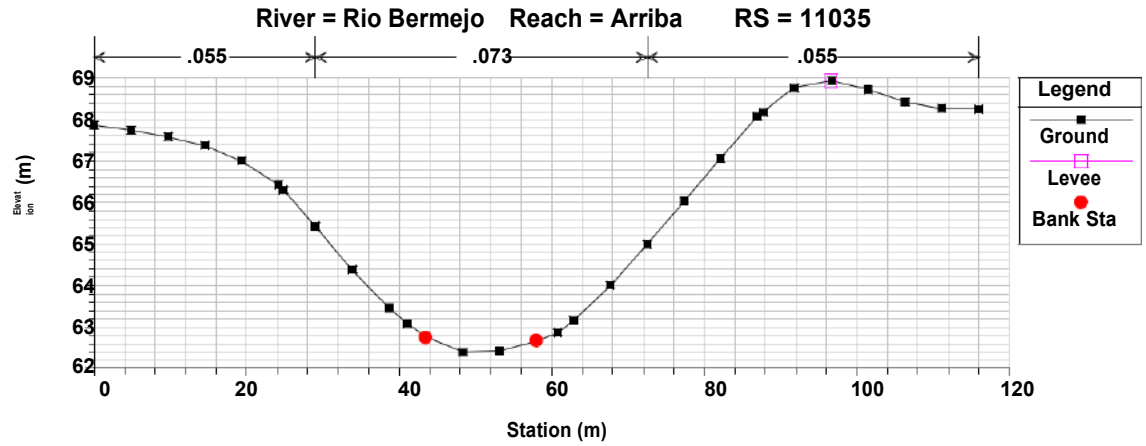

River = Rio Bermejo Reach = Arriba RS = 13496
.055
.073
.055
Station (m)
Legend
Ground
Bank Sta

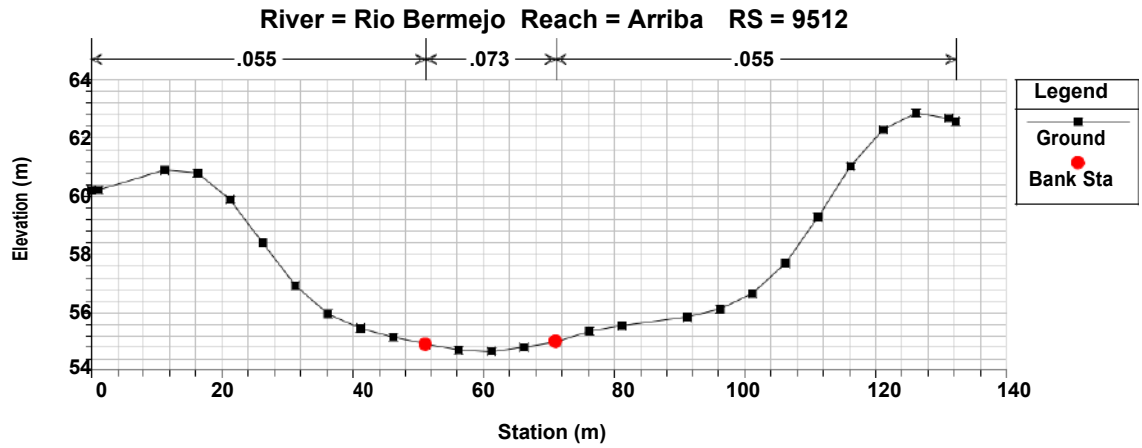

River = Rio Bermejo Reach = Arriba RS = 13358
.055
.05
.073
.055
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

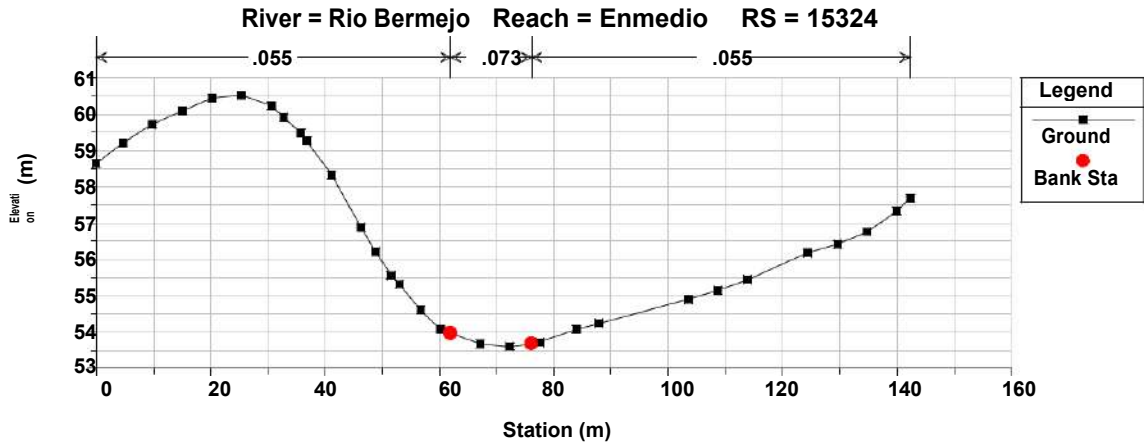

River = Rio Bermejo Reach = Arriba RS = 12811
.055
.073
.075
.055
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

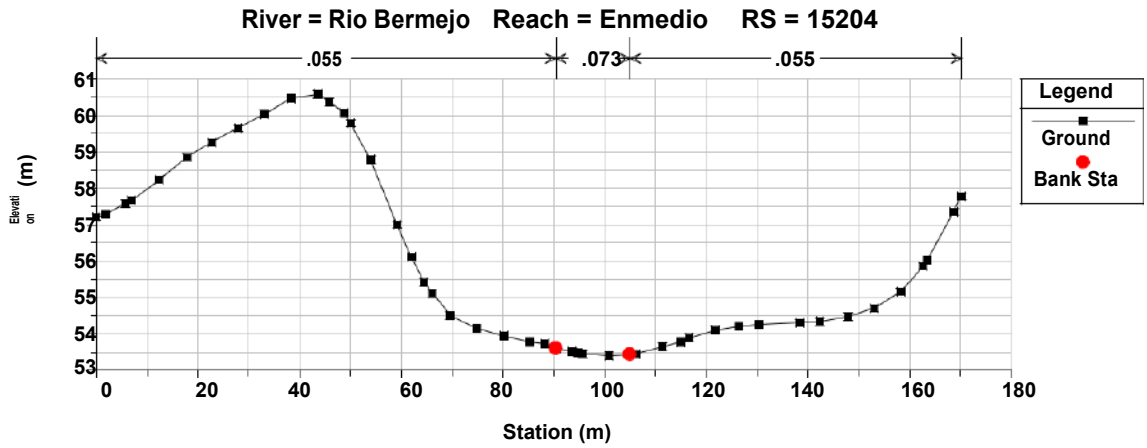

River = Rio Bermejo Reach = Arriba RS = 12578
.055
.055
.073
.075
.055
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

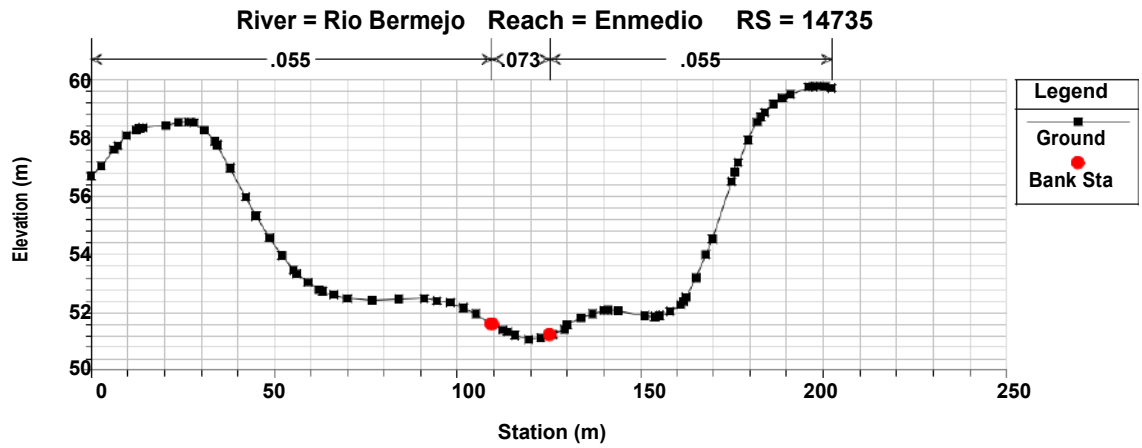

River = Rio Bermejo Reach = Arriba RS = 11279
.055
.073
.055
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

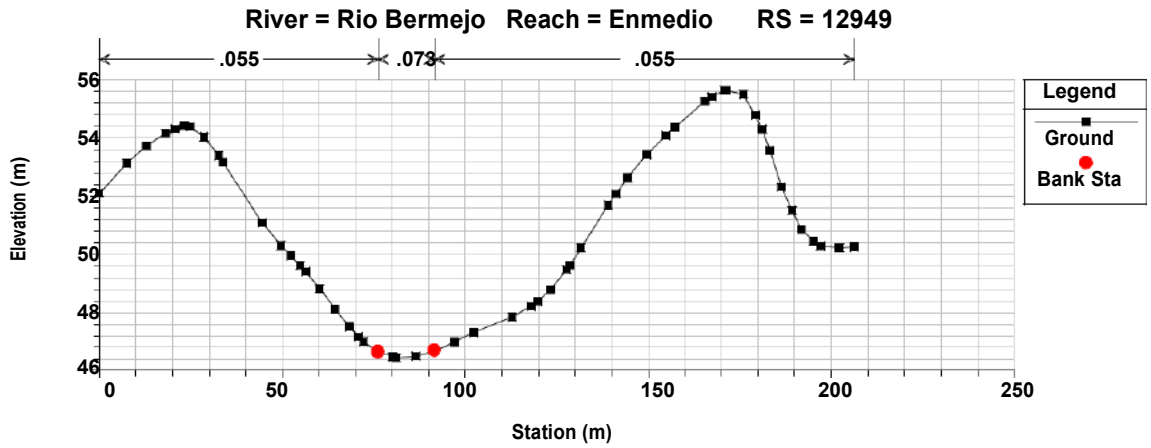

River = Rio Bermejo Reach = Arriba RS = 11035
.055
.073
.055
Elevation (m)
Station (m)
Legend
Ground
Levee
Bank Sta

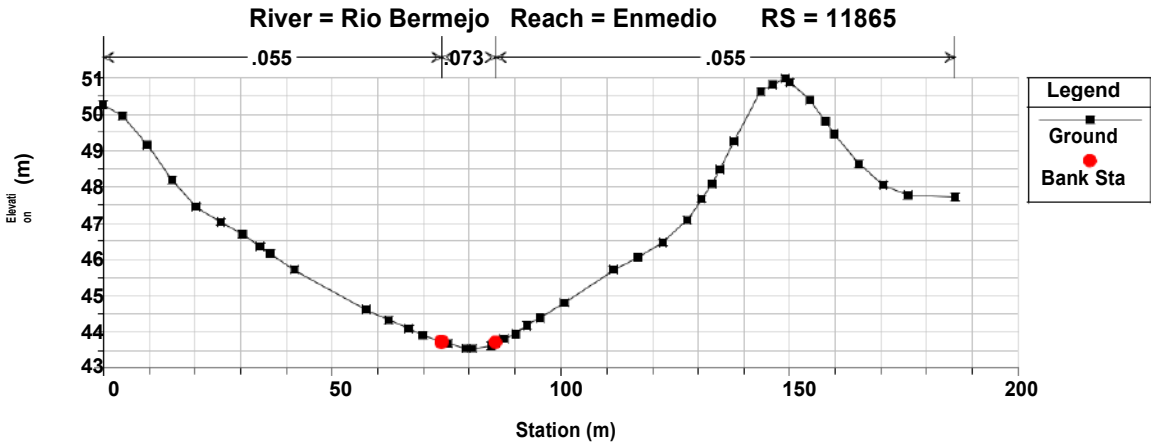

River = Rio Bermejo Reach = Arriba RS = 9512
.055
.073
.055
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

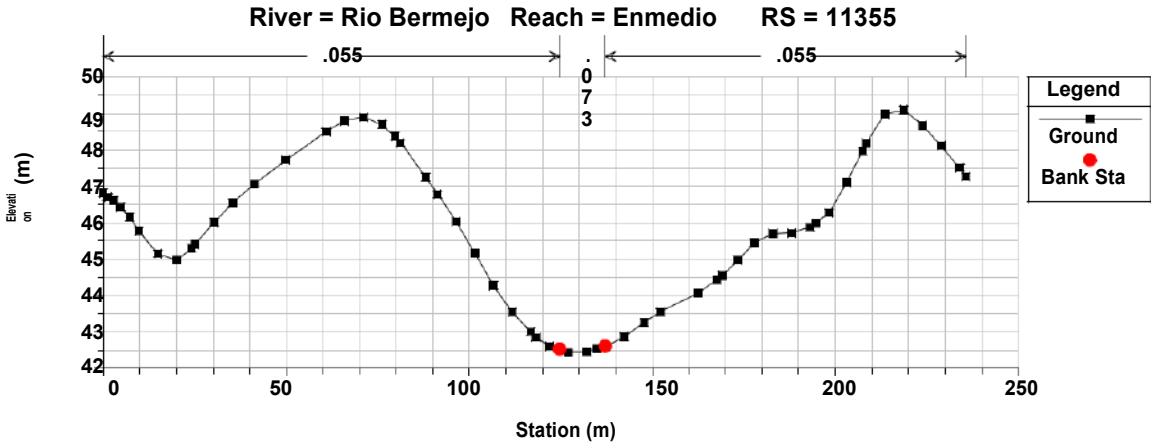

River = Rio Bermejo Reach = Enmedio RS = 15324
.055
.073
.055
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

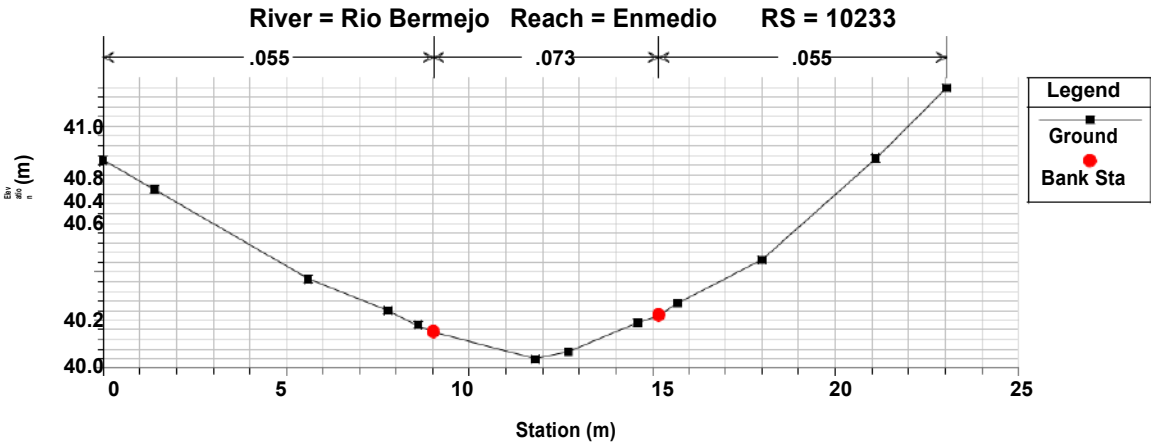

River = Rio Bermejo Reach = Enmedio RS = 15204
.055
.073
.055
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

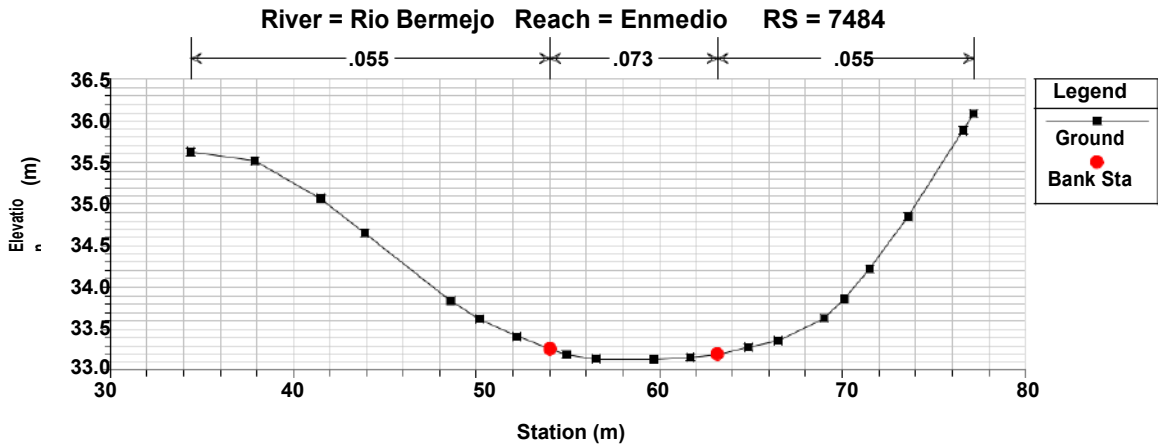

River = Rio Bermejo Reach = Enmedio RS = 14735
.055
.073
.055
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

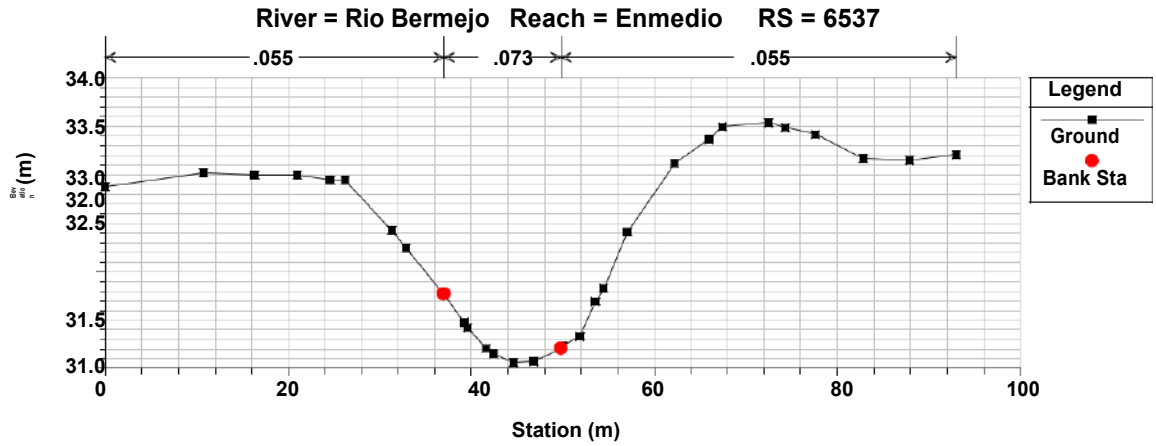

River = Rio Bermejo Reach = Enmedio RS = 12949
.055
.073
.055
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

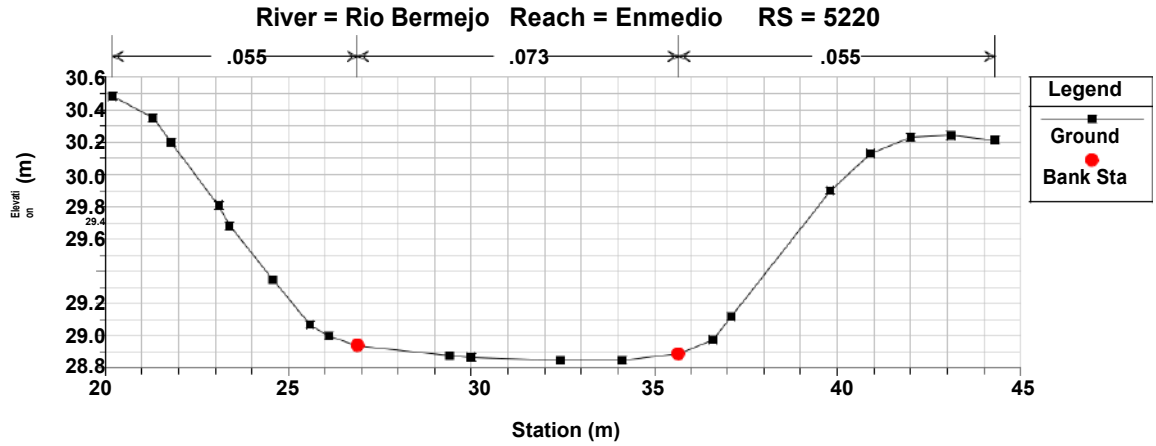

River = Rio Bermejo Reach = Enmedio RS = 11865
.055
.073
.055
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

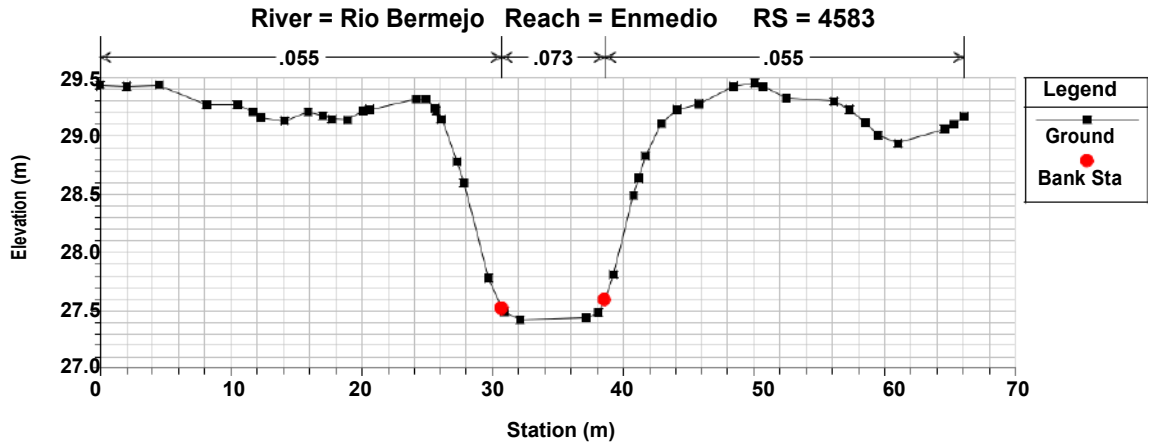

River = Rio Bermejo Reach = Enmedio RS = 11355
.055
.073
.055
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

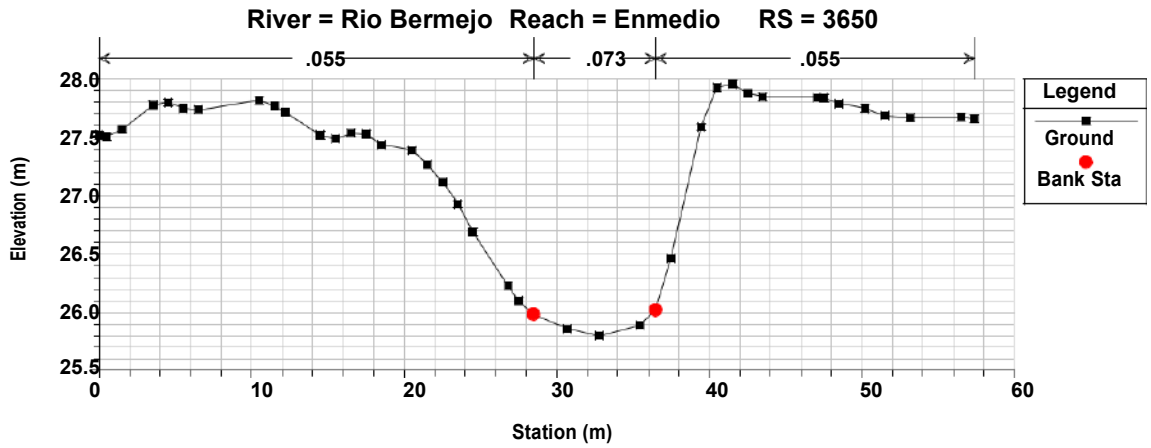

River = Rio Bermejo Reach = Enmedio RS = 10233
.055
.073
.055
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

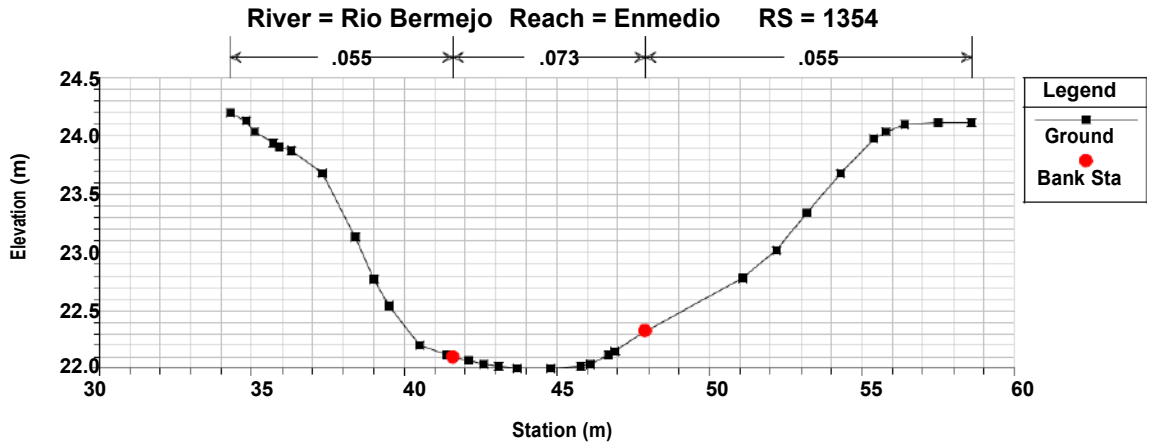

River = Rio Bermejo Reach = Enmedio RS = 7484
.055
.073
.055
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

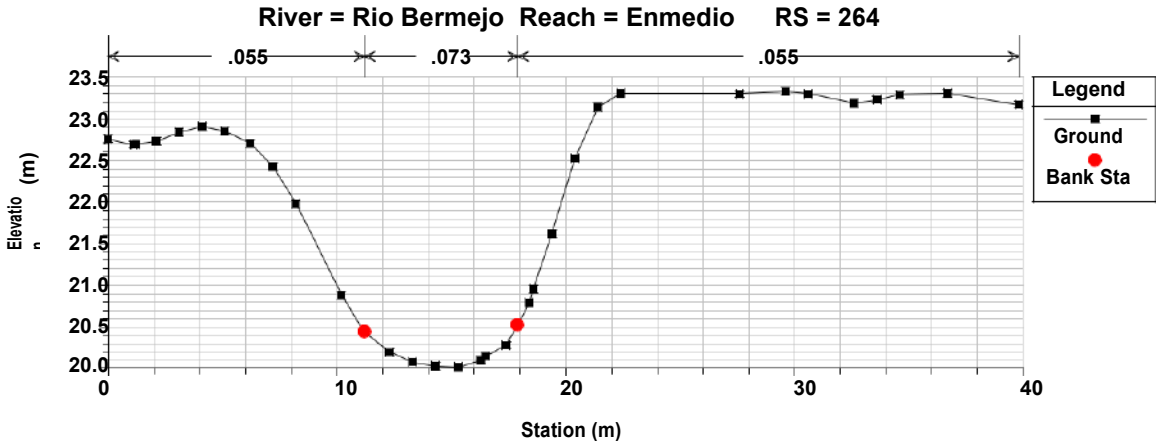

River = Rio Bermejo Reach = Enmedio RS = 6537
.055
.073
.055
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

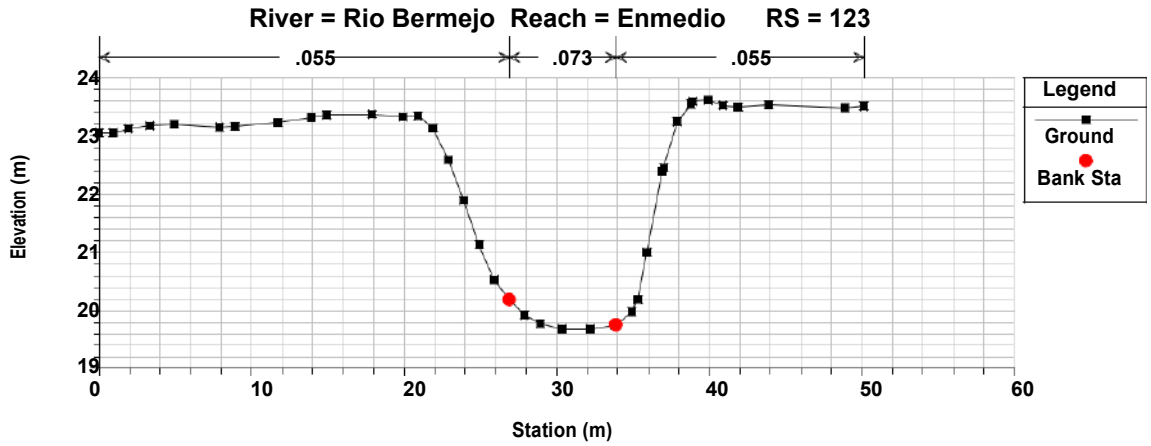

River = Rio Bermejo Reach = Enmedio RS = 5220
.055
.073
.055
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

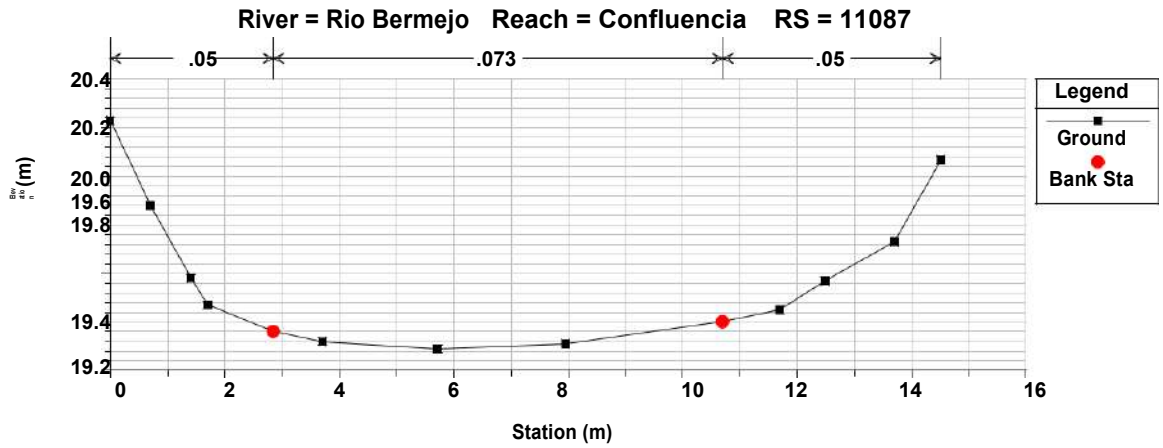

River = Rio Bermejo Reach = Enmedio RS = 4583
.055
.073
.055
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

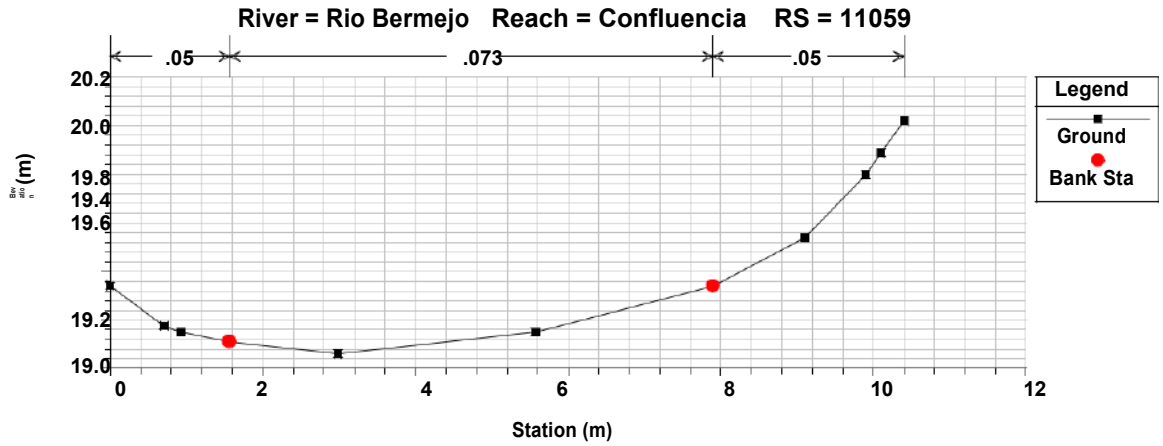

River = Rio Bermejo Reach = Enmedio RS = 3650
.055
.073
.055
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

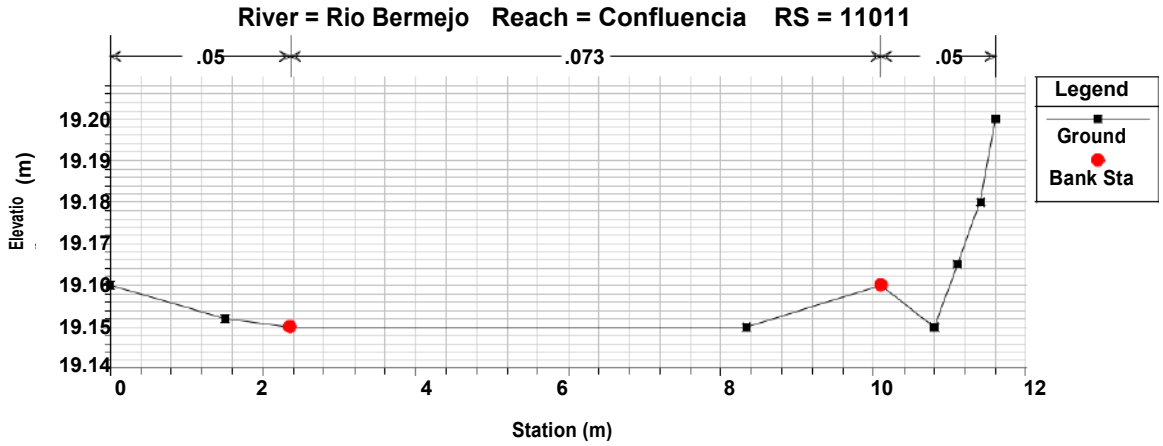

River = Rio Bermejo Reach = Enmedio RS = 1354
.055
.073
.055
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

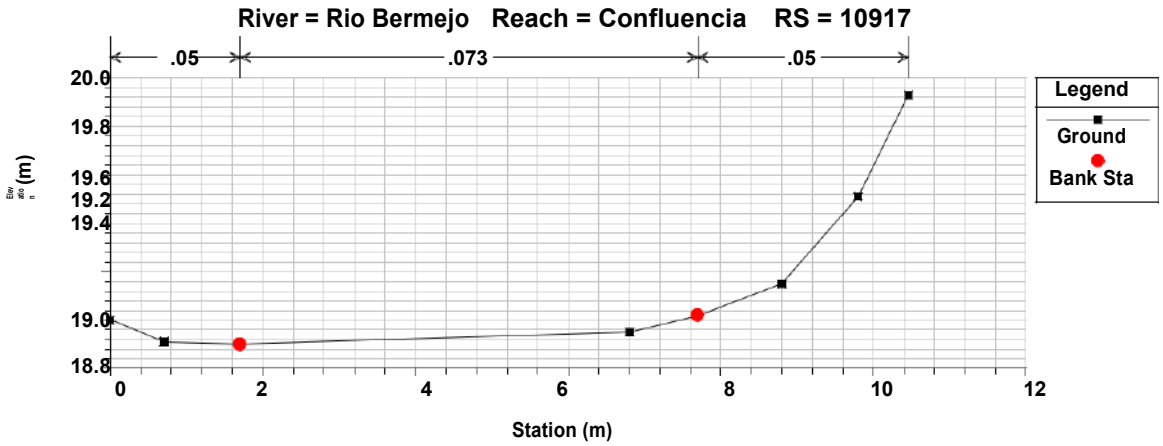

River = Rio Bermejo Reach = Enmedio RS = 264
.055
.073
.055
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

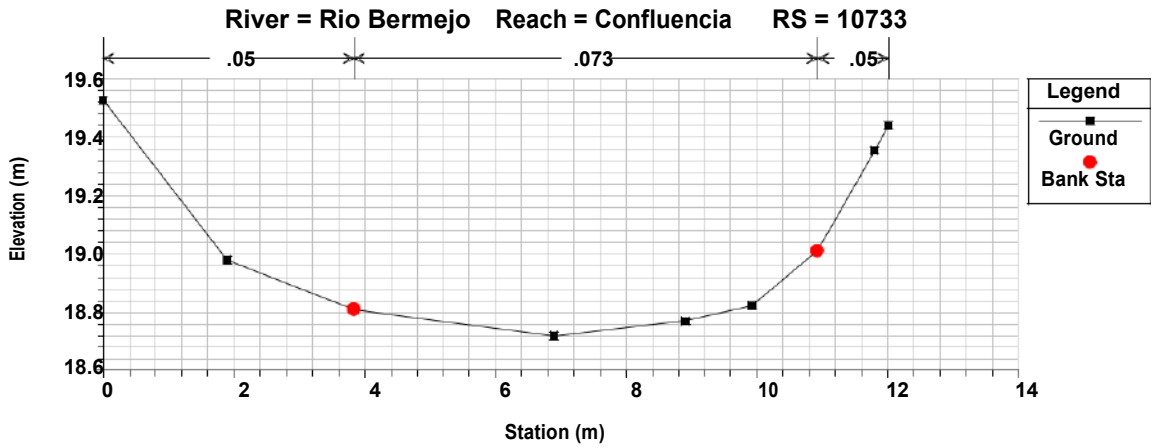

River = Rio Bermejo Reach = Enmedio RS = 123
.055
.073
.055
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

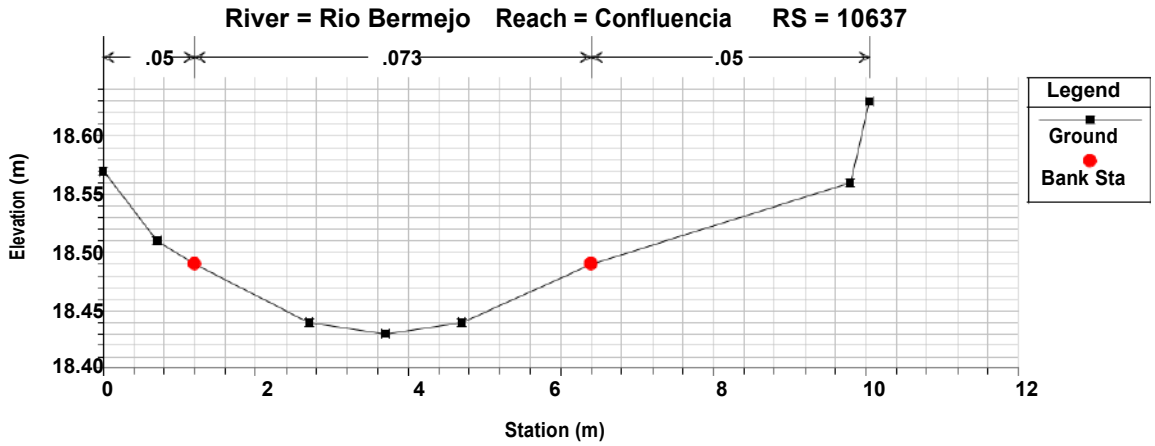

River = Rio Bermejo Reach = Confluencia RS = 11087
.05
.073
.05
Legend
Ground
Bank Sta
Station (m)

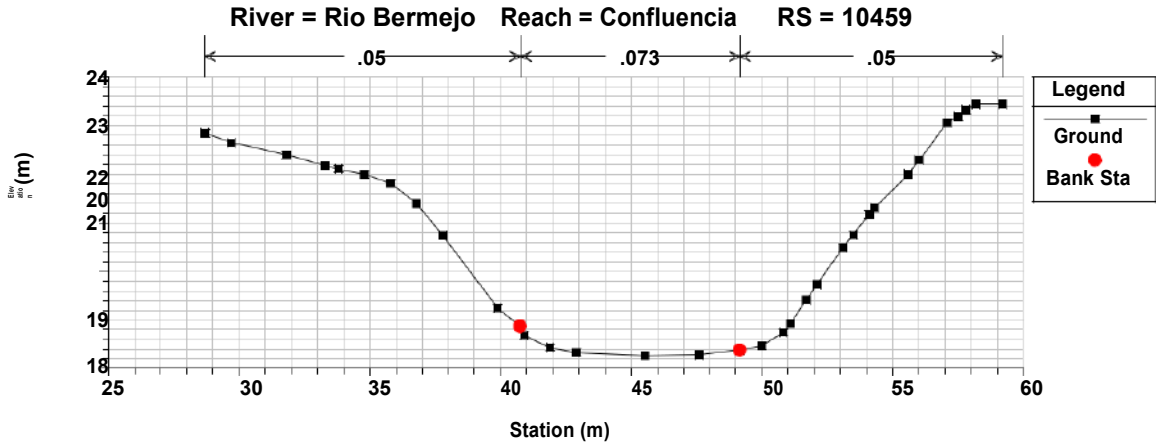

River = Rio Bermejo Reach = Confluencia RS = 11059
.05
.073
.05
Legend
Ground
Bank Sta
Station (m)

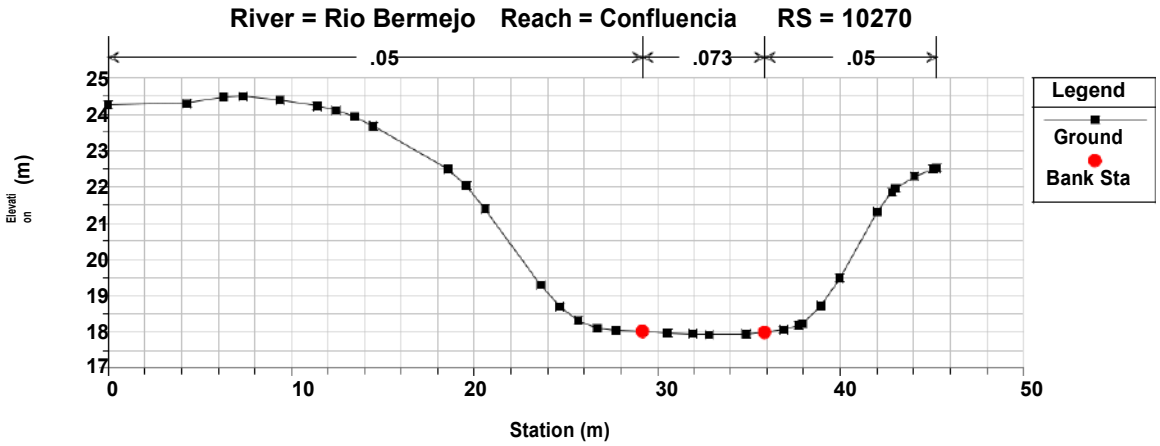

River = Rio Bermejo Reach = Confluencia RS = 11011
.05
.073
.05
Elevatio (m)
Legend
Ground
Bank Sta
Station (m)


River = Rio Bermejo Reach = Confluencia RS = 10917
.05
.073
.05
Legend
Ground
Bank Sta
Station (m)

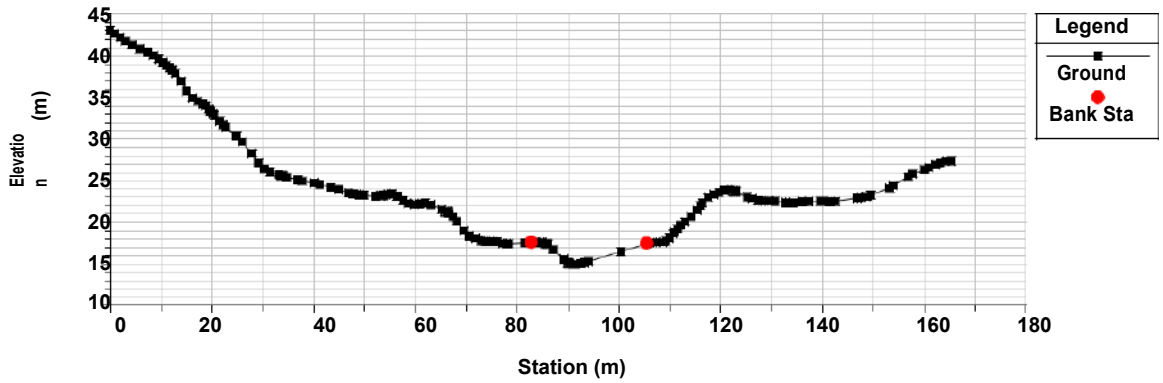

River = Rio Bermejo Reach = Confluencia RS = 10733
.05
.073
.05
Elevation (m)
Station (m)
Legend
Ground
Bank Sta


River = Rio Bermejo Reach = Confluencia RS = 10637
.05
.073
.05
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

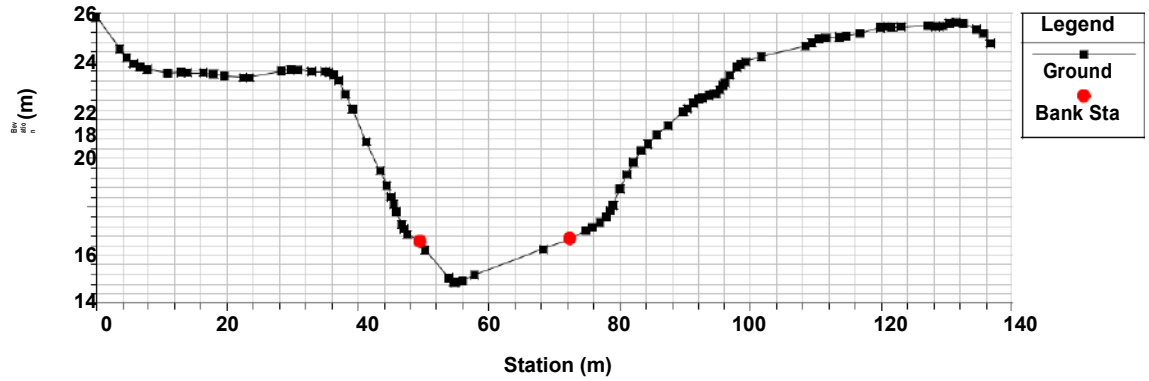

River = Rio Bermejo Reach = Confluencia RS = 10459
.05
.073
.05
Station (m)
Legend
Ground
Bank Sta


River = Rio Bermejo Reach = Confluencia RS = 10270
.05
.073
.05
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

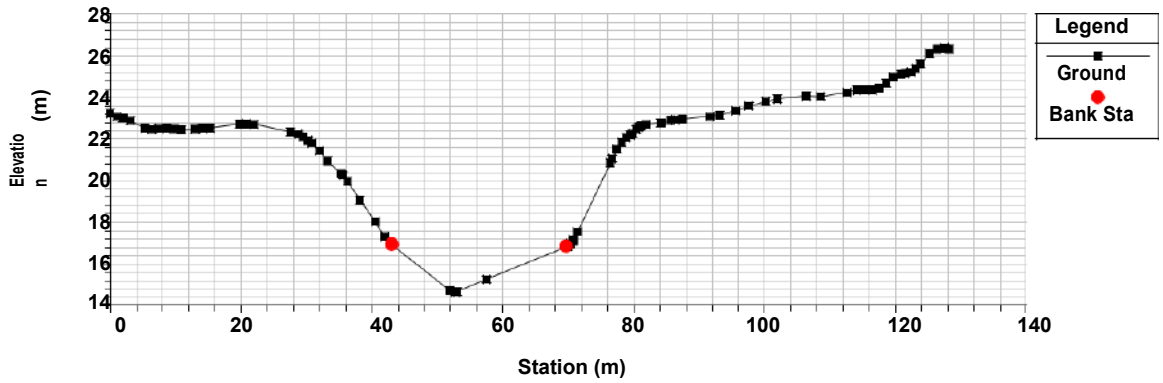
River = Rio Chamelecon Reach = limites1 RS = 5858



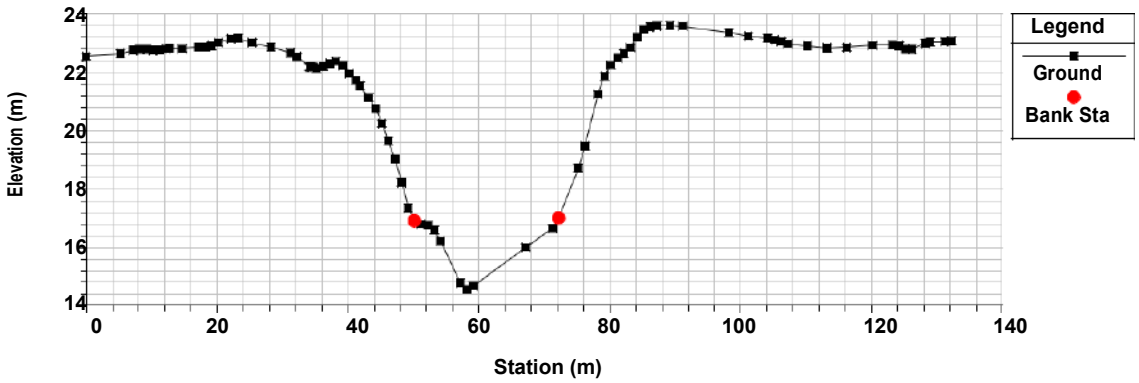
River = Rio Chamelecon Reach = limites1 RS = 5381



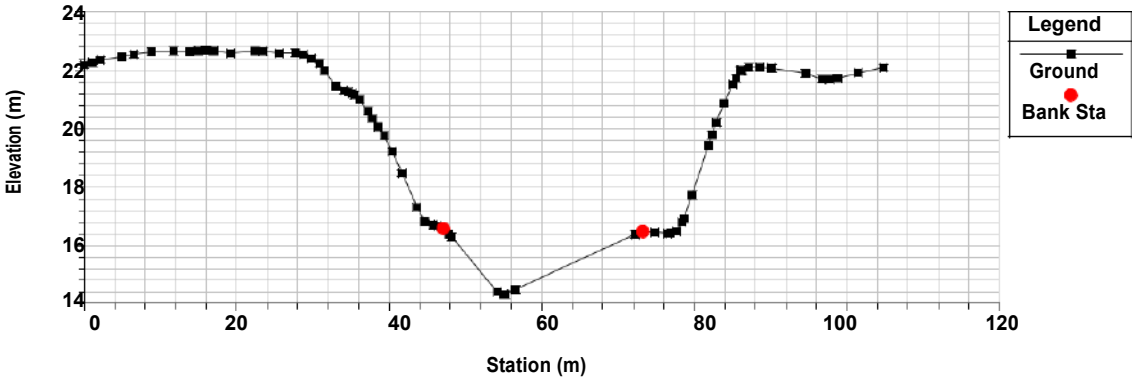
River = Rio Chamelecon Reach = limites1 RS = 4894



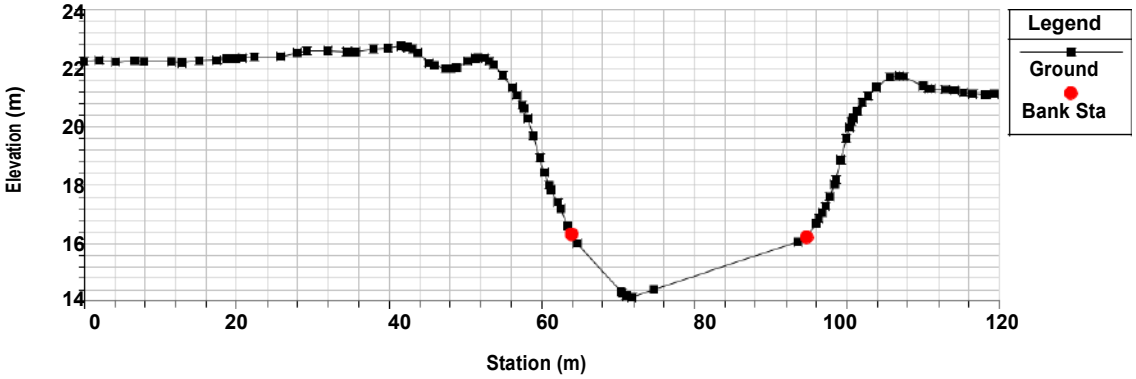
River = Rio Chamelecon Reach = limites1 RS = 4536



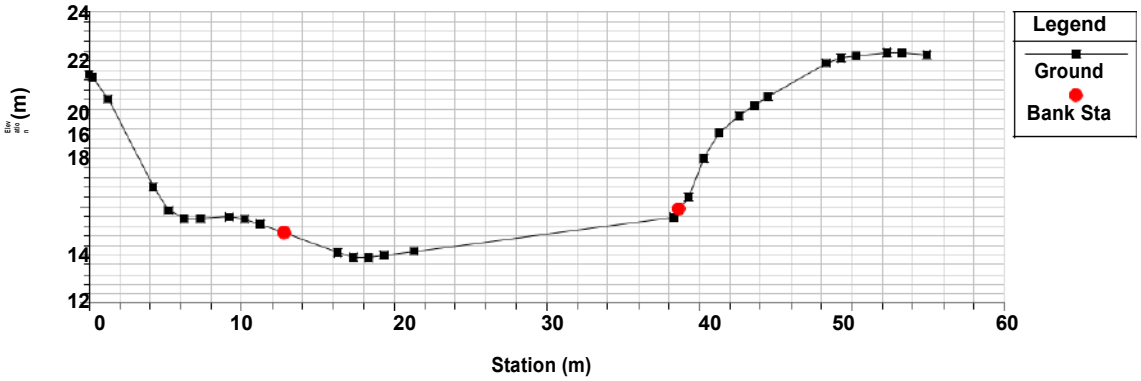
River = Rio Chamelecon Reach = limites1 RS = 3802



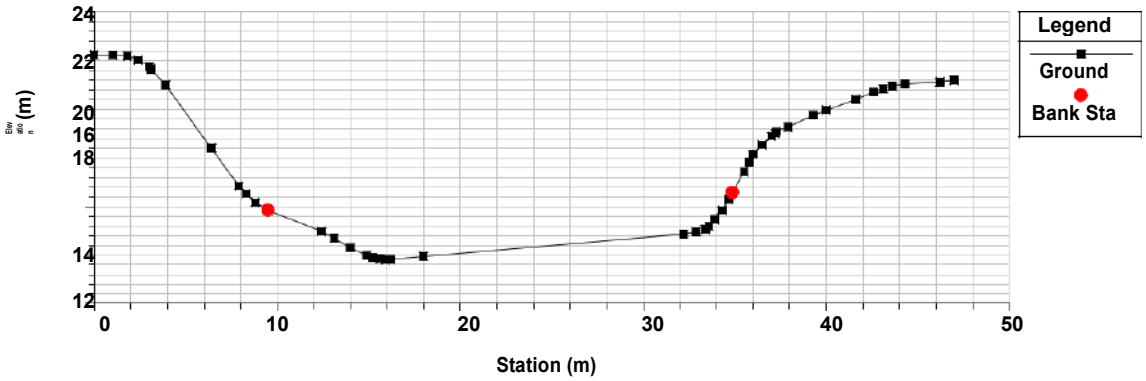
River = Rio Chamelecon Reach = limites1 RS = 3431



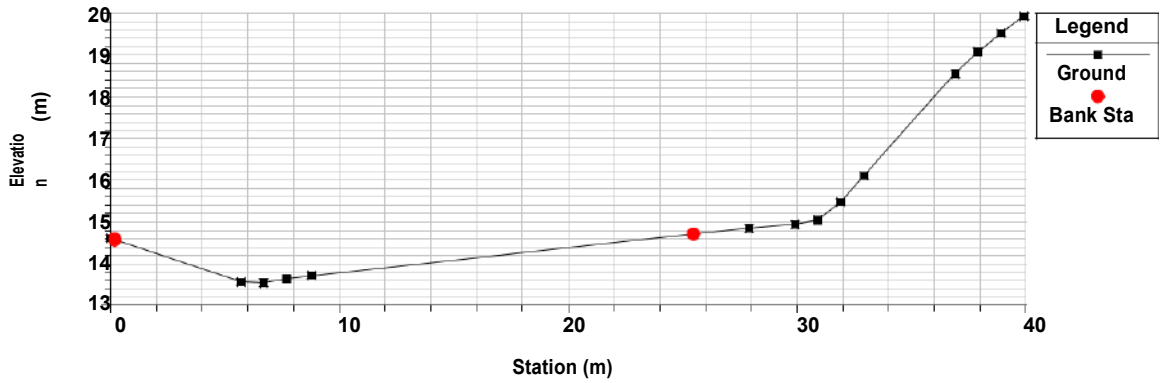
River = Rio Chamelecon Reach = limites1 RS = 2711



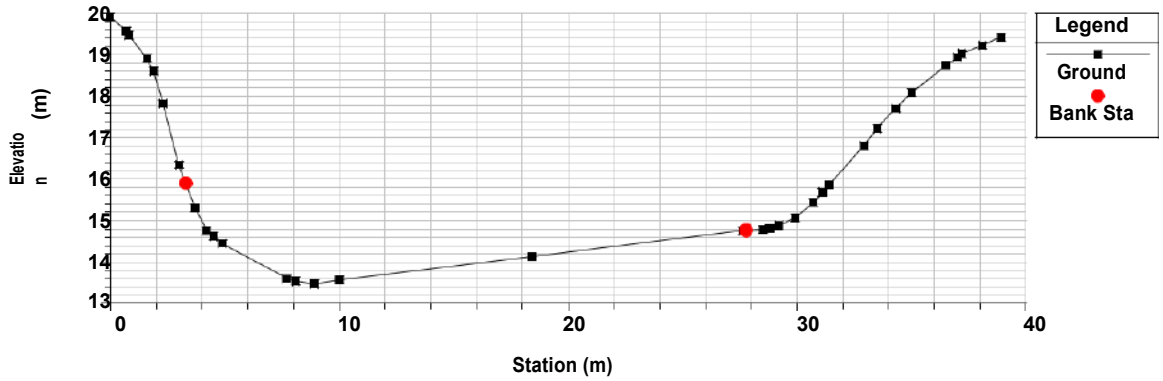
River = Rio Chamelecon Reach = limites1 RS = 2454



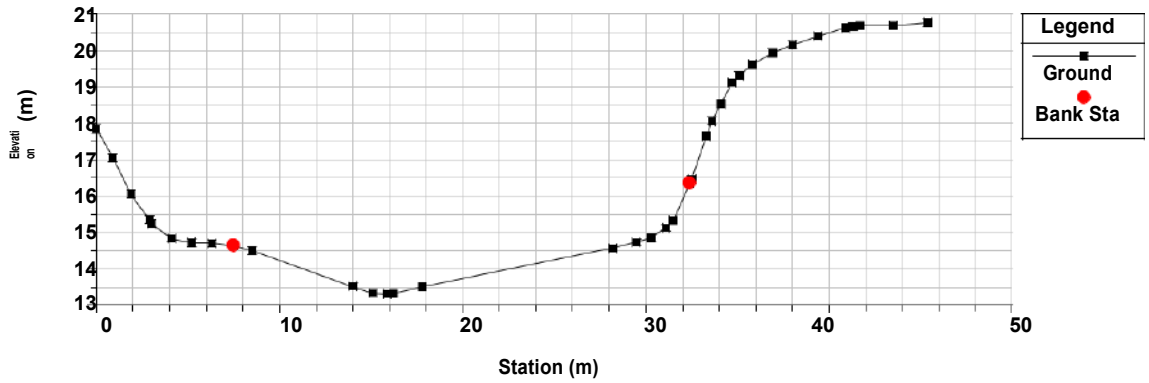
River = Rio Chamelecon Reach = limites1 RS = 1672



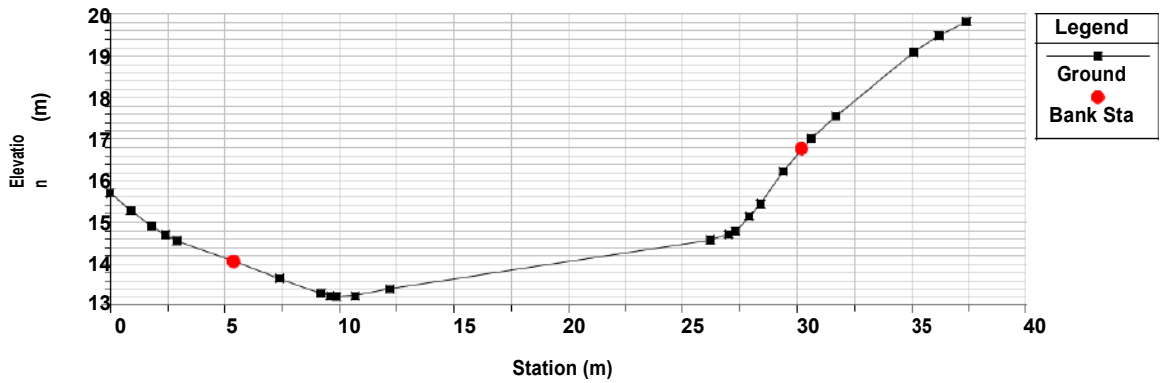
River = Rio Chamelecon Reach = limites1 RS = 1400



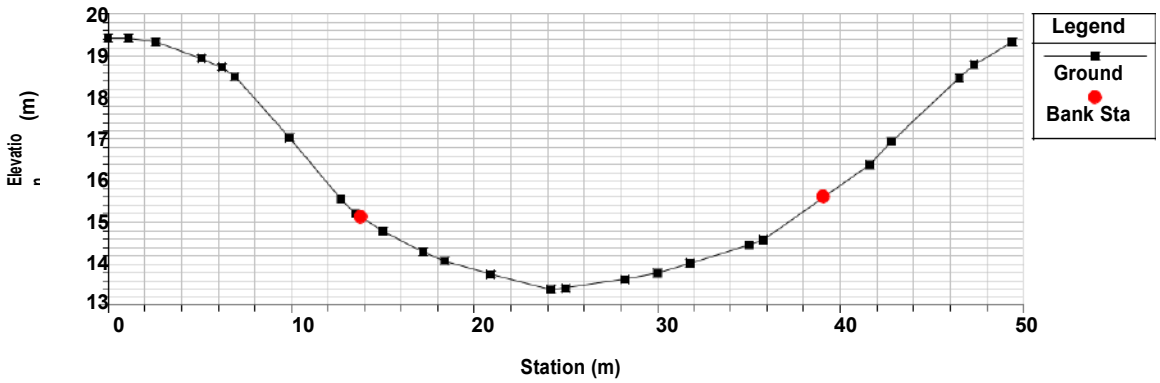
River = Rio Chamelecon Reach = limites1 RS = 1000



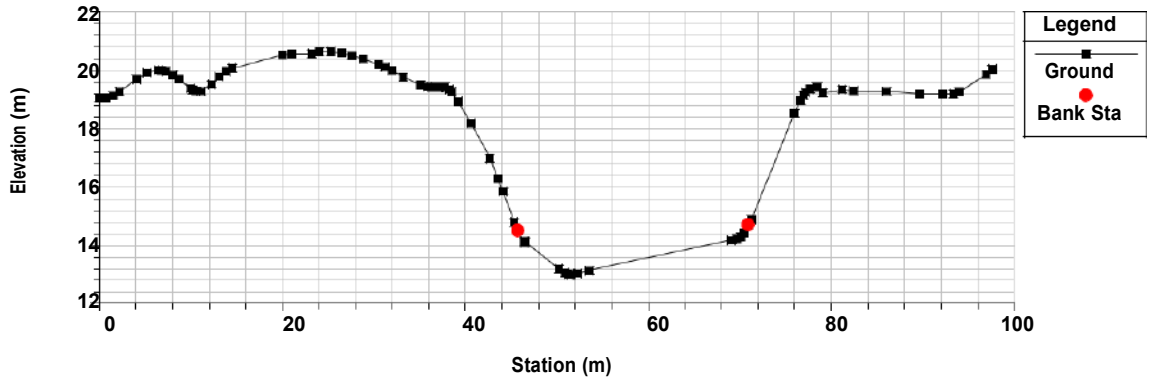
River = Rio Chamelecon Reach = limites1 RS = 682



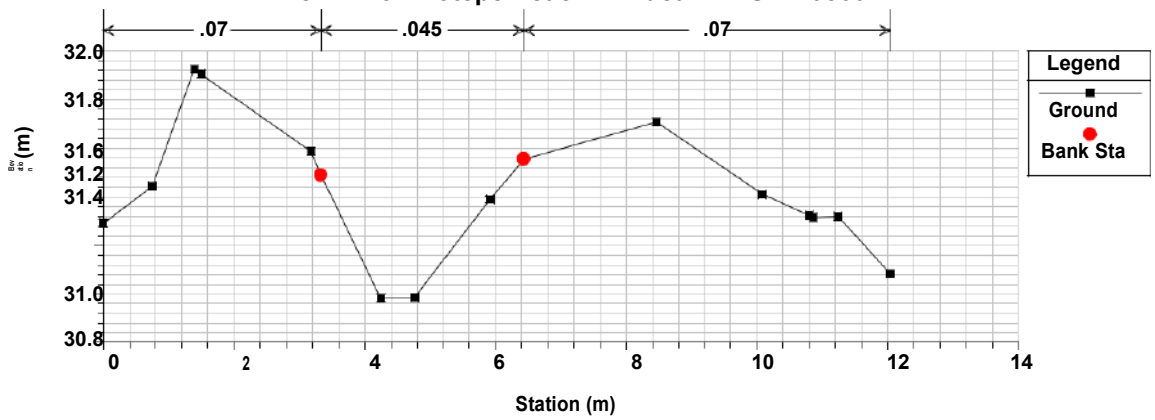
River = Rio Chamelecon Reach = limites1 RS = 465



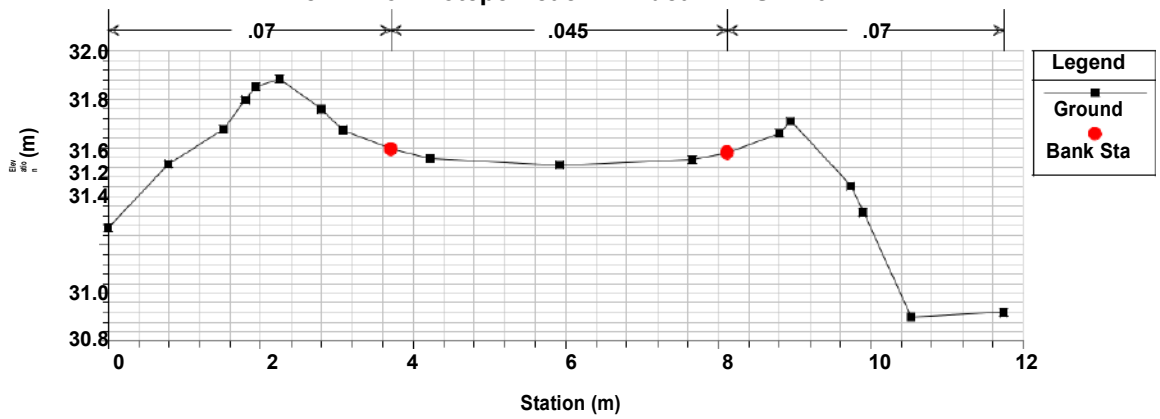
River = Rio Chamelecon Reach = limites1 RS=20

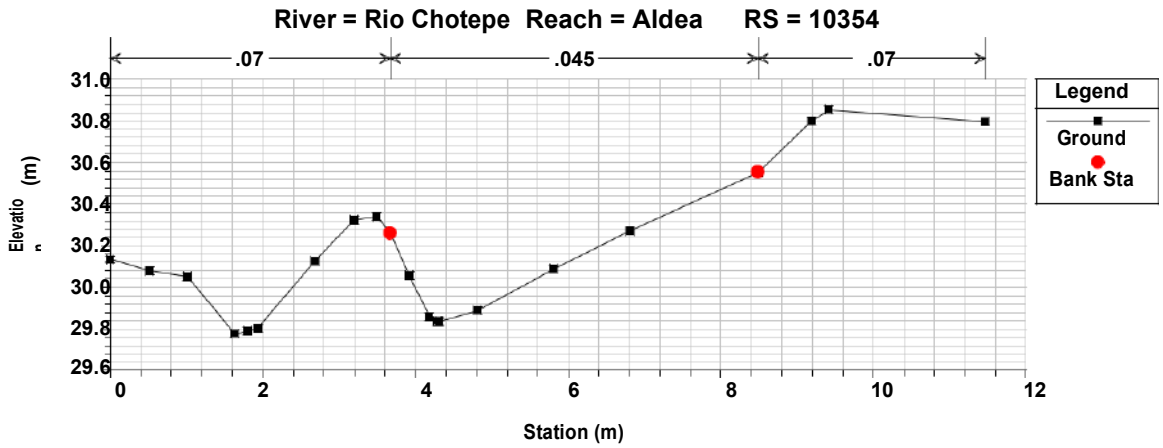


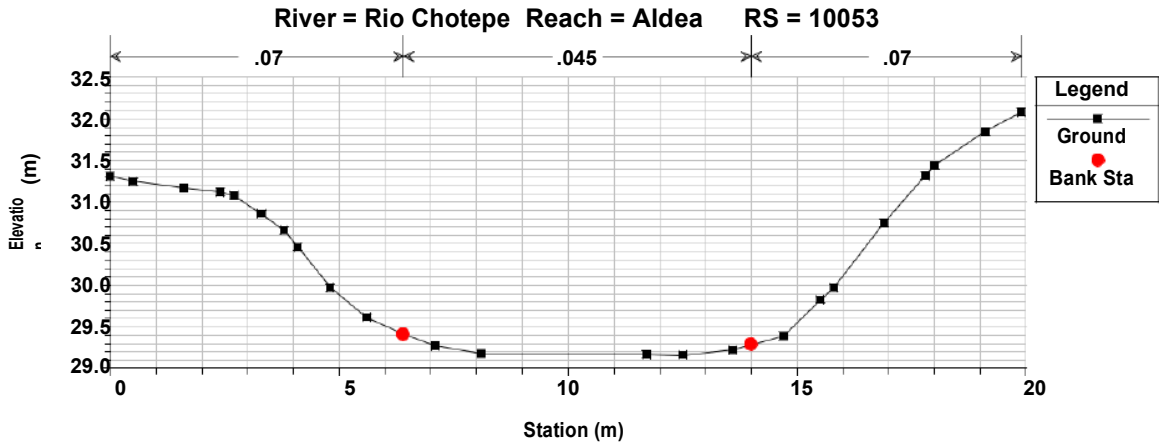
River = Rio Chotepe Reach = Aldea RS = 10560

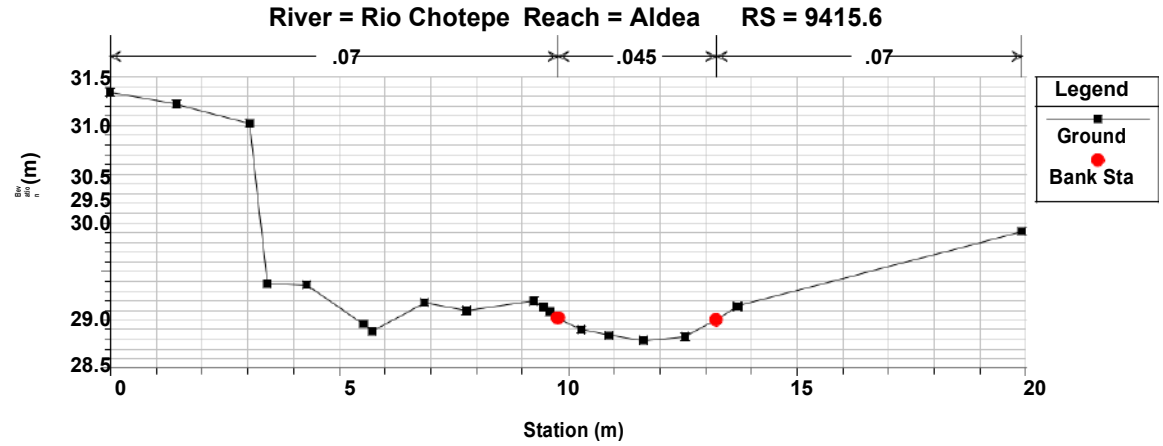


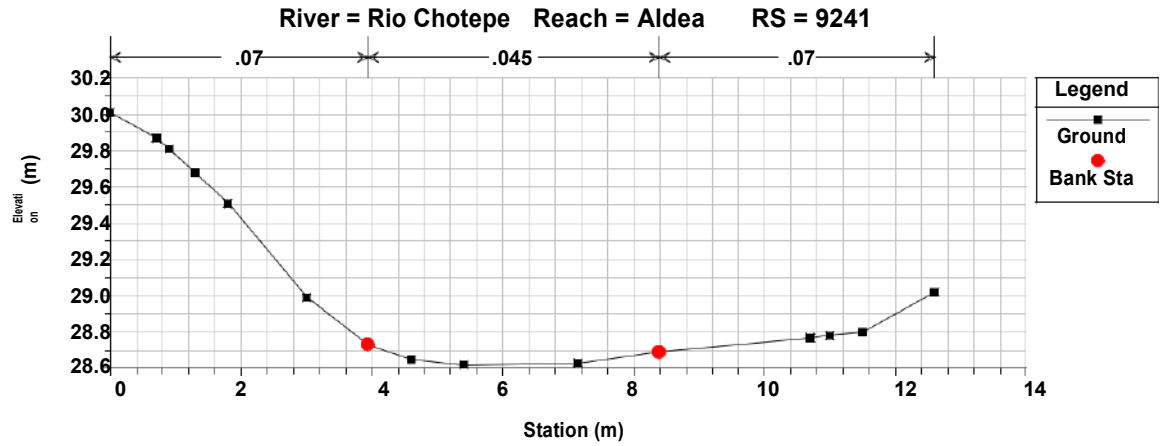
River = Rio Chotepe Reach = Aldea RS = 10424

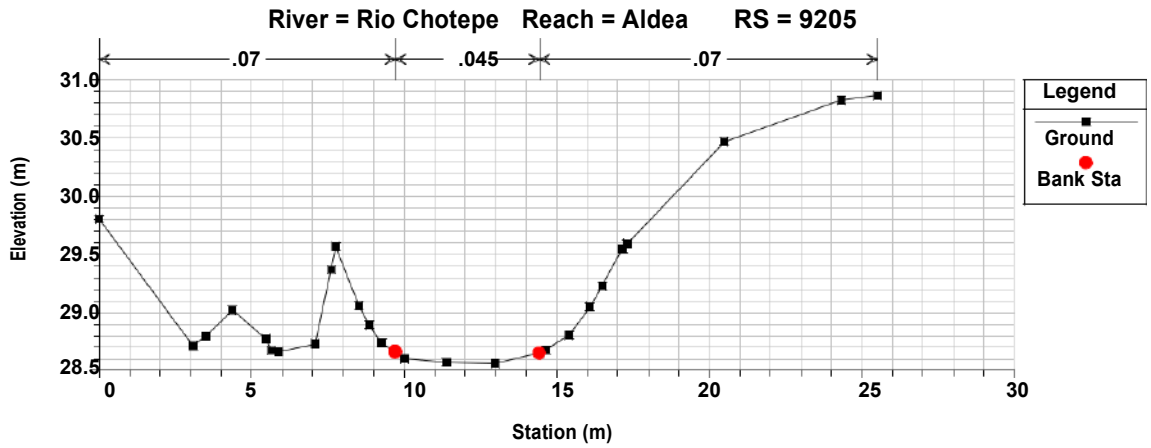


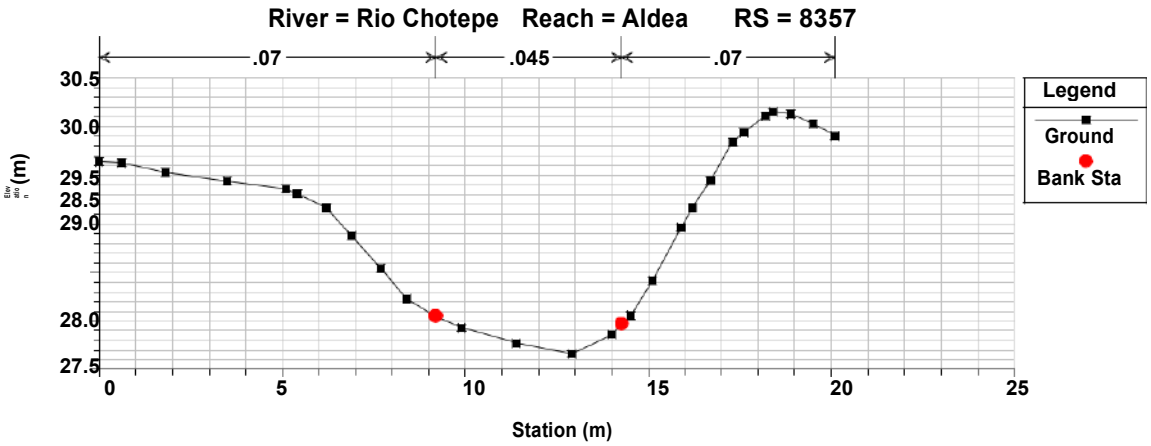

River = Rio Chotepe Reach = Aldea RS = 10354
.07
.045
.07
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

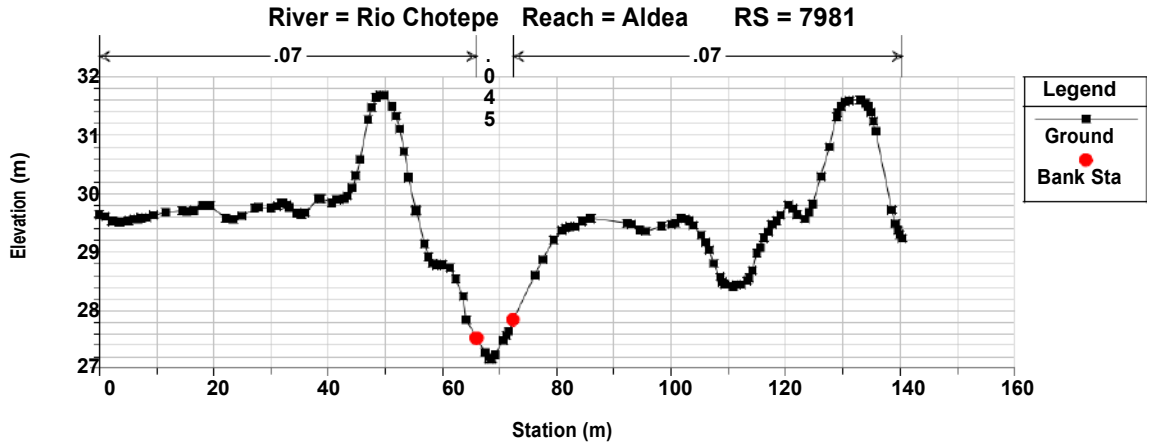

River = Rio Chotepe Reach = Aldea RS = 10053
.07
.045
.07
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

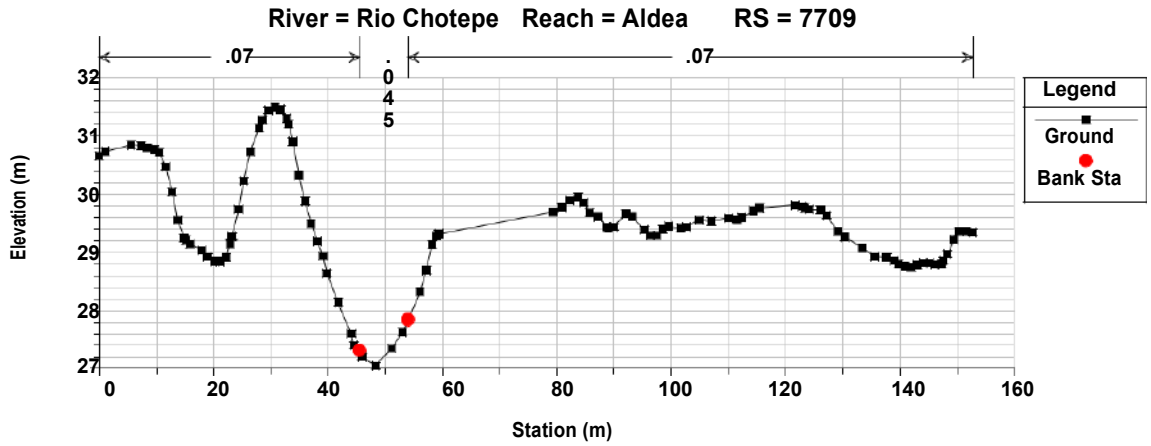

River = Rio Chotepe Reach = Aldea RS = 9415.6
.07
.045
.07
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

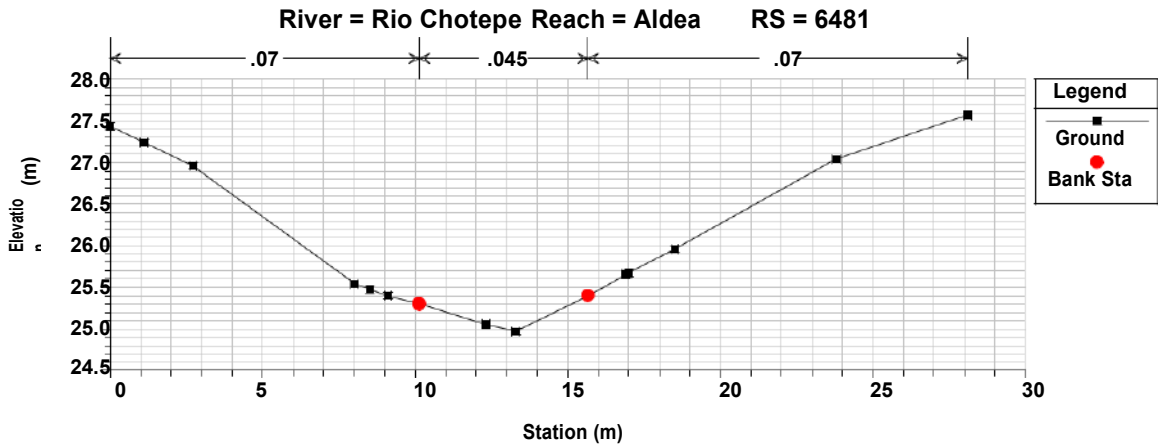

River = Rio Chotepe Reach = Aldea RS = 9241
.07
.045
.07
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

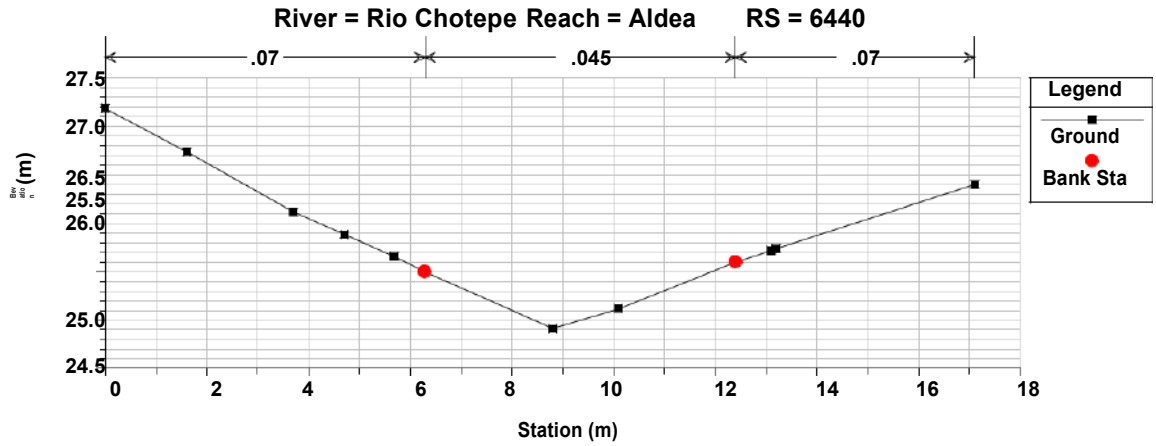

River = Rio Chotepe Reach = Aldea RS = 9205
.07
.045
.07
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

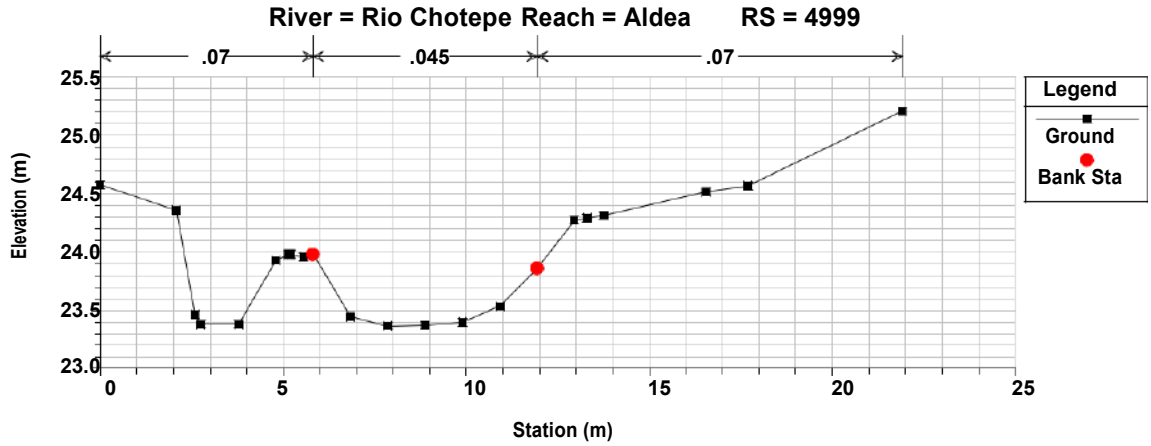

River = Rio Chotepe Reach = Aldea RS = 8357
.07
.045
.07
Station (m)
Legend
Ground
Bank Sta

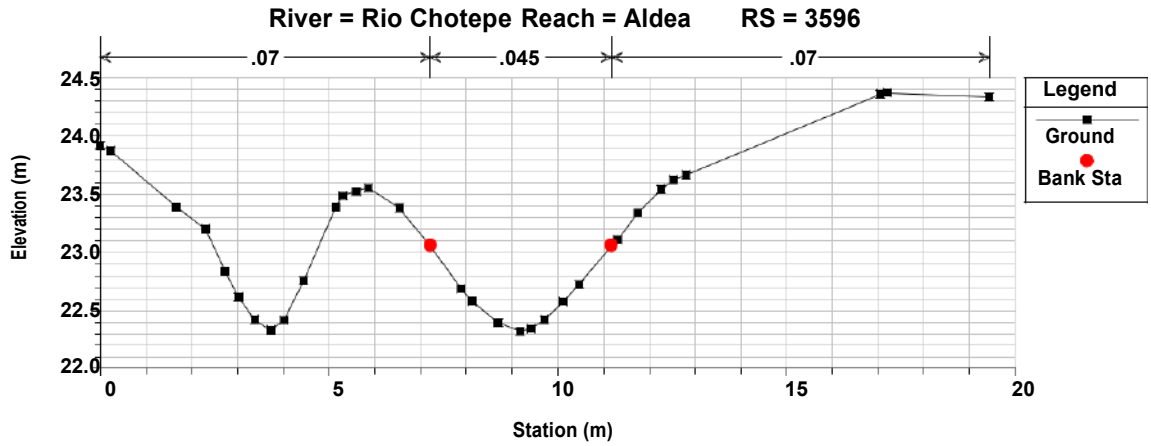

River = Rio Chotepe Reach = Aldea RS = 7981
.07
.045
.07
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

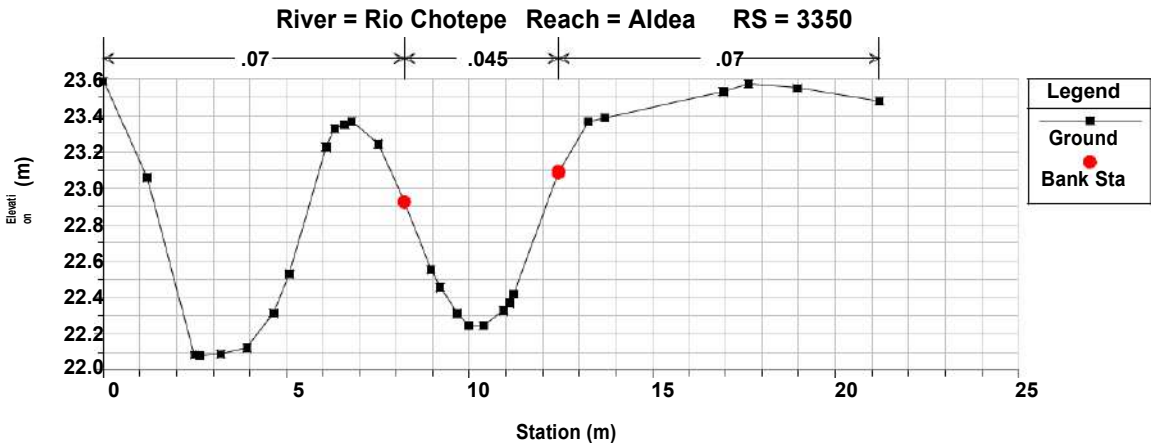

River = Rio Chotepe Reach = Aldea RS = 7709
.07
.045
.07
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

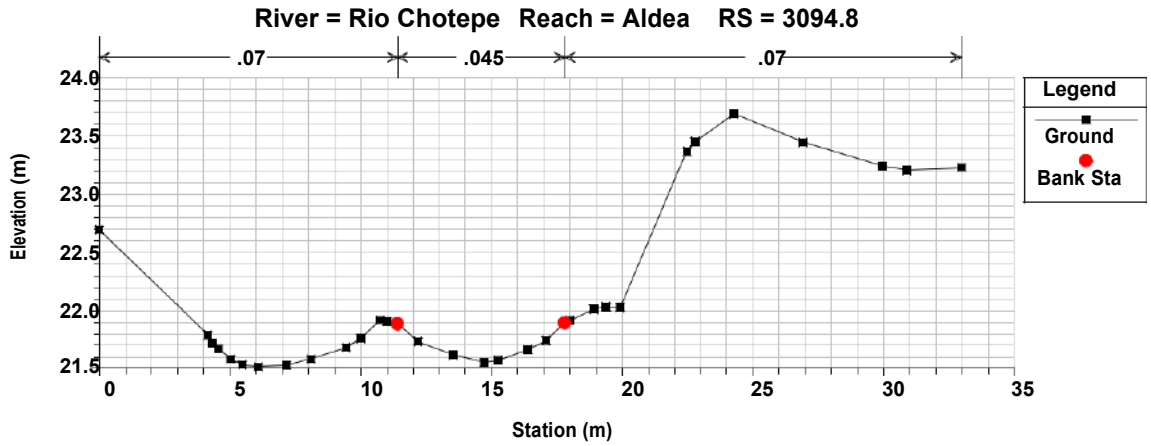

River = Rio Chotepe Reach = Aldea RS = 6481
.07
.045
.07
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

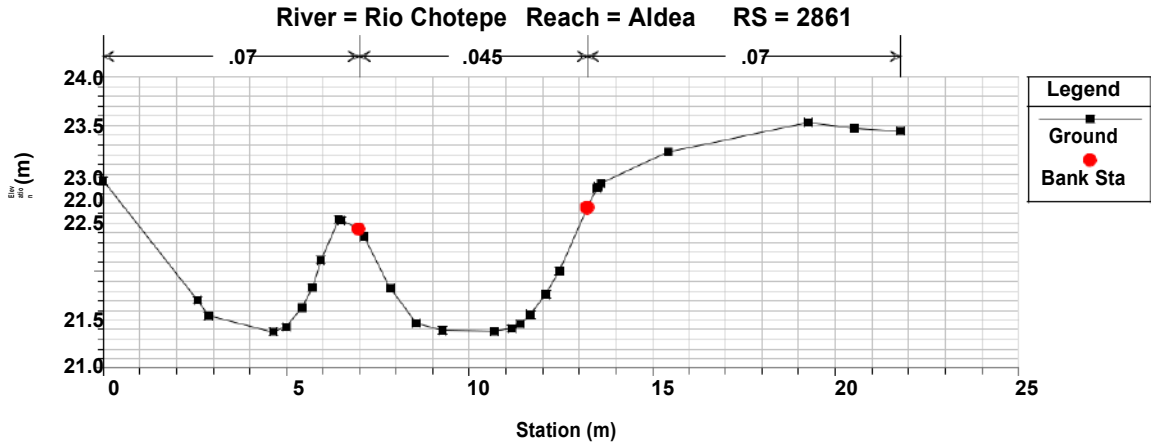

River = Rio Chotepe Reach = Aldea RS = 6440
.07
.045
.07
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

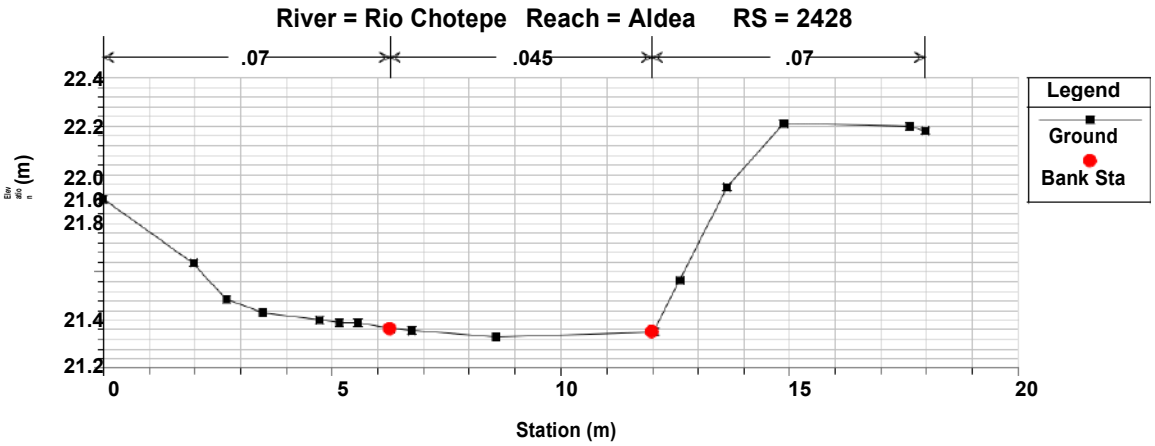

River = Rio Chotepe Reach = Aldea RS = 4999
.07
.045
.07
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

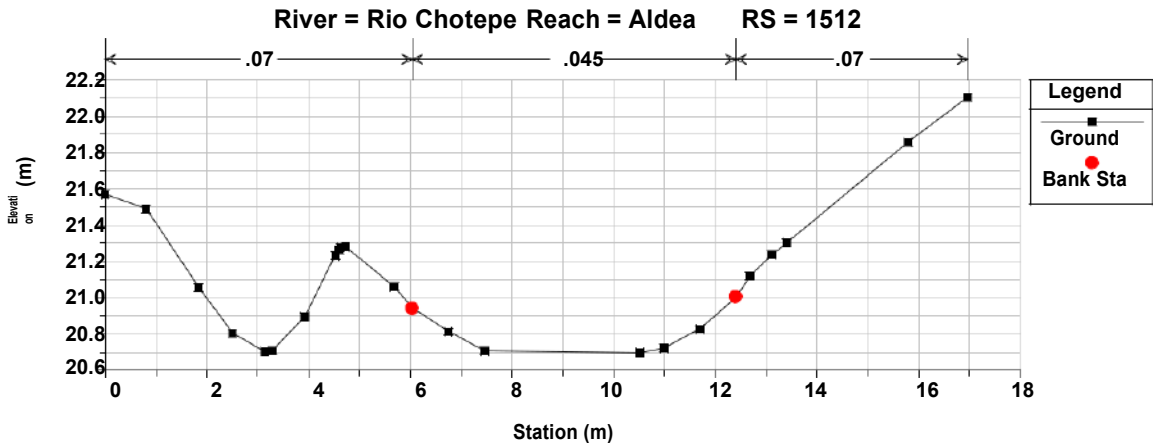

River = Rio Chotepe Reach = Aldea RS = 3596
.07
.045
.07
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

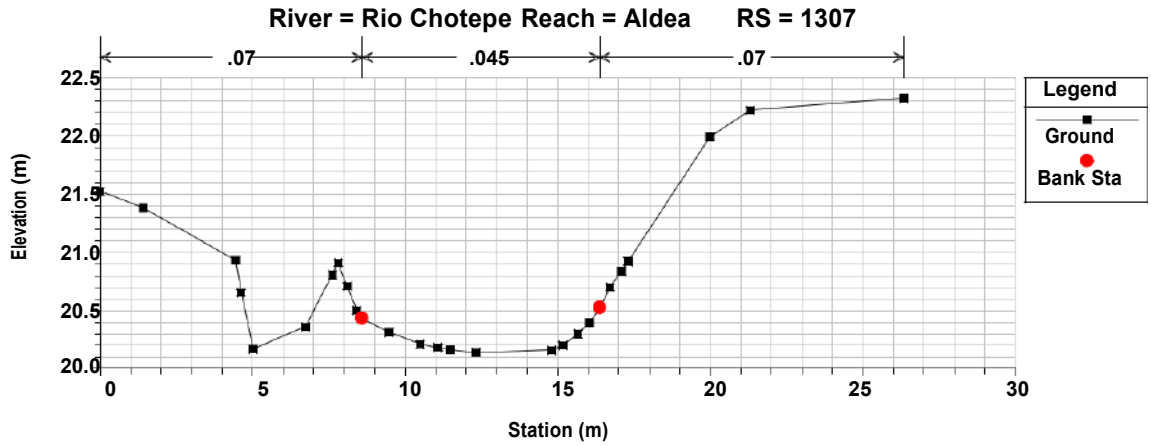

River = Rio Chotepe Reach = Aldea RS = 3350
.07
.045
.07
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

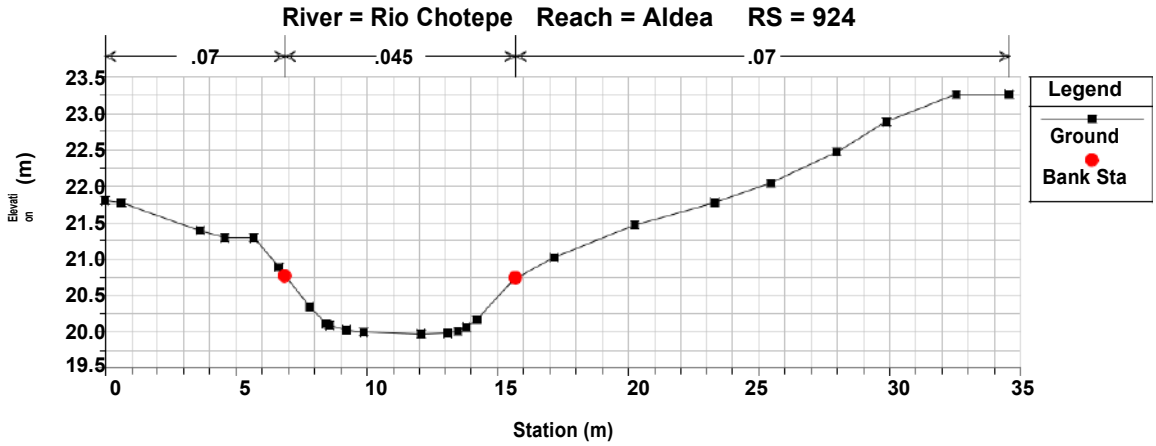

River = Rio Chotepe Reach = Aldea RS = 3094.8
.07
.045
.07
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

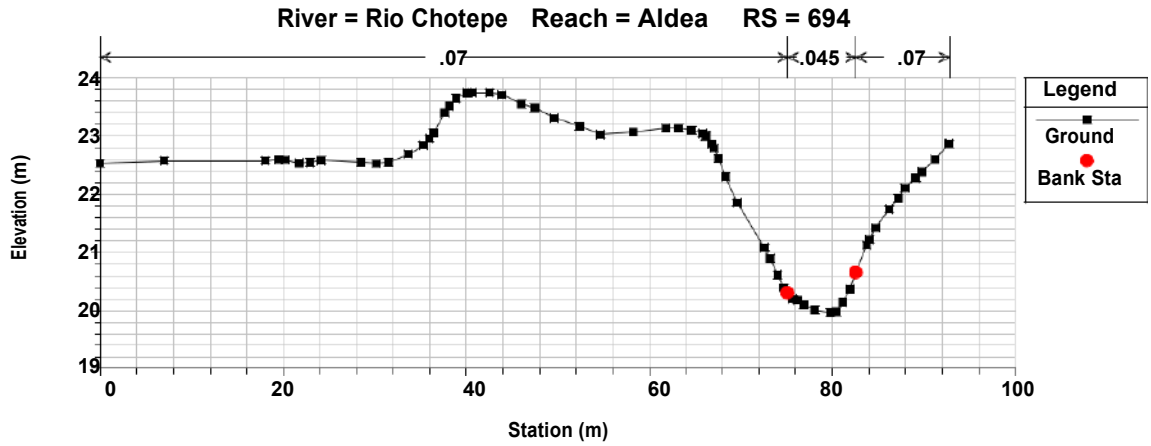

River = Rio Chotepe Reach = Aldea RS = 2861
.07
.045
.07
Legend
Ground
Bank Sta
Station (m)

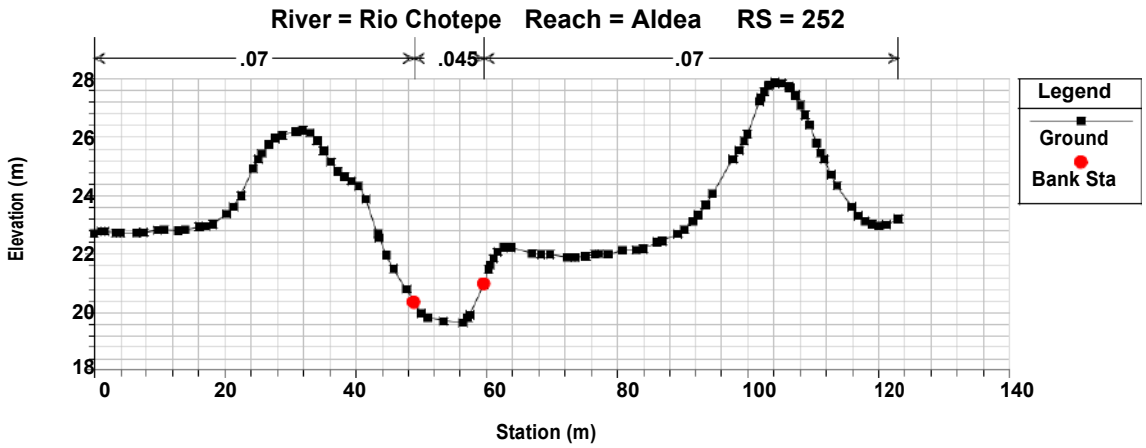

River = Rio Chotepe Reach = Aldea RS = 2428
.07
.045
.07
Legend
Ground
Bank Sta
Station (m)

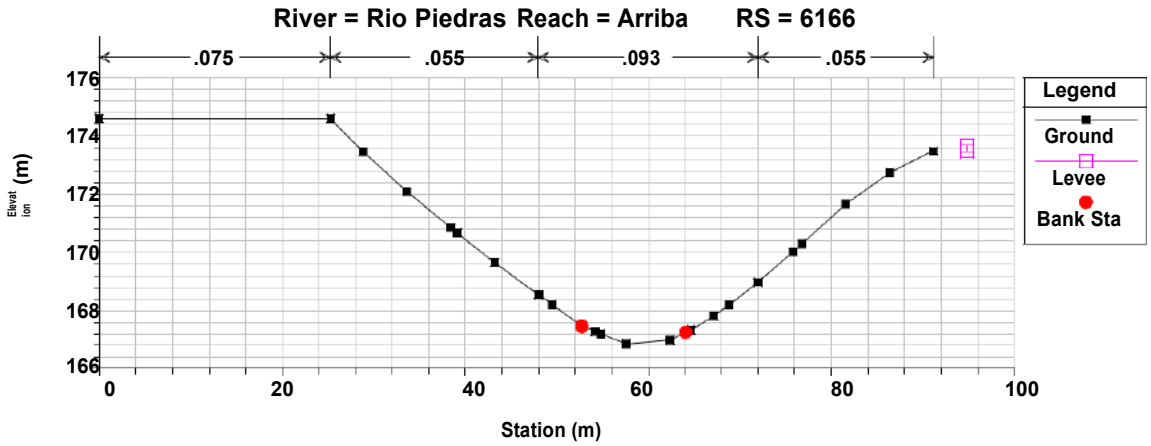

River = Rio Chotepe Reach = Aldea RS = 1512
.07
.045
.07
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

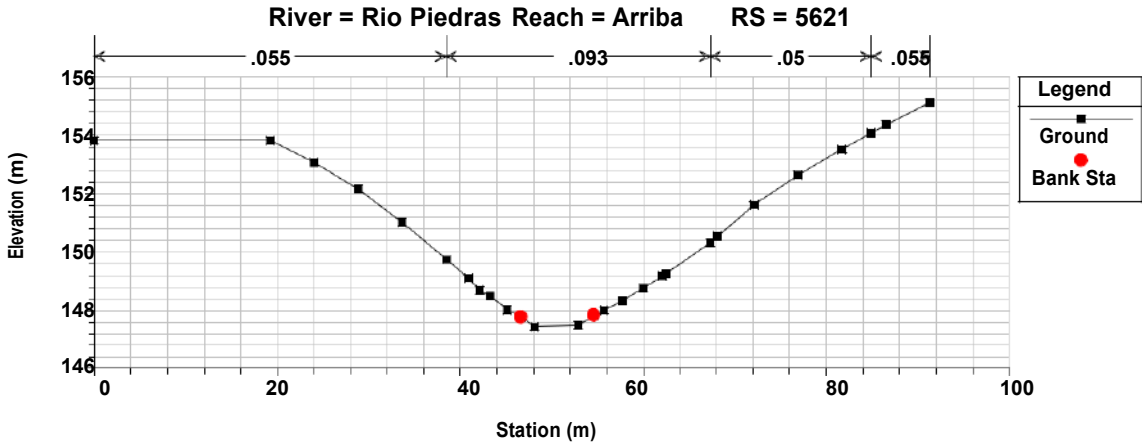

River = Rio Chotepe Reach = Aldea RS = 1307
.07
.045
.07
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

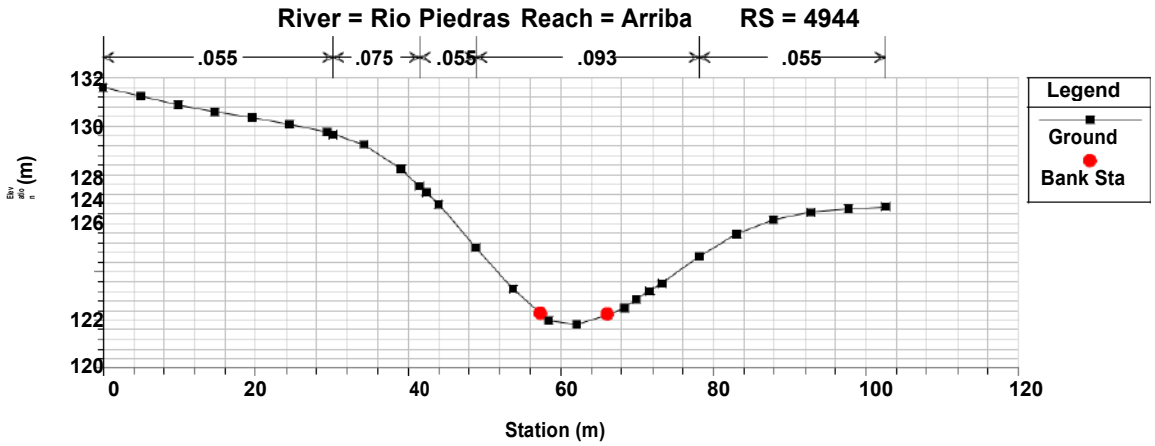

River = Rio Chotepe Reach = Aldea RS = 924
.07
.045
.07
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

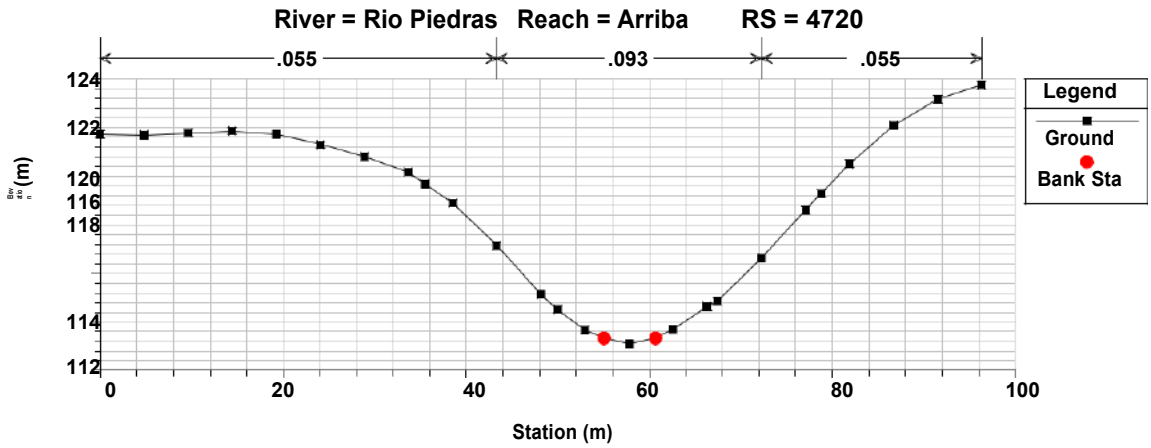

River = Rio Chotepe Reach = Aldea RS = 694
.07
.045
.07
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

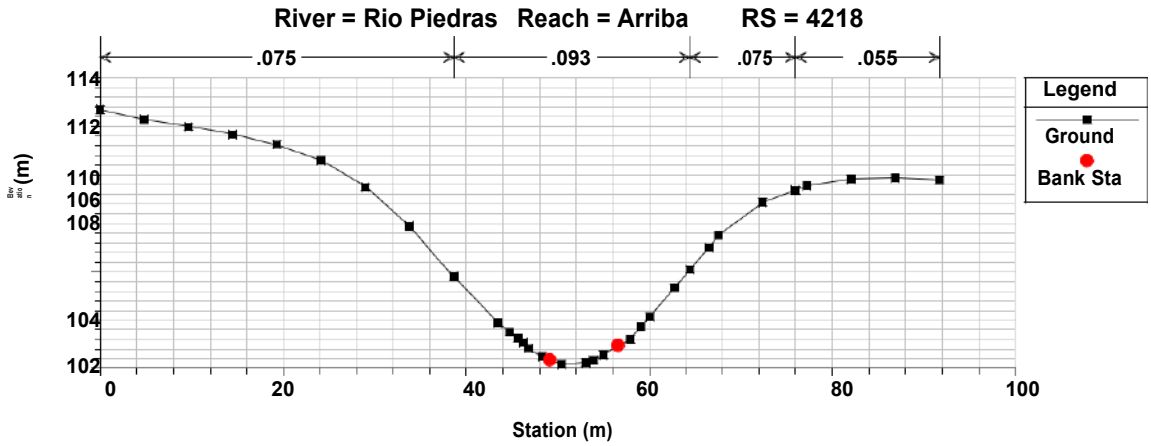

River = Rio Chotepe Reach = Aldea RS = 252
.07
.045
.07
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

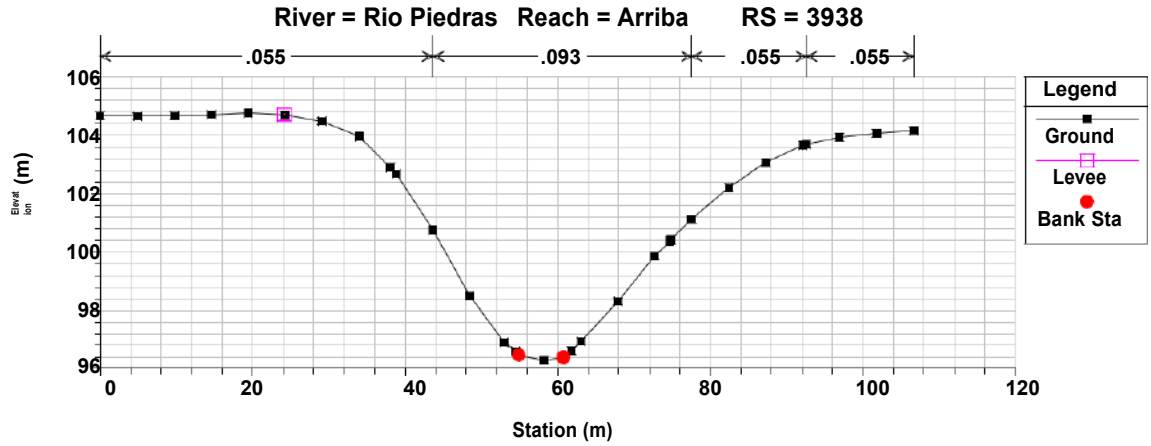

River = Rio Piedras Reach = Arriba RS = 6166
.075
.055
.093
.055
Elevation (m)
Station (m)
Legend
Ground
Levee
Bank Sta

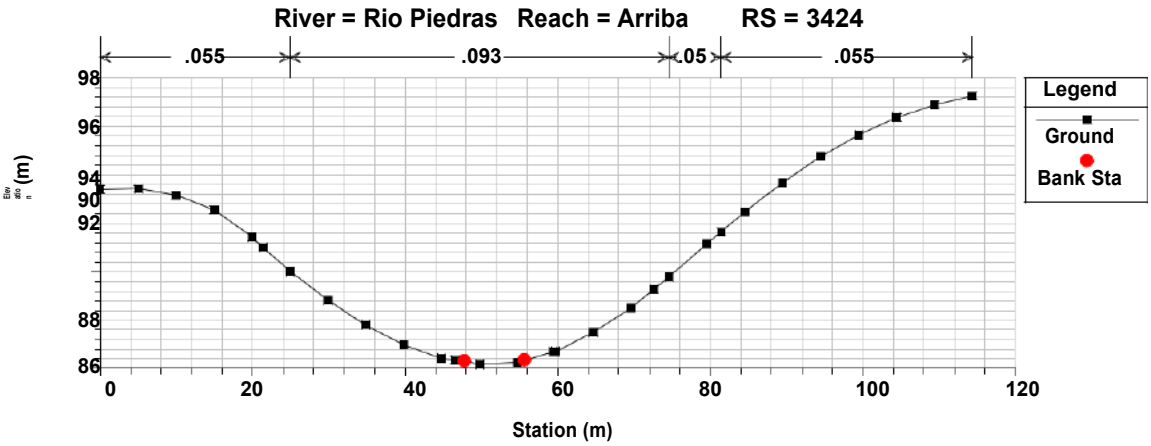

River = Rio Piedras Reach = Arriba RS = 5621
.055
.093
.05
.055
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

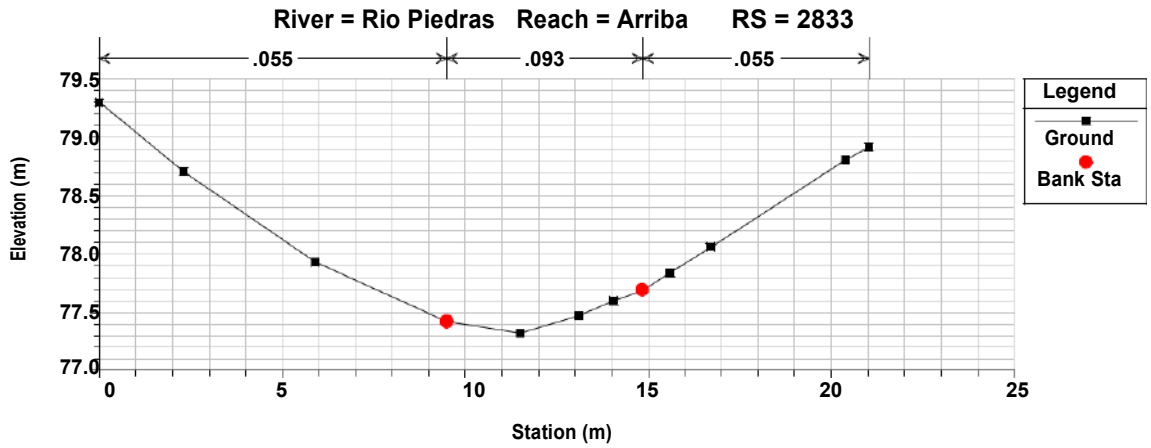

River = Rio Piedras Reach = Arriba RS = 4944
.055
.075
.055
.093
.055
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

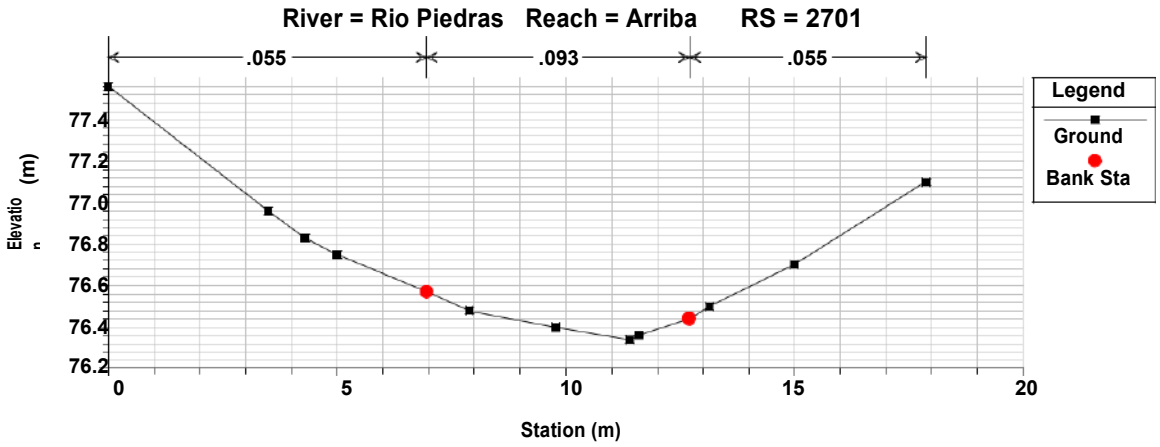

River = Rio Piedras Reach = Arriba RS = 4720
.055
.093
.055
Legend
Ground
Bank Sta
Station (m)

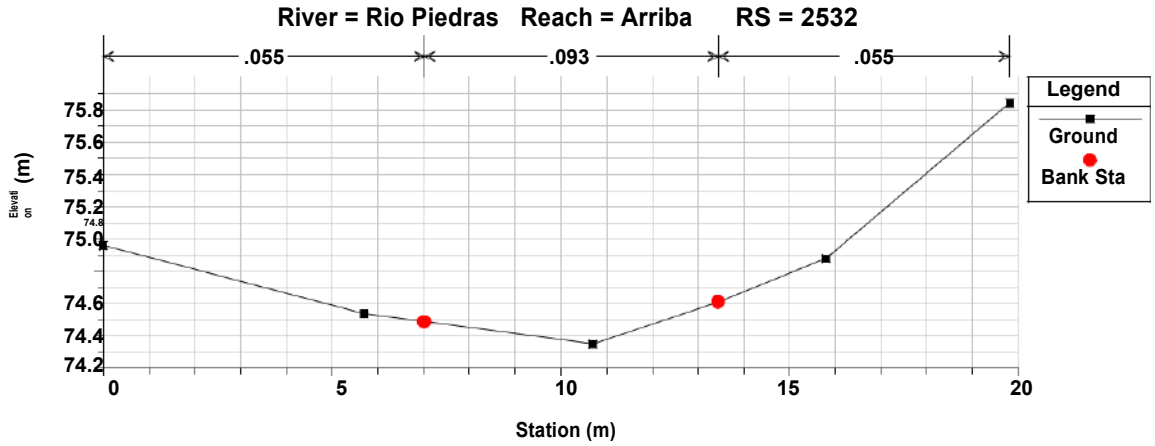

River = Rio Piedras Reach = Arriba RS = 4218
.075
.093
.075
.055
Legend
Ground
Bank Sta
Station (m)

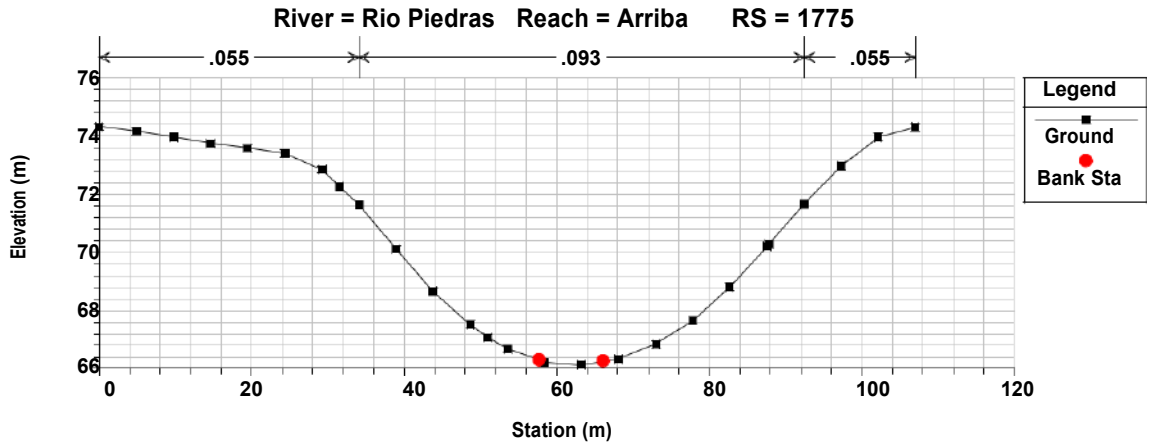

River = Rio Piedras Reach = Arriba RS = 3938
.055
.093
.055
.055
Legend
Ground
Levee
Bank Sta
Station (m)

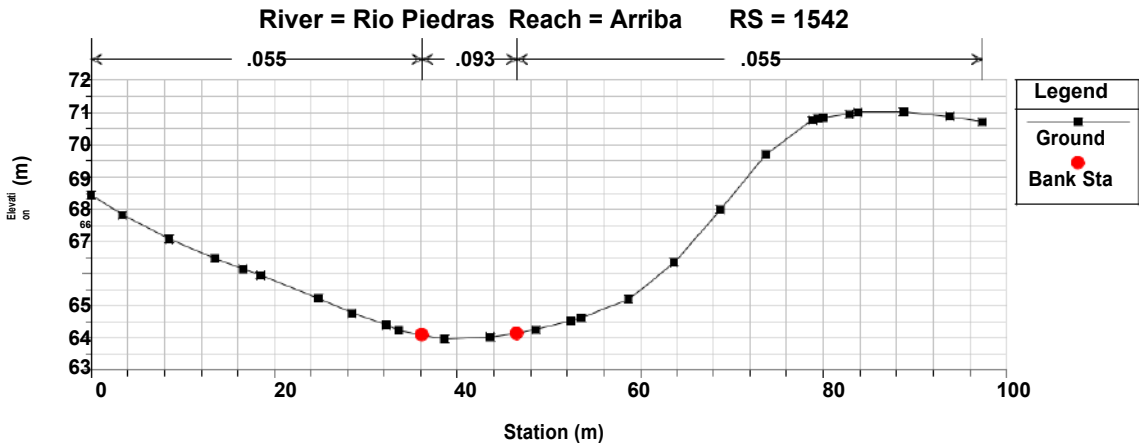

River = Rio Piedras Reach = Arriba RS = 3424
.055
.093
.05
.055
Legend
Ground
Bank Sta
Station (m)

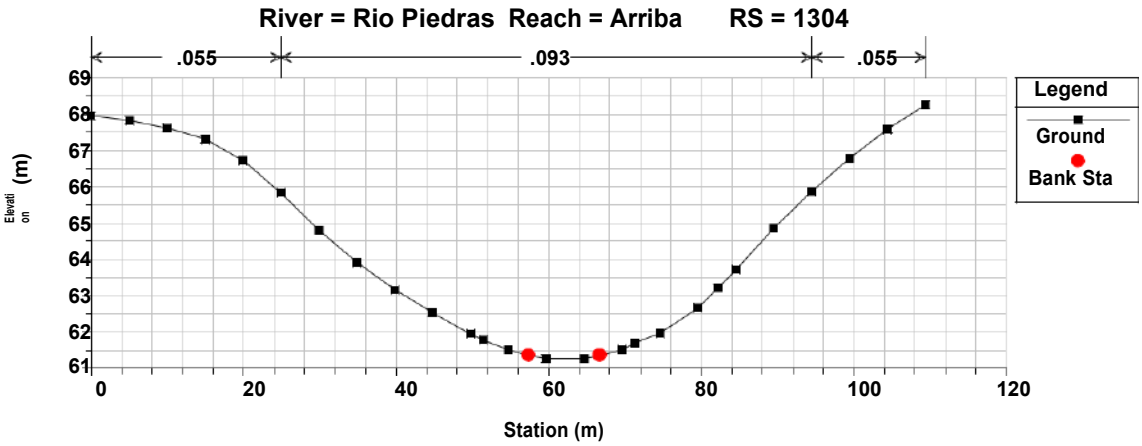

River = Rio Piedras Reach = Arriba RS = 2833
.055
.093
.055
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

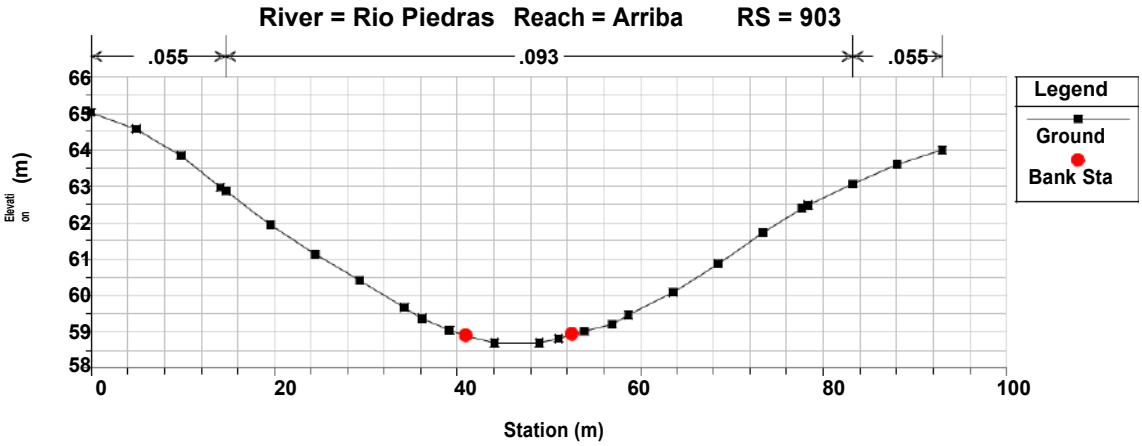

River = Rio Piedras Reach = Arriba RS = 2701
.055
.093
.055
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

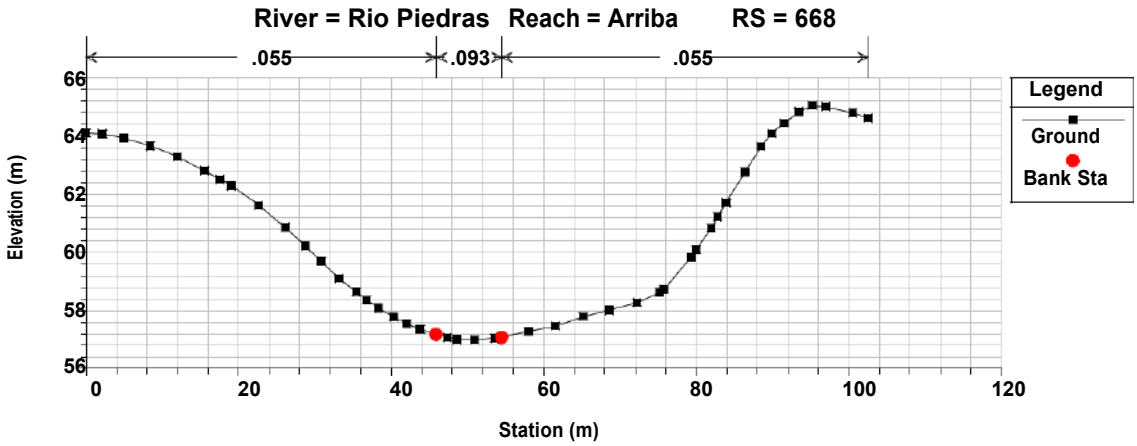

River = Rio Piedras Reach = Arriba RS = 2532
.055
.093
.055
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

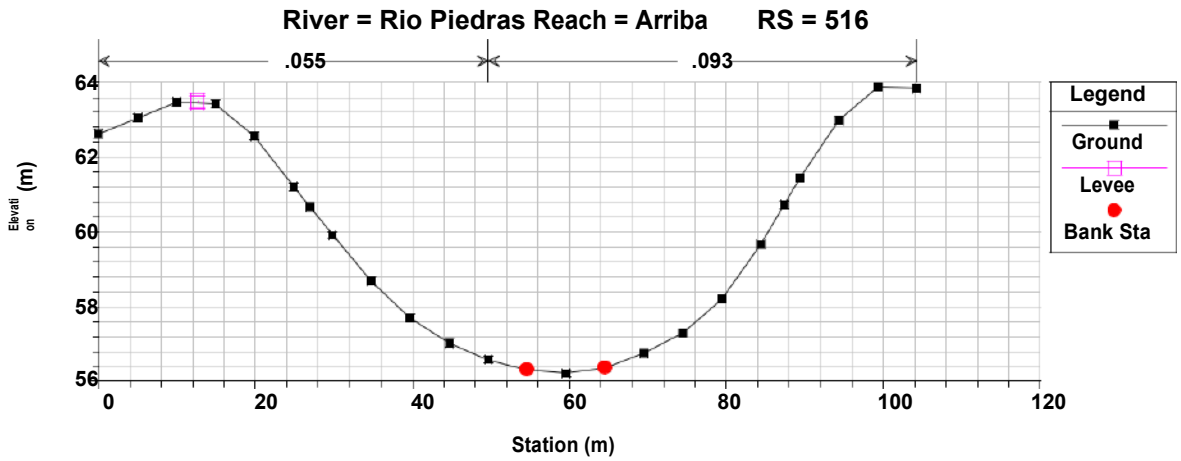

River = Rio Piedras Reach = Arriba RS = 1775
.055
.093
.055
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

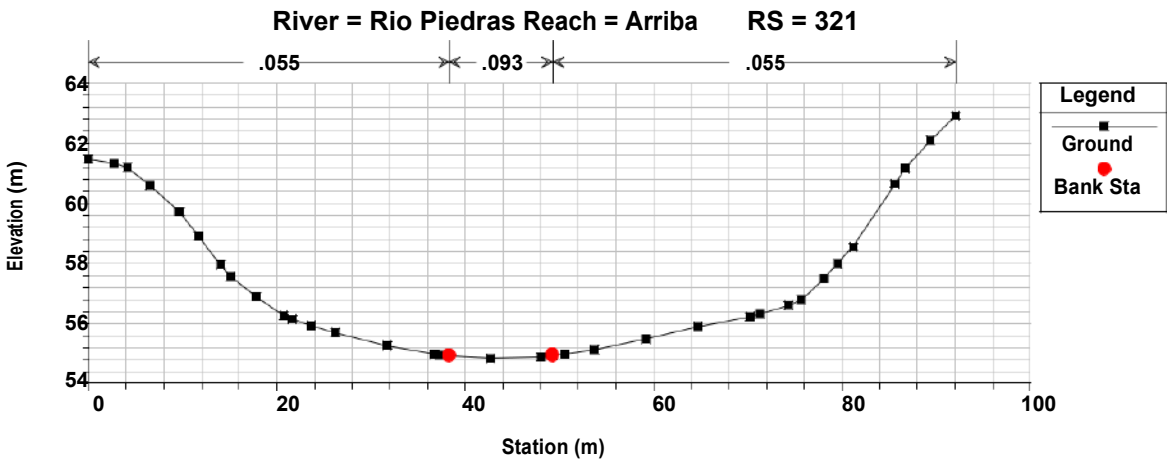

River = Rio Piedras Reach = Arriba RS = 1542
.055
.093
.055
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

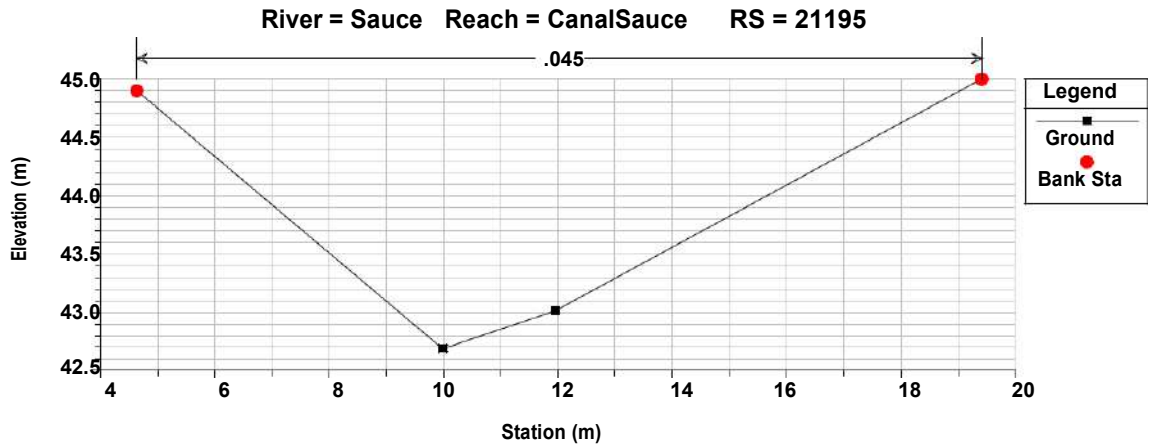

River = Rio Piedras Reach = Arriba RS = 1304
.055
.093
.055
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

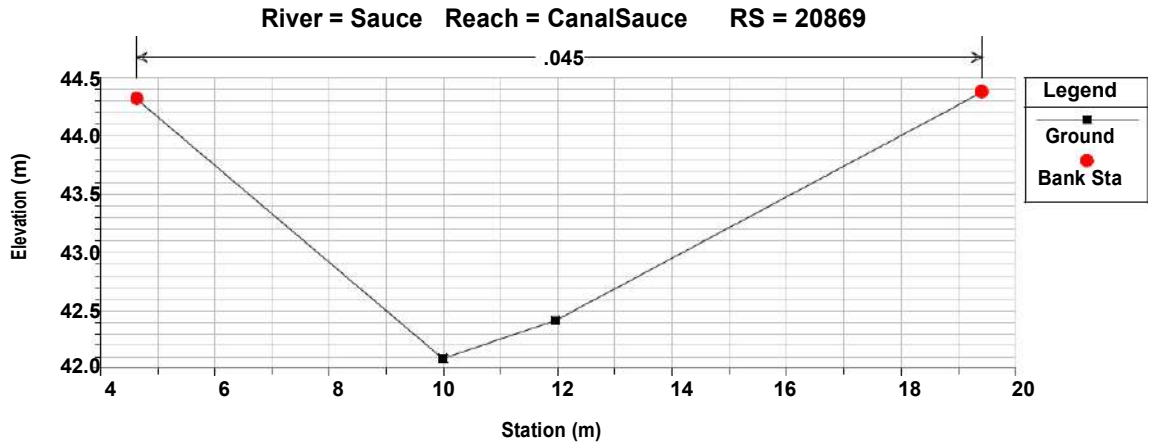

River = Rio Piedras Reach = Arriba RS = 903
.055
.093
.055
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

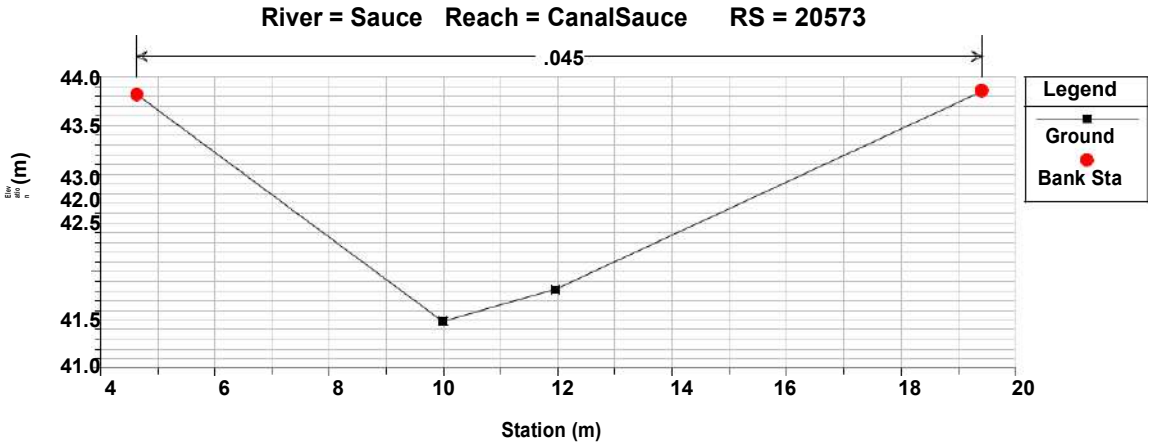

River = Rio Piedras Reach = Arriba RS = 668
.055
.093
.055
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

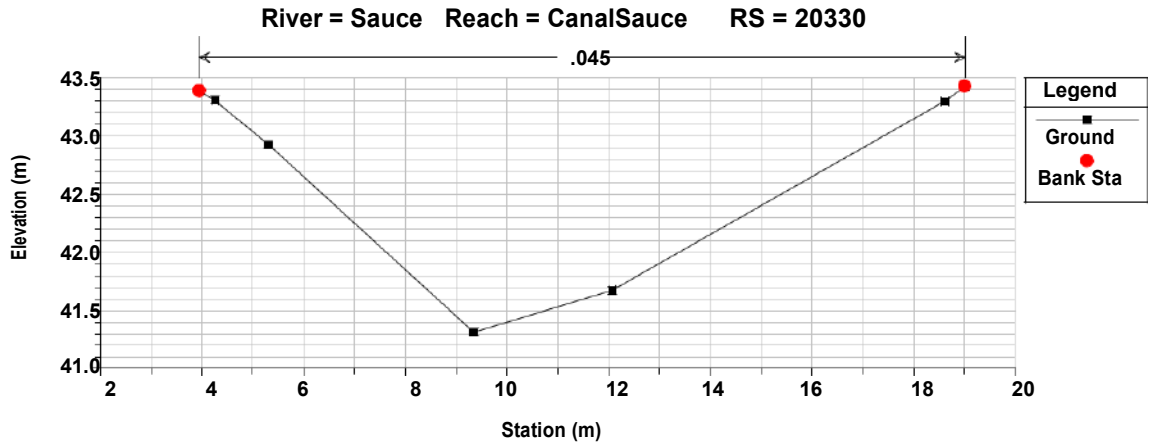

River = Rio Piedras Reach = Arriba RS = 516
.055
.093
Elevation (m)
Station (m)
Legend
Ground
Levee
Bank Sta

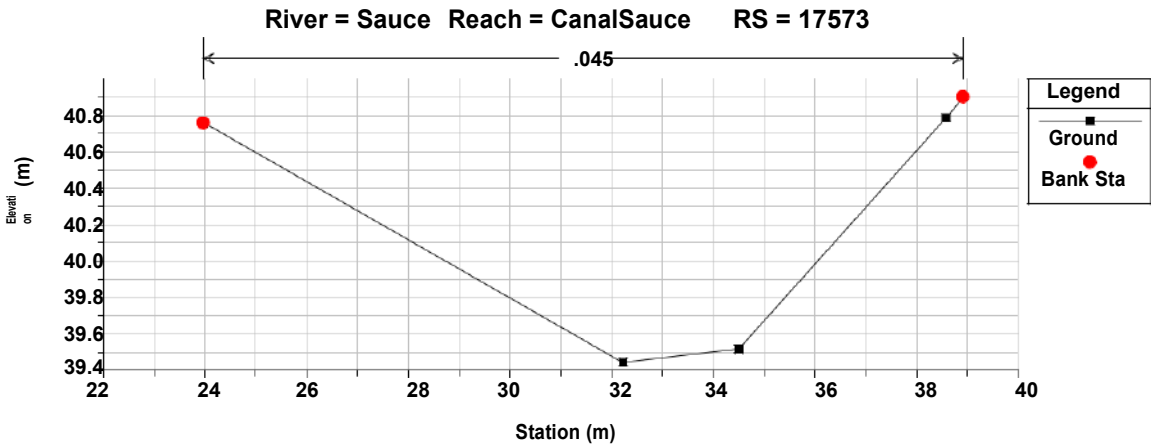

River = Rio Piedras Reach = Arriba RS = 321
.055
.093
.055
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

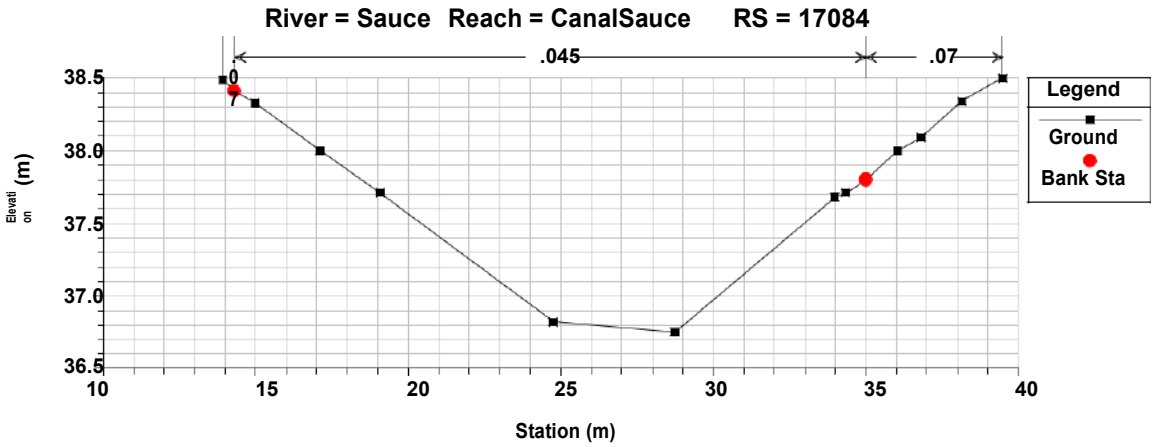

River = Sauce Reach = CanalSauce RS = 21195
.045
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

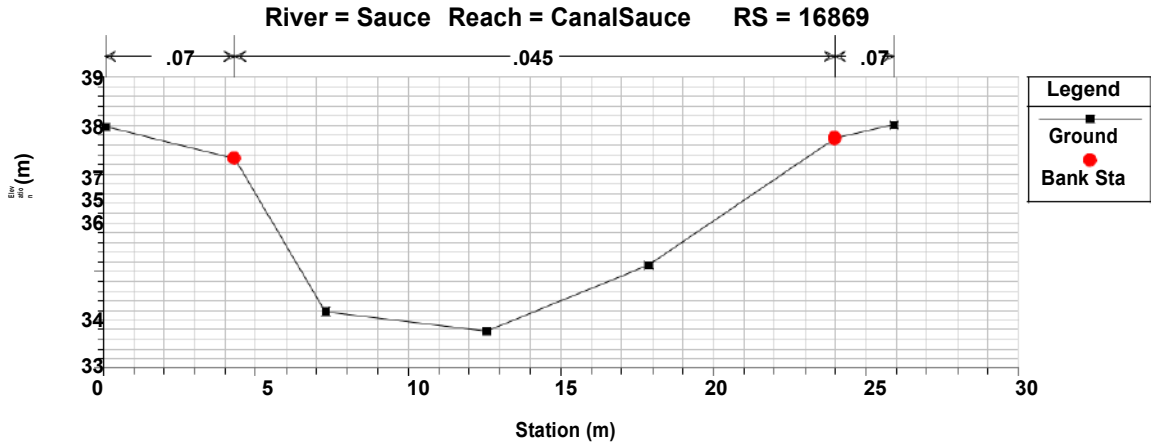

River = Sauce Reach = CanalSauce RS = 20869
.045
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

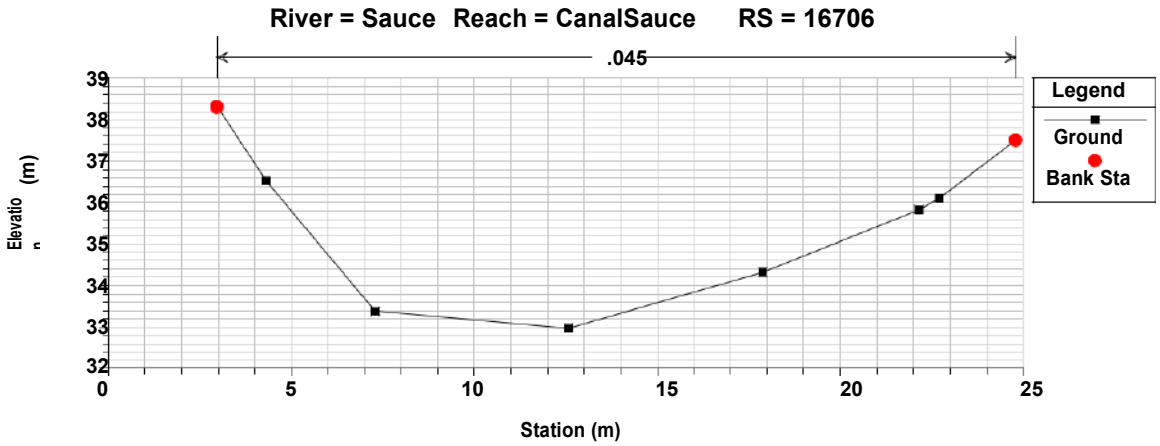

River = Sauce Reach = CanalSauce RS = 20573
.045
Station (m)
Legend
Ground
Bank Sta

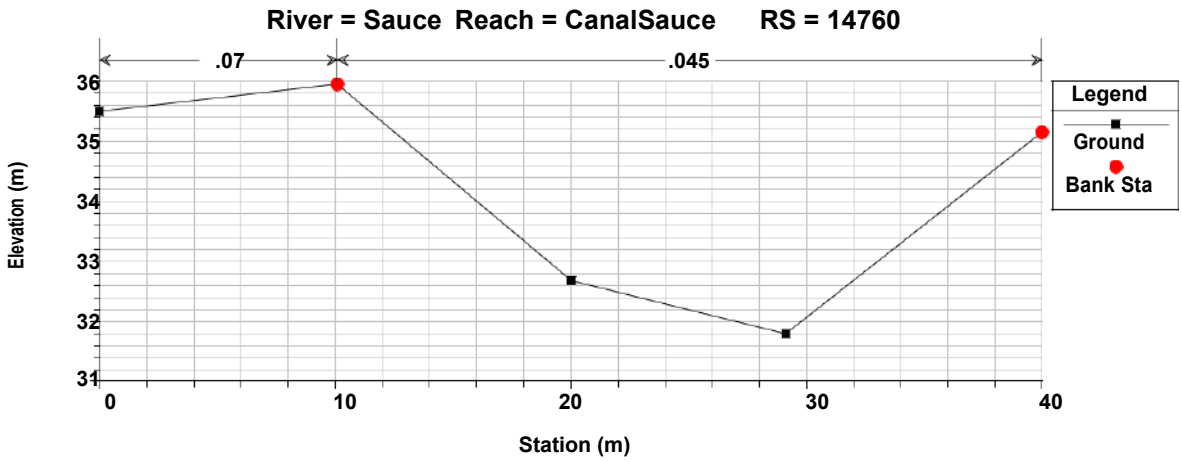

River = Sauce Reach = CanalSauce RS = 20330
.045
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

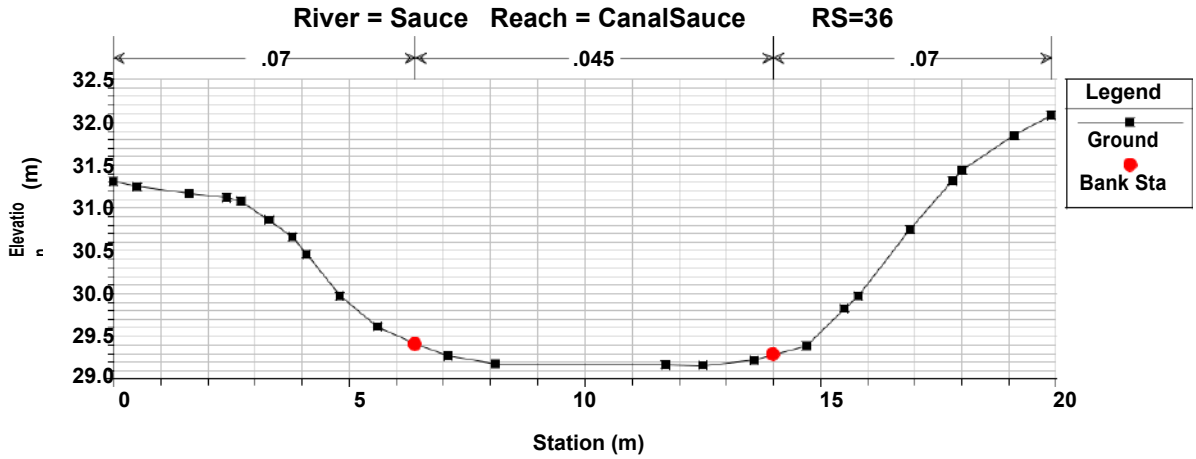

River = Sauce Reach = CanalSauce RS = 17573
.045
Legend
Ground
Bank Sta
Elevation (m)
Station (m)


River = Sauce Reach = CanalSauce RS = 17084
.045
.07
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

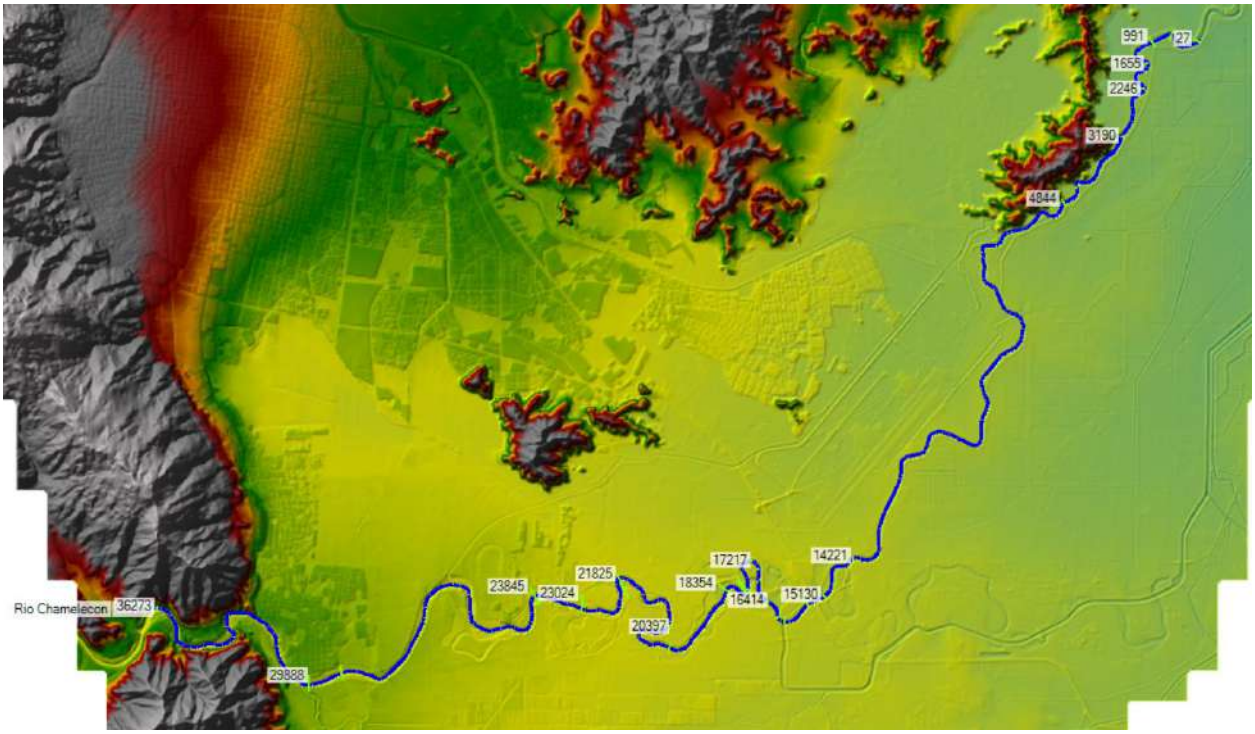

River = Sauce Reach = CanalSauce RS = 16869
.07
.045
.07
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

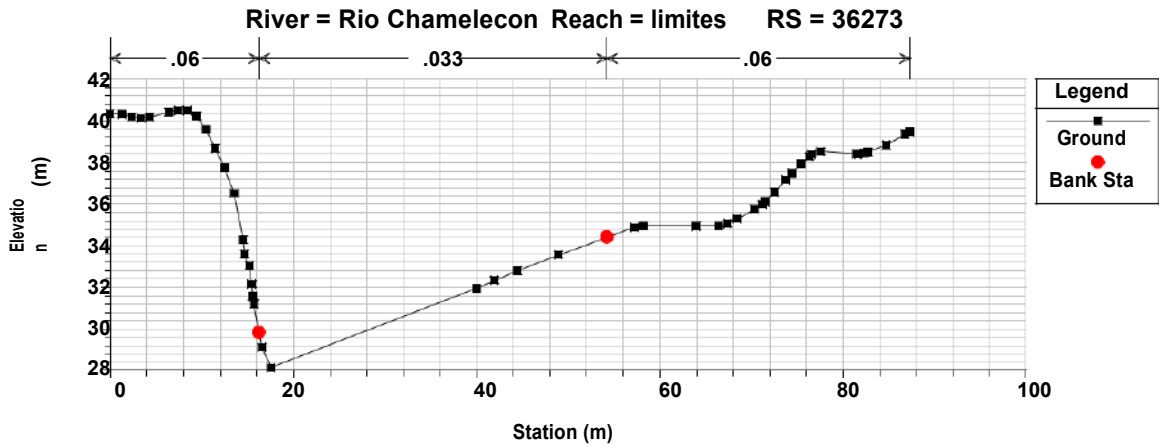

River = Sauce Reach = CanalSauce RS = 16706
.045
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

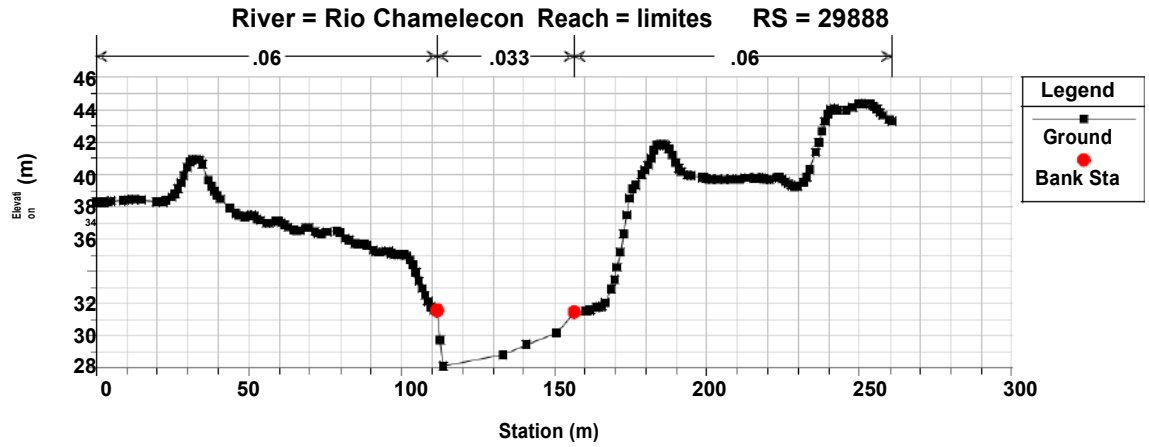

River = Sauce Reach = CanalSauce RS = 14760
.07
.045
Legend
Ground
Bank Sta
Elevation (m)
36
35
34
33
32
31
0
10
20
30
40
Station (m)

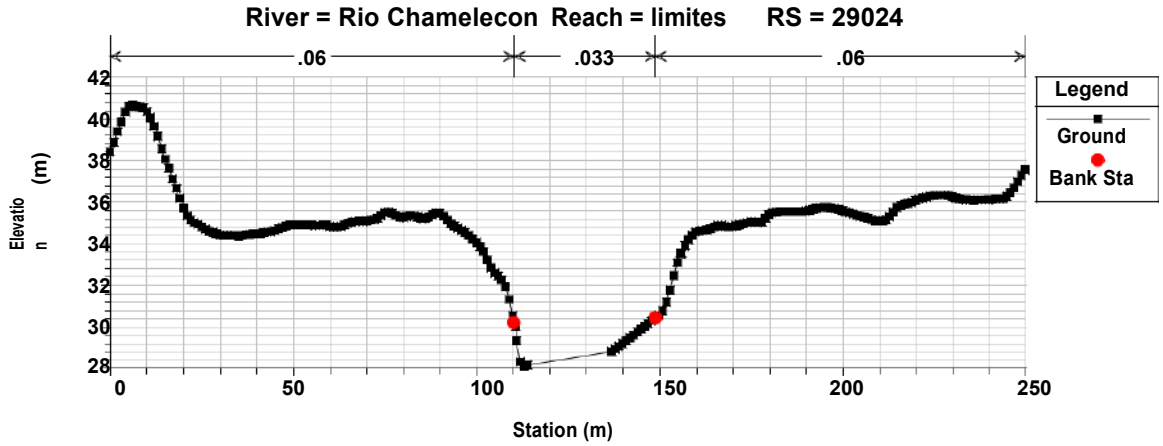

River = Sauce Reach = CanalSauce RS=36
.07
.045
.07
Legend
Ground
Bank Sta
32.5
32.0
31.5
31.0
30.5
30.0
29.5
29.0
0
5
10
15
20
Station (m)

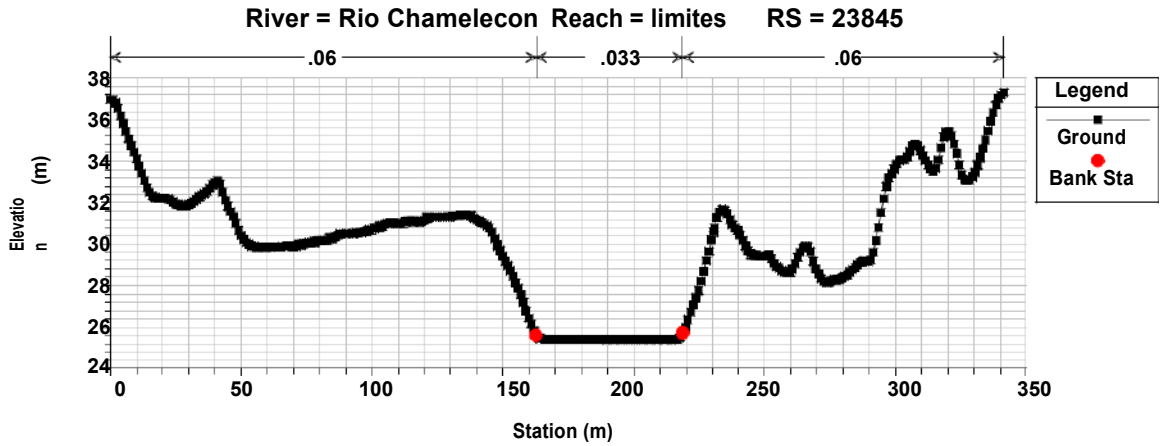
A3 Crosssections Model Río Chamelecón

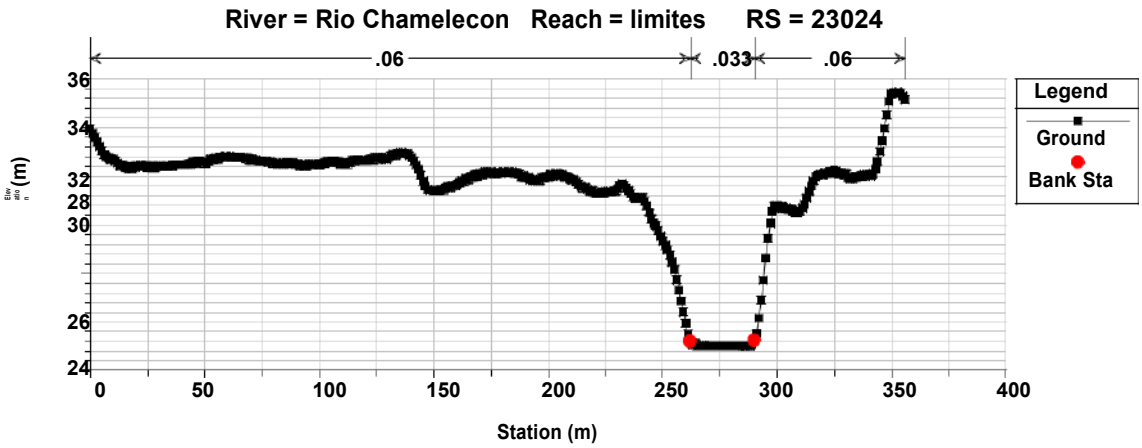


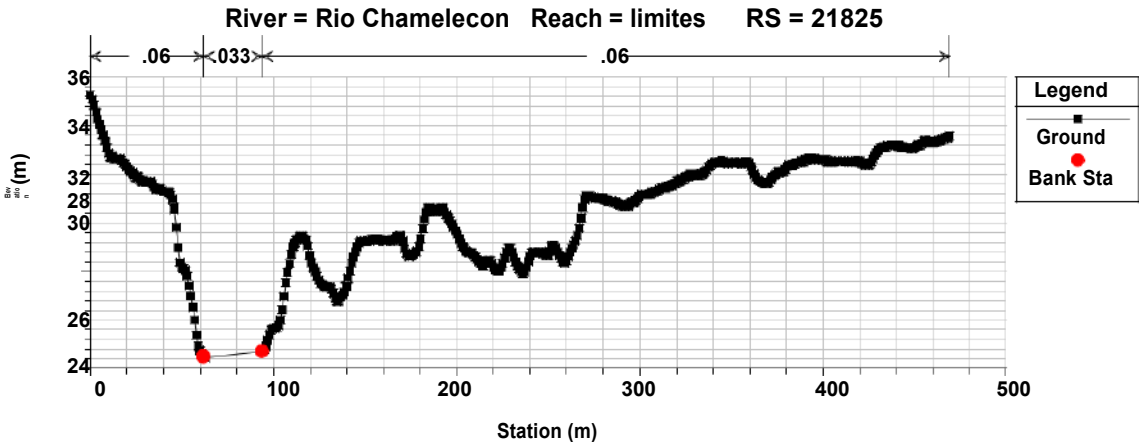

River = Rio Chamelecon Reach = limites RS = 36273
.06
.033
.06
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

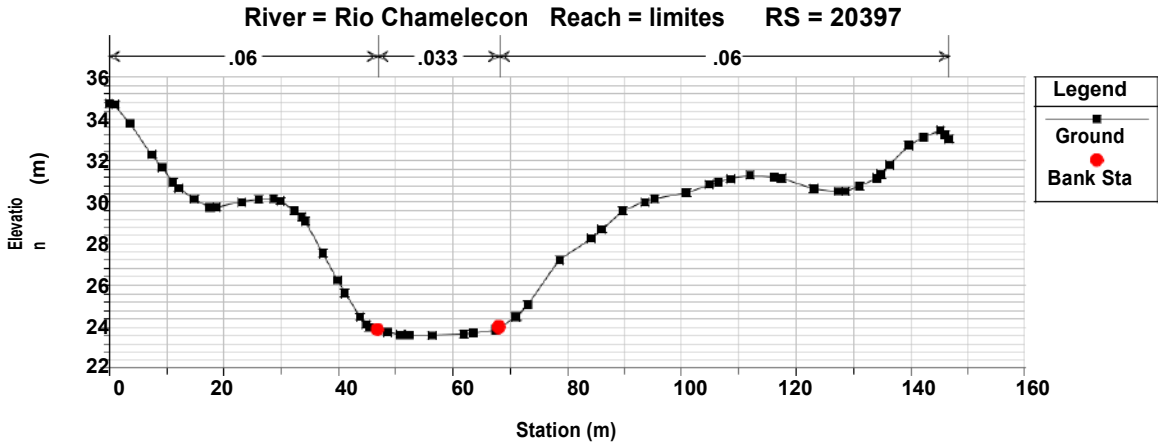

River = Rio Chamelecon Reach = limites RS = 29888
.06
.033
.06
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

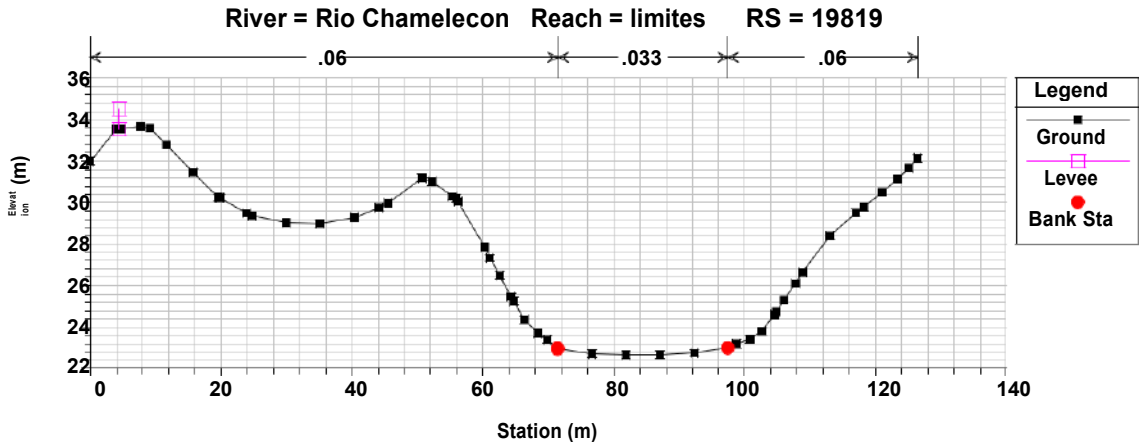

River = Rio Chamelecon Reach = limites RS = 29024
.06
.033
.06
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

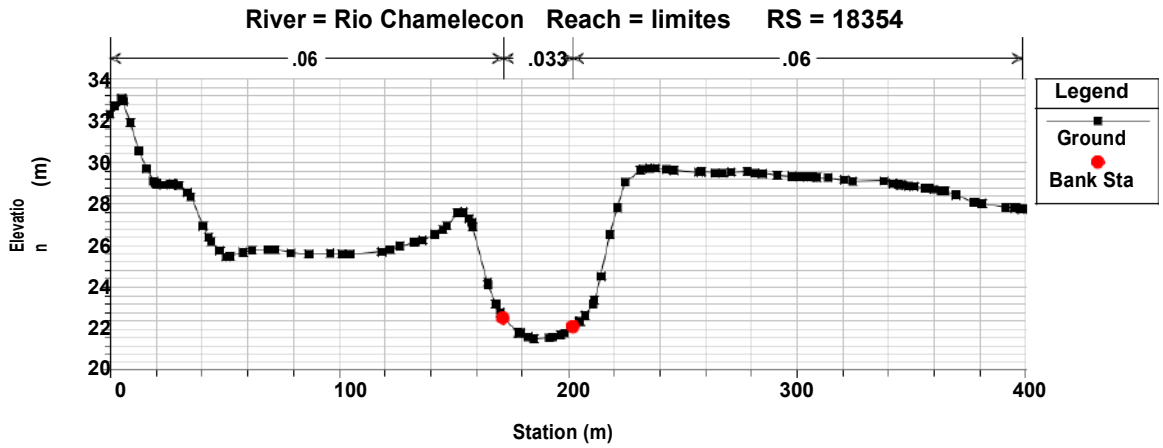

River = Rio Chamelecon Reach = limites RS = 23845
.06
.033
.06
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

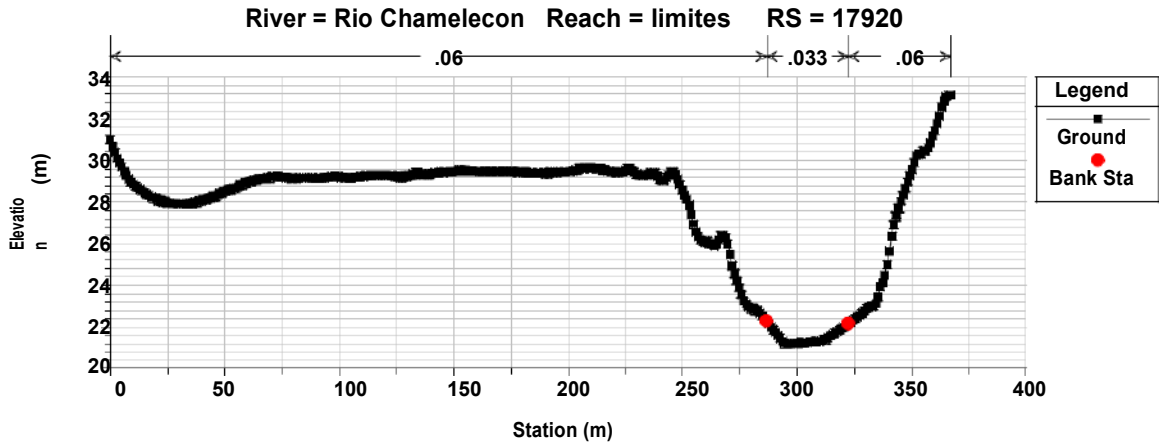

River = Rio Chamelecon Reach = limites RS = 23024
.06
.033
.06
Legend
Ground
Bank Sta
Station (m)

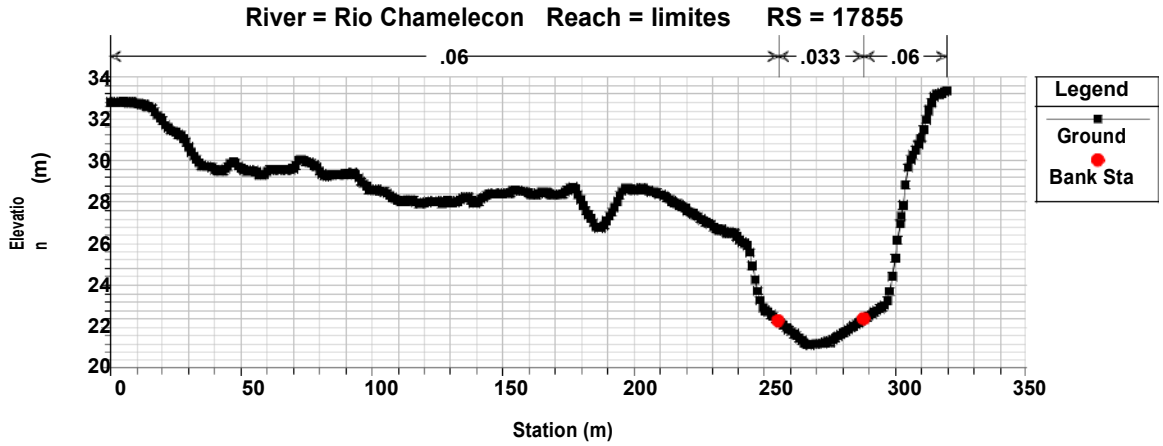

River = Rio Chamelecon Reach = limites RS = 21825
.06
.033
.06
Legend
Ground
Bank Sta
Station (m)

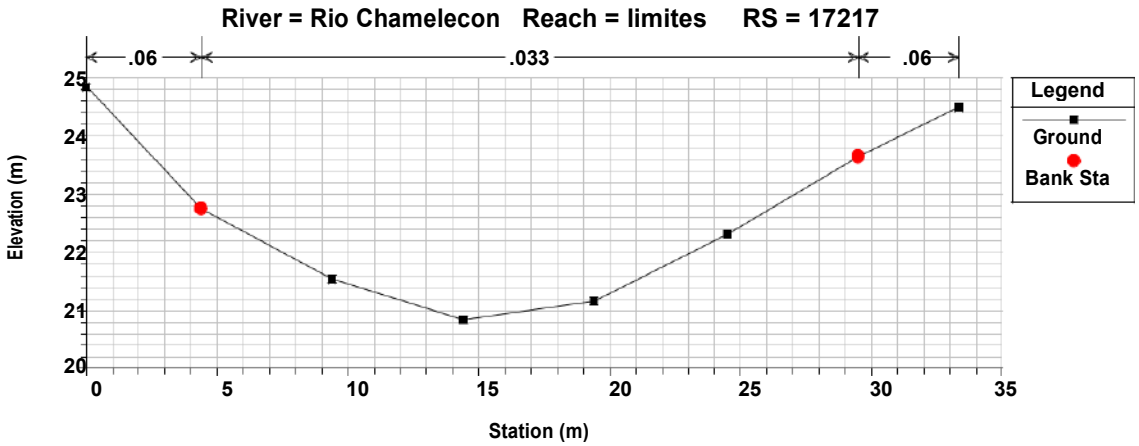

River = Rio Chamelecon Reach = limites RS = 20397
.06
.033
.06
Elevation (m)
Legend
Ground
Bank Sta
Station (m)

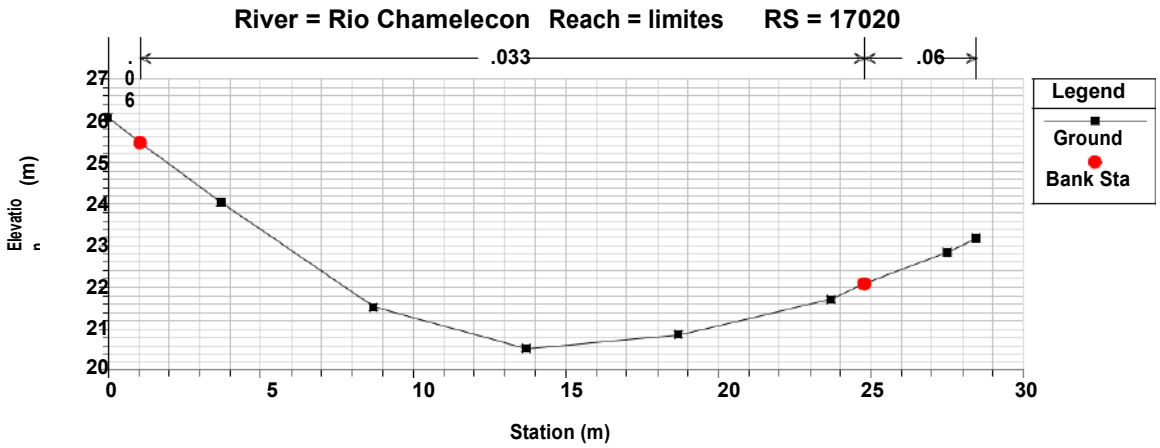

River = Rio Chamelecon Reach = limites RS = 19819
.06
.033
.06
Elevation (m)
Legend
Ground
Levee
Bank Sta
Station (m)

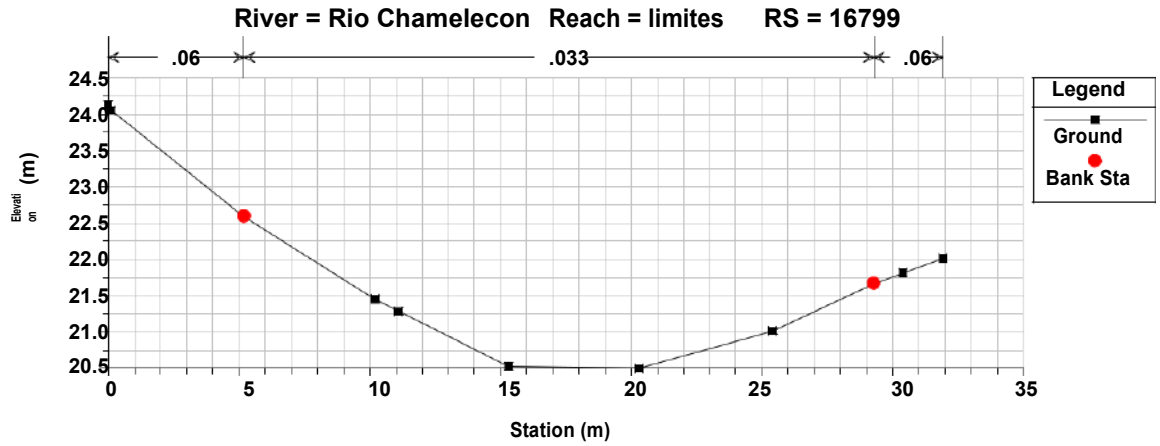

River = Rio Chamelecon Reach = limites RS = 18354
.06
.033
.06
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

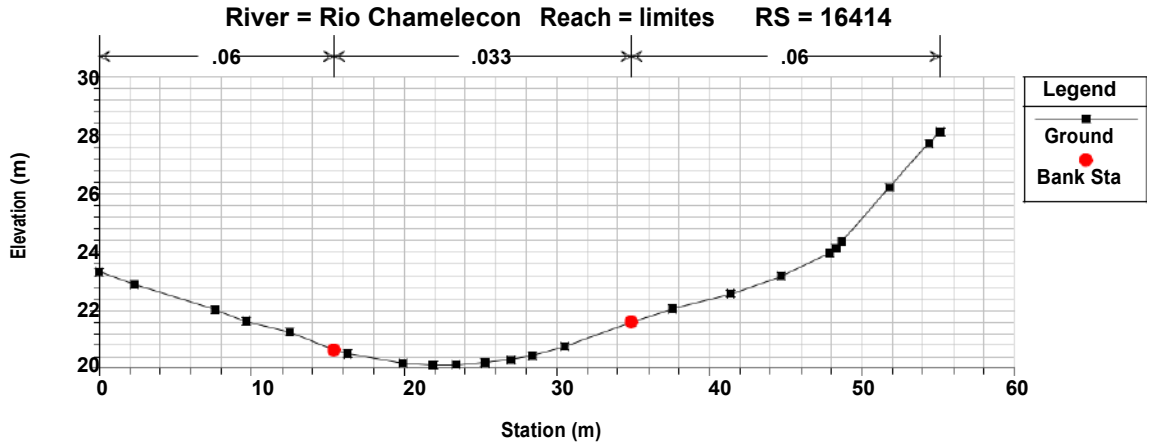

River = Rio Chamelecon Reach = limites RS = 17920
.06
.033
.06
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

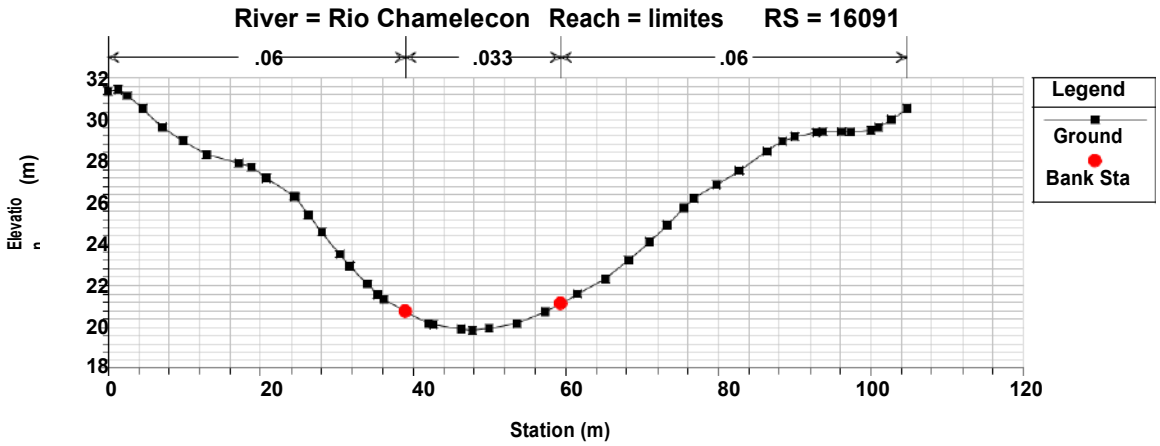

River = Rio Chamelecon Reach = limites RS = 17855
.06
.033
.06
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

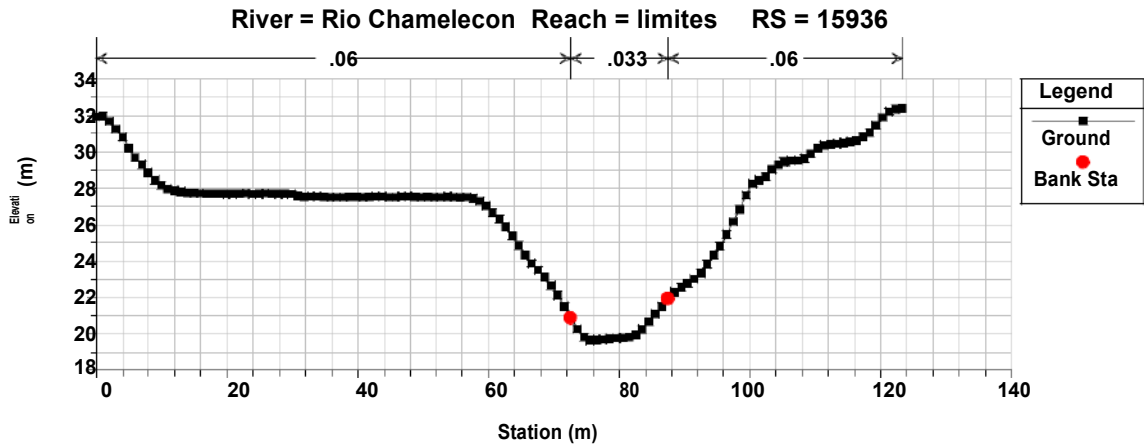

River = Rio Chamelecon Reach = limites RS = 17217
.06
.033
.06
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

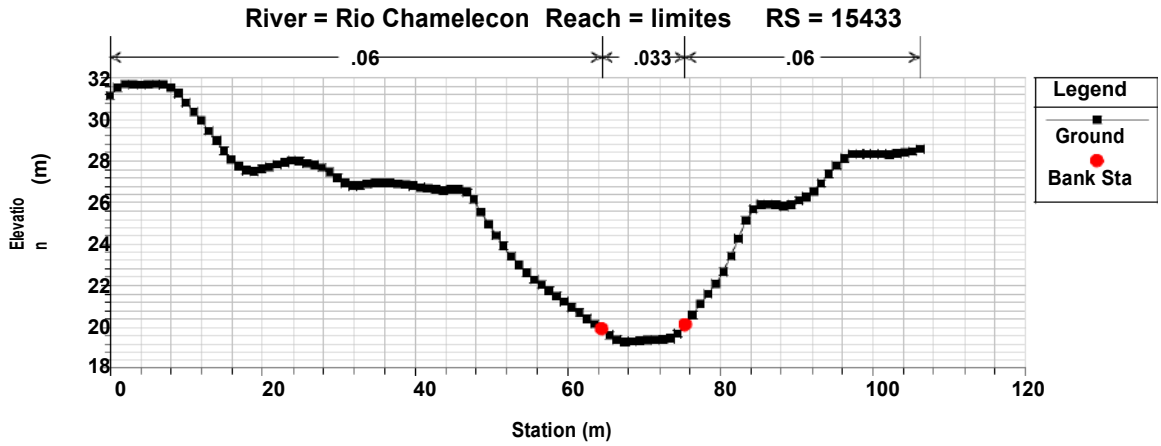

River = Rio Chamelecon Reach = limites RS = 17020
.06
.033
.06
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

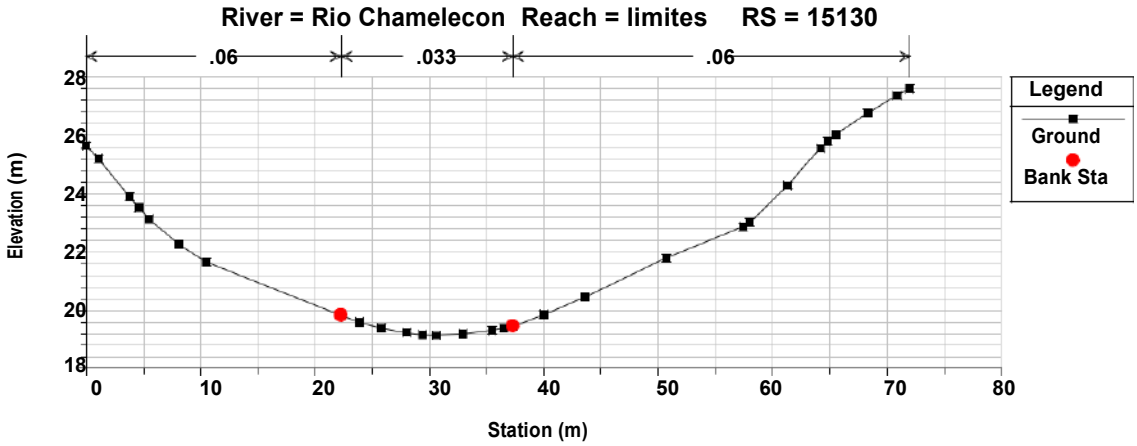

River = Rio Chamelecon Reach = limites RS = 16799
.06
.033
.06
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

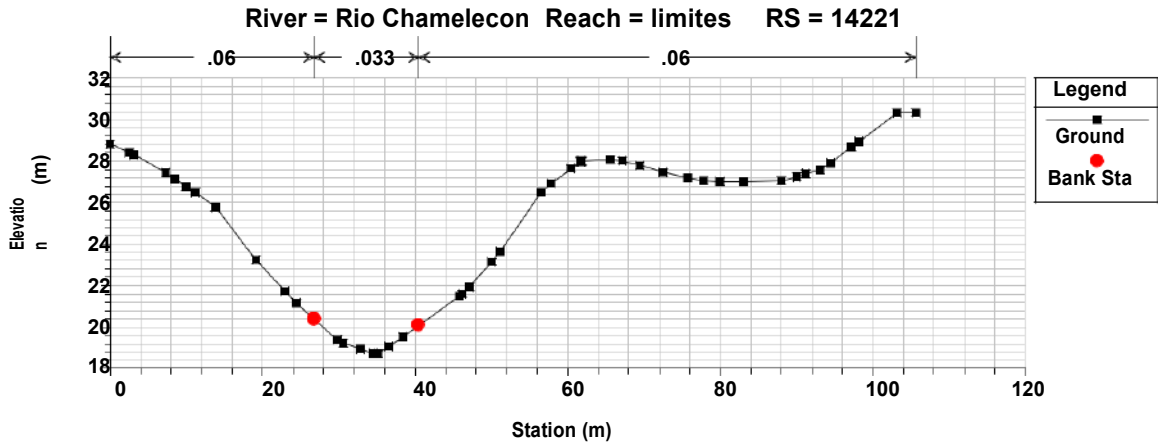

River = Rio Chamelecon Reach = limites RS = 16414
.06
.033
.06
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

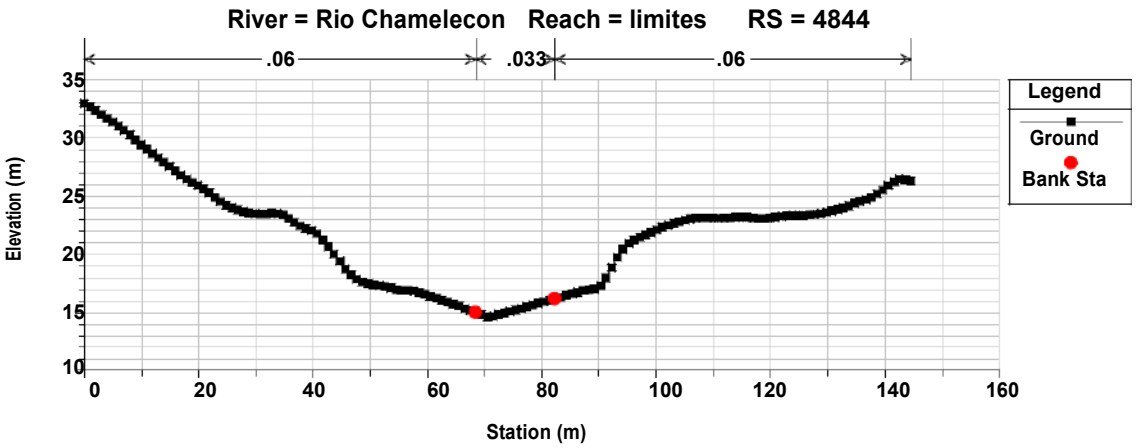

River = Rio Chamelecon Reach = limites RS = 16091
.06
.033
.06
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

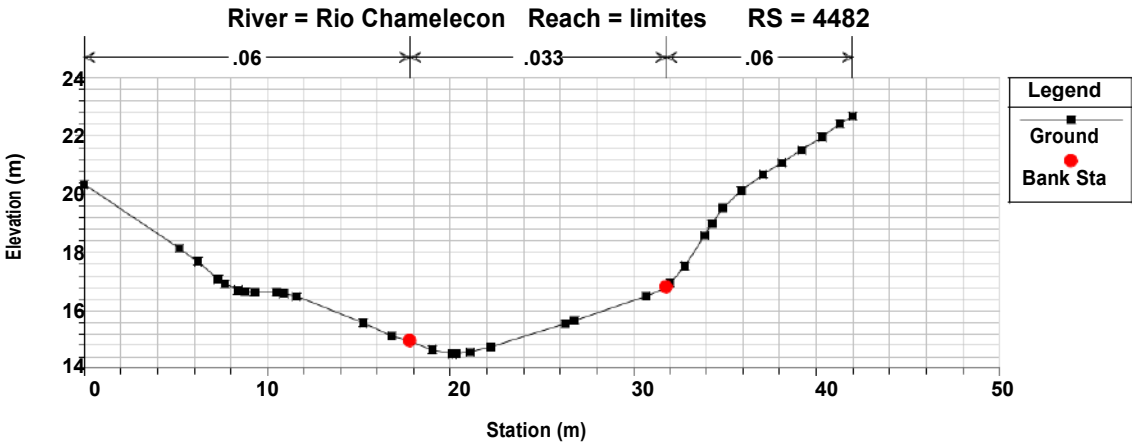

River = Rio Chamelecon Reach = limites RS = 15936
.06
.033
.06
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

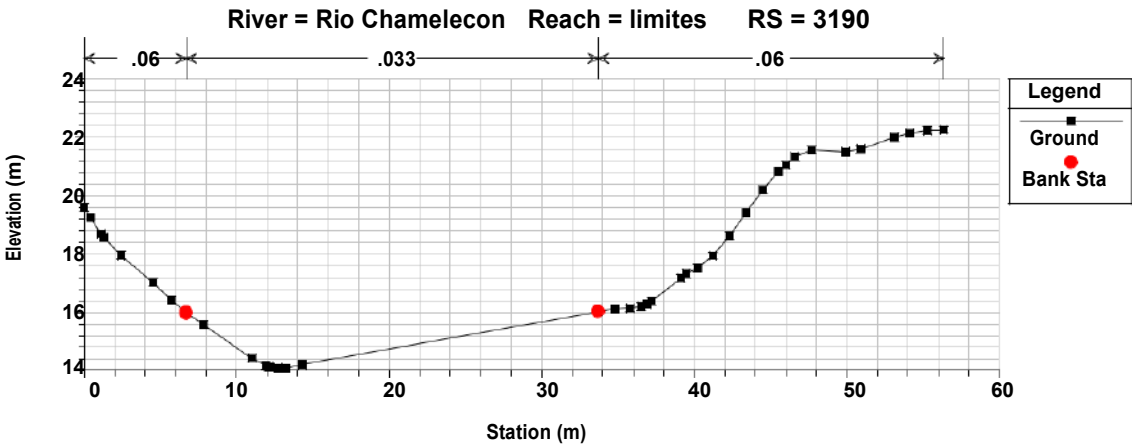

River = Rio Chamelecon Reach = limites RS = 15433
.06
.033
.06
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

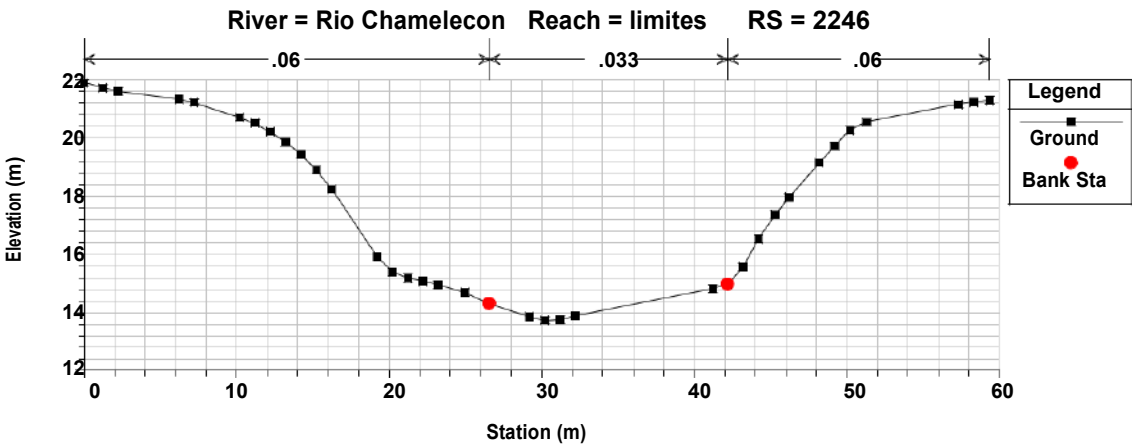

River = Rio Chamelecon Reach = limites RS = 15130
.06
.033
.06
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

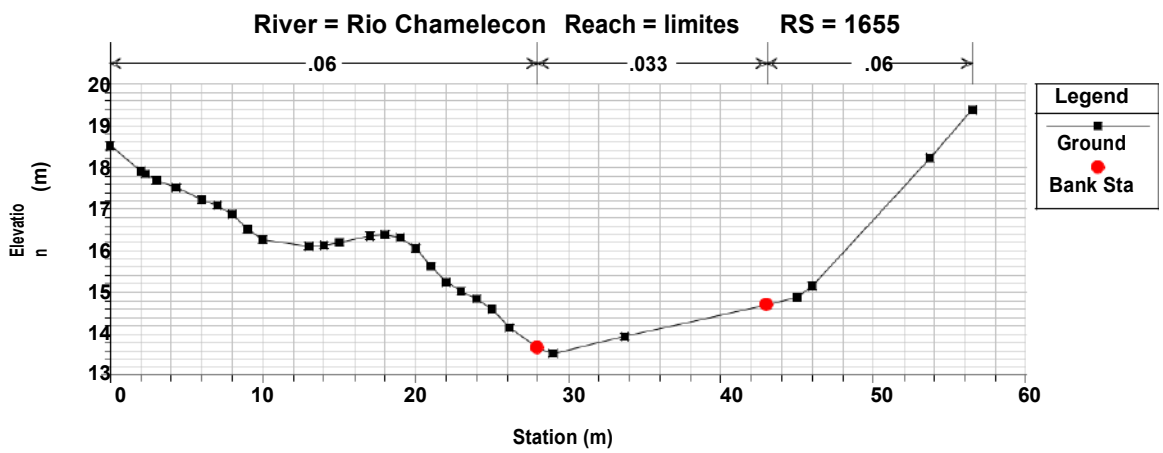

River = Rio Chamelecon Reach = limites RS = 14221
.06
.033
.06
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

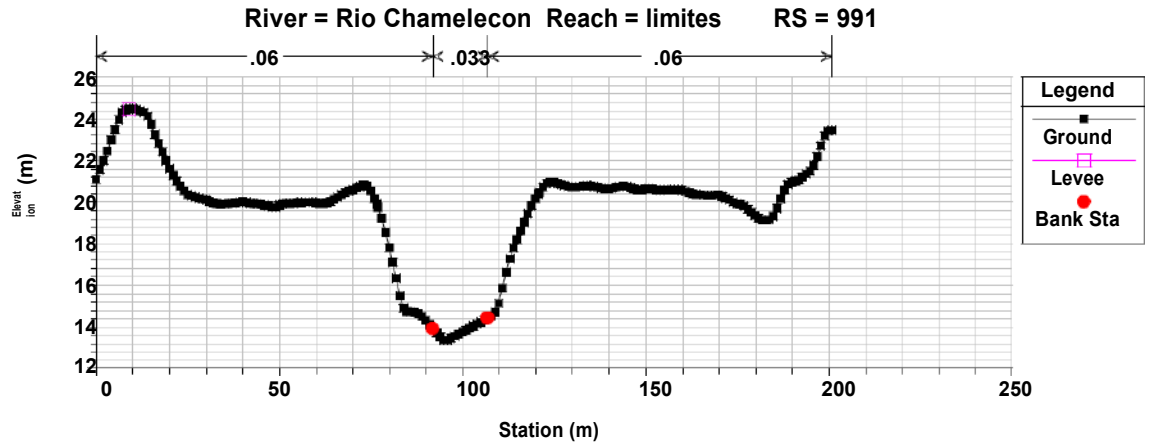

River = Rio Chamelecon Reach = limites RS = 4844
.06
.033
.06
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

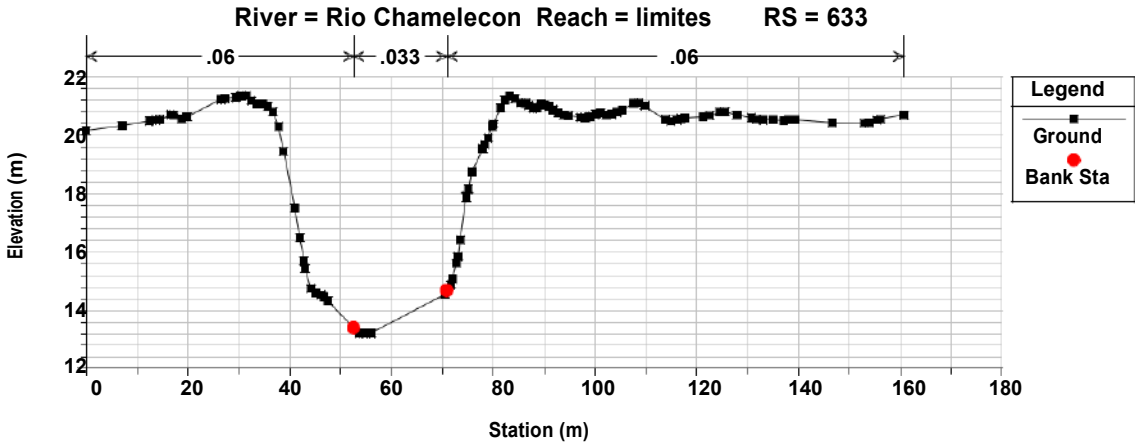

River = Rio Chamelecon Reach = limites RS = 4482
.06
.033
.06
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

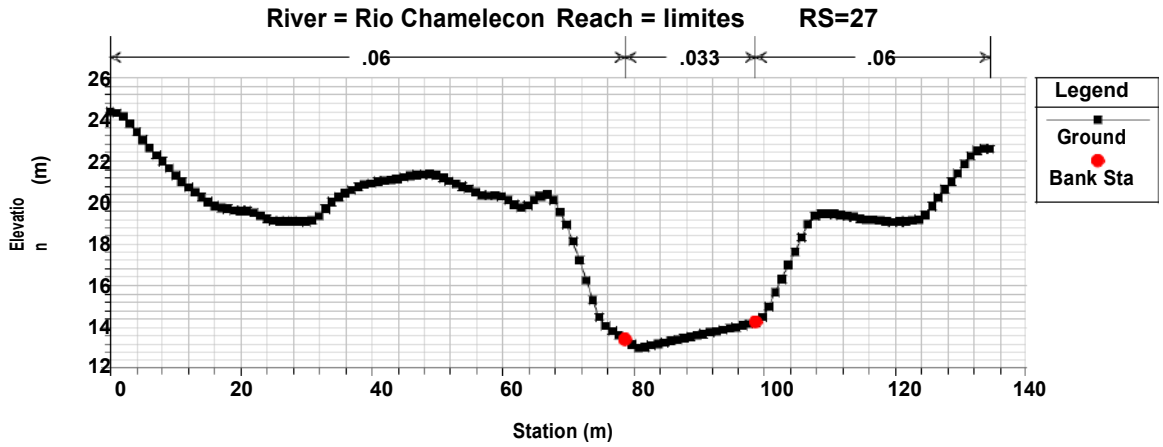

River = Rio Chamelecon Reach = limites RS = 3190
.06
.033
.06
Legend
Ground
Bank Sta
Elevation (m)
Station (m)


River = Rio Chamelecon Reach = limites RS = 2246
.06
.033
.06
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

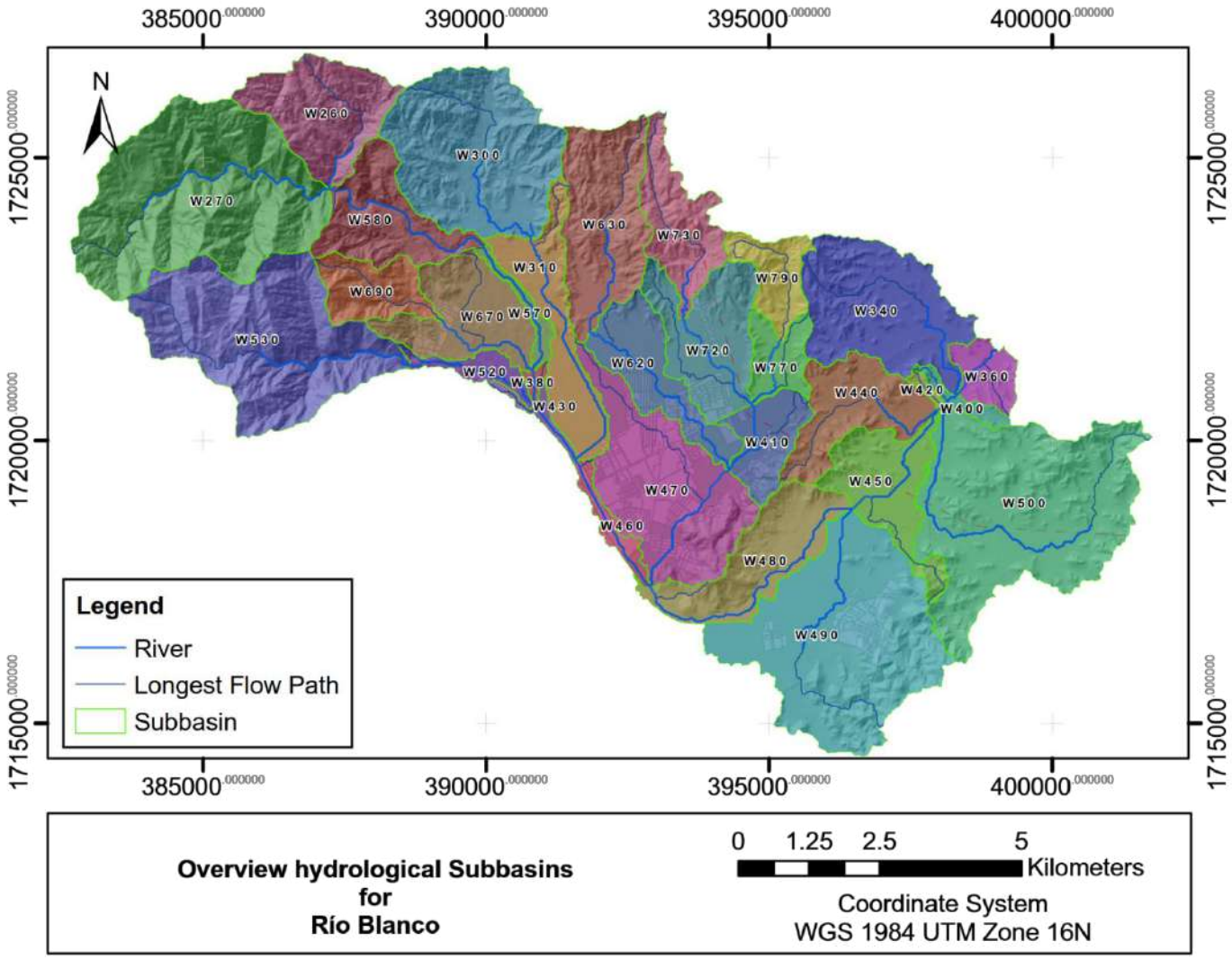

River = Rio Chamelecon Reach = limites RS = 1655
.06
.033
.06
Elevation (m)
Station (m)
Legend
Ground
Bank Sta


River = Rio Chamelecon Reach = limites RS = 991
.06
.033
.06
Elevation (m)
Station (m)
Legend
Ground
Levee
Bank Sta


River = Rio Chamelecon Reach = limites RS = 633
.06
.033
.06
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

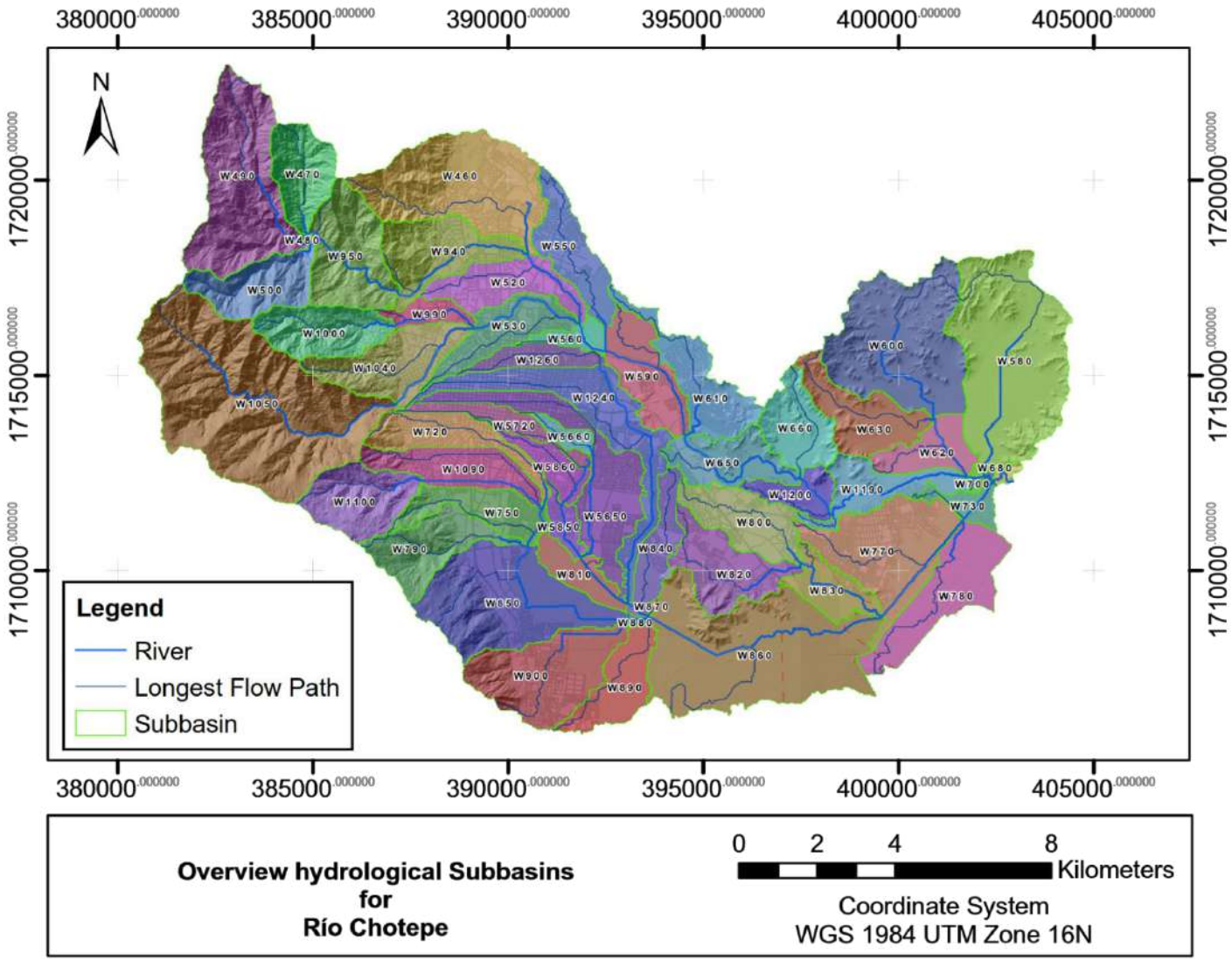

River = Rio Chamelecon Reach = limites RS=27
.06
.033
.06
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

A4 Hydrological Overview Model Río Blanco



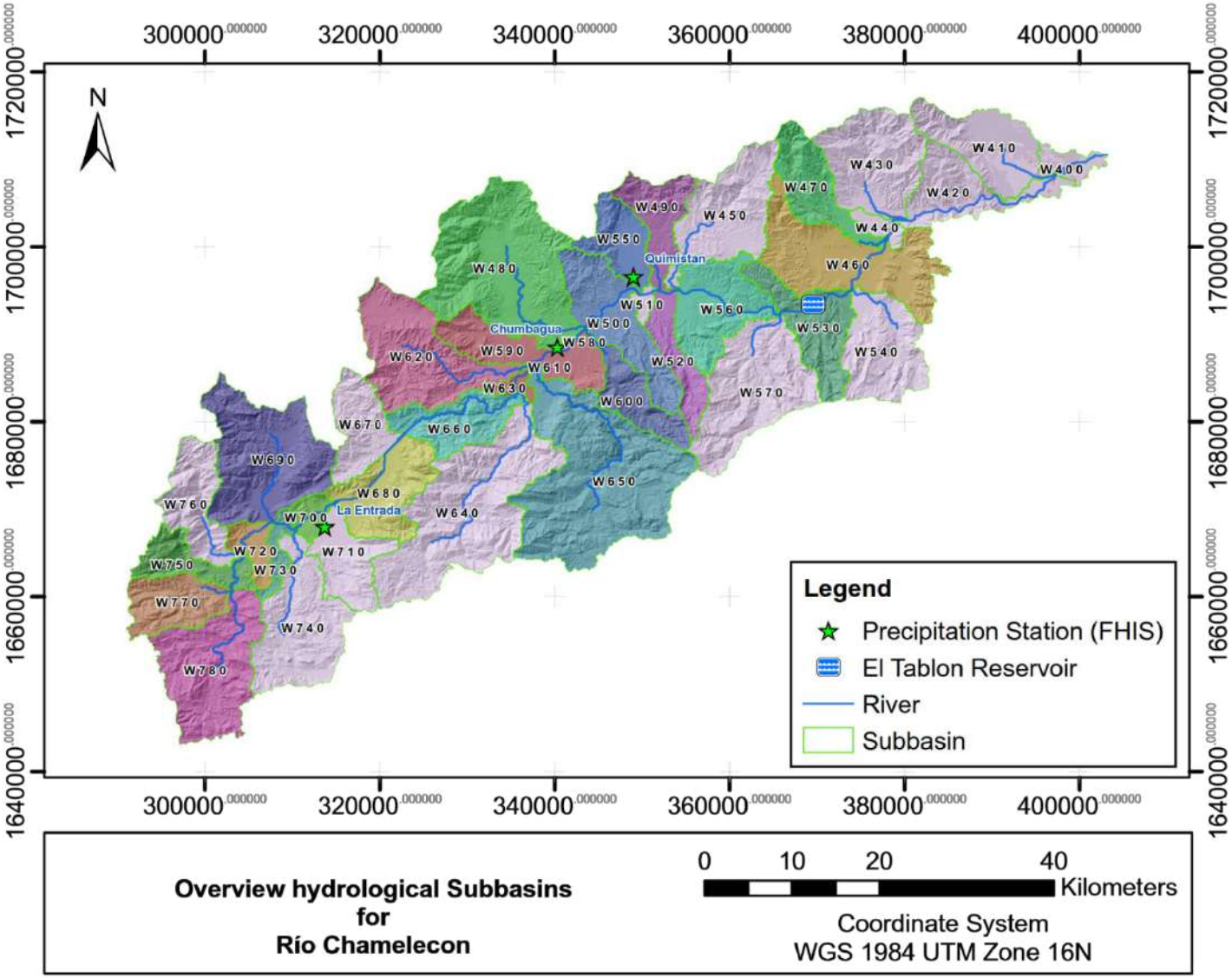
Overview hydrological Subbasins for Río Blanco

A5 Hydrological Overview Model Río Chotepe



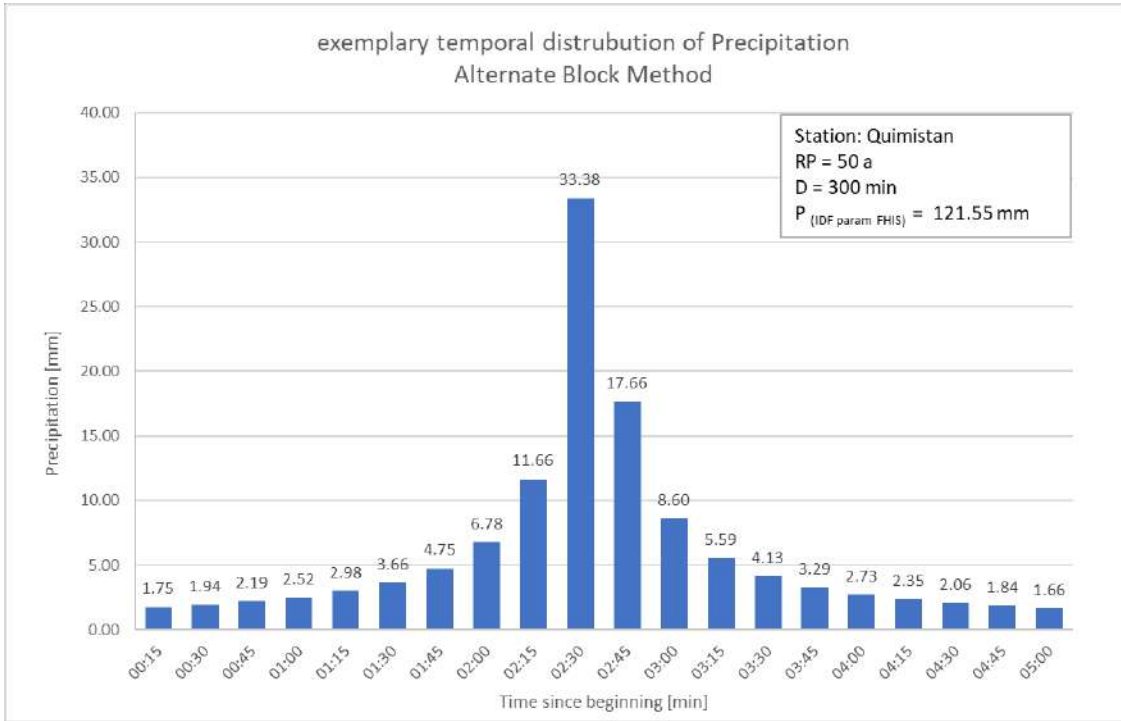
Overview hydrological Subbasins for Río Chotepe

A6 Hydrological Overview Model Río Chamelecón



Overview hydrological Subbasins for Río Chamelecon

A7 exemplary temporal Distribution of Precipitation via Alternate Block Method



A8 IDF Parameter and Precipitation depth and Precipitation Factor of Future Scenario of relevant station, FHIS (2002)

				IDF-Parameters out of Hydrological Manual (FIHS)														
Station	X	Y	Z	TR2_a	TR2_b	TR2_n	TR5_a	TR5_b	TR5_n	TR10_a	TR10_b	TR10_n	TR20_a	TR20_b	TR20_n	TR50_a	TR50_b	TR50_n
Chumbagua	340267	1688571	214.88	5817	34.3	1.0624	7597	32.8	1.0625	8744	32	1.0625	9830	31.4	1.0625	11221	30.7	1.0625
El Modelo	393582	1702402	32.52	935	12.1	0.786	1528	17	0.786	1917	19	0.786	2290	20.5	0.786	2774	21.9	0.786
La Entrada	313698	1668021	448.20	2300	18	0.9195	2946	18.6	0.9191	3378	18.9	0.9192	3786	19.1	0.919	4339	19.4	0.9197
La Union	348983	1656552	438.70	1427	29.9	0.8352	1926	23	0.8352	2258	20.99	0.8352	2578	19.5	0.8352	2989	18.3	0.8352
Quimistan	348971	1696626	190.98	2124	14.3	0.9015	2924	17	0.9015	3553	18.2	0.9015	4101	19.2	0.9015	4807	20.1	0.9015
Santa Rita	406102	1679948	46.29	1328	14.8	0.825	2089	21	0.825	2598	23.9	0.825	3088	26	0.825	3726	28.2	0.825
Santa Rosa de	306270	1635960	1096.69	5941	37	1.03	8187	36.7	1.03	9670	36.6	1.03	11096	36.6	1.03	12933	36.5	1.03
Tela	449440	1744237	14.04	771	12.5	0.629	1127	14.5	0.629	1360	15.3	0.629	1582	15.8	0.629	1870	16.3	0.629
Ulapa	327467	1655868	347.75	2184	21	0.9192	2952	22	0.9192	3455	22.4	0.9192	3936	22.7	0.9192	4555	23	0.9192
El Jaral	391947	1651556	641.91	4579	30.5	0.956	6419	39.6	0.956	7635	44.3	0.956	8801	48.1	0.956	10309	52.3	0.956
El Cajón	418805	1660268	467.94	819	9.9	0.7838	1465	17	0.7838	1895	20	0.7838	2310	22.1	0.7838	2847	24.1	0.7838
El Tablon	343725	1628989	906.34	1264	17.83	0.8516	1800	13	0.8516	2157	11.6	0.8516	2498	10.7	0.8516	2943	9.9	0.8516
El Nispero	355984	1633400	656.09	1036	16.1	0.889	2640	17	0.889	3162	17.3	0.889	3658	17.4	0.889	4298	17.6	0.889
Pito Solo	391119	1633585	1066.18	1480	19.89	0.7871	2214	23	0.7871	2702	24.3	0.7871	3168	25.21	0.7871	3773	26.11	0.7871

a, b, n = Coefficient of IDF

FHIS (2002): Annex 12.3 and p.70

	Precipitation according IDF and Storm duration 420			Precipitation according IDF and Storm duration 300			future Scenario PrecipFactor		future Scenario PrecipFactor		future Scenario PrecipFactor		future Scenario PrecipFactor		future Scenario PrecipFactor		future Scenario PrecipFactor		future Scenario PrecipFactor	
Station	p_025_420	p_050_420	p_100_420	p_025_300	p_050_300	p_100_300	RT2_rcp45	RT2_rcp85	RT5_rcp45	RT5_rcp85	RT10_rcp45	RT10_rcp85	RT20_rcp45	RT20_rcp85	RT25_rcp45	RT25_rcp85	RT50_rcp45	RT50_rcp85	RT100_rcp45	RT100_rcp85
Chumbagua	107.68	118.95	132.64	106.82	118.06	131.76	1.022	1.024	1.049	1.105	1.066	1.177	1.080	1.170	1.088	1.180	1.071	1.293	1.082	1.394
El Modelo	140.80	161.81	185.46	129.11	148.27	169.60	1.142	1.139	1.189	1.206	1.206	1.263	1.213	1.318	1.213	1.336	1.207	1.386	1.189	1.427
La Entrada	102.32	112.68	124.51	98.00	107.93	119.22	1.034	1.089	1.040	1.115	1.038	1.133	1.031	1.152	1.028	1.159	1.016	1.178	1.000	1.197
La Union	116.36	130.08	146.78	108.50	121.37	137.34	1.076	1.202	1.037	1.195	1.000	1.191	0.958	1.193	0.944	1.196	0.896	1.214	0.845	1.256
Quimistan	123.98	139.25	156.55	118.07	132.53	148.79	1.058	1.075	1.063	1.105	1.065	1.132	1.064	1.167	1.063	1.181	1.059	1.237	1.052	1.333
Santa Rita	174.99	163.40	192.84	136.85	156.48	177.65	1.017	1.117	1.065	1.193	1.111	1.300	1.167	1.537	1.161	1.635	1.426	1.527	1.584	1.685
Santa Rosa de	147.21	165.03	185.42	143.91	161.38	181.28	1.221	1.259	1.293	1.375	1.253	1.410	1.022	1.208	1.030	1.266	1.010	1.287	1.027	1.212
Tela	253.04	286.12	324.33	221.32	250.20	283.44	0.928	0.944	0.990	1.007	1.048	1.079	1.117	1.176	1.141	1.214	1.224	1.359	1.320	1.555
Ulapa	105.73	117.76	131.76	100.98	112.46	125.77	1.106	1.161	1.121	1.222	1.128	1.273	1.133	1.333	1.135	1.355	1.139	1.431	1.144	1.520
El Jaral	179.38	200.34	223.19	169.95	189.38	210.12	1.019	1.073	0.988	1.050	0.951	1.022	0.904	0.991	0.885	0.983	0.821	0.971	0.745	1.014
El Cajón	144.14	167.64	194.42	131.92	153.28	177.59	0.981	1.027	0.987	1.078	0.987	1.106	0.976	1.120	0.970	1.121	0.943	1.111	0.901	1.079
El Tablon	104.30	117.85	133.67	98.41	111.23	126.33	0.962	0.967	0.985	1.023	1.009	1.088	1.036	1.172	1.045	1.203	1.072	1.319	1.092	1.469
El Nispero	119.91	135.05	152.93	113.90	128.27	145.23	1.072	1.103	1.088	1.130	1.099	1.138	1.109	1.140	1.112	1.140	1.121	1.136	1.129	1.126
Pito Solo	191.91	216.97	247.44	175.81	198.33	226.25	1.079	1.174	1.114	1.241	1.141	1.284	1.173	1.327	1.185	1.342	1.225	1.389	1.273	1.441

p_025_420 = precipitation for TR 25 and Storm duration 420 min

RT20_rcp45 = derived precipitation Factor for Future Scenario RCP4.5

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A9 Precipitation Subbasins Rio Blanco (HecHMS)

		Present state, Storm duration 420 min			Present state, Storm duration 300 min				applied Present state according to Stormduration		
	[km²]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[min]	[mm]	[mm]	[mm]
Subbasin	Area_HecHMS	p_025_420	p_050_420	p_100_420	p_025_300	p_050_300	p_100_300	Stormduratio	p025	p050	p100
W260	3.818	142.63	161.67	185.16	130.03	148.85	169.84	300	130.03	148.85	169.84
W270	10.7348	141.89	160.95	184.30	129.51	148.25	169.15	300	129.51	148.25	169.15
W570	0.5418	142.38	162.04	185.72	129.88	148.90	170.09	300	129.88	148.90	170.09
W300	7.3471	142.97	162.24	185.89	130.26	149.22	170.35	300	130.26	149.22	170.35
W310	3.3529	142.39	162.11	185.80	129.90	148.93	170.14	300	129.90	148.93	170.14
W620	2.8477	142.38	162.21	185.95	129.89	148.97	170.22	420	142.38	162.21	185.95
W720	3.7185	142.70	162.44	186.21	130.09	149.19	170.45	300	130.09	149.19	170.45
W340	5.5572	143.45	163.04	186.93	130.58	149.73	171.06	300	130.58	149.73	171.06
W360	1.1226	143.48	163.10	187.02	130.58	149.76	171.11	300	130.58	149.76	171.11
W520	0.803	142.07	161.85	185.50	129.68	148.70	169.89	300	129.68	148.70	169.89
W380	0.1771	142.13	161.97	185.65	129.73	148.77	169.99	300	129.73	148.77	169.99
W400	0.4583	143.19	162.89	186.78	130.39	149.56	170.90	300	130.39	149.56	170.90
W410	1.8187	142.33	162.29	186.06	129.86	148.98	170.27	300	129.86	148.98	170.27
W420	0.1628	143.10	162.82	186.69	130.34	149.49	170.83	300	130.34	149.49	170.83
W430	0.3846	142.02	161.93	185.61	129.66	148.71	169.94	300	129.66	148.71	169.94
W440	3.1715	142.71	162.55	186.37	130.10	149.23	170.54	300	130.10	149.23	170.54
W450	3.1291	142.42	162.40	186.20	129.91	149.06	170.37	420	142.42	162.40	186.20
W460	0.7038	141.76	161.93	185.63	129.52	148.62	169.89	300	129.52	148.62	169.89
W470	6.4371	141.95	162.04	185.76	129.64	148.74	170.01	420	141.95	162.04	185.76
W480	3.7963	141.85	162.07	185.80	129.59	148.71	170.01	420	141.85	162.07	185.80
W490	10.1591	141.73	162.05	185.79	129.52	148.66	169.97	420	141.73	162.05	185.79
W500	10.9243	142.82	162.67	186.53	130.14	149.31	170.65	420	142.82	162.67	186.53
W530	8.9307	141.74	161.23	184.70	129.43	148.31	169.34	300	129.43	148.31	169.34
W580	3.2928	142.41	161.76	185.33	129.88	148.79	169.88	300	129.88	148.79	169.88
W630	4.6812	143.03	162.51	186.25	130.31	149.35	170.57	300	130.31	149.35	170.57
W670	3.4298	142.24	161.88	185.52	129.78	148.78	169.94	300	129.78	148.78	169.94
W690	1.8684	142.13	161.64	185.21	129.70	148.63	169.73	300	129.70	148.63	169.73
W730	2.7336	143.25	162.73	186.52	130.46	149.53	170.78	300	130.46	149.53	170.78
W770	1.2833	142.77	162.53	186.34	130.14	149.25	170.54	300	130.14	149.25	170.54
W790	1.5502	143.24	162.83	186.66	130.45	149.56	170.85	300	130.45	149.56	170.85

		Future Scenario T=25a, RCP4.5			Future Scenario T=25a, RCP8.5			Future Scenario T=50a, RCP4.5			Future Scenario T=50a, RCP8.5			Future Scenario T=100a, RCP4.5			Future Scenario T=100a, RCP8.5		
	[km²]	[-] PrecipitationFac	[mm]	[mm]	[-] PrecipitationFac	[mm]	[mm]	[-] PrecipitationFac	[mm]	[mm]	[-] PrecipitationFac	[mm]	[mm]	[-] PrecipitationFac	[mm]	[mm]	[-] PrecipitationFac	[mm]	[mm]
Subbasin	Area_HecHMS	pFac_025_45	p_025_420_45	p_025_300_45	pFac_025_85	p_025_420_85	p_025_300_85	pFac_050_45	p_050_420_45	p_050_300_45	pFac_050_85	p_050_420_85	p_050_300_85	pFac_100_45	p_100_420_45	p_100_300_45	pFac_100_85	p_100_420_85	p_100_300_85
W260	3.818	1.166	166.27	151.58	1.315	187.56	170.99	1.181	190.93	175.80	1.356	219.14	201.77	1.182	218.81	200.71	1.416	262.26	240.57
W270	10.7348	1.166	165.39	150.97	1.314	186.39	170.13	1.179	189.80	174.82	1.355	218.01	200.81	1.179	217.24	199.38	1.415	260.73	239.29
W570	0.5418	1.180	168.00	153.25	1.326	188.78	172.21	1.192	193.20	177.53	1.367	221.49	203.52	1.190	220.95	202.36	1.423	264.24	242.00
W300	7.3471	1.171	167.45	152.57	1.320	188.74	171.97	1.186	192.49	177.05	1.360	220.72	203.01	1.187	220.60	202.17	1.420	263.96	241.90
W310	3.3529	1.181	168.19	153.44	1.327	188.93	172.35	1.193	193.44	177.71	1.368	221.74	203.71	1.190	221.19	202.55	1.423	264.47	242.18
W620	2.8477	1.185	168.65	153.86	1.330	189.30	172.70	1.196	194.03	178.19	1.371	222.34	204.18	1.193	221.80	203.04	1.425	265.01	242.59
W720	3.7185	1.183	168.81	153.89	1.329	189.69	172.93	1.196	194.27	178.43	1.370	222.54	204.39	1.194	222.28	203.46	1.426	265.45	242.98
W340	5.5572	1.181	169.48	154.28	1.330	190.85	173.73	1.197	195.20	179.26	1.370	223.40	205.16	1.197	223.76	204.77	1.427	266.82	244.17
W360	1.1226	1.184	169.82	154.55	1.333	191.24	174.05	1.200	195.66	179.66	1.372	223.83	205.52	1.199	224.32	205.23	1.429	267.27	244.53
W520	0.803	1.182	167.93	153.29	1.327	188.47	172.03	1.193	193.08	177.39	1.368	221.41	203.42	1.189	220.61	202.04	1.423	263.93	241.71
W380	0.1771	1.184	168.22	153.55	1.328	188.74	172.27	1.194	193.46	177.69	1.369	221.78	203.71	1.191	221.02	202.38	1.424	264.31	242.02
W400	0.4583	1.185	169.69	154.52	1.333	190.92	173.86	1.200	195.48	179.48	1.373	223.67	205.36	1.199	223.93	204.90	1.429	266.90	244.21
W410	1.8187	1.188	169.11	154.30	1.332	189.64	173.03	1.199	194.61	178.66	1.374	222.92	204.64	1.195	222.35	203.49	1.427	265.50	242.98
W420	0.1628	1.185	169.56	154.44	1.333	190.72	173.71	1.199	195.30	179.31	1.373	223.51	205.21	1.198	223.68	204.67	1.428	266.68	244.02
W430	0.3846	1.185	168.33	153.68	1.329	188.72	172.30	1.195	193.57	177.77	1.370	221.92	203.80	1.191	221.04	202.38	1.424	264.34	242.02
W440	3.1715	1.187	169.33	154.37	1.333	190.18	173.38	1.199	194.96	178.98	1.373	223.21	204.92	1.197	223.02	204.08	1.428	266.09	243.49
W450	3.1291	1.190	169.46	154.58	1.334	190.06	173.36	1.201	195.08	179.06	1.375	223.36	205.02	1.197	222.93	203.98	1.429	265.99	243.38
W460	0.7038	1.191	168.90	154.32	1.332	188.86	172.55	1.199	194.19	178.23	1.375	222.62	204.32	1.193	221.39	202.62	1.426	264.71	242.27
W470	6.4371	1.190	168.94	154.29	1.332	189.10	172.71	1.199	194.30	178.35	1.374	222.68	204.41	1.193	221.69	202.89	1.426	264.95	242.48
W480	3.7963	1.194	169.32	154.69	1.334	189.29	172.93	1.202	194.74	178.69	1.377	223.15	204.76	1.195	222.02	203.15	1.428	265.27	242.72
W490	10.1591	1.197	169.62	155.01	1.336	189.38	173.07	1.204	195.04	178.92	1.379	223.48	205.02	1.196	222.19	203.27	1.429	265.44	242.84
W500	10.9243	1.189	169.83	154.75	1.336	190.79	173.85	1.203	195.61	179.55	1.376	223.82	205.44	1.200	223.83	204.77	1.430	266.75	244.04
W530	8.9307	1.174	166.47	152.02	1.320	187.10	170.85	1.186	191.19	175.88	1.361	219.49	201.90	1.183	218.52	200.34	1.418	261.96	240.17
W580	3.2928	1.172	166.96	152.27	1.320	187.98	171.45	1.186	191.86	176.48	1.361	220.10	202.46	1.185	219.63	201.32	1.419	263.01	241.08
W630	4.6812	1.176	168.27	153.31	1.325	189.46	172.62	1.191	193.58	177.90	1.365	221.82	203.86	1.191	221.76	203.09	1.423	265.02	242.71
W670	3.4298	1.179	167.70	153.01	1.325	188.43	171.93	1.191	192.81	177.20	1.366	221.10	203.21	1.188	220.46	201.95	1.422	263.79	241.63
W690	1.8684	1.176	167.09	152.48	1.322	187.88	171.45	1.188	192.01	176.56	1.363	220.29	202.57	1.186	219.60	201.25	1.420	262.97	241.00
W730	2.7336	1.177	168.63	153.58	1.326	189.92	172.97	1.192	194.06	178.31	1.366	222.29	204.25	1.192	222.40	203.63	1.424	265.62	243.20
W770	1.2833	1.184	169.06	154.11	1.331	189.98	173.18	1.197	194.61	178.71	1.371	222.87	204.65	1.195	222.69	203.82	1.427	265.82	243.28
W790	1.5502	1.180	169.05	153.96	1.329	190.30	173.31	1.195	194.63	178.77	1.369	222.85	204.69	1.195	223.01	204.12	1.426	266.15	243.61

A10 Precipitation Subbasins Rio Chotepe (HecHMS)

		Present state, Storm duration 420 min			Present state, Storm duration 300 min				applied Present state according to Stormduration		
	[km²]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[min]	[mm]	[mm]	[mm]
Subbasin	Area_HecHMS	p_025_420	p_050_420	p_100_420	p_025_300	p_050_300	p_100_300	Stormduration	p025	p050	p100
W460	9.465	141.75	161.66	185.28	129.48	148.50	169.68	300	129.48	148.50	169.68
W470	3.368125	141.41	160.99	184.43	129.22	148.08	169.10	300	129.22	148.08	169.10
W480	0.035	141.30	161.10	184.59	129.17	148.09	169.17	300	129.17	148.09	169.17
W490	9.47375	141.14	160.59	183.92	129.04	147.81	168.74	300	129.04	147.81	168.74
W500	3.776875	141.09	160.91	184.36	129.05	147.94	168.98	300	129.05	147.94	168.98
W940	4.60875	141.50	161.60	185.22	129.35	148.39	169.59	300	129.35	148.39	169.59
W520	3.684375	141.47	161.75	185.41	129.36	148.44	169.69	420	141.47	161.75	185.41
W530	3.360625	141.34	161.75	185.41	129.30	148.40	169.67	300	129.30	148.40	169.67
W990	1.215	141.33	161.61	185.24	129.27	148.33	169.56	300	129.27	148.33	169.56
W550	3.61375	141.67	161.88	185.56	129.47	148.57	169.83	420	141.67	161.88	185.56
W560	0.9425	141.37	161.83	185.51	129.33	148.44	169.73	300	129.33	148.44	169.73
W1040	4.6975	141.21	161.56	185.18	129.21	148.27	169.50	300	129.21	148.27	169.50
W580	12.851875	142.82	162.61	186.51	130.07	149.26	170.61	420	142.82	162.61	186.51
W590	3.963125	141.32	161.87	185.56	129.31	148.45	169.75	420	141.32	161.87	185.56
W600	10.379375	142.16	162.28	186.08	129.73	148.90	170.23	420	142.16	162.28	186.08
W610	4.121875	141.35	161.90	185.60	129.33	148.47	169.78	420	141.35	161.90	185.60
W620	2.4875	141.75	162.07	185.84	129.50	148.66	169.99	300	129.50	148.66	169.99
W630	4.09	141.61	162.02	185.76	129.44	148.60	169.92	300	129.44	148.60	169.92
W650	3.499375	141.16	161.86	185.55	129.24	148.40	169.71	420	141.16	161.86	185.55
W660	3.324375	141.38	161.93	185.65	129.34	148.49	169.81	300	129.34	148.49	169.81
W680	0.290625	142.11	162.19	186.01	129.65	148.82	170.16	300	129.65	148.82	170.16
W690	0.065	141.98	162.14	185.94	129.59	148.76	170.09	300	129.59	148.76	170.09
W700	0.2175	141.87	162.10	185.89	129.54	148.71	170.04	300	129.54	148.71	170.04
W1090	3.774375	141.05	161.73	185.38	129.18	148.30	169.59	300	129.18	148.30	169.59
W720	3.33	141.10	161.70	185.35	129.19	148.31	169.58	300	129.19	148.31	169.58
W730	1.17875	141.74	162.04	185.82	129.48	148.64	169.97	420	141.74	162.04	185.82
W750	3.1275	140.99	161.76	185.42	129.16	148.30	169.61	300	129.16	148.30	169.61
W770	7.1925	141.27	161.90	185.61	129.28	148.44	169.77	420	141.27	161.90	185.61
W780	5.41375	141.39	161.93	185.66	129.32	148.49	169.81	420	141.39	161.93	185.66
W790	4.035625	140.97	161.75	185.40	129.15	148.29	169.59	300	129.15	148.29	169.59
W800	3.84875	141.04	161.84	185.52	129.20	148.35	169.68	420	141.04	161.84	185.52
W810	1.884375	140.90	161.81	185.47	129.14	148.30	169.62	420	140.90	161.81	185.47
W820	4.355	140.95	161.83	185.49	129.16	148.32	169.64	420	140.95	161.83	185.49
W830	2.351875	141.04	161.85	185.53	129.19	148.35	169.68	420	141.04	161.85	185.53
W840	2.555	140.95	161.82	185.48	129.16	148.31	169.64	420	140.95	161.82	185.48
W860	14.695	140.89	161.82	185.48	129.14	148.30	169.63	420	140.89	161.82	185.48
W870	0.06125	140.87	161.81	185.47	129.13	148.29	169.62	300	129.13	148.29	169.62
W880	0.150625	140.86	161.81	185.47	129.13	148.29	169.61	300	129.13	148.29	169.61
W890	3.22625	140.82	161.81	185.46	129.12	148.28	169.61	420	140.82	161.81	185.46
W900	6.575	140.84	161.81	185.46	129.12	148.28	169.61	300	129.12	148.28	169.61
W850	9.391875	140.90	161.79	185.45	129.14	148.29	169.61	300	129.14	148.29	169.61
W950	5.405625	141.36	161.33	184.87	129.24	148.21	169.35	300	129.24	148.21	169.35
W1000	3.806875	141.19	161.31	184.86	129.15	148.15	169.31	300	129.15	148.15	169.31
W1050	19.424375	140.96	161.05	184.53	129.00	147.95	169.06	300	129.00	147.95	169.06
W1100	4.199375	141.03	161.63	185.26	129.15	148.25	169.52	300	129.15	148.25	169.52
W1190	3.236875	141.41	161.95	185.67	129.35	148.51	169.83	420	141.41	161.95	185.67
W1200	1.785	141.18	161.88	185.57	129.25	148.41	169.73	420	141.18	161.88	185.57
W1240	6.793125	141.15	161.80	185.48	129.23	148.37	170.00	420	129.23	148.37	170.00
W1260	1.753125	141.29	161.78	185.45	129.28	148.40	169.68	300	129.28	148.40	169.68
W5650 / W760	5.755625	-	-	-	129.20	148.34	170.00	300	129.20	148.34	170.00
W5660 / W470_Sauce4	0.70625	-	-	-	129.22	148.35	170.00	300	129.22	148.35	170.00
W5850/ W740_Sauce1	1.025	-	-	-	129.16	148.31	170.00	300	129.16	148.31	170.00
W5720/ W740_Sauce3	1.759375	-	-	-	129.21	148.34	170.00	300	129.21	148.34	170.00
W5860/ W740_Sauce2	1.608125		-	-	129.19	148.33	170.00	300	129.19	148.33	170.00

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A10 Precipitation Subbasins Rio Chotepe (HecHMS) (cont)

		Future Scenario T=25a, RCP4.5			Future Scenario T=25a, RCP8.5			Future Scenario T=50a, RCP4.5			Future Scenario T=50a, RCP8.5			Future Scenario T=100a, RCP4.5			Future Scenario T=100a, RCP8.5		
	[km²]	[-] PrecipitationFactor	[mm]	[mm]	[-] PrecipitationF	[mm]	[mm]	[-] PrecipitationF	[mm]	[mm]	[-] PrecipitationF	[mm]	[mm]	[-] PrecipitationF	[mm]	[mm]	[-] PrecipitationF	[mm]	[mm]
Subbasin	Area_HecHMS	pFac_025_45	p_025_420_45	p_025_300_45	pFac_025_85	p_025_420_85	p_025_300_85	pFac_050_45	p_050_420_45	p_050_300_45	pFac_050_85	p_050_420_85	p_050_300_85	pFac_100_45	p_100_420_45	p_100_300_45	pFac_100_85	p_100_420_85	p_100_300_85
W460	9.465	1.1845	167.89	153.37	1.327	188.13	171.85	1.194	192.97	177.26	1.369	221.35	203.33	1.189	220.22	201.68	1.423	263.60	241.41
W470	3.368125	1.1760	166.30	151.97	1.320	186.68	170.59	1.186	190.94	175.63	1.362	219.27	201.68	1.182	218.01	199.89	1.418	261.51	239.77
W480	0.035	1.1807	166.82	152.51	1.323	186.93	170.89	1.189	191.57	176.09	1.365	219.96	202.19	1.184	218.50	200.25	1.419	262.02	240.13
W490	9.47375	1.1727	165.52	151.32	1.317	185.89	169.95	1.183	189.92	174.81	1.359	218.23	200.87	1.179	216.84	198.94	1.416	260.39	238.90
W500	3.776875	1.1805	166.56	152.34	1.322	186.55	170.62	1.188	191.20	175.79	1.365	219.61	201.91	1.182	217.98	199.80	1.419	261.55	239.74
W940	4.60875	1.1884	168.16	153.72	1.329	188.03	171.89	1.196	193.22	177.42	1.372	221.67	203.54	1.189	220.20	201.62	1.423	263.65	241.40
W520	3.684375	1.1929	168.76	154.32	1.332	188.40	172.27	1.199	193.92	177.96	1.375	222.41	204.11	1.191	220.82	202.10	1.425	264.26	241.85
W530	3.360625	1.1959	169.03	154.63	1.333	188.39	172.34	1.200	194.16	178.13	1.377	222.71	204.33	1.191	220.87	202.12	1.426	264.36	241.92
W990	1.215	1.1922	168.50	154.12	1.331	188.04	172.00	1.198	193.55	177.64	1.374	222.07	203.82	1.189	220.32	201.67	1.424	263.82	241.50
W550	3.61375	1.1921	168.88	154.34	1.332	188.72	172.48	1.199	194.13	178.17	1.375	222.58	204.28	1.192	221.23	202.47	1.426	264.59	242.15
W560	0.9425	1.1978	169.33	154.91	1.334	188.62	172.56	1.202	194.51	178.42	1.378	223.07	204.62	1.193	221.22	202.41	1.427	264.69	242.18
W1040	4.6975	1.1937	168.56	154.24	1.331	187.92	171.94	1.198	193.56	177.63	1.375	222.12	203.84	1.189	220.17	201.53	1.424	263.74	241.41
W580	12.851875	1.1920	170.24	155.04	1.341	191.46	174.37	1.207	196.19	180.09	1.379	224.31	205.90	1.204	224.62	205.47	1.433	267.27	244.49
W590	3.963125	1.2006	169.66	155.25	1.336	188.76	172.72	1.204	194.85	178.70	1.380	223.44	204.92	1.193	221.46	202.59	1.428	264.94	242.37
W600	10.379375	1.1952	169.91	155.05	1.339	190.29	173.65	1.205	195.60	179.47	1.380	223.89	205.44	1.200	223.29	204.27	1.431	266.26	243.58
W610	4.121875	1.2009	169.76	155.32	1.336	188.90	172.84	1.204	194.99	178.82	1.381	223.57	205.02	1.194	221.65	202.76	1.428	265.09	242.50
W620	2.4875	1.1998	170.07	155.37	1.340	189.98	173.56	1.207	195.66	179.48	1.382	224.04	205.51	1.200	222.96	203.95	1.431	266.01	243.33
W630	4.09	1.2002	169.96	155.35	1.339	189.58	173.29	1.206	195.42	179.24	1.382	223.88	205.34	1.198	222.49	203.52	1.430	265.69	243.03
W650	3.499375	1.2049	170.08	155.72	1.337	188.77	172.83	1.206	195.19	178.95	1.383	223.86	205.24	1.194	221.53	202.62	1.429	265.10	242.46
W660	3.324375	1.2023	169.98	155.51	1.338	189.15	173.05	1.206	195.27	179.06	1.382	223.83	205.25	1.196	221.99	203.05	1.429	265.36	242.73
W680	0.290625	1.1976	170.19	155.27	1.342	190.76	174.03	1.208	196.00	179.85	1.383	224.23	205.75	1.203	223.82	204.75	1.433	266.59	243.87
W690	0.069	1.1984	170.16	155.31	1.342	190.52	173.89	1.208	195.91	179.74	1.383	224.18	205.68	1.202	223.57	204.50	1.433	266.41	243.70
W700	0.2175	1.1994	170.15	155.36	1.342	190.31	173.78	1.208	195.84	179.66	1.383	224.16	205.64	1.201	223.34	204.30	1.432	266.26	243.56
W1090	3.774375	1.2022	169.58	155.31	1.334	188.23	172.38	1.203	194.54	178.39	1.380	223.25	204.71	1.191	220.76	201.95	1.427	264.45	241.92
W720	3.33	1.2003	169.37	155.07	1.334	188.19	172.31	1.202	194.36	178.26	1.379	223.02	204.55	1.191	220.68	201.90	1.426	264.33	241.84
W730	1.17875	1.2006	170.17	155.45	1.341	190.13	173.69	1.208	195.80	179.60	1.383	224.16	205.62	1.201	223.14	204.11	1.432	266.13	243.43
W750	3.1275	1.2050	169.90	155.64	1.335	188.27	172.47	1.204	194.80	178.59	1.382	223.56	204.96	1.191	220.85	202.02	1.427	264.61	242.04
W770	7.1925	1.2052	170.26	155.81	1.340	189.23	173.17	1.208	195.53	179.27	1.384	224.13	205.49	1.197	222.11	203.15	1.430	265.50	242.83
W780	5.41375	1.2046	170.32	155.77	1.341	189.59	173.40	1.209	195.71	179.47	1.385	224.23	205.62	1.199	222.52	203.52	1.431	265.76	243.07
W790	4.035625	1.2050	169.87	155.63	1.335	188.20	172.42	1.204	194.74	178.54	1.382	223.52	204.92	1.191	220.76	201.93	1.427	264.54	241.98
W800	3.84875	1.2072	170.27	155.97	1.337	188.64	172.80	1.207	195.27	178.99	1.384	224.01	205.34	1.193	221.38	202.48	1.429	265.05	242.42
W810	1.884375	1.2092	170.38	156.16	1.336	188.29	172.57	1.206	195.15	178.86	1.384	224.01	205.31	1.191	220.92	202.05	1.428	264.80	242.17
W820	4.355	1.2091	170.42	156.16	1.337	188.46	172.70	1.207	195.27	178.98	1.385	224.09	205.39	1.192	221.15	202.25	1.428	264.95	242.31
W830	2.351875	1.2081	170.39	156.08	1.338	188.74	172.89	1.207	195.40	179.11	1.385	224.15	205.46	1.194	221.51	202.59	1.429	265.16	242.52
W840	2.555	1.2087	170.36	156.11	1.337	188.41	172.65	1.206	195.20	178.90	1.384	224.02	205.32	1.192	221.07	202.19	1.428	264.88	242.26
W860	14.695	1.2108	170.58	156.36	1.337	188.37	172.66	1.207	195.32	179.00	1.385	224.20	205.47	1.192	221.02	202.13	1.428	264.91	242.27
W870	0.06125	1.2106	170.54	156.33	1.337	188.28	172.59	1.207	195.24	178.93	1.385	224.14	205.41	1.191	220.90	202.03	1.428	264.83	242.20
W880	0.150625	1.2109	170.57	156.37	1.336	188.25	172.57	1.207	195.24	178.93	1.385	224.15	205.42	1.191	220.86	201.98	1.428	264.81	242.17
W890	3.22625	1.2121	170.69	156.50	1.336	188.17	172.53	1.207	195.25	178.93	1.386	224.21	205.46	1.190	220.73	201.87	1.428	264.76	242.13
W900	6.575	1.2113	170.60	156.41	1.336	188.18	172.53	1.206	195.22	178.90	1.385	224.15	205.41	1.190	220.76	201.89	1.428	264.76	242.13
W850	9.391875	1.2089	170.33	156.11	1.336	188.24	172.53	1.206	195.08	178.80	1.384	223.94	205.25	1.191	220.84	201.98	1.427	264.73	242.12
W950	5.405625	1.1844	167.43	153.07	1.326	187.40	171.33	1.192	192.31	176.68	1.368	220.74	202.79	1.186	219.24	200.83	1.421	262.74	240.68
W1000	3.806875	1.1878	167.71	153.41	1.327	187.37	171.39	1.194	192.58	176.86	1.370	221.07	203.03	1.186	219.29	200.84	1.422	262.86	240.74
W1050	19.424375	1.1866	167.26	153.07	1.325	186.81	170.96	1.192	191.96	176.34	1.369	220.46	202.53	1.184	218.49	200.17	1.421	262.13	240.15
W1100	4.199375	1.1998	169.21	154.95	1.333	187.98	172.15	1.201	194.13	178.06	1.379	222.82	204.37	1.190	220.38	201.65	1.425	264.08	241.64
W1190	3.236875	1.2031	170.13	155.62	1.339	189.40	173.25	1.207	195.50	179.28	1.383	224.03	205.44	1.197	222.30	203.33	1.430	265.60	242.93
W1200	1.785	1.2053	170.17	155.79	1.338	188.92	172.95	1.207	195.33	179.08	1.384	223.99	205.35	1.195	221.72	202.79	1.429	265.24	242.60
W1240	6.793125	1.2027	169.76	155.42	1.335	188.50	172.58	1.204	194.80	178.63	1.381	223.48	204.92	1.192	221.13	202.68	1.427	264.75	242.66
W1260	1.753125	1.1983	169.31	154.92	1.334	188.48	172.46	1.202	194.44	178.35	1.379	223.02	204.57	1.192	221.04	202.24	1.427	264.56	242.06
W5650 / W760	5.755625	1.2047	-	155.65	1.336	-	172.58	1.205	-	178.69	1.382	-	205.03	1.192	-	202.63	1.428	-	242.68
W5660 / W470_Sauce4	0.70625	1.2033	-	155.48	1.336	-	172.58	1.204	-	178.63	1.381	-	204.94	1.192	-	202.66	1.427	-	242.66
W5850/ W740_Sauce1	1.025	1.2073	-	155.94	1.336	-	172.58	1.206	-	178.79	1.384	-	205.19	1.192	-	202.56	1.428	-	242.71
W5720/ W740_Sauce3	1.759375	1.2013	-	155.21	1.335	-	172.43	1.203	-	178.42	1.380	-	204.71	1.191	-	202.53	1.427	-	242.54
W5860/ W740_Sauce2	1.608125	1.2045	-	155.61	1.336	-	172.56	1.204	-	178.66	1.382		205.00	1.192	-	202.61	1.427	-	242.66

A11 Precipitation Subbasins Rio Chamelecón (HecHMS)

		Present state, Storm duration 420 min			Present state, Storm duration 300 min				applied Present state according to Stormduration		
	[km²]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[min]	[mm]	[mm]	[mm]
Subbasin	Area_HecHMS	p_025_420	p_050_420	p_100_420	p_025_300	p_050_300	p_100_300	Stormduration	p025	p050	p100
W400	20.78	141.16	161.87	185.57	129.24	148.40	169.72	420	141.16	161.87	185.57
W410	91.65	140.98	161.63	185.25	129.13	148.23	169.50	420	140.98	161.63	185.25
W420	78.79	140.90	161.61	185.23	129.09	148.20	169.48	420	140.90	161.61	185.23
W430	116.55	138.54	157.37	179.89	127.28	145.46	165.77	420	138.54	157.37	179.89
W440	13.88	139.37	158.38	181.23	127.75	146.17	166.72	300	127.75	146.17	166.72
W450	112.61	123.86	138.93	156.31	117.86	132.31	148.63	420	123.86	138.93	156.31
W460	153.15	134.04	151.10	171.99	124.18	141.10	160.08	420	134.04	151.10	171.99
W470	67.20	130.97	147.31	167.16	122.22	138.38	156.56	420	130.97	147.31	167.16
W480	225.31	112.21	124.57	139.27	109.84	121.97	136.36	420	112.21	124.57	139.27
W490	57.81	123.50	138.64	155.84	117.72	132.09	148.28	420	123.50	138.64	155.84
W500	101.98	118.39	132.27	148.34	114.17	127.52	142.91	420	118.39	132.27	148.34
W510	7.73	123.72	138.93	156.17	117.89	132.30	148.52	300	117.89	132.30	148.52
W520	46.17	120.21	134.47	150.97	115.29	128.99	144.68	420	120.21	134.47	150.97
W530	81.74	129.73	144.43	163.52	121.19	136.65	154.14	420	129.73	144.43	163.52
W540	99.19	141.82	156.42	178.93	128.31	146.03	165.83	420	141.82	156.42	178.93
W550	52.33	123.57	138.74	155.95	117.78	132.16	148.36	420	123.57	138.74	155.95
W560	95.65	122.77	137.63	154.70	117.15	131.36	147.45	420	122.77	137.63	154.70
W570	148.50	122.31	136.27	153.38	116.24	130.20	146.30	420	122.31	136.27	153.38
W580	0.03	108.64	120.15	134.05	107.48	118.91	132.77	300	107.48	118.91	132.77
W590	81.41	108.23	119.63	133.44	107.13	118.48	132.26	420	108.23	119.63	133.44
W600	54.23	112.37	124.73	139.51	109.79	121.94	136.41	420	112.37	124.73	139.51
W610	0.32	107.75	119.04	132.75	106.87	118.12	131.83	300	106.87	118.12	131.83
W620	138.81	108.48	120.04	133.81	106.03	117.38	130.88	420	108.48	120.04	133.81
W630	10.91	108.01	119.36	133.12	106.99	118.29	132.04	300	106.99	118.29	132.04
W640	231.06	106.88	118.57	132.31	102.90	114.18	127.41	420	106.88	118.57	132.31
W650	277.52	112.43	125.02	140.21	108.03	120.21	134.94	420	112.43	125.02	140.21
W660	67.07	107.49	118.88	132.43	104.96	116.13	129.41	420	107.49	118.88	132.43
W670	62.62	103.75	114.43	126.72	99.59	109.86	121.63	300	99.59	109.86	121.63
W680	86.58	103.20	113.80	125.97	98.92	109.10	120.73	420	103.20	113.80	125.97
W690	166.44	103.09	113.61	125.66	98.77	108.87	120.37	420	103.09	113.61	125.66
W700	18.47	102.33	112.69	124.52	98.01	107.94	119.23	300	98.01	107.94	119.23
W710	63.17	102.83	113.40	125.49	98.47	108.59	120.12	420	102.83	113.40	125.49
W720	24.98	102.87	113.35	125.33	98.55	108.60	120.03	300	98.55	108.60	120.03
W730	17.55	102.70	113.14	125.07	98.37	108.38	119.77	300	98.37	108.38	119.77
W740	128.24	110.21	122.11	135.78	105.93	117.39	130.49	420	110.21	122.11	135.78
W750	46.46	106.70	117.88	130.70	102.39	113.14	125.41	300	102.39	113.14	125.41
W760	73.97	104.43	115.21	127.57	100.10	110.46	122.27	300	100.10	110.46	122.27
W770	63.86	113.42	125.76	139.94	109.22	121.14	134.76	300	109.22	121.14	134.76
W780	143.04	128.83	143.71	160.77	125.02	139.50	156.03	420	128.83	143.71	160.77

		Future Scenario T=25a, RCP4.5			Future Scenario T=25a, RCP8.5			Future Scenario T=50a, RCP4.5			Future Scenario T=50a, RCP8.5			Future Scenario T=100a, RCP4.5			Future Scenario T=100a, RCP8.5		
	[km²]	[-] PrecipitationFactor	[mm]	[mm]	[-] PrecipitationFactor	[mm]	[mm]	[-] PrecipitationFactor	[mm]	[mm]	[-] PrecipitationFactor	[mm]	[mm]	[-] PrecipitationFactor	[mm]	[mm]	[-] PrecipitationFactor	[mm]	[mm]
Subbasin	Area_HecHMS	pFac_025_45	p_025_420_45	p_025_300_45	pFac_025_85	p_025_420_85	p_025_300_85	pFac_050_45	p_050_420_45	p_050_300_45	pFac_050_85	p_050_420_85	p_050_300_85	pFac_100_45	p_100_420_45	p_100_300_45	pFac_100_85	p_100_420_85	p_100_300_85
W400	20.78	1.207	170.37	155.99	1.339	189.00	173.05	1.208	195.49	179.22	1.385	224.17	205.51	1.195	221.82	202.87	1.430	265.34	242.68
W410	91.65	1.202	169.45	155.20	1.333	187.98	172.17	1.202	194.27	178.17	1.380	223.00	204.52	1.190	220.37	201.64	1.426	264.13	241.68
W420	78.79	1.203	169.56	155.34	1.334	187.91	172.15	1.202	194.32	178.19	1.380	223.10	204.58	1.189	220.27	201.54	1.426	264.10	241.64
W430	116.55	1.160	160.70	147.64	1.302	180.36	165.70	1.167	183.66	169.76	1.346	211.76	195.74	1.162	209.08	192.67	1.405	252.84	232.99
W440	13.88	1.165	162.34	148.80	1.309	182.50	167.28	1.173	185.77	171.46	1.351	214.01	197.52	1.168	211.66	194.72	1.409	255.40	234.95
W450	112.61	1.074	133.00	126.55	1.197	148.30	141.11	1.071	148.83	141.74	1.255	174.36	166.05	1.067	166.73	158.53	1.346	210.33	200.00
W460	153.15	1.131	151.65	140.50	1.275	170.95	158.38	1.139	172.16	160.76	1.320	199.45	186.25	1.137	195.51	181.98	1.389	238.92	222.38
W470	67.20	1.114	145.96	136.21	1.254	164.28	153.31	1.120	164.96	154.95	1.303	191.88	180.25	1.117	186.77	174.92	1.377	230.17	215.57
W480	225.31	1.078	121.00	118.45	1.185	132.92	130.11	1.066	132.83	130.05	1.275	158.82	155.50	1.071	149.13	146.01	1.370	190.80	186.81
W490	57.81	1.066	131.61	125.45	1.184	146.18	139.34	1.061	147.13	140.18	1.243	172.28	164.14	1.055	164.42	156.45	1.337	208.42	198.31
W500	101.98	1.071	126.80	122.28	1.183	140.02	135.03	1.063	140.54	135.49	1.257	166.33	160.36	1.061	157.43	151.67	1.353	200.77	193.43
W510	7.73	1.064	131.67	125.46	1.181	146.15	139.26	1.060	147.23	140.21	1.239	172.20	163.98	1.053	164.44	156.38	1.335	208.51	198.29
W520	46.17	1.066	128.17	122.92	1.187	142.74	136.90	1.059	142.40	136.60	1.253	168.55	161.69	1.055	159.28	152.65	1.346	203.14	194.67
W530	81.74	1.090	141.42	132.12	1.239	160.79	150.21	1.098	158.64	150.09	1.284	185.44	175.45	1.099	179.64	169.33	1.363	222.86	210.07
W540	99.19	1.122	159.15	143.98	1.300	184.40	166.83	1.150	179.93	167.98	1.325	207.29	193.53	1.159	207.33	192.15	1.395	249.68	231.40
W550	52.33	1.065	131.57	125.40	1.182	146.03	139.19	1.060	147.08	140.11	1.241	172.12	163.96	1.054	164.31	156.32	1.336	208.36	198.23
W560	95.65	1.068	131.16	125.16	1.189	146.01	139.33	1.064	146.44	139.77	1.250	172.05	164.20	1.059	163.87	156.20	1.343	207.72	197.99
W570	148.50	1.065	130.26	123.80	1.208	147.76	140.43	1.062	144.67	138.22	1.262	172.03	164.36	1.058	162.20	154.71	1.344	206.17	196.66
W580	0.03	1.085	117.87	116.60	1.180	128.23	126.86	1.070	128.51	127.18	1.286	154.56	152.97	1.079	144.61	143.22	1.387	185.89	184.11
W590	81.41	1.085	117.38	116.19	1.182	127.92	126.63	1.069	127.89	126.65	1.288	154.05	152.57	1.078	143.88	142.60	1.386	184.95	183.31
W600	54.23	1.073	120.53	117.77	1.188	133.45	130.39	1.060	132.18	129.22	1.274	158.88	155.32	1.062	148.15	144.85	1.366	190.63	186.38
W610	0.32	1.087	117.13	116.17	1.180	127.18	126.14	1.071	127.44	126.45	1.291	153.73	152.54	1.081	143.54	142.55	1.392	184.79	183.51
W620	138.81	1.070	116.05	113.43	1.191	129.20	126.28	1.058	126.95	124.13	1.267	152.12	148.75	1.059	141.64	138.55	1.344	179.81	175.88
W630	10.91	1.085	117.14	116.04	1.183	127.73	126.53	1.069	127.57	126.43	1.289	153.83	152.45	1.078	143.52	142.35	1.387	184.62	183.12
W640	231.06	1.078	115.25	110.96	1.246	133.17	128.21	1.070	126.91	122.21	1.309	155.19	149.45	1.067	141.19	135.96	1.378	182.34	175.59
W650	277.52	1.043	117.22	112.64	1.205	135.52	130.22	1.022	127.83	122.91	1.270	158.76	152.65	1.011	141.76	136.44	1.344	188.46	181.38
W660	67.07	1.069	114.91	112.20	1.195	128.45	125.43	1.056	125.58	122.68	1.270	150.93	147.45	1.057	139.92	136.73	1.344	177.97	173.91
W670	62.62	1.043	108.20	103.86	1.180	122.47	117.56	1.032	118.07	113.35	1.216	139.09	133.54	1.021	129.38	124.18	1.252	158.61	152.25
W680	86.58	1.042	107.50	103.04	1.183	122.04	116.98	1.031	117.31	112.47	1.214	138.11	132.40	1.019	128.33	122.98	1.246	156.95	150.42
W690	166.44	1.033	106.53	102.06	1.169	120.47	115.42	1.022	116.08	111.24	1.193	135.53	129.88	1.008	126.63	121.30	1.217	152.95	146.51
W700	18.47	1.028	105.20	100.77	1.159	118.61	113.61	1.016	114.48	109.66	1.179	132.85	127.26	1.000	124.54	119.25	1.198	149.22	142.89
W710	63.17	1.041	107.06	102.52	1.184	121.79	116.62	1.031	116.90	111.95	1.211	137.37	131.55	1.018	127.74	122.28	1.240	155.55	148.89
W720	24.98	1.033	106.25	101.78	1.170	120.36	115.30	1.021	115.76	110.90	1.193	135.21	129.54	1.007	126.22	120.89	1.214	152.20	145.77
W730	17.55	1.032	105.95	101.49	1.167	119.89	114.84	1.020	115.40	110.55	1.190	134.58	128.92	1.005	125.75	120.42	1.211	151.40	144.99
W740	128.24	1.051	115.80	111.31	1.217	134.12	128.91	1.041	127.14	122.23	1.250	152.68	146.78	1.035	140.52	135.05	1.273	172.91	166.18
W750	46.46	1.046	111.57	107.06	1.209	128.97	123.77	1.035	122.02	117.12	1.240	146.14	140.27	1.029	134.43	128.99	1.259	164.51	157.85
W760	73.97	1.033	107.92	103.44	1.169	122.04	116.98	1.022	117.72	112.86	1.193	137.45	131.78	1.008	128.56	123.22	1.217	155.28	148.82
W770	63.86	1.046	118.60	114.21	1.209	137.10	132.02	1.035	130.19	125.40	1.240	155.92	150.19	1.029	143.93	138.60	1.259	176.14	169.62
W780	143.04	1.046	134.71	130.73	1.209	155.73	151.12	1.035	148.77	144.41	1.240	178.17	172.95	1.029	165.36	160.48	1.259	202.36	196.40

ANNEX 3

Survey Methodological Report

ANNEX 3

METHODOLOGICAL REPORT

SURVEY ON THE IMPACT OF FLOODING ON COMMUNITIES IN VULNERABLE AREAS OF SAN PEDRO SULA 2020

SAN PEDRO SULA
February 2020

1. INTRODUCTION

At the request of the Institute for Environment and Human Security of the United Nations University (UNU-EHS) and the Insulresilient Solutions Fund, for the purpose of implementing the methodology of Economics of Climate Change Adaptation (ECA). The Municipality of San Pedro Sula and the Department of Municipal Research and Statistics (DIEM), through the Census and Surveys Unit and with the guidance of the Competitiveness Office, carried out the survey for the study on the impact of floods on communities in vulnerable areas of the city.

2. OVERALL GOAL

Generate accurate and reliable information on the damage caused to the communities located in the vulnerable areas of the city, in the face of extreme weather events, specifically floods. Ensure that this information serves as a basis for the generation of proposals on adaptation measures based on cost-efficiency criteria and that the relevant agents optimize the use of available resources as well as apply to international funds for additional financing.

3. SURVEY TEAM

General Coordination:	Edgardo Jaco
Field Coordination:	Norma Yessica García
Data Processing Coordination:	Jorge Rivelino Hernández
Coordination of map digitalization:	Eliseo Medrano
Information Validation:	Bertila Bermúdez

Group supervisors:

1. Luis Matamoros
2. Jorge Contreras

Interviewers:

1. Irma Andará
2. Alejandra Sosa
3. Kevin Dominguez
4. Elizabeth Nataren
5. Michelle Villeda
6. Pedro Zavala
7. Margarita in Love
8. Cindy Chavarría
9. Mario Pineda
10. Lariza Arévalo
11. Carmen Cartagena

Revision and Codification:

1.- Ana Delia Tabora
2.- Marco Tulio Duarte

Digitizers:

1. Ovid Florentino
2. Davison Gentleman
3. Herick Quintanilla

4. GEOGRAPHICAL SCOPE (BORDOS AND COLONIAS)

1. Bordo Pueblo Nuevo
2. Bordo Bográn - 2do. Anillo
3. Bordo Rio Blanco
4. Bordo Guadalupe - 2do Anillo
5. Bordo El Limonar
6. Bordo Agua Azul
7. Col. Santa Martha
8. Col. Santa Clara
9. Bordo Dixie
10. Bordo Gavión
11. Col. Fesitranh II 2da etapa
12. Col. Fesitranh II
13. Col. Leonardo Callejas
14. Col. R. Gonzales
15. Col. El Paraíso 2
16. Col. El Paraíso
17. Col. Flor de Cuba
18. Col. El Paraíso 3
19. Col. Alfonso Lacayo
20. Asentamientos Humanos 6 de Mayo
21. Col. Sabillón Cruz
22. Col. Morales 3
23. Col. San José
24. Col. Fe y Esperanza
25. Col. San Jorge
26. Col. Morales4

5. PREPARATION PROCESS

To execution this survey the following preparation steps were carried out:

1. Discussion-meetings and definition of activities with Leaders of Patronages, Community Municipal Friends (AMC) Family Guides and community leaders, according to the tour calendar.
2. Training of personnel according to their functions.
    a. Supervisors
    b. Surveyors
    c. Information Evaluator (Validation)
    d. Critical- encoders
    e. Digitators
3. Preparation of materials by work groups according to the day and place to be visited.
4. Coordination of transportation by group according to the planning of the colonies and borders to be surveyed.
5. Transfer and distribution of field staff according to planning.
6. Supervision during the information collection process
    a. Validation of the information.
7. Review, critique, coding and numbering of the surveys.
8. Processing of collected information.
    a. Validation of the information processed.
    b. Edition of the database
    c. Map digitization
    d. Preparation of the digital base of the maps

6. METHODOLOGY

1. The planning, execution and processing stages of the survey were in charge of the Department of Research and Municipal Statistics (DIEM) with the collaboration of the staff of the Citizen Participation and Community Services Management and under the direction of the Competitiveness Office of the Municipality.
2. The tours in the selected Colonias and Bordos were carried out with the accompaniment of representatives of Patronages, Community Municipal Friends (AMC) Family Guides and community leaders as coordinated during the discussion of the Survey.
3. The research was carried out in the vulnerable areas of districts # 1, 2, 3, 14, 15, 16 and 18.
4. Two work teams were formed, each made up of
    a. 1 Field supervisor
    b. 5 Interviewers
    c. 1 Critical-coding
    d. 1 Digitator
5. The surveys applied by both teams were validated by a random sample by one evaluator.
6. The maps worked by both supervisors were processed by one digitizer.
7. The selection of the houses to be interviewed was made taking into account some aspects:
    a. In Los Bordos: The first option was to interview the houses located on the riverbed or on the internal slope of the riverbank. The second option was to interview the houses located on the crown of the riverbank.
    b. For the Colonias: The houses that are most exposed to flooding were taken

For any of the places visited (Colonias or Bordos) to be included in the survey, they needed to have been "affected by any flooding between 1998 to 2019".

8. The interviews were conducted with men and women of legal age, preferably heads of household and/or spouses or any adult member of the household, with ample knowledge of the floods and damages suffered in the home. It was developed in a face-to-face manner.
9. The tour to each Colonia or Bordo selected was a single visit.
10. The Field Supervisors were responsible for:
    a. Distributing the surveyors in the area
    b. Review the correct completion of the survey
    c. Identify the homes where each survey was completed on the maps
    d. Check and match the ballots with the map.
11. Once the field work is done, the ballots and the map go through the process of critique and codification with the procedure is as follows:
    a. Perform the criticism and consistency test of the ballots coming from the field.
    b. Codify the open questions, the neighborhoods and districts.
    c. Highlight in red the answers obtained from the selection questions.
    d. Sort the ballots by neighborhood.
    e. List the ballots by neighborhood.
12. The already reviewed, coded and numbered surveys were delivered for processing in the "SPSS" software, following the following activities:
    a. Design of the structure
    b. Data entry, validation or consistency
    c. Data editing
13. The worked maps were reviewed and delivered to the Digitization area for their respective processing in the "Auto CAD" Software. And their activities are:

a. To update in the digital base for this project, the location of the surveyed houses in the borders as well as in the colonies.
b. Passing all the updated maps to PDF format.

7. JUSTIFICATION FOR REFORMS

The surveying process faced some setbacks, as explained below, so it was necessary to make some modifications in what was originally planned. These modifications were:

1. 2 Colonias and 1 Bordo were replaced, as it was not possible to obtain the necessary accompaniment from a community leader or organization to access these communities safely. The changes were:

Original Selection	Replacement
a. Aldea Copen	Settlement 6 de Mayo
b. Colonia Palmira	Colonia Morales 3
c. Bordo Santa Ana 2	Colonia Morales 4

2. In 1 Bordo and 3 Colonias it was not possible to comply with the predefined sample due to different situations, which is why it was necessary to increase the sample in other communities of the pre-selected ones. The situations were the following:
   a. Scarce housing or without inhabitants with a report of floods experienced.
   b. Many houses closed or without adult informants (only children in the house).
   c. Many people are reluctant to provide information.
3. The process of digitizing the maps was greater than planned, since it was done with only one digitizer.

8. QUESTIONNAIRE

I. GEOGRAPHICAL IDENTIFICATION

District: __
Neighborhood: _____
Apple: …….
Edification:…….
Unit: ……..

II. INTERVIEW CONTROL

Date: _____/_____/ _____
Surveyor: _____
Supervisor: _____

III. HOUSING DATA

1. Exact address

_____
_____

2. Material of the walls **(**Quality assessment of surveyor: High, Medium, Low**)**

a. [ ] Brick, stone or block
b. [ ] Wood

c. [ ] Asbestos / panelit
d. [ ] Waste
e. [ ] Adobe
f. [ ] Plate
g. [ ] Other
h. [ ] Does not have

3. Roof material **(**Quality assessment of surveyor: High, Medium, Low)

a. [ ] Asbestos
b. [ ] Zinc
c. [ ] Tile
d. [ ] Straw / palm
e. [ ] Waste
f. [ ] Does not have

4. Floor material (Quality assessment of surveyor: High, Medium, Low)

a. [ ] Cement brick
b. [ ] Mud brick
c. [ ] Cement sheet
d. [ ] Wood
e. [ ] Earth
f. [ ] Other

5. Tenure (mark with X)

a. [ ] Own
b. [ ] Rented
c. [ ] Loan / borrowed

6. Do you have any insurance that responds in case of damage?
YES/ NO

7. Does the house have access to the following basic services?

a. Drinking water YES/ NO
b. Electricity YES/ NO

8. The sewage system used in the house is (mark with X)

a. [ ] Connected to sewer
b. [ ] Hydraulic latrine
c. [ ] Simple latrine
d. [ ] Does not have

9. What is the *average* FAMILY income per month (Lps.) (mark with X)

a. [ ] Up to 5000
b. [ ] From 5001— 10,000
c. [ ] From 10001 - 15000
d. [ ] From 15001 - 20000
e. [ ] More than 20000

10. How long has the house been built (mark with X)

a. [] Less than 1 year
b. [] From 1 to 5 years

c. [] From 5 to 10 years old
d. [] From 10 to 20 years old
e. [] More than 20 years
f. [] Don't know

11. How many floors does the house have? _____

12. How many pieces does the house have (Do *not count the bathroom*)? ____

13. Do you have in this house any of the following devices or appliances? (Quantity)

a. [ ] Refrigerator
b. [ ] Washing machine
c. [ ] Television
d. [ ] Fan
e. [ ] Air conditioning
f. [ ] Computer
g. [ ] Radio, sound system
h. [ ] Stove
i. [ ] Microwave
j. [ ] Electronic games: Wii, Nintendo, PlayStation
k. [ ] Beds
l. [ ] Furniture
m. [ ] Vehicle

14. Have livestock or pets in this home? (Quantity)

a. [ ] Cattle (Cows, Bulls)
b. [ ] Sheep
c. [ ] Pigs
d. [ ] Horses
e. [ ] Mares
f. [ ] Dogs
g. [ ] Cats
h. [ ] Birds
i. [ ] Fish

IV. DAMAGE FROM ADVERSE EVENTS

15. Flood caused by Hurricane MITCH - October 1998 (Cost from damage in Lps. due to:**)**

a. Water / mud cleaning _____
b. Affectation in potable water supply _____
c. Affectation in electricity supply _____
d. Damage to the structure of the building _____
e. Loss of livestock / pets _____
f. Damage in computers _____
g. Damage in beds _____
h. Damage in fans _____
i. Damage in air conditioning _____
j. Damage in home appliances _____
k. Damage in furniture _____
l. Damage in electronic games: Xbox, Nintendo, PlayStation _____
m. Damage in vehicle _____
n. Damage in TV / Sound equipment _____
o. Injured people _____
p. Dead people _____
q. Other: _____

16. Flood caused by the Cold Front - January to March 2014

a. Water / mud cleaning _____
b. Affectation in potable water supply _____
c. Affectation in electricity supply _____
d. Damage to the structure of the building _____
e. Loss of livestock / pets _____
f. Damage in computers _____
g. Damage in beds _____
h. Damage in fans _____

i. Damage in air conditioning _____
j. Damage in home appliances _____
k. Damage in furniture _____
l. Damage in electronic games: Xbox, Nintendo, PlayStation _____
m. Damage in vehicle _____
n. Damage in TV / Sound equipment _____
o. Injured people _____
p. Dead people _____
q. Other: _____

17. Flood of January to March 2017

a. Water / mud cleaning _____
b. Affectation in potable water supply _____
c. Affectation in electricity supply _____
d. Damage to the structure of the building _____
e. Loss of livestock / pets _____
f. Damage in computers _____
g. Damage in beds _____
h. Damage in fans _____
i. Damage in air conditioning _____
j. Damage in home appliances _____
k. Damage in furniture _____
l. Damage in electronic games: Xbox, Nintendo, PlayStation _____
m. Damage in vehicle _____
n. Damage in TV / Sound equipment _____
o. Injured people _____
p. Dead people _____
q. Other: _____

18. Other flood event that your remember Year _____

a. Water / mud cleaning _____
b. Affectation in potable water supply _____
c. Affectation in electricity supply _____
d. Damage to the structure of the building _____
e. Loss of livestock / pets _____
f. Damage in computers _____
g. Damage in beds _____
h. Damage in fans _____
i. Damage in air conditioning _____
j. Damage in home appliances _____
k. Damage in furniture _____
l. Damage in electronic games: Xbox, Nintendo, PlayStation _____
m. Damage in vehicle _____
n. Damage in TV / Sound equipment _____
o. Injured people _____
p. Dead people _____
q. Other: _____

9. GENERAL STATISTICS

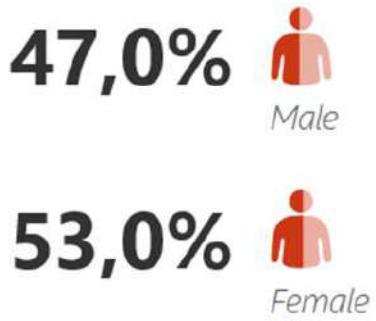


Figure 1 Gender distribution in surveyed sample

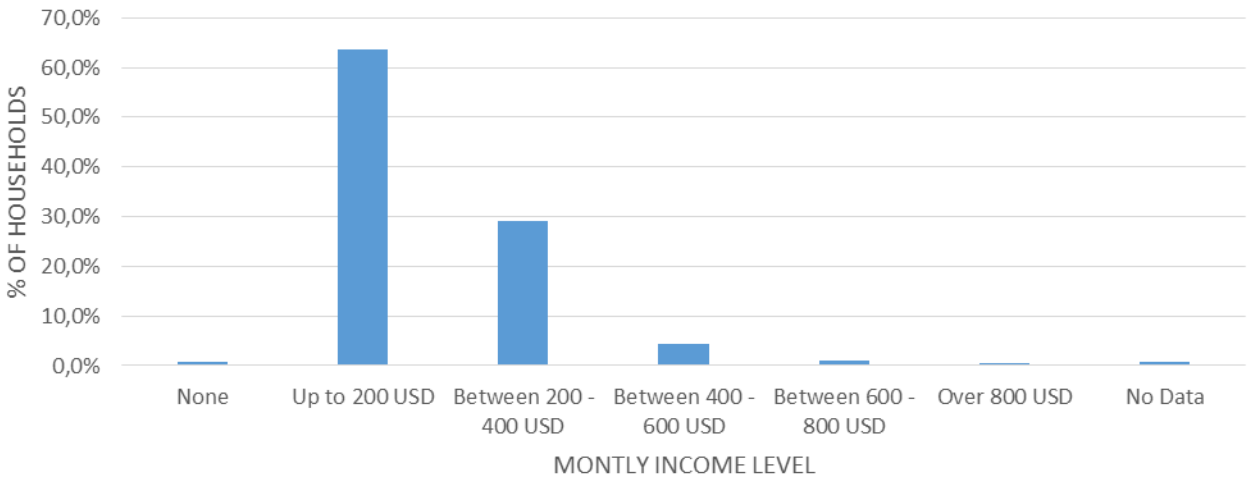


Figure 2 Monthly income level in surveyed sample

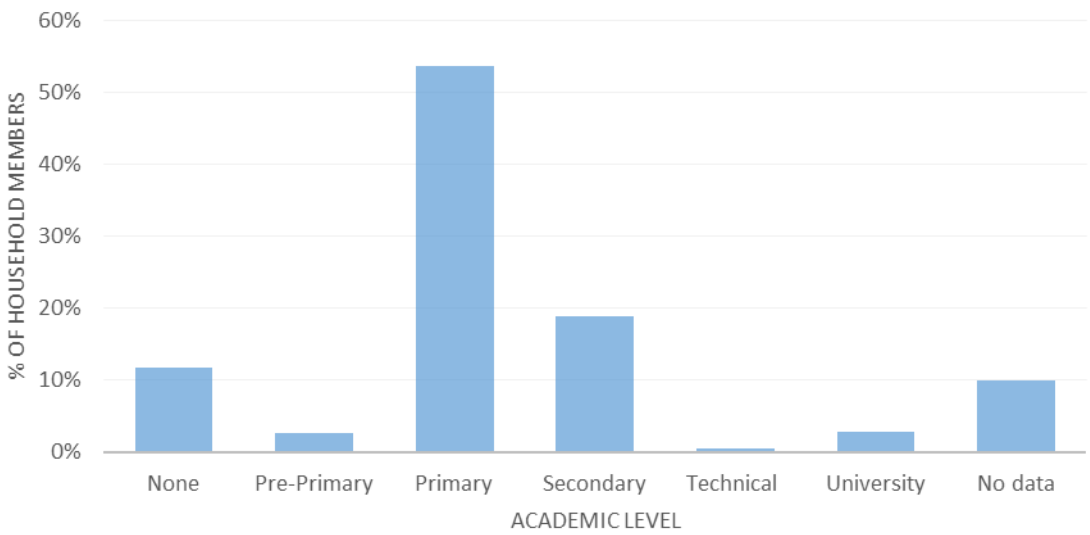


Figure 3 Academic level in surveyed group

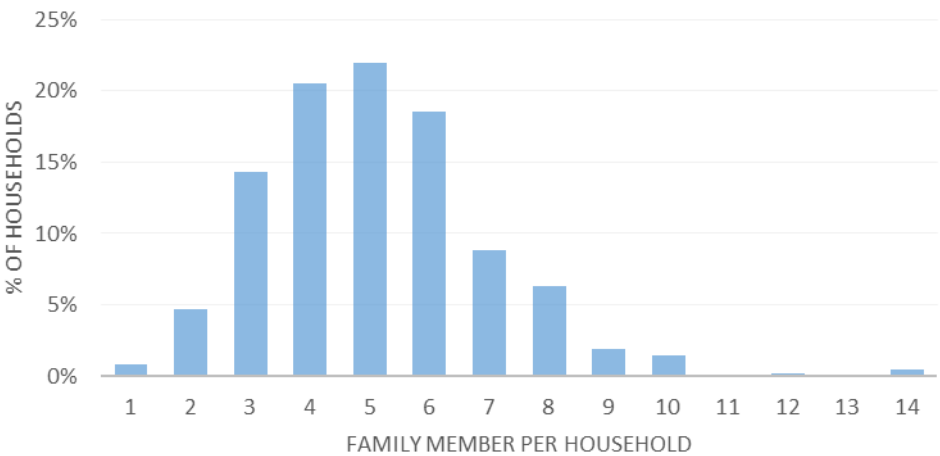


Figure 4 Family membesr per household

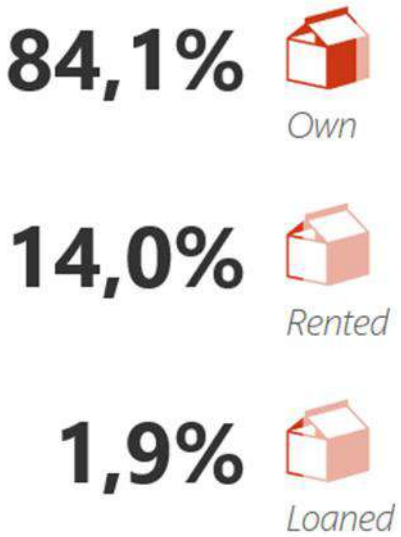


Figure 5 Home tenure on the surveyed group

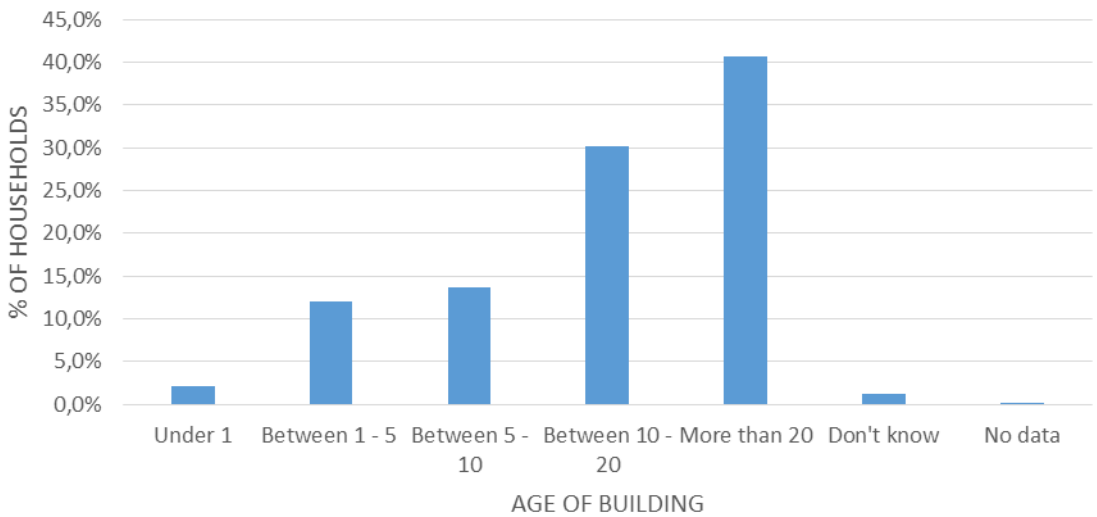


Figure 6 Age of buildings within the surveyed sample

10. PHOTOGRAPHIC DOCUMENTATION OF THE SURVEY

ANNEX 4

Housing Value Los Bordos

ANNEX 4

VALUATION OF HOUSES IN LOS BORDOS

Using the results of the field survey concerning building material and quality, predominantly of the walls and the floor as indicators, the score on build quality, as a foundation for the value estimation of housing in Los Bordos, was developed as follows.

The wall and floor materials as proxies for wealth and housing value were assigned values outlined in Table 1 below.

Table 1 Wall and Floor material factor

Wall material	**Wall value indicator** $\boldsymbol{W}$	**Floor material**	**Floor value indicator** $\boldsymbol{F}$
Brick, stone or block	1	Brick and mortar	1
Wood	0.67	Mud brick	1
Asbestos / panelit	0.67	Cement plate	1
Waste	0.33	Wood	1
Adobe	0.33	Dirt	0
Sheet	0.33	Other	0
other	0.33		
none	0.33		

Depending on the quality of the individual wall and floor material used at the time of the survey the factors were discounted by a quality weight according to three classes as presented in Table 2.

Table 2 Building quality weights

Quality	**Quality weight** $\boldsymbol{q}$
Good	1
Regular	0.9
Bad	0.7

The material value indicators as well as the corresponding quality weights where then applied to the following formula resulting in final value indicators for each surveyed house:

$$Y_i = \frac{W_i q_{W,i} + F_i q_{F,i}}{2}$$

Where:

$$Y_i: value\ indicator\ for\ house\ i$$

$$W_i: wall\ material\ factor\ of\ house\ i$$

$$F_i: floor\ material\ factor\ of\ house\ i$$

$$q_{F,i}: quality\ factor\ of\ the\ floor\ of\ house\ i$$

$$q_{W,i}: quality\ factor\ of\ the\ wall\ of\ house\ i$$

The resulting value indicator Y_i hence lies between a value of 0.1155 and 1 which then was multiplied by the assumed maximum housing value of 5000 USD resulting in a value scale from 577.5 USD to 5000 USD.

Similarly, the same value indicator was used as a family's wealth proxy to determine the probable value of the possessions at risk within the house, e.g. electrical appliances and furniture. Following the same rationale the individual value indicator Y_i was multiplied by the assumed maximum value of the household assets of 5,300 USD based on regional estimates resulting in a scale from 612.15 USD to 5,300 USD.

ANNEX 5

Measure selection procedure

ANNEX 5

MEASURES' SELECTION PROCESS

1. Background

In the case of the municipality San Pedro Sula and the associated flood risk, a set of adaptation measures had to be identified and tailored to the existing flood risk for the selected assets and population. The selection and introduction of adaptation measures is an essential part of the ECA framework and requires specific steps of engagement and participation with key stakeholders in order to determine and validate their economic viability and sustainability. The following sections describe the process of selecting appropriate adaptation measures, starting from a pre-selection ("Long List") of measures up to a final selection of measures ("Short List"), that are parameterised and introduced to the probabilistic modelling tool CLIMADA.

2. Defining a "Long List" of Adaptation Measures

The initial phase of identifying adaptation measures has been based on comprehensive literature review, consultations with key experts and members of the municipality of San Pedro Sula. The following key aspects have been considered in the process of selecting a long list of adaptation measures:

- Include international best practice of urban flood mitigation and adaptation.
- Include and respect local existing master plans on climate adaptation or municipal strategies for infrastructure development, i.e. what adaptation measures are already included in local and national climate strategies and action plans?
- Include best practice of local context, similar to the regions' condition, i.e. what adaptation measures have been used for urban flood risk, e.g. in neighbouring countries or regions?

With regard to the last aspect, one of the key documents was San Pedro Sula's "C7 - *Plan de Acción de Gobierno Municipal*" from November 2017. This document has been part of the municipals master plan with a vision of 25 years ahead and describes planned programs and projects which a key to the city's development and well-being.

As a result, and considering the mentioned key aspects the following list of measures have been compiled, covering 47 measures in total, divided into 10 clusters (see Table 1).

Table 1: *"Long List" of identified flood adaptation measures for San Pedro Sula.*

Cluster	Measures
1. Improvement and establishment of flood drainage system	1. Establishment of flood collectors which have been designed but construction is pending, e.g. tender processes 2. Proposed construction of two new collectors 3. Proposed improvements to existing flood drainage systems 4. Maintenance of open drainage channels (CDR = Channel Debris Removal)

2. Improvement of water supply and sanitation systems	5. Elimination of leaks in the drinking water network
3. Improvement & enforcement of river systems (incl. slopes and beds)	6. Side Weirs (Relief Channels) 7. Levees to protect flood plains 8. Gabion Riverbank Protection 9. Flood walls 10. Ecological restoration of river bank slopes (Riparian restoration) 11. Submergible pathways (incl. bicycle lanes) 12. Green Corridors in riverbeds
4. Flood proofing of electricity infrastructure	13. Reinforce poles (anchoring, hardening) 14. Elevate flood-prone substations 15. Segmenting transmission system ("Smart Grid") 16. Protective walls for substations 17. Underground transmission lines 18. Tree Maintenance (pruning)
5. Improvement of (semi-) urban green areas	19. Dry Detention Basins 20. Wet Retention Ponds 21. Urban Forestry (Urban Catchment Forestry)
6. Improvement of building design (flood proofing)	22. Elevated houses 23. Green Roofs/ Rooftop gardens 24. Water collection in existing buildings 25. Dry Flood-Proofing (housing) 26. Wet Flood-Proofing (housing)
7. Flood resilient road networks (main & secondary) & public sealed areas	27. Check dams along streets (made from recessed rock) 28. Vegetated swales 29. Improved street inlets 30. Improvement of culverts 31. Modular water retention systems under sealed areas 32. Infiltration trenches/wells 33. Permeable paving (porous, open-cell paving) 34. Water plazas (reservoirs) 35. Elevated Roads 36. Vegetation along roads
8. Large infrastructure projects	37. “El Tablon” Hydropower Dam 38. "El Carmen" Metropolitan Park (conservation of aquifer recharge area)
9. Non-structural measures	39. Flood Awareness & Preparedness Campaign 40. Improved solid waste management 41. Garbage-free areas 42. Cleaning of watercourses 43. Enhancement of zoning and land use planning to guide urban development away from high-risk areas 44. Improvement of mechanisms for data collection, storage and dissemination for better flood monitoring 48. Flow & Discharge Stations 49. Weather Stations
10. Risk Transfer (Insurance)	45. Sovereign Flood Fund 46. Rent Insurance 47. Flood Index Insurance

3. Stakeholder Assignment No. 1 - Validation and Allocation of Measures

In order to validate and further reduce the amount of measures on the long list, an assignment has been designed for key stakeholders of San Pedro Sula. For this reason, a list presenting the clusters and respective measures (as of Table 1) including exemplary photos has been created to provide a better understanding of the measures (Figure 1). Furthermore, a flood map of San Pedro Sula, showing the districts (ECA study area) and suggestions of cluster allocations has been enclosed (Figure 2). Thirteen participants of the municipality of San Pedro Sula have been identified for the assignment. The following has been requested:

1. Asses the locations of the adaptation clusters and decide whether you like to add or remove a cluster for a respective district.
2. Once you agree with the allocated clusters in the districts, which measure(s) from each cluster would you choose? Select measures (max. 3) from each cluster and name.
3. In case, a cluster does not contain a specific measure you prefer, feel free to insert a new measure.

Figure 1: *List of adaptation cluster with respective measures - as presented in the assignment.*

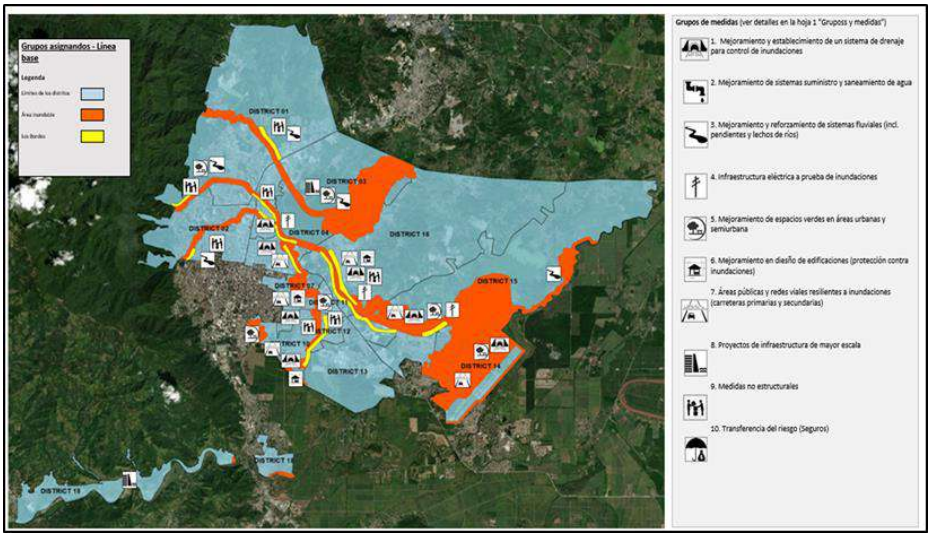


Figure 2: *Flood map of San Pedro Sula with mapped suggestions of adaptation clusters.*

As a result, 30 measures have been mentioned most, i.e. 3-5 mentions among the 13 participating stakeholders. From these, two new measures have been named. The locations of the clusters and the respective measures have been adjusted and validated as well. These 30 measures will be subject to a *Multi-Criteria Analysis*, in order to identify a "Short List" of measures which can be imported to CLIMADA. The results of the assignment can be found in Table 1.

Table 2: *List of measures mentioned most in the assignment (3-5 mentions), including locations based on districts.*

#	Measure	District
1	Establishment of flood collectors which have been designed but construction is pending, e.g. tender processes	3, 4, 7, 10, 13, 14, 16
2	Proposed construction of new collectors	3, 4, 7, 10, 13,14,15,16
3	Proposed improvements to existing flood drainage systems	3, 4, 7, 10, 13, 14, 15, 16
4	Maintenance of open drainage channels (CDR = Channel Debris Removal)	15
5	Side Weirs (Relief Channels)	15
6	Gabion Riverbank Protection	1, 2, 3, 13, 15, 18
7	Ecological restoration of river bank slopes (Riparian restoration)	1, 2, 3, 18
8	Green Corridors in riverbeds	2
9	Reinforce poles (anchoring, hardening)	15, 16
10	Segmenting transmission system ("Smart Grid")	15, 16
11	Protective walls for substations	4
12	Tree Maintenance (pruning)	4, 15, 16
13	Dry Detention Basins	1, 2, 3, 11, 14, 15
14	Wet Retention Ponds	1, 2, 3, 10, 11, 14, 15, 18
15	Improvement and Reforestation of all green spaces in (semi) urban areas	All
16	Green Roofs	7, 10, 16,
17	Water collection in existing buildings	7, 10, 16
18	Dry Flood-Proofing (housing)	7, 10
19	Vegetated swales	7

20	Improved street inlets	14, 15, 16
21	Improvement of culverts	7, 10, 14, 15, 16, 18
22	Flood Awareness & Preparedness Campaign	1, 2, 3, 12, 16
23	Improved solid waste management	1, 3, 10, 12
24	Cleaning of watercourses	1, 2, 3, 10, 12, 16
25	Enhancement of zoning and land use planning to guide urban development away from high-risk areas	1, 2
26	Rent Insurance	4, 7, 10
27	Flood Index Insurance	4, 7, 10
28	Infiltration trenches/wells	3,4,7, 14,15,16
29	Weather Stations	NA
30	Flow & Discharge Stations	NA

4. Assignment No. 2 – Validation and Weighting of Selection Criteria

After identifying a long list of 30 measures, the most promising adaptation measures should be parameterised within CLIMADA. To do so, it is best practice to reduce the long list of adaption measures into a "Short List", based on specific selection criteria. Selection criteria are attributes or characteristics that have been identified of being essential to address food risk but also to satisfy requirements such as sustainability and economic relevance. The following selection criteria have been validated by 13 key stakeholders:

1. Ecosystem-based Adaptation (EbA): EbA is officially defined by the Convention on Biological Diversity (CBD) as 'the use of biodiversity and ecosystem services [...] to help people to adapt to the adverse effects of climate change' which may include 'sustainable management, conservation and restoration of ecosystems, as part of an overall adaptation strategy that takes into account the multiple social, economic and cultural co-benefits for local communities'[1].

2. No-Regret Options (Risk Gradient): Adaptation strategies can be useful even in the absence of climate change or in case of uncertainty regarding future climate change impacts (risk-independent) or they can be risk-specific, where their implementation is only sensible when a risk is actually present (e.g. insurances).

3. Beneficial to Assets: Adaptation measures should target two important assets: Vulnerable People and Informal Settlements ('Los Bordos').

4. Social Acceptance: An indicator for assessing adaptation measures is the interest that stakeholders show in a strategy or measure, as this crucially determines future uptake/acceptance and implementation. This acceptance can be based individually on environmental, social, financial, physical, health or ethical parameters.

5. Spatial Requirement: Some measures might require valuable urban space which, in many times, is scarce. This criteria deals with the spatial dimension of adaptation measures.

[1] Secretariat of the Convention on Biological Diversity (2009). *Connecting Biodiversity and Climate Change Mitigation and Adaptation: Report of the Second Ad Hoc Technical Expert Group on Biodiversity and Climate Change*. Montreal, Technical Series No. 41, 126 pages.

6. Contribution to the municipalities' Master Plan (PMDM): Adaptation measures should align with existing strategies or municipal master plans, such as the report *Plan de Acción de Gobierno Municipal (C7),* which outlines planned programs and projects.

After validating the above mentioned selection criteria, another assignment with key stakeholders was carried out to *weigh the criteria* for a later use in a Multi-Criteria Analysis. Stakeholders were asked to rank the validated criteria by assigning a score varying from 6 (most important) to 1 (least important). For each criterion, the average value of all assigned scores represents the weight. This weight will be applied in the Multi-Criteria Analysis. The results of the ranking and the resulting weight of each criterion is shown in Table 3.

Table 3: *Weighting of selection criteria. Rank from 6 (most important) to 1 (least important). Rank values could be used multiple times. Names of the 13 participants have been made anonymous and stated as "P1" (Person 1) to "P13" (Person 13).*

CRITERION	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	WEIGHT
EbA	6	6	6	4	6	4	6	3	6	3	6	4	6	**5,1**
No-Regret Options	1	1	5	3	3	2	3	2	3	1	3	4	1	**2,5**
Beneficial To Assets	3	2	3	4	4	4	5	6	4	6	5	5	3	**4,2**
Social Acceptance	4	3	4	5	6	6	4	5	5	1	5	4	4	**4,3**
Spatial Requirement	4	4	4	3	3	3	2	1	3	2	2	3	2	**2,8**
PMDM Contribution	5	5	3	6	5	5	2	4	4	5	4	5	5	**4,5**

As a result, the criterion *Ecosystem-based Adaptation (EbA)* and *PMDM Contribution* have given the highest weight. The criterion *Spatial Requirement* has been given a low weight, hence less significant for a potential adaptation measure. These weights (as of Table 3) have been used in a Multi-Criteria Analysis, to further reduce measures from the "Long List".

5. Multi-Criteria Analysis - Defining a "Short-List" of Adaptation Measures

A Multi-Criteria Analysis (MCA) describes a structured approach used to determine overall preferences among alternative options, where the options accomplish several objectives. MCA is a type of decision analysis tool that is particularly applicable to cases where a single-criterion approach falls short (e.g. cost-benefit), and where multiple criterion need to be included.

The MCA has been applied to the remaining measures (i.e. 30) to further shorten the list of measures and to conclude a short list that can be introduced to CLIMADA. Results of the MCA are shown in Figure 3. The final "Short-List" of measures, as a result of the MCA is shown in Table 4.

Table 4: *"Short List" of flood adaptation measures for San Pedro Sula, based on the results from the Multi-Criteria Analysis (Figure 3). Measures are listed according to their respective type. 'Grey' measures refer to technological and engineering solutions. 'Green' measures refer to ecosystem-based (or nature-based) approaches and make use of multiple services*

*provided by natural ecosystems. 'Operational' measures focus on any type of maintenance/operation that is introduced or improved. 'Monitoring' measures include instruments/tools that improve monitoring and information bases. 'Insurance' solutions cover residual risks, which occur when adaptation measures are not cost-efficient. Measures indicated with a * are not introduced to CLIMADA, rather stated as a recommendation.*

#	Name of Measure	Type of Measure
1	Establishment of flood collectors (drainage system)	Grey
2	Water collection in existing buildings	Grey
3	Dry Flood-Proofing (housing)	Grey
4	"El Tablon" Hydropower Dam	Grey
5	Ecological restoration of river bank slopes	Green
6	Dry Detention Basins	Green
7	Improvement & Reforestation of green spaces in urban areas	Green
8	Green Roofs	Green
9	Vegetated swales	Green
10	Flood Awareness & Preparedness Campaign (impact on persons)	Operational
11	Community based solid waste management	Operational
12	Flood Index Insurance	Insurance
13	Weather Stations*	Monitoring
14	Discharge Stations*	Monitoring

Multi-Criteria Analysis Decision Matrix

#	Measures Long List	EbA	No-Regret	Assets	Social	Spatial	PMDM	Total Score	Short List
	Criteria:	EbA	No-Regret	Assets	Social	Spatial	PMDM		
	Weight:	5,1	2,5	4,2	4,3	2,8	4,5		
1	Establishment of flood collectors which have been designed but construction is pending, e.g. tender processes	0,0	0,0	1,0	1,0	1,0	1,0	**15,8**	1
2	Proposed construction of new collectors	0,0	0,0	1,0	0,5	1,0	1,0	**13,65**	
3	Proposed improvements to existing flood drainage systems	0,0	0,0	0,5	1,0	1,0	1,0	**13,7**	
4	Maintenance of open drainage channels (CDR = Channel Debris Removal)	0,0	1,0	0,0	0,5	1,0	0,0	**7,45**	
5	Side Weirs (Relief Channels)	1,0	0,0	0,0	1,0	0,0	0,0	**9,4**	
6	Gabion Riverbank Protection	0,0	0,0	0,0	0,5	0,5	0,0	**3,55**	
7	Ecological restoration of river bank slopes (Riparian restoration/Green Corridors)	1,0	1,0	0,0	1,0	0,0	1,0	**16,4**	2
8	Green Corridors in riverbeds	1,0	1,0	0,0	1,0	0,0	1,0	**16,4**	
9	Reinforce poles (anchoring, hardening)	0,0	0,0	0,0	0,0	1,0	0,0	**2,8**	
10	Segmenting transmission system ("Smart Grid")	0,0	0,0	0,0	0,5	1,0	1,0	**9,45**	
11	Protective walls for substations	0,0	0,0	0,0	0,0	1,0	0,0	**2,8**	
12	Tree Maintenance	0,0	1,0	0,0	0,5	1,0	0,0	**7,45**	3
13	Dry/Wet Detention Basins	1,0	1,0	0,0	1,0	0,0	0,0	**11,9**	4
14	Wet Retention Ponds	1,0	0,5	0,0	1,0	0,0	0,0	**10,65**	
15	Improvement and Reforestation of all green spaces in (semi) urban areas (Urban/Upper Catchment Forestry)	1,0	1,0	0,0	1,0	0,5	1,0	**17,8**	5
16	Green Roofs	1,0	1,0	0,0	1,0	0,5	0,0	**13,3**	6
17	Water collection in existing buildings	0,0	1,0	0,5	0,5	1,0	0,0	**9,55**	7
18	Dry Flood-Proofing	0,0	1,0	0,0	0,5	1,0	1,0	**11,95**	8
19	Vegetated swales	1,0	1,0	0,0	1,0	1,0	1,0	**19,2**	9
20	Improved street inlets	0,0	1,0	0,0	0,5	1,0	1,0	**11,95**	10
21	Improvement of culverts	0,0	0,0	0,0	0,5	1,0	0,0	**4,95**	
22	Flood Awareness & Preparedness Campaign	0,0	0,0	1,0	1,0	1,0	1,0	**15,8**	11
23	Community based solid waste management	0,0	1,0	1,0	1,0	1,0	1,0	**18,3**	12
24	Cleaning of watercourses	0,0	1,0	1,0	1,0	1,0	1,0	**18,3**	
25	Infiltration wells	1,0	1,0	1,0	1,0	0,5	0,0	**17,5**	13
26	Enhancement of zoning and land use planning to guide urban development away from high-risk areas	0,0	1,0	1,0	0,5	0,5	0,0	**10,25**	
27	Rent Insurance	0,0	0,0	0,0	1,0	1,0	0,0	**7,1**	
28	Flood Index Insurance	0,0	0,0	1,0	1,0	1,0	0,0	**11,3**	14
29	Weather Stations	0,0	1,0	0,5	1,0	1,0	0,0	**11,7**	15
30	Flow & Discharge Stations	0,0	1,0	0,5	0,5	1,0	1,0	**14,05**	16

Figure 3: *Results of the MCA. The selection criteria have been applied to the remaining measures of the long list. The criteria were applied to the measures with the following values: EbA [Yes (1), No (0)], No-Regret Options [Yes (1), No (0)], Benefit to Assets [Yes (1), No (0)], Social Acceptance [High (1), Medium (0.5), Low], Spatial Requirement [High (0), Medium (0.5), Low], PMDM Contribution [Yes (1), No (0)]. Measures indicated in 'red' are considered to be merged with the measure stated before. Measures indicated in 'green' representing the "Short List" of identified measures.*

ANNEX 6

Detailed description of measures

ANNEX 6

Description of Flood Adaptation Measures

For the study area of San Pedro Sula, 14 adaptation measures have been identified based on specific selection criteria (see Annex 6.1). The final selection of measures is classified into different adaptation types, of which 5 consist of grey infrastructure, 5 of green infrastructure and ecosystem-based approaches, 2 of operational measures, 2 of monitoring measures to better collect meteorological and hydrological data, and one risk transfer solution, such as flood index insurance. The list of selected measures is shown below in Table 1.

Table 1: *Overview List of Flood Adaptation Measures for San Pedro Sula. 'Grey' measures refer to technological and engineering solutions. 'Green' measures refer to ecosystem-based (or nature-based) approaches and make use of multiple services provided by natural ecosystems. 'Operational' measures focus on any type of maintenance/operation that is introduced or improved. 'Monitoring' measures include instruments/tools that improve monitoring and information bases. 'Insurance' solutions cover residual risks, which occur when adaptation measures are not cost-efficient.*

#	Name of Measure	Type of Measure
1	Establishment of flood collectors (drainage system)	Grey
2	Water collection in existing buildings	Grey
3	Dry Flood-Proofing (housing)	Grey
4	"El Tablon" Hydropower Dam	Grey
5	Ecological restoration of river bank slopes	Green
6	Dry Detention Basins	Green
7	Improvement & Reforestation of green spaces in urban areas	Green
8	Green Roofs	Green
9	Vegetated swales	Green
10	Flood Awareness & Preparedness Campaign (impact on persons)	Operational
11	Community based solid waste management	Operational
12	Flood Index Insurance	Insurance
13	Weather Stations*	Monitoring
14	Discharge Stations*	Monitoring

*Measures not introduced to CLIMADA. Stated as additional recommendations in a separate chapter.

1. Context

The major rivers, which have led to flooding events in the past, posing a risk to San Pedro Sula and its outskirts, are the rivers *Río Blanco*, *Río Bermejo*, *Río Piedras*, *Río Chotepe* and *Río Chamelecón*. In order to efficiently model the effects of flooding for certain events, it was necessary to distribute the rivers of interest into several models. The achievement of results with a high spatial resolution, for a region of interest of this extent, was only possible by the division of the area into three separate models. Río Blanco being a separate river system was easily distinguishable. The "Model Río Blanco" (Zone A) is identified as the yellow region in Figure 1. The "Model Río Chotepe" (Zone B) consists of the rivers Río Chotepe, Piedras and Bermejo and is indicated in red in the figure below. Finally, it was decided to "Model Río Chamelecón" (Zone C) separately (blue area in Figure 1), despite river Bermejo, forming an inflow to the former. This decision was based on the different catchment extents and the locations of the areas of interests, as well as total number of cells and the resulting computational costs of each model. The measures described below have been allocated to the respective river catchments, which

we refer to in the following as **Zone A** (Río Blanco), **Zone B** (Río Chotepe) and **Zone C** (Río Chamelecón) as illustrated on the map below in Figure 1.

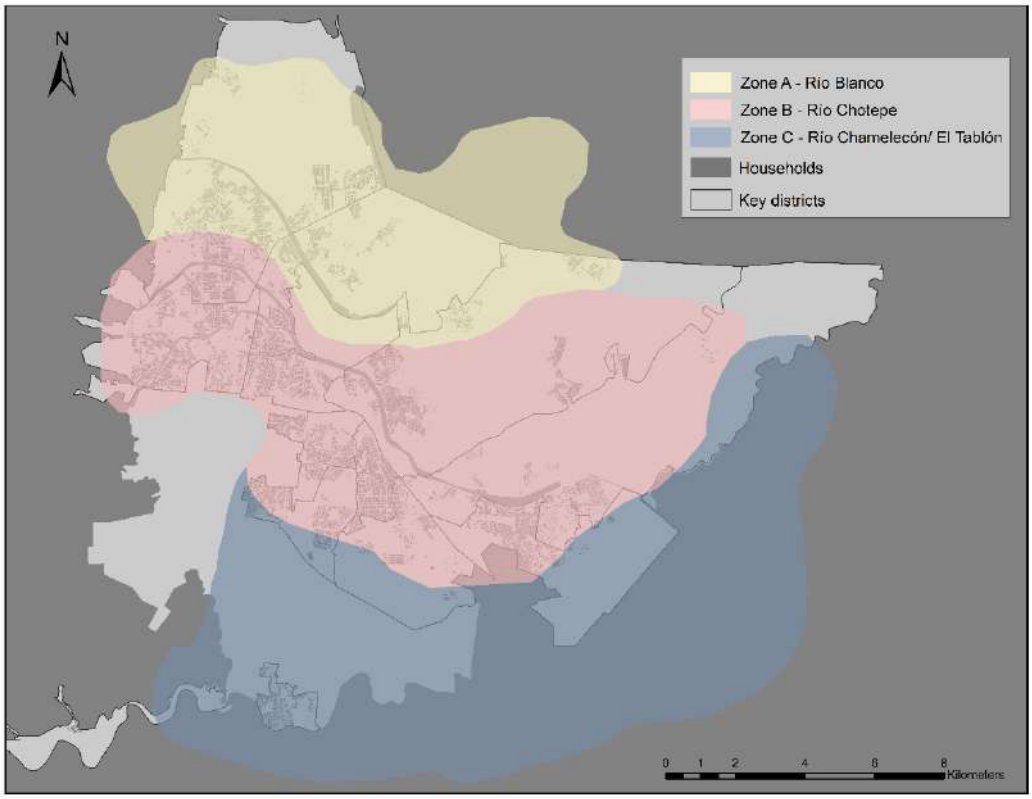


Figure 1: *Overview of the zonation: A.) Río Blanco catchment, B.) Río Chotepe, Río Bermejo, Río Piedras and Canal Sauce catchment, C.) Río Chamelecón catchment*

The modelling for the three river catchments was carried out for the return periods of 25, 50 and 100 years, combining two future scenarios, RCP4.5 and RCP8.5. The following tables show simulation results for peak flows of Rio Blanco, Rio Chamelecón and Rio Chotepe (Figure 2).

Rio Blanco	RP 25	RP 50	RP 100
Q Present state	1'110.5 m³/s	1'331.4 m³/s	1'425.0 m³/s
Q Future Scenario RCP4.5	1'229.4 m³/s	1'514.5 m³/s	1'854.4 m³/s
Q Future Scenario RCP8.5	1'446.1 m³/s	1'869.0 m³/s	2'392.9 m³/s

Rio Chotepe	RP 25	RP 50	RP 100
Q Present state	999 m³/s	1'229.1 m³/s	1'493.2 m³/s
Q Future Scenario RCP4.5	1'294.5 m³/s	1'585.5 m³/s	1'883.6 m³/s
Q Future Scenario RCP8.5	1'513.1 m³/s	1'917.7 m³/s	2'396.0 m³/s

Rio Chamelecón	RP 25	RP 50	RP 100
Q Present state	1'210.0 m³/s	1'792.0 m³/s	2'108.0 m³/s
Q Future Scenario RCP4.5	1'282.5 m³/s	1'685.4 m³/s	2'213.0 m³/s
Q Future Scenario RCP8.5	1'707.5 m³/s	2'398.8 m³/s	3'470.1 m³/s

Figure 2: *Simulation results for peak flows of Rio Blanco, Rio Chamelecón and Rio Chotepe.*

2. Establishment of Flood Collectors (Drainage System)

The municipals' storm water drainage system is crucial to collect high quantities of water which accumulate in large amounts on the streets and passages. All systems consist of reinforced concrete channels, mainly of trapezoidal shape. This study considers sections of the drainage system that are in planning and design as well as existing systems that are planned to be improved, i.e. maintained and appropriately cleaned to ensure a full functioning. Sediment build-up in the drainage channels reduces their capacity and increases the potential for flooding; it also results in higher pollutant concentrations flushed out during large storm events. Other problems that could reduce the conveyance capacity of the channels could be root intrusion from vegetation or simple debris and other blockage. The following collector system are targeted to be improved and cleaned to ensure the drainage capacities. It is recommended that all the storm water channels be cleaned every year, with costs representing 2% of the total construction costs. Since the exact dimensions of the open concrete drainage systems is not known, we assume an average drainage collector dimension (U-profile) of 0.7 meter in width and 0.5 meter in depth, which represents a storage capacity of 0,35 m^3 (1m*0.7m*0.5m) per running meter of drainage system.

2.1 New collectors (Designed & Planned)

Table 2: *Establishment of flood collectors which have been designed and planned but not constructed yet. Collectors for the selected study area. The costs are provided in Lempira and US Dollar.*

Name Collector	Length (m)	Type/Material	Cost (Lempira)	Cost (USD)	District	Zone
Designed and planned (new collectors)						
Zona Industrial Satélite	2430.88	Concrete	23.613.494,36	956.855,39	11, 15	B
Jardines del Valle	1004.25	Concrete	43.470.824,01	1.761.505,17	1	B
El Zapotal, Río Blanco	741.67	Concrete	31.955.345,93	1.300.583,88	1	A
Santa Mónica, Río Blanco	740.49	Concrete	31.904.504,95	1.298.514,65	1	A
Canal Circuito Norte	2494.66	Concrete	12.174.763,90	495.546,25	1	B
Morazan, Las Vegas	1303.71	Concrete	78.493.941,16	3.194.706,60	4	B
Zona Industrial - Calpules	8368.64	Concrete	360.568.430,34	14.675.149,79	13	B
TOTAL	**17084.30**		**582.181.304,65**	**23.682.861,73**		

The collectors *El Zapotal* and *Santa Mónica* are planned to mitigate peak flows from **Rio Blanco (Zone A)**, i.e. 2392.9 m^3/sec (RCP8.5; TR100). Combined they have a total length of 1482.16 meters. Considering a U-profile (1m*0.7m*0.5m), this represents a storage capacity of 592.86 m^3. Assuming a clean state of the channels (no debris, no blockage through household waste or illegal garbage), we consider that the collectors can theoretically absorb 24.78% of the flow peak of extreme flood. However, collectors have an optimum working capacity by 80%. It means only 19.82% (24.78*0.8) can be actually channelled from the peak flow by theses collectors. In addition, very often, collectors are impaired by debris and household waste. This leads to a reduction of the hydraulic capacity of

collectors from 20% to 65%.[1] Consequently, the actual reduction capacity of the collectors under these assumptions is 15.85% (19.82*0.8) to 6.93% (19.82*0.35).[2] We recommend to use a reduction capacity of 6.93% for old channels (not refurbished) and 15.85% for recently refurbished collectors.

The remaining collectors (see Table 2) will contribute to the mitigation of peak flows from **Rio Chotepe (Zone B)** with 2396.0 m³/sec (RCP8.5; TR100). Combined they have a total length of 15602.14 meters. Considering a U-profile (1m*0.7m*0.5m), this represents a storage capacity of 5460.74 m³. Assuming a clean state of the channels (no debris, no blockage through household waste or illegal garbage), we consider that the collectors can theoretically absorb 100% of the flow peak of extreme flood. They theoretically have a capacity of 228% that performs beyond the projected peak flow and could handle peak flows up to 5462.88m³/sec. However, collectors have an optimum working capacity by 80%. It means only 182.4% (228*0.8) can be actually channelled from the peak flow by theses collectors. In addition, very often, collectors are impaired by debris and household waste. This leads to a reduction of the hydraulic capacity of collectors from 20% to 65%.[3] Consequently, the actual reduction capacity of the collectors under these assumptions is 145.76% (182.2*0.8) to 63.84% (182.4*0.35). We recommend to use a reduction capacity of 63.84% for old channels (not refurbished) and 145.76% for recently refurbished collectors.

2.2 Existing Collectors (Maintained & Refurbished)

Table 3: *Improvement and cleaning of existing storm water collectors of the drainage system. The costs are provided in Lempira and US Dollar.*

Name Collector	Length (meters)	Type	Cost (Lempira)*	Cost (USD)	District	Zone
Refurbishment						
Canal Castaños	1719.15	Concrete	472.030.118,57	19.397,17	3	A
Canal Fesitranh	2283.58	Concrete	627.006.682,46	25.765,63	1	A
Canal Campisa	1913.27	Concrete	525.329.997,35	21.587,43	3	A
Canal Tepeaca	1643.55	Concrete	451.272.490,11	18.544,17	7	B
Canal El Sauce	5890.68	Concrete	1.617.414.640,28	66.464,54	4, 7, 11, 10, 13	B
Canal Santa Martha – Lomas Dl Cármen	1058.92	Concrete	290.749.575,75	11.947,79	16	B
Canal 27 Calle	3647.96	Concrete	1.001.626.961,77	41.159,93	10, 12, 13	B
Canal Satélite	1896.68	Concrete	520.774.851,11	21.400,24	11, 12	B
Canal Felipe Zelaya	5674.22	Concrete	1.557.980.827,37	64.022,22	15	B
Canal 6 de Mayo	1301.55	Concrete	357.368.932,80	14.685,39	15	B

[1] Leitão, J. P., Simões, N. E., Pina, R. D., Ochoa-Rodriguez, S., Onof, C., & Marques, A. S. (2017). Stochastic evaluation of the impact of sewer inlets' hydraulic capacity on urban pluvial flooding. *Stochastic environmental research and risk assessment*, 31(8), 1907-1922.

[2] (CHANEL m3 of total length*100/PEAK FLOW)*0.8*0.8= clean collectors impact reduction capacity
(CHANEL m3 of total length*100/PEAK FLOW)*0.8*0.35= "old" collectors impact reduction capacity

[3] Leitão, J. P., Simões, N. E., Pina, R. D., Ochoa-Rodriguez, S., Onof, C., & Marques, A. S. (2017). Stochastic evaluation of the impact of sewer inlets' hydraulic capacity on urban pluvial flooding. *Stochastic environmental research and risk assessment*, 31(8), 1907-1922.

Canal Guillen	1130.64	Concrete	310.441.865,61	12.757,01	10	B
Canal Sunsery	2593.72	Concrete	712.162.382,06	29.264,94	10	B
Canal Celio Gonzalez	3592.35	Concrete	986.358.023,69	40.532,48	14	B
Canal Ceibita	1110.20	Concrete	304.829.617,91	12.526,39	18	C
TOTAL	**35456,47**		**9.735.346.966,84**	**400.055,33**		

* Cost estimations based on PMDM SPS, C3.3 Sistema de Drenaje Pluvial (2017)

The collectors/canals which are planned to be maintained and refurbished will need to mitigate peak flows from **Rio Blanco (Zone A)**, i.e. 2392.9 m³/sec (RCP8.5; TR100). Combined they have a total length of 5916 meters. Considering a U-profile (1m*0.7m*0.5m), this represents a storage capacity of 2070.6 m³. Assuming a clean state of the channels (no debris, no blockage through household waste or illegal garbage), we consider that the collectors can theoretically absorb 86.53% of the flow peak of extreme flood. However, collectors have an optimum working capacity by 80%. It means only 69.22% (86.53*0.8) can be actually channelled from the peak flow by theses collectors. In addition, very often, collectors are impaired by debris and household waste. This leads to a reduction of the hydraulic capacity of collectors from 20% to 65%.[4] Consequently, the actual reduction capacity of the collectors under these assumptions is 55.37% (69.22*0.8) to 24.22% (69.22*0.35). We recommend to use a reduction capacity of 24.22% for old channels and 55.37% for recently refurbished collectors.

Ten collectors (see Table 3) will contribute to the mitigation of peak flows from **Rio Chotepe (Zone B)** with 2396.0 m³/sec (RCP8.5; TR100). Combined they have a total length of 28430.27 meters. Considering a U-profile (1m*0.7m*0.5m), this represents a storage capacity of 9950.59 m³. Again we make use of the assumptions as above: (CHANEL m³ total length*100/PEAK FLOW)*0.8*0.35 = "old" collector's impact reduction capacity. This applied, we recommend to use a reduction capacity of 116%.

One collector/canal is planned to be maintained and refurbished will need to mitigate peak flows from **Río Chamelecón" (Zone C)** with 3470.10 m³/sec (RCP8.5; TR100). The canal has a total length of 1110.20 meters. Considering a U-profile (1m*0.7m*0.5m), this represents a storage capacity of 388.57 m³. Assuming a clean state of the channels (no debris, no blockage through household waste or illegal garbage), we consider that the collectors can theoretically absorb 11.2% of the flow peak of extreme flood. Again we make use of the assumptions as above: (CHANEL m³ total length*100/PEAK FLOW)*0.8*0.35 = "old" collector's impact reduction capacity. This applied, we recommend to use a reduction capacity of 4.47%.

[4] Leitão, J. P., Simões, N. E., Pina, R. D., Ochoa-Rodriguez, S., Onof, C., & Marques, A. S. (2017). Stochastic evaluation of the impact of sewer inlets' hydraulic capacity on urban pluvial flooding. *Stochastic environmental research and risk assessment*, 31(8), 1907-1922.

Table 4: *Costs overview and impact reduction for (1) new collectors and (2) existing collectors/canals that are planned to be refurbished.*

	Zone A	***Zone B***	***Zone C***
New collectors			
Total Length (m)	1482.16	15602.14	-
Impact reduction (%)	15.85%	145.76%	-
TOTAL COST (USD)	2.599.098,53	21.083.763,2	-
*Ann. maintenance cost (USD)**	51.981,97	421.675,26	-
Refurbished collectors (existing)			
Total Length (m)	5916	28430	1110
Impact reduction (%)	55.37%	116%	4.47%
TOTAL COST (USD)	66.750,23	320.778,71	12.526,39
*Ann. maintenance cost (USD)**	8.181,68	13.032,27	7.147,50

*Ann. maintenance cost is 2% of total construction/refurbishment cost. Cost estimations based on PMDM SPS, *C3.3 Sistema de Drenaje Pluvial* (2017).

2.2.1 Further Recommendation: Improved Street Inlets

An efficient functioning of storm water drainage systems requires an appropriate network of street inlets. Drain street inlets collect water from roads and parking lots and convey it to an underground storm drain system. The primary purpose of storm drain inlets is to intercept excess surface runoff and convey it into a storm drainage system, thereby reducing or eliminating surface flooding. Roadway geometry often dictates the location of street inlets located along the curb and gutter. In general, inlets are placed at all low points (sumps). There are two major types of inlets approved for use, curb opening and grate (or both combined). Inlets are further classified as being on a 'continuous grade' or in a 'sump'. The term 'continuous grade' refers to an inlet placed in curb and gutter such that the grade of the street has a continuous slope past the inlet and, therefore, water ponding does not occur at the inlet.[5,6]

While planning drainage systems, it is advised to strengthen and maintain existing drain inlets. For example the establishment of combined grate and kerb storm drain inlets at prescribed locations can support a functional storm water conveyance system. Curb inlets are less affected by blockage and all roads in urban areas shall generally be provided with an integral kerb and gutter system. A kerb and gutter combination forms a triangular channel that can convey runoff equal to or less than the design flow without interruption of the traffic. Also, the combination inlets with curb and gutter take advantage of the debris removal capabilities of a curb-opening inlet and the capture efficiency of a grate inlet.

[5] Waugh, P. D., Jones, J. E., Urbonas, B. R., MacKenzie, K. A., & Guo, J. C. (2002). Denver urban storm drainage criteria manual. In *Global Solutions for Urban Drainage* (pp. 1-8).
[6] Brown, S. A., Schall, J. D., Morris, J. L., Stein, S., & Warner, J. C. (2009). *Urban drainage design manual: hydraulic engineering circular 22* (No. FHWA-NHI-10-009). National Highway Institute (US).

3. Water collection in existing buildings

This measure aims to collect rainwater in public and private buildings that have the capacity to accommodate one or more rainwater collection tanks with a specified capacity ca. 3,500 litres. These collection tanks will be connected to public storm drainage systems or other waterways for discharge. Its effective use depends on the acceptance and uptake of potential users, who can be companies and commercial buildings, public buildings or private residential buildings and households who want to contribute to reducing the effects of flooding. This measure aims to lower runoff peak by collecting volumes of water in tanks. It is intended to introduce water collection tanks to district 1 and 3. Combined, there is a potential of installation for 1296 buildings. The cost per unit is USD 800, including material and labour for construction of the cistern, filters, roof connections and the spill line.[7] The total cost is USD 1.036.800 with additional maintenance cost of USD 15.552,00 annually, representing 1.5% of total cost. Thus, with 1296 buildings and water collection tanks, an approximate volume of 4479.57 m^3. Monitoring is required to ensure an appropriate operation of the measure. Maintenance work should be performed every two years, including the cleaning of pipes and control of tanks walls for possible cracks.

Water collection tanks are planned in Zone A, the catchment of Rio Blanco. The entire measure is designed to cover Rio Blanco's peak flows between 1200 and 1446.1 m^3/sec (RCP8.5; TR25) for a duration of 60 minutes.[8] The volume of the expected peak flow, for the expected duration of 60 minutes, is 360.000 m^3.[9] The approximate volume of (all) water collection tanks is 4479.57 m^3, hence taking up 1.24% of the peak flow volume of Rio Blanco.[10]

Table 5: *Measure 2 – Water collection in existing buildings. Overview of technical details.*

Feature	***Unit***	***Quantity***
Height	meters	2
Diameter	meters	1.5
Volumen/unit	litre	3534 (3.53m^3)
Units	pieces	1296
Total Capacity	m^3	4479.57
Cost/unit	USD	800
Lifetime	years	20-30
Total Cost	USD	1.036.800
Impact reduction	%	1.24%
Maintenance cost	USD/annually	15.552

[7] Lukes, R., & Kloss, C. (2010). *Managing wet weather with green infrastructure, Municipal handbook, Green streets, Low impact development center*. EPA-833-F-08-009. https://www.epa.gov/sites/production/files/2015-10/documents/gi_munichandbook_harvesting.pdf (16.10.2020).

[8] Peak flows between 1200 and 1446.1 m^3/sec (200 m^3/sec flow difference) for a duration of 60 minutes (3600 sec).

[9] Water volume for peak flow (1200 and 1446.1 m^3/sec): (3600 sec * 200 m^3/sec)/2 = 360.000 m^3

[10] Peak Flow Reduction of Rio Blanco (Impact Reduction) in percentage: (4479.57/360000)*100 = 1.24%

Figure 3: *Examples of water collection tanks (e.g. for residential buildings)*

4. Dry Flood-Proofing (housing)

Dry flood-proofing involves sealing the exterior of a building to prevent the entry of flood waters. It reduces the potential for flood damage by reducing the probability that the building interior will be inundated due to a variety of measures. It can be an appropriate alternative for flood mitigation when relocating or elevating buildings is not cost-effective or technically feasible. It is advised to apply the following combination of measures for selected houses in the municipality:

Backwater valve (blocker): A backwater valve (sometimes called a backflow blocker) is a valve installed in the sewer line and is designed to allow water or sewage to flow only one way, preventing sewage entering the houses basement. Anytime there is a sudden heavy rainfall, the city sewer lines can become overwhelmed, causing water or sewage to flow back towards houses. With a backwater valve in place, sewage will not be able to flow back into houses. Regular maintenance is important and an annual inspection is recommended. A 4" PVC Backwater Valve costs USD 230 and includes the installation incl. retrofitting and accessing sewer line (USD 1000).[11]

Waterproof coating to the exterior walls: Waterproof coatings on below-grade walls provide a capillary break that excludes the rainwater that saturates the surrounding fill of the building. The average cost to seal interior and exterior basement walls is about USD 60 per square meter. It' assumed that coating is established from the houses' fundament up to 3 meters (not exceeding 1 meter aboveground). The average perimeter is 36 meters for houses with an average size of 82 m² representing district 7, 10 and 16. The coating protection should not exceed 1 meter above the ground level. The expected cost for interior and exteriors wall coating is estimated to be USD 6.480 (3 m x 36 m x 60 USD) per house.[12]

Installing flood shields over doors, windows and other openings: The type of shield that is used depends on the size of the opening that needs to be protected and the duration of flooding. Most flood shields are mounted against the exterior of the opening, allowing rising floodwaters to further compress the gaskets and seals between the flood shield and the wall system or frame of the opening. For longer and larger flood shields, such as for vehicle entrances, are normally constructed of steel

[11] Aerts, J. C. (2018). A review of cost estimates for flood adaptation. *Water*, 10(11), 1646.
[12] FEMA Building Science, Flood Building Codes, Chapter 7 – Dry Flood Proofing. Retrieved from https://www.fema.gov/media-library-data/20130726-1608-20490-9182/fema_551_ch_07.pdf (28.10.2020)

plate or heavy aluminium plate. For pedestrian doors passive flood shields can be used until floodwaters reach a certain height. Passive flood shield systems may require room under the opening to allow the flood shield to be stored when it is not in use. An average aluminium flood shield for doors costs USD 375.[13] For all measures combined, annual maintenance cost (cleaning, seal replacement, etc.) consist of 1.5% of the total construction cost.

It is intended to adapt houses with dry flood proofing in district 1 and 3 (Zone A) and 18 (Zone C), consisting of 1424 buildings in total with an average size of 82m². It should be noted that dry-flood proofing is appropriate primarily for buildings with concrete or solid masonry walls. Concrete and masonry are easier so seal, more resistant to flood damage, and stronger than other conventional construction materials, such as wood. In addition, a guaranteed flood protection level of 100% for a house is considered to a flood depth up to 1 meter. This means flood impact reduction for 1 meter flood depth is 100%.

Table 6: *Measure 3 – Dry Flood Proofing. Overview of technical details.*

	Units	***Zone A***	***Zone C***
Unites	Houses (avg. 82m²)	1269	155
Impact reduction	meter	-1	-1
TOTAL COST	USD	10.259.865	1.253.175
*Ann. maintenance cost (USD)**		153.897	18.797

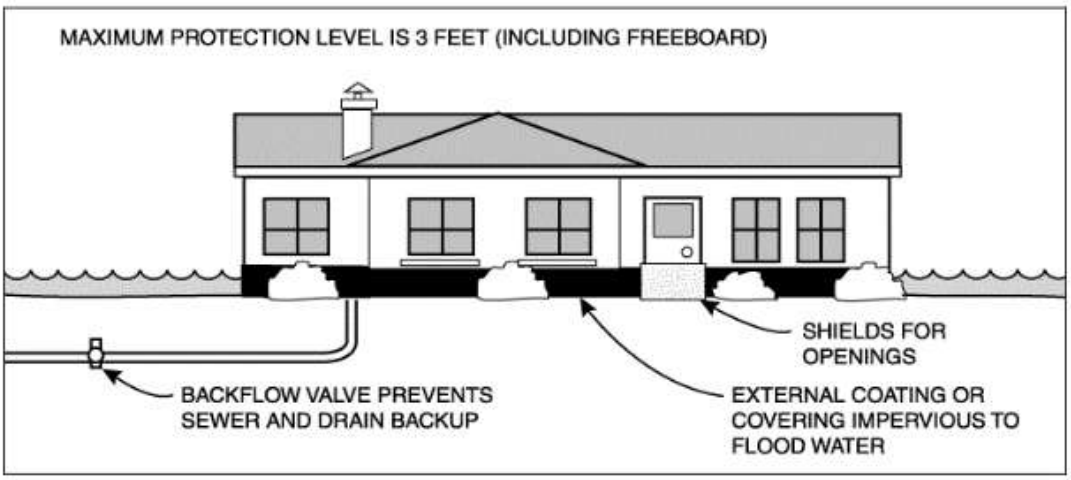


Figure 4: *Measure 3 - Dry Flood Proofing. Illustration of a combination of measures to prevent entry of flood waters into buildings.*

5. "El Tablon" Hydropower Dam

The "El Tablón" Hydropower Dam project aims to protect of the Sula Valley against floods caused by the Chamelecón River as well as the generation of electric energy based on renewable resources, with a targeted capacity of 20 MW and yearly energy generation of 99 GWh. In addition, the hydropower dam will support planned project components for drinking water supply in the Sula Valley (capacity of 4 m3/sec) and irrigated agriculture in the Naco Valley, covering 3.000 ha. The hydropower dam will be constructed in the Chamelecón River, 1.9 km south of the village El Tablón. The dam will be

[13] Aerts, J. C. (2018). A review of cost estimates for flood adaptation. *Water*, 10(11), 1646.

approximately 20 km southwest of San Pedro Sula and 2.5 km downstream from the confluence with the La Mina ravine, in the department of Santa Bárbara, municipalities of Quimistán and Petoa. The area of the dam reservoir includes jurisdictions of the municipalities of Quimistan, Petoa and San Marcos. The construction period is set at 7 years.

The dam will be constructed of compacted concrete with a height of 76 meters (about 250 feet), a crest length of 320 meters (1,050 feet) and a crest width of 5.24 meters (17.2 feet of crest width). The hydropower will be generated with two turbines, each generating 10 megawatts. On the environmental side, the dam will form a lake/reservoir that will bring favourable changes to the area and will be a favourable site for tourism[14]. Total construction cost is estimated to be USD 212.500.000. Operation and maintenance account for 1.5% of construction cost.

The El Tablon hydropower dam is planned to be built in Zone 3, the catchment of Rio Rio Chamelecon. The dam is designed to cover 100% of Rio Chamelecon's peak flows ranging between 2500 m³/sec and 3470.10 m³/sec (RCP8.5; TR100) for a duration of 675 minutes.[15] The volume of the expected peak flow, for the expected duration of 675 minutes, is 20.250.000 m³.[16] The newly designed hydropower dam is expected to cut of the peak flows by 100%, consisting of a water volume of 20.250.000 m³ (Figure 5).

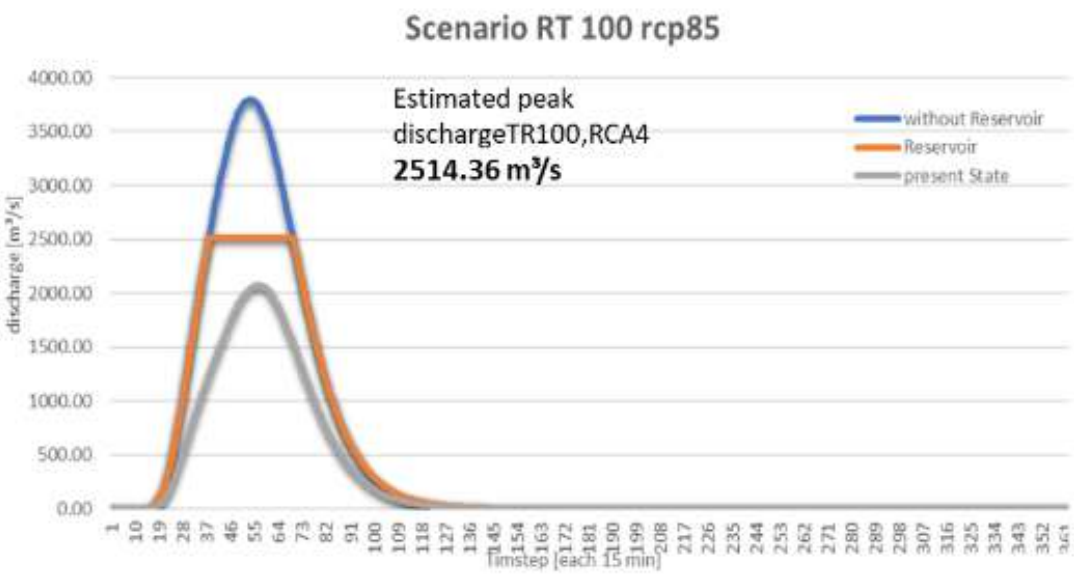


Figure 5: *Estimated peak discharge for Rio Chamelecon. Cutting off the peak discharge by the influence of the El Tablonb reservoir.*

[14] INVEST Honduras, El proyecto 'El Tablón'. Retrieved from http://www.investhonduras.hn/el-tablon/ (14.10.2020).

[15] Peak flows between 2500 m³/sec and 3470.10 m³/sec (1000 m³/sec flow difference) for a duration of 675 minutes (40500 sec).

[16] Water volume for peak flow (2500 and 3470.10 m³/sec): (40500 sec * 1000 m³/sec)/2 = 20.250.000 m³

Figure 6: *Model of the planned "El Tablon" hydropower dam.*

Table 7: *Measure 6 – "El Tablon" Hydropower Dam. Overview of technical details.*

Feature	***Unit***	***Quantity***
Height	meters	76
Length	meters	320
Reservoir Volume (approx.)	m³	20250000
Lifetime	years	50-80
Total Cost	USD	212.500.000
Impact reduction	%	100 %
Maintenance cost	USD/annually	3.187.500

6. Ecological restoration of river bank slopes

This measure introduces re- and/or afforestation practices in undeveloped areas close to the riverbanks and slopes to replace grass or fallow land with dispersed vegetation. The purpose is to reduce the run-off volumes, overland flow and potential erosion of slopes. Re-or afforestation along the slopes of rivers should involve preparations such as terracing to allow angles of rest. To provide a permanent ground cover, the surface of the new compacted slope is sown with vetiver grass species which protects the slope from soil saturation and erosion. This measure requires specific agreements with landowners, complementary regulation and perhaps incentives for the use of forest for recreational, sport, ecological purposes or exploitation and marketing of wood.

This reforestation measure promotes native species including Pine (Pinus spp), Cedar (Cedrella odorata) and Mahogany (Swietenia macrophylla). Costs for this measure would include land preparation, purchase and planting of trees, sowing of grass and maintenance works. It is planned to create 3 green corridors (Bermejo River, Piedras River and Blanco River) with a total length of 13.4 km that is subject for ecological restoration with a suitable area for planting of 87 ha in Zone A and 103 ha in Zone B. 157 plants per ha are considered with a spacing of 8 x 8 meters, which results in 30.061 trees to be planted (Table 8). Average planting cost per tree is USD 106 which includes the tree saplings, transport, site preparation and tree planting equipment including personnel. Annual maintenance cost is estimated between USD 160-200 per hectare. Maintenance operations in urban green spaces is more intensive compared to natural vegetation in forests. Trees in urban spaces have to undergo annual pruning cycles and have to fulfil safety standards to ensure people and infrastructures safety. The annual interception rate of broadleaf evergreen trees lies between 0.8 m³

(DBH 3.5 cm) and 20.8 m³ (DBH 38 cm) of water.[17] The calculations used the derived mean value of 9.6 m³.

Table 8: *Overview of planting and ann. maintenance costs per zone.*

Zone A	Cost (USD)	Zone B	Cost (USD)
Planting Material	8.963,50	Planting Material	10.576,15
Planting (incl. site preparation, transport, personal)	27.833,86	Planting (incl. site preparation, transport, personal)	32.840,40
Sub-Total	**36.797,36**	**Sub-Total**	**43.416,55**
Ann. maintenance (87 ha)	17.053,10	Ann. maintenance (103 ha)	17.242,69

Ecological restoration for the river banks of Rio Blanco are located in Zone A (District 1 and 3). Restoration measures are designed to cushion Rio Blanco's peak flows, which range between 1200 and 1446.1 m³/sec (RCP8.5; TR25) for a duration of 45 minutes. [18] The volume of the expected peak flow, for the expected duration of 45 minutes, is 270.000 m³.[19] The planted trees in this zone are able to intercept a 132.384 m³, hence taking up 49% of the peak flow volume of Rio Blanco.[20]

Ecological restoration for the river banks of Bermejo and Piedras River are located in Zone B. Restoration measures are designed to cushion both rivers peak flows, which range between 1300 and 1513.1.1 m³/sec (RCP8.5; TR25) for a duration of 90 minutes. [21] The volume of the expected peak flow, for the expected duration of 90 minutes, is 540.000 m³.[22] The planted trees in this zone are able to intercept a 156201 m³, hence taking up 29% of the peak flow volume of River Bermejo and Piedras.[23]

Table 9: *Measure 6 – Ecological restoration of river bank slopes. Overview of technical details.*

River	***Zone A***	***Zone B***
Rio Blanco - Area (ha)	109.78	-
Bermejo - Area (ha)	-	85.09
Piedras - Area (ha)	-	44.46
Total Area for planting (ha) *(-20% due to riverbed)*	87.84	103.64
Trees to be planted	13790	16271
Annual interception (m³)	132384	156201
Total Cost *in USD (incl. trees, planting, site prep, transport)*	**36.797,36**	**43.416,55**
Ann. Maintenance cost	17.053,10	17.242,69

[17] Xiao, Q., & McPherson, E. G. (2002). Rainfall interception by Santa Monica's municipal urban forest. *Urban ecosystems*, *6*(4), 291-302.
[18] Peak flows between 1200 and 1446.1 m³/sec (200 m³/sec flow difference) for a duration of 45 minutes (2700 sec).
[19] Water volume for peak flow (1200 and 1446.1 m³/sec): (2700 sec * 200 m³/sec)/2 = 270.000 m³
[20] Peak Flow Reduction of Rio Blanco (Impact Reduction) in percentage: (132384 /270000)*100 = 49.03%
[21] Peak flows between 1300 and 1513.1.1 m³/sec (200 m³/sec flow difference) for a duration of 90 minutes (5400 sec).
[22] Water volume for peak flow (1300 and 1513.1.1 m³/sec): (5400 sec * 200 m³/sec)/2 = 540.000 m³
[23] Peak Flow Reduction of Rio Blanco (Impact Reduction) in percentage: (156201 /270000)*100 = 28.93%

Figure 7: *Measure 6 – Ecological restoration of river bank slopes*

7. Dry Detention Basins

Detention basins are dry vegetated depressions in the ground. They are usually designed to provide short term storage of water and remain dry outside of storm periods. Detention basins can retain flood events, reducing peak flows and limiting the risk of flooding. Detention basins are constructed with an inlet and low level outlet orifice to allow a controlled in- and outward water flow. Dry detentions basins are generally simply to design and construct and easy to maintain. Detention basins are able to control extreme floods such as a 1 in 100-year flood event. The basins are typically built during the construction of new land development projects such as residential subdivisions or shopping centres.

In general, co-benefits of dry detention basins include: (1) positive impacts on the price of properties in close vicinity, (2) the use of basins as multifunctional areas (e.g. sports grounds) and opportunities for recreation, (3) reduction of pollutants through vegetation, (4) an aesthetic value - bringing green to grey areas, (5) raises community awareness and understanding of local flood risk.[24]

General design considerations for a single dry detention basin lie between areas of 4 to maximum 30 hectares. The maximum depth of a basin should not exceed 3 meters. Vegetated embankments should be less than 6 meters in height and shall have side slopes no steeper than 2:1 (horizontal to vertical). The bottom area of the basin should be graded toward the outlet to prevent standing water conditions. A low flow channel across the facility bottom from the inlet to the outlet (e.g. constructed with riprap) is recommended to convey low flows and prevent standing water conditions. The inlet should not be more than 15% higher than the outlet to ensure the correct amount of water flow through the system. If needed, additional structures on the ground can act as a deterrent to slow water flow and collect extra debris. Maximum drain time should be less than 72 hours (ideally 24 hours) to allow for sufficient volume recovery. The outlet structure typically has orifices that will release 1-year, 2-year, 5-year, 10-year, 25-year and 100-year storms at the specified predevelopment peak flow rates.[25]

Maintenance operation for dry basins consists of the following activities: 1) removal of debris from basin surface to minimize outlet clogging and improve aesthetics (annually or after flood event), 2) sediment monitoring and removal when required (based on inspection), 3) repair or revegetate

[24] Denver Urban Storm Drainage Manual, Volume 2, (January 2016). Retrieved from: https://udfcd.org/wp-content/uploads/uploads/vol1%20criteria%20manual/USDCM%20Volume%201%202016.pdf (07.10.2020).
[25] Georgia Stormwater Management Manual, Volume 2, Technical Handbook (August 2001). Retrieved from: https://www.lex-co.com/Departments/PublicWorks/GSMMVol2.pdf (07.10.2020).

eroded areas (based on inspection), 4) structural repairs to inlet and outlets (based on inspection). Annual maintenance cost can de estimated with 5% of base construction costs.

It is planned to establish 10 detention basins in the municipalities area, covering district 1, 3, and 4 (see Table 10) which is in the catchment of Rio Blanco (Zone A). Each basin will be designed with a depth of 1 meter to allow the multifunctional purpose of the basins. In total, an area of 123.50 ha is planned, with a storage capacity of 1.235.000 m³. The average cost for a detention consists of USD 26/m³, which results in total construction costs of USD 12.350.000, of which 2% will be incurred for annual maintenance cost.[26] The basins will have a reduction capacity of 54.9% for 75 min of peak flow consisting of 2250000 m³ (RCP8.5; TR100).

Table 10: *Location and size of planned dry detention basins.*

#	District	Area in hectares	Depth (m)	Storage in cubic meter (m³)	Zone
1	3	11.65	1	116500	A
2	1	4.20	1	42000	A
3	3	19.42	1	194200	A
4	1	4.20	1	42000	A
5	3	39.76	1	397600	A
6	3	11.45	1	114500	A
7	3	10.17	1	101700	A
8	3	13.00	1	130000	A
9	4	5.91	1	59100	A
10	4	3.74	1	37400	A
TOTAL		**123.50**		**1.235.000**	

Dry Detention Basins are planned in Zone A, the catchment of Rio Blanco. The entire measure is designed to cover Rio Blanco's peak flows between 1500 and 2392.9 m³/sec (RCP8.5; TR100) for a duration of 75 minutes.[27] The volume of the expected peak flow, for the expected duration of 75 minutes, is 2.250.000 m³.[28] The approximate volume (capacity) of (all) dry detention basins is 1.235.000 m³, hence taking up 54.89 % of the peak flow volume of Rio Blanco.[29]

Table 11: *Measure 7– Dry Detention Basins. Overview of technical details.*

Feature	***Unit***	***Quantity***
Height	meters	1
Volume (all basins)	m³	1.235.000
Area	ha	123.50
Units	pieces	10
Cost/unit	USD	26 (per m³)
Lifetime	years	>30
Total Cost	USD	12.350.000
Impact reduction	%	54.9%
Maintenance cost	USD/annually	247.000

[26] U.S. Environmental Protection Agency (EPA), Costs and Benefits of Storm Water Best Management Practices. Retrieved from: https://www3.epa.gov/npdes/pubs/usw_d.pdf (07.10.2020).
[27] Peak flows between 1500 and 2392.9 m³/sec (1000 m³/sec flow difference) for a duration of 75 minutes (4500 sec).
[28] Water volume for peak flow (1500 and 2392.9 m³/sec): (4500 sec * 1000 m³/sec)/2 = 2250000 m³
[29] Peak Flow Reduction of Rio Blanco (Impact Reduction) in percentage: (1235000/2250000)*100 = 54.89%

Figure 8: *Examples of dry detentions basins*

8. Improvement and Reforestation of green spaces in urban areas

A healthy forest for urban and semi-urban areas can reduce the amount of runoff and pollutant loading in receiving waters in four primary ways: (1) through evapotranspiration, trees draw moisture from the soil ground surface, thereby increasing soil water storage potential, (2) leaves, branch surfaces, and trunk bark intercept and store rainfall, thereby reducing runoff volumes and delaying the onset of peak flows, (3) root growth and decomposition increase the capacity and rate of soil infiltration by rainfall and reduce overland flow, and (4) tree canopies reduce soil erosion by diminishing the impact of raindrops on barren surfaces.

Urban green spaces have been identified in the municipality. These public spaces such as, city parks and local parks will be further refined to host native tree species. The long-term goal is to create an urban forest heritage, in which every tree element that is located in public areas will be considered as heritage, so its protection, care and maintenance is important for GHG mitigation and the reduction of the effects of climate change, among other benefits to the municipality. This measure considers reforestation with native species in urban green spaces including Pine (*Pinus spp*), Cedar (*Cedrella odorata*) and Mahogany (*Swietenia macrophylla*).[30] In total, 37 green spaces have been identified with an area covering 361.47 ha. All identified urban green spaces have a different use (recreation, parks, etc.) and space to plant trees is limited and in competition with other land use, hence we assume that 30% of the total area is suitable for reforestation purposes. This means, out of 361 ha of green spaces, 108 ha will be used for reforestation. The exact planting pattern for each species and total cost calculation can be found in Table 11-14.

Table 12: *Overview of intended planting area per species incl. respective amount of tree species to be planted.*

Species	Green space (ha)	Planting area (ha)	Plants per ha	No. of trees
Pine	72,294 ha (20%)	21,6882 ha (30%)	1110 plants/ha (3x3 meter)	24.073
Cedar	144,588 ha (40%)	43,3764 ha (30 %)	157 plants/ha (8x8 meter)	6.810
Mahogany	144,588 ha (40%)	43,3764 ha (30 %)	157 plants/ha (8x8 meter)	6.810
TOTAL	**361,47 ha**	**108,44 ha**		**37.693**

[30] Based on PMDM SPS, C7 Plan de Acción de Gobierno Municipal, Directrices, Programas y Proyectos Específicos (2017).

Table 13: *Overview of cost calculation for planting Pine, Cedar and Mahogany.*

Pine	Cost (USD)	Cedar & Mahogany	Cost (USD)
Planting Material	9.869,93	Planting Material	8.853
Planting (incl. site preparation, transport, personal)	26.305,40	Planting (incl. site preparation, transport, personal)	109.638,18
Sub-Total	**36.175,33**	**Sub-Total**	**118.491,18**
TOTAL	**154.666,51**		
Annual maintenance	376.930,00	(10 USD/tree)	

Reforestation activities for existing urban green spaces are planned in **Zone A**, the catchment of Rio Blanco. The reforestation measure is designed to cover Rio Blanco's peak flows between 1200 and 1446.1 m³/sec (RCP8.5; TR25) for a duration of 45 minutes.[31] The volume of the expected peak flow, for the expected duration of 45 minutes, is 270.000 m³.[32] The planted trees in Zone A, have in total the capacity to intercept 152.918 m³ of rain water, hence taking up 56.6 % of the peak flow volume of Rio Blanco (see Table 13).[33]

Reforestation activities for existing urban green spaces are planned in **Zone B**, the catchment of Rio Chotepe. The reforestation measure is designed to cover Rio Chotepe's peak flows between 1300 and 1513.1 m³/sec (RCP8.5; TR25) for a duration of 90 minutes.[34] The volume of the expected peak flow, for the expected duration of 90 minutes, is 540.000 m³.[35] The planted trees in Zone B, have in total the capacity to intercept 71.430 m³ of rain water, hence taking up 12.7 % of the peak flow volume of Rio Chotepe (see Table 13).[36]

Reforestation activities for existing urban green spaces are planned in **Zone C**, the catchment of Rio Chamelecon. The reforestation measure is designed to cover Rio Chamelecon's peak flows between 1400 and 1707.5 m³/sec (RCP8.5; TR25) for a duration of 360 minutes.[37] The volume of the expected peak flow, for the expected duration of 360 minutes, is 3.240.000 m³.[38] The planted trees in Zone C, have in total the capacity to intercept 140.361 m³ of rain water, hence taking up 4.33 % of the peak flow volume of Rio Chamelecon (see Table 13).[39]

Table 14: *Overview of planting area, total cost, tree interception and impact reduction per Zone.*

Zone	Green Spaces (ha)	Planting area (ha)	No. of trees	Interception (ann. in m³ for all trees)	Total cost	Ann. maint.	Impact Reduction
Zone A	152,7	45.83	15929	152.918	65.366	159.290	56.64 %
Zone B	68,52	20.55	7143	68.572	29.310	71.430	12.7 %
Zone C	140,2	42.06	14621	140.361	59.989	146.210	4.33 %
TOTAL		**108.44**	**37.693**		**154.666**		

[31] Peak flows between 1200 and 1446,1 m³/sec (200 m³/sec flow difference) for a duration of 45 minutes (2700 sec).
[32] Water volume for peak flow (1200 and 1446,1 m³/sec): (2700 sec * 200 m³/sec)/2 = 270.000 m³
[33] Peak Flow Reduction of Rio Blanco (Impact Reduction) in percentage: (152.918 /270.000)*100 = 56.64%
[34] Peak flows between 1300 and 1513.1 m³/sec (200 m³/sec flow difference) for a duration of 90 minutes (5400 sec).
[35] Water volume for peak flow (1300 and 1513.1 m³/sec): (5400 sec * 200 m³/sec)/2 = 540.000 m³
[36] Peak Flow Reduction of Rio Blanco (Impact Reduction) in percentage: (68.572/540.000)*100 = 12.7%
[37] Peak flows between 1400 and 1707.5 m³/sec (300 m³/sec flow difference) for a duration of 360 minutes (21.600 sec).
[38] Water volume for peak flow (1400 and 1707.5 m³/sec): (21.600 sec * 300 m³/sec)/2 = 3.240.000 m³
[39] Peak Flow Reduction of Rio Blanco (Impact Reduction) in percentage: (140.361/3.240.000)*100 = 4.33%

Table 15: *Measure 9 – Improvement & Reforestation of green spaces in urban areas. Overview of technical details.*

Feature	***Unit***	***Quantity***
Area	ha	108,44
Units	trees	37.693
Annual interception of trees	m^3	248773.8
Lifetime	years	60-100
Total Cost	USD	154.666,51
Maintenance cost	USD/annually	376.930,00

Figure 9: *Reforestation of (semi) urban spaces*

9. Green Roofs

Green roofs consist of a growing material placed over a waterproofing membrane on a relatively flat roof. Green roofs not only provide an attractive roofing option but also use evapotranspiration to reduce runoff volume, and provides some detention storage. Green roofs may reduce some pollutants from the rainwater as well, they usually are significant sources of phosphorus due to leaching from the growing media. In addition, they can create habitats for wildlife and help to lower urban air temperatures and also positively influence the temperature of the building itself. There are two types of green roofs, extensive and intensive. An extensive green roof has low lying plants designed to provide maximum groundcover, water retention, erosion resistance, and transpiration of moisture. Extensive green roofs usually use plants with foliage from 5 to 15 cm in height and from 5 to 10 cm of soil. An intensive green roof is intended to be more of a natural landscape, installed on a rooftop. Intensive green roofs may use plants with foliage from 30 cm to 4.5 meters in height and may require several meters of soil depth and are therefore not common. A green roof can have a life expectancy of 40 years, under good maintenance conditions[40,41].

Design considerations: A green roof typically consists of the following layers (from to bottom): 1) Vegetation, 2) Growing medium, 3) Filter membrane, 4) Drainage layer, 5) Root barrier, 6) Waterproof membrane, 7) Cover board, 8) Thermal insulation, 9) Vapor barrier.[42]

[40] Keating, K., Keeble, H., Pettit, A., & Stark, D. (2015). Delivering Benefits through Evidence: Cost Estimation for SUDS. *Environment Agency, Bristol, UK*.
[41] Shin, E., & Kim, H. (2015). Analysing Green Roof Effects in an Urban Environment: A Case of Bangbae-dong, Seoul. Journal of Asian Architecture and Building Engineering, 14(2), 315-322.
[42] Oberndorfer, E., Lundholm, J., Bass, B., Coffman, R. R., Doshi, H., Dunnett, N., & Rowe, B. (2007). Green roofs as urban ecosystems: ecological structures, functions, and services. *BioScience*, *57*(10), 823-833.

Proposed configuration of green roofs in San Pedro Sula:

- Type: Semi-intensive
- System maximum height: 30 cm
- System volume per m²: 0.3m³
- Slope: 10°
- Vegetation: Semi-dense flora
- Vegetation height: 150 mm
- Substrate: organic clay
- Substrate max. thickness: 130mm
- Draining mat thickness: 40 mm
- Water-saturated weight: 195 kg/m²

In general, green roof installation costs per square meter decrease as size increases. For a semi-intensive roof, USD 120 per square meter can be calculated. Annual maintenance cost lies in average at USD 5 per square meter.[43] The costs of maintaining a roof decrease after the plants cover the entire roof. It is intended to establish green roofs in district 1 and 3, in Zone A (Rio Blanco catchment). There is a potential to introduce 1269 green roofs, with an average rooftop size of ca. 80 m².

Green roofs are planned to be introduced in Zone A, the catchment of Rio Blanco. The entire measure is designed to cover Rio Blanco's peak flows between 1200 and 1446.1 m³/sec (RCP8.5; TR25) for a duration of 60 minutes.[44] The volume of the expected peak flow, for the expected duration of 60 minutes, is 360.000 m³.[45] The approximate water storage volume of (all) installed green roofs is 30456 m³, hence taking up 8.46% of the peak flow volume of Rio Blanco.[46]

Table 16: *Measure 9 – Green Roofs. Overview of technical details.*

Feature	***Unit***	***Quantity***
Area	m²/unit	80
Height/depth	m/unit	0,3
Units	pieces	1269
Total Volume of Green Roofs	m³	30456
Cost/unit	USD	14.400
An. Maintenance cost/unit	USD	2.448
Lifetime	years	40
Total Cost	USD	12.182.400
Impact reduction	%	8.46%
Maintenance cost	USD/annually	507.600

[43] Keating, K., Keeble, H., Pettit, A., & Stark, D. (2015). Delivering Benefits through Evidence: Cost Estimation for SUDS. *Environment Agency, Bristol, UK*.
[44] Peak flows between 1200 and 1446.1 m³/sec (200 m³/sec flow difference) for a duration of 60 minutes (3600 sec).
[45] Water volume for peak flow (1200 and 1446.1 m³/sec): (3600 sec * 200 m³/sec)/2 = 360.000 m³
[46] Peak Flow Reduction of Rio Blanco (Impact Reduction) in percentage: (30456/360000)*100 = 8.46%

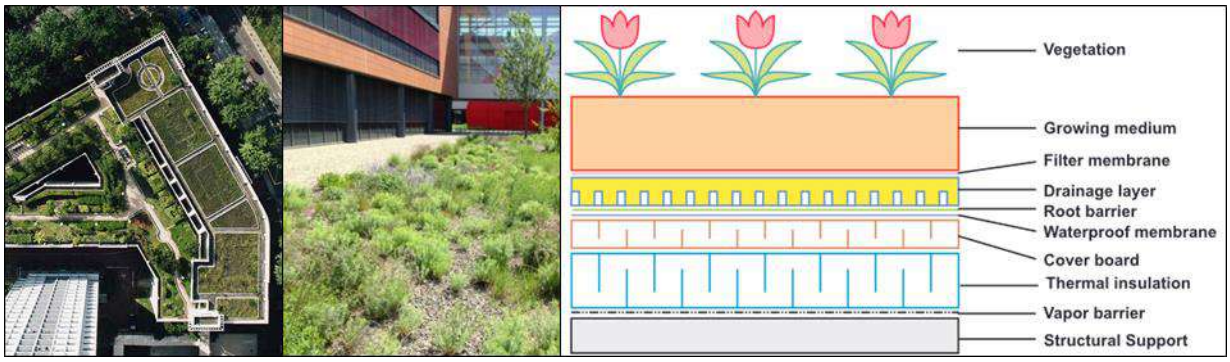


Figure 10: *Examples of Green Roof configurations*

Vegetated swales

Vegetated swales are frequently used to convey runoff and disconnect impervious areas. A vegetated swale (or bio swale, dry swale) is a broad, shallow, trapezoidal or parabolic channel, densely planted with a variety of trees, shrubs, and grasses. It is designed to attenuate and in some cases infiltrate runoff volume from adjacent impervious surfaces, allowing some pollutants to settle out in the process. In steeper slope situations, check dams are used to further enhance attenuation and infiltration opportunities. A vegetated swale can enhance the aesthetic value of a site through the selection of appropriate native vegetation. Swales may also discreetly blend in with landscaping features, especially when adjacent to roads.[47]

This measure proposes the establishment of grass swales of parabolic form to reduce runoff from roadways and/or sidewalks by allowing water to infiltrate. It is planned to establish swales of 2 meters depth and 3 meters width, representing 6 m^3 per meter. Total construction costs for 100 meter grass swales consist of USD 3900 and includes components of site preparation (clearing, excavation, grubbing) and site development (salvaged topsoil, seeds and mulch).[48]

It is very important that swale depths and side slopes be shallow for safety and maintenance reasons. Annual operation and maintenance costs include debris removal, grass mowing, spot reseeding and sodding, weed control, swale inspection, and administration for inspections. Hence, annual maintenance costs are estimated to be 6% of total construction costs per meter, which represents USD 234 per 100 meters / USD 2.34 per meter. It should be noted that swales are not practicable in areas with too steep grades, or in wet or poorly drained soils. Table 17 shows the planned considerations of grassed swales. We recommend to establish vegetated swales along the road network in the catchment area of Rio Blanco (Zone A) in District 1, 3 as well in the catchment area of Río Chamelecón (Zone C) in District 18.

Vegetated swales are planned to be introduced in Zone A, the catchment of Rio Blanco. The entire measure is designed to cover Rio Blanco's peak flows between 1400 and 2392.9 m^3/sec (RCP8.5;

[47] U.S. Environmental Protection Agency (EPA), Sustainable Drainage Systems, Tennessee Stormwater Manual, Chapter 5.4.3 Vegetaded Swale. Retrieved from: https://tnpermanentstormwater.org/manual/11%20Chapter%205.4.3%20Vegetated%20Swales.pdf (07.10.2020).

[48] U.S. Environmental Protection Agency (EPA), Costs and Benefits of Storm Water Best Management Practices. Retrieved from: https://www3.epa.gov/npdes/pubs/usw_d.pdf (07.10.2020).

TR100) for a duration of 75 minutes.[49] The volume of the expected peak flow, for the expected duration of 75 minutes, is 2.250.000 m³.[50] The approximate water storage capacity of (all) installed vegetated swales is 595.526 m³, hence taking up 26.47% of the peak flow volume of Rio Blanco.[51]

Vegetated swales are planned to be introduced in Zone 3, the catchment of Rio Rio Chamelecon. The swales are designed to cover Rio Chamelecon's peak flows ranging between 3000 m³/sec and 3470.10 m³/sec (RCP8.5; TR100) for a duration of 360 minutes.[52] The volume of the expected peak flow, for the expected duration of 360 minutes, is 5.400.000 m³.[53] The approximate water storage capacity of (all) installed vegetated swales is 259.733 m³, hence taking up 4.81% of the peak flow volume of Rio Chamelecon.[54]

Table 17: *Overview of planned grass swales in respective districts, including length.*

	Zone A	***Zone C***
Vegetated Swales		
Depth (m)	2	2
Width (m)	3	3
Total length (m)	99254.36	43288.86
Total Volume (m³)	595526.16	259733.16
Total Cost (USD)	232.255,20	101.295,93
Ann. Maintenance cost	13.935,31	6.077,75
Impact reduction	26.47%	4.81%

Figure 11: *Examples of vegetated swales along roads and parking areas.*

[49] Peak flows between 1400 and 2392.9 m³/sec (1000 m³/sec flow difference) for a duration of 75 minutes (4500 sec).
[50] Water volume for peak flow (1200 and 1446.1 m³/sec): (4500sec * 1000 m³/sec)/2 = 2.250.000 m³
[51] Peak Flow Reduction of Rio Blanco (Impact Reduction) in percentage: (595526/2250000)*100 = 26.47%
[52] Peak flows between 3000 m³/sec and 3470.10 m³/sec (500 m³/sec flow difference) for a duration of 360 minutes (21600 sec).
[53] Water volume for peak flow (3000 and 3470.10 m³/sec): (21600 sec * 500 m³/sec)/2 = 5.400.000 m³
[54] Peak Flow Reduction of Rio Blanco (Impact Reduction) in percentage: (259733/5400000)*100 = 4.81%

10. Flood Awareness & Preparedness Campaign

Flood preparedness refers to 'the ability to predict, respond to and cope with the effect of floods'. Flood awareness programmes should inform the individuals about the risks as well as flood preparedness measures. Activities to prepare against flood should be planned in advance. Through flood preparedness programmes, understanding and awareness regarding the flood events is strengthened among the local community. Community members are focal point of preparedness programmes, therefore, educating public and providing training for flood preparedness is vital. Some of the activities that could include: follow latest information and updates about the flood from local radio, TV stations, or any other communication portal; be well informed about the evacuation route; be informed about local emergency shelter; prepare an emergency kit. Awareness and preparedness campaign should also include information on what should be done during and after a flood event. Awareness programmes should be designed community and context specific.[55]

The framework for raising awareness comprises seven steps: (1) identify awareness level, (2) find need of the target groups, (3) find best ways for information dissemination, (4) start the campaign, and (5) evaluation. If planned appropriately, an awareness and preparedness campaign should include social aspects as well, such as using an (6) participatory approach (involvement of all community members), (6) indigenous and vulnerable people should be identified and prioritised, and (7) taking a gender based approach.[56]

In San Pedro Sula, the flood awareness and preparedness campaign will focus on the most vulnerable group exposed to flood. For this reason, it is intended to target the campaign on households living in the "Los Bordos" areas along the urban riverbanks. In total, 6.778 households have been identified. It is intended to enrol every 8 years a flood awareness and preparedness program for the most vulnerable people along the river banks and risk flood prone areas with costs of USD 485.733 per program. These campaigns are carried out by municipal agencies in collaboration with respective community associations. It is estimated that each flood awareness and preparedness campaign for all residing households in "Los Bordos" will cost USD 1.457.199 in total.[57]

Table 18: *Measure 13 – Flood Awareness & Preparedness Campaign. Overview of technical details.*

Feature	***Unit***	***Quantity***
Target Group	people	Most vulnerable
No. of potential participants	households	6.778
Area	name	Los Bordos
Lifetime	years	every 8 years (3 times until 2042)
Total Cost	USD	1.457.199
Impact Reduction on People	%	80%

[55] Mekong River Commission. (2016). Manual on Flood Preparedness Program for Provincial and District level Authorities in the Lower Mekong Basin Countries. Retrieved from: https://www.preventionweb.net/files/13076_Flood09.pdf (04.11.2020).
[56] Raising Flood Awareness and Self-Efficacy, Framework to Develop and Implement a Successful Social Marketing Program. May 2013. Retrieved from: http://www.flood-aware.com/topics/final_report_activity_2.pdf (04.11.2020).
[57] Cost based on World Bank Project Appraisal Document for Natural Disaster Mitigation, Honduras (2020). Retrieved from: http://documents1.worldbank.org/curated/en/397401468750305928/pdf/multi-page.pdf (04.11.2020).

11. Community based solid waste management

Unmanaged disposal of waste frequently leads to blockages in drainage and watercourses, this reduces their capacity of storage and conveyance and leads to flooding and increased inundation areas. During a flood, waste and other debris collected by floodwaters can cause increased damage to property and lead to higher flood losses. Debris accumulates on bridge piers and various places with embankments and generates pressure on structures and causes water impoundment. Also, deposition of waste can block access and be a source of toxins and breeding ground for diseases. The management of solid waste along watercourses and drainage systems is considered to be a low-regret option for reducing flood risk as well as contributing to the quality of life, health and development, while also lowering the impact of flood events.

The negative impacts and causes of waste disposal are often derived from communities where waste management services may not be comprehensive and where drainage systems are inadequate or absent, or where informal housing has been built in flood-prone areas. In addition, informal settlements are partly not considered by waste disposal systems or solid waste collection programs.

For this reason, engagement of communities in risk reduction is helpful in increasing resources and in generating the necessary awareness and motivation to reduce dumping. Waste management measures implemented without community participation are often undermined by poor waste disposal habits. Inhabitants along rivers and streams often do not have access to timely garbage collection services and therefore deposit their garbage on the slopes and in the riverbeds, which strongly accumulates over time and affects the flow or contaminates the water. This measure proposes a community based solid waste management program for areas with informal settlements along the riverbeds. Solid waste collections schemes should be organized and scheduled among the communities in the "Los Bordos" areas. Primary goal is to remove accumulating trash within the riverbeds and among the slopes. Attention is given to areas with a high risk of trash accumulation, such as bridges or street culverts. These areas must remain garbage free on annual basis. Such a community waste management and collection scheme for watercourses will also reduce the vulnerability people who live in the immediate proximity of rivers. Such a program will raise social awareness for solid waste management and its relation to urban flood risk. These activities will take place in close liaison with local authorities, social service departments and existing community leadership structures. Effective operation of waste collection schemes is guaranteed through enhanced awareness and capacities that encompass various trainings, especially with focus on health and hygienic aspects during collection activities. Estimated costs for such a program would include USD 120/year per household residing in the "Los Bordos" area.[58]

A solid waste management program should involve the following activities: [59]

1. **Residents of "Los Bordos" become more involved in maintaining their immediate surroundings.**

[58] Leitão, J. P., Simões, N. E., Pina, R. D., Ochoa-Rodriguez, S., Onof, C., & Marques, A. S. (2017). Stochastic evaluation of the impact of sewer inlets' hydraulic capacity on urban pluvial flooding. *Stochastic environmental research and risk assessment*, 31(8), 1907-1922.

[59] Rigasa, Y. A., Badamasi, A. G., Galadimawa, N., & Abubakar, G. U. (2017). Community based solid waste management strategy: A case study of Kaduna metropolis. *WIT Transactions on Ecology and the Environment*, 210, 761-772.

a. Encouraging residents to maintain a clean environment or organizing clean-up events
b. Building a sense of common purpose and educating residents can build a sense of agency.
c. Establish means of communication and set common goals/slogans
d. Organize Public/Stakeholder Meetings
e. Over the long term, residents need to become more aware of the role waste management plays in their everyday lives and communities

2. Clean riverbanks and canal systems and maintain drainage capacity

a. Organize and schedule yearly clean-up events and make its positive impacts public
b. Perform ad hoc local drain cleanings prior to rain events
c. Provision of alternative waste dumping facilities

Table 19: *Measure 14 – Community based solid waste management. Overview of technical details.*

Feature	***Unit***	***Quantity***
Target Group	people	Most vulnerable
No. of potential participants	households	6.778
Area	name	Los Bordos
Cost/unit	USD/household	120
Total Cost	USD	1.794.590,90
Impact reduction	%	42,5%

12. Flood Index Insurance

Index-based flood insurance is an innovative approach to developing effective payout schemes for low-income, flood-prone communities. Index insurance schemes make use of modelling and satellite imagery with other data to predetermine flood thresholds, which could trigger rapid compensation payouts. Effective end-to-end solutions will be developed in collaboration with a range of organizations and experts from central and state government bodies, private insurance firms, community-based organizations (CBOs) and nongovernmental organizations (NGOs). **NOTE: More details will be added in the final version.**

13. Overview

Table 20: *Overview of all measures applied in Zone A, B and C, incl. the total cost until year 2042 (incl. construction & maintenance) and the respective impact reduction.*

Measure (incl. Zone)	**Total Cost in USD**(for 22 years, incl. construction & maintenance)	**Impact Reduction**
New collectors (A)	3.742.701,87	15.85%
New collectors (B)	29.990.926,63	145.76%
Refurbished Collectors (A)	246.769,20	55.37%
Refurbished Collectors (B)	607.488,65	116%
Refurbished Collectors (C)	169.771,28	4.47%
Water Collection (A)	563.256,97	1.24%
Dry Flood-Proofing (A)	4.543.685,97	-1
Dry Flood-Proofing (C)	1.699.896,97	-1
Infiltration wells (A)	1.504.336,72	8.18%
El Tablon (C)	279.489.490,97	100%
Ecological restoration (A)	411.965,65	49.03%
Ecological restoration (B)	422.755,81	28.93%
Detention Basins (A)	17.588.985,97	54.9%
Refor. Urban Green Spaces (A)	3.462.443,68	56.64%
Refor. Urban Green Spaces (B)	1.581.328,15	12.7%
Refor. Urban Green Spaces (C)	3.182.386,58	4.33%
Green Roofs (A)	22.893.987,97	8.46%
Vegetated swales (A)	576.885,68	26.47%
Vegetated swales (C)	280.916,65	4.81%
Flood Awareness (A,B,C)	1.457.199,00	80%
Waste management (Los Bordos), (A,B)	1.794.590,90	42,50%

ANNEX 7

Economic scenario as applied in CLIMADA

ANNEX 7

Economic scenario as applied in CLIMADA

Table 1 Details of the economic scenario

Year	INE population estimates in '000 (resulting annual estimates in *italic*)	Annual average growth rate	CPI growth rate (estimates from 2020 onward)	GDP growth rate (estimates from 2019 onward)
2016	754			
2017	*777*		3,93%	4,79%
2018	*802*		4,35%	3,75%
2019	*826*		4,37%	3,72%
2020	852	3,1%	3,84%	2,93%
2021	*880*		3,84%	2,81%
2022	*908*		3,74%	2,70%
2023	*937*		3,67%	2,60%
2024	*968*		3,60%	2,50%
2025	999	3,2%	3,53%	2,41%
2026	*1025*		3,47%	2,33%
2027	*1052*		3,41%	2,25%
2028	*1080*		3,35%	2,17%
2029	*1109*		3,29%	2,10%
2030	1138	2,6%	3,23%	2,04%
2031	*1162*		3,18%	1,98%
2032	*1186*		3,13%	1,92%
2033	*1211*		3,08%	1,86%
2034	*1237*		3,03%	1,81%
2035	1263	2,1%	2,98%	1,76%
2036	*1285*		2,94%	1,72%
2037	*1307*		2,89%	1,67%
2038	*1329*		2,85%	1,63%
2039	*1352*		2,81%	1,59%
2040	1375	1,7%	2,77%	1,55%
2041	*1397*		2,73%	1,51%
2042	1419	1,6%	2,69%	1,48%
Annual average 25 years in 2042		2,46%	3,30%	2,24%
Mean of projection			3,22%	2,13%
Median of projection			3,18%	2,01%
Standard deviation of projection			0,37%	0,55%

ANNEX 8

Estimations discharge in the Chamelecón River with and without El Tablón dam for return periods 25, 50 and 100 years

ANNEX 8

Estimations discharge in the Chamelecón River with and without El Tablón dam for return periods 25, 50 and 100 years

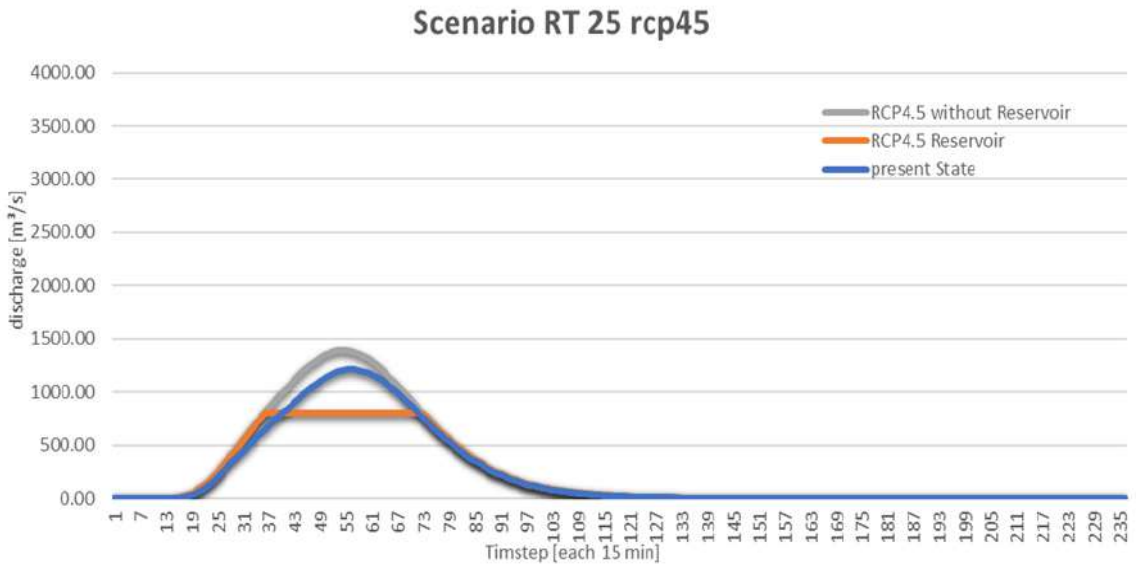


Figure 1 Simulation of Chamelecón River discharges return period 25 years RCP 4.5

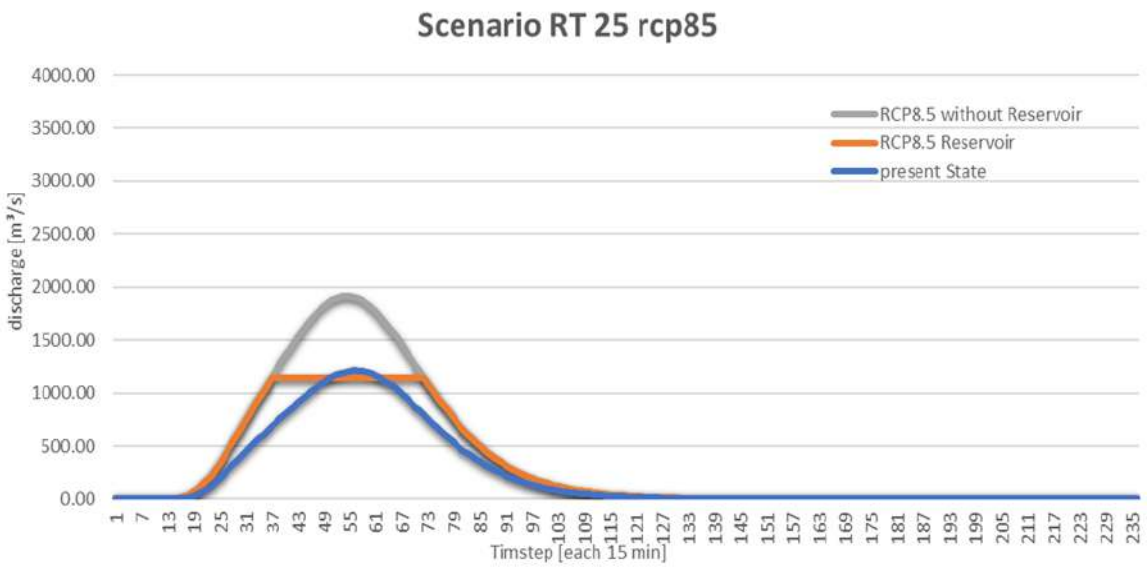


Figure 2 Simulation of Chamelecón River discharges return period 25 years RCP 8.5

Table 1 Peak values return period 25 years

	Location: El Tablon dam				Location: Catchment / Model Outflow	
	In Flow (without Res.)		Outflow (Reservoir)			
	Maximum [m³/s]	Volume [m³]	Maximum [m³/s]	Volume [m³]	Maximum [m³/s]	Volume [m³]
Present State	**1211.5**	48’043’620	-	-	1’210.0	66’195’090
RCP 4.5	**1392.3**	54’823’950	**807.00**	42’880’860	1’282.5	69’042’256
RCP 8.5	**1913.8**	74’935’530	**1144.00**	59’820’750	1’707.5	94’041’649

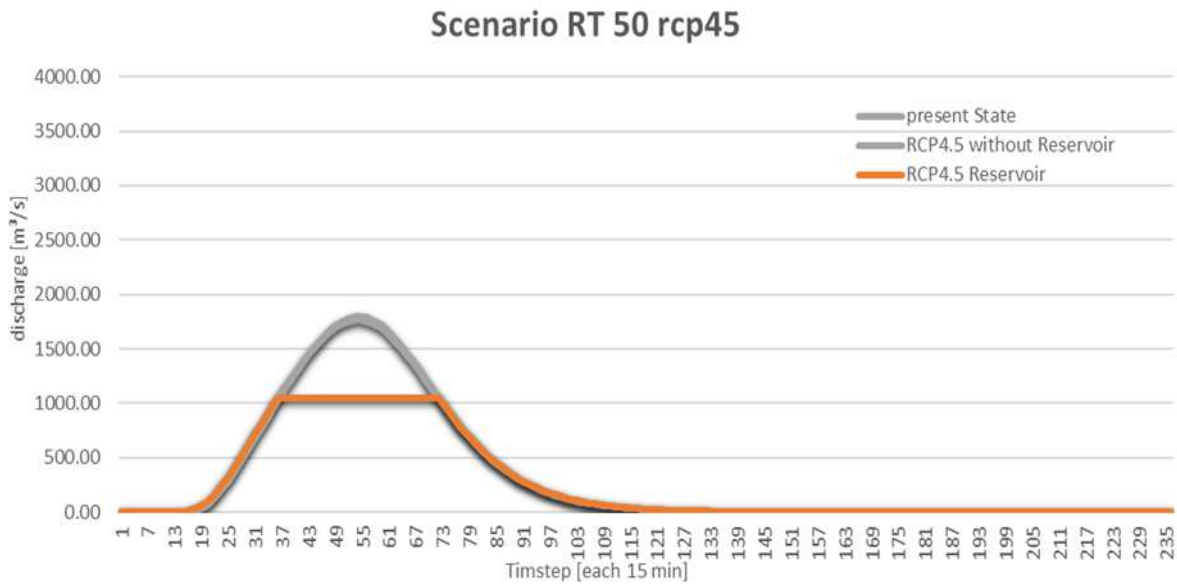


Figure 3 Simulation of Chamelecón River discharges return period 50 years RCP 4.5

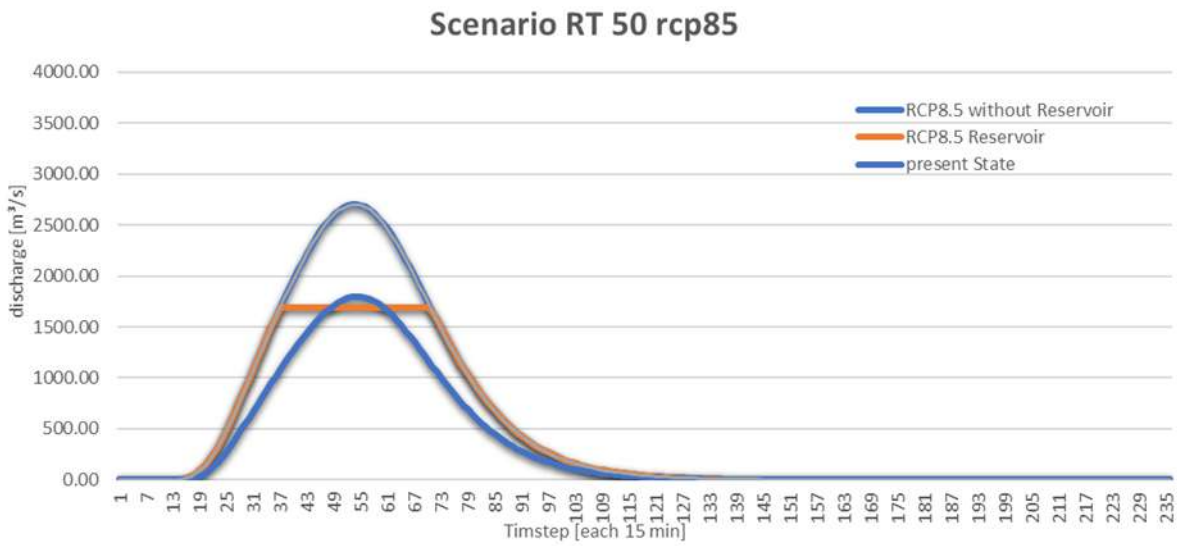


Figure 4 Simulation of Chamelecón River discharges return period 50 years RCP 8.5

Table 2 Peak values return period 50 years

	Location: El Tablon Reservoir				Location: Catchment / Model Outflow	
	In Flow (without Res.)		Outflow (Reservoir)			
	Maximum [m³/s]	Volume [m³]	Maximum [m³/s]	Volume [m³]	Maximum [m³/s]	Volume [m³]
Present State	1798.0	69’470’460	%	%	1’792.0	93’663’260
RCP 4.5	1766.0	69’704’190	1048.0	55’249’200	1’685.4	133’479’677
RCP 8.5	2701.5	105’813’630	1685.0	86’452’560	2’398.8	90’094’528

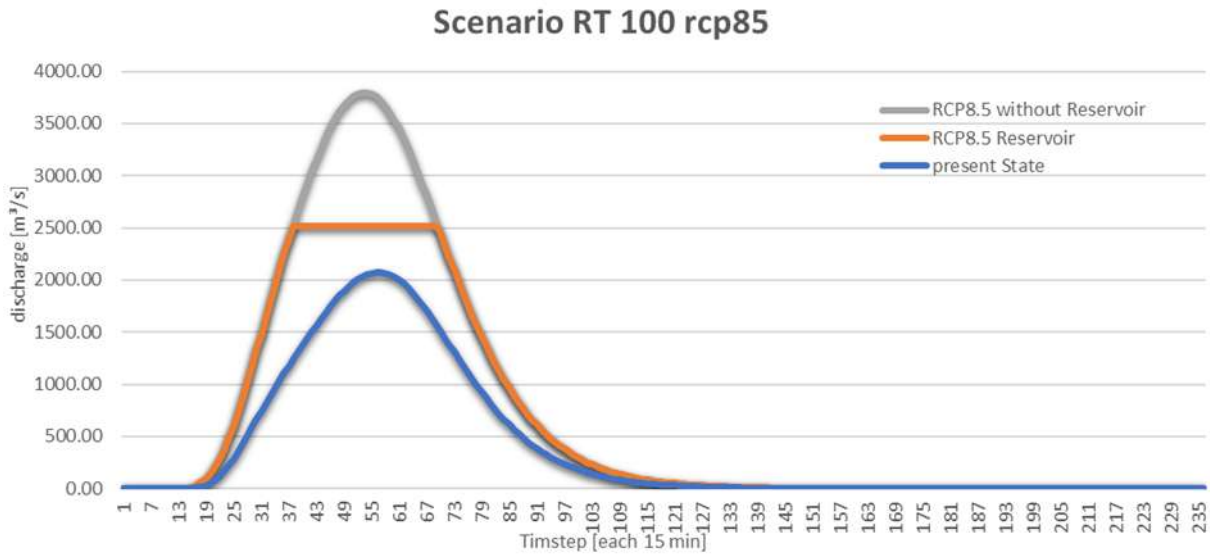


Figure 5 Simulation of Chamelecón River discharges return period 100 years RCP 4.5

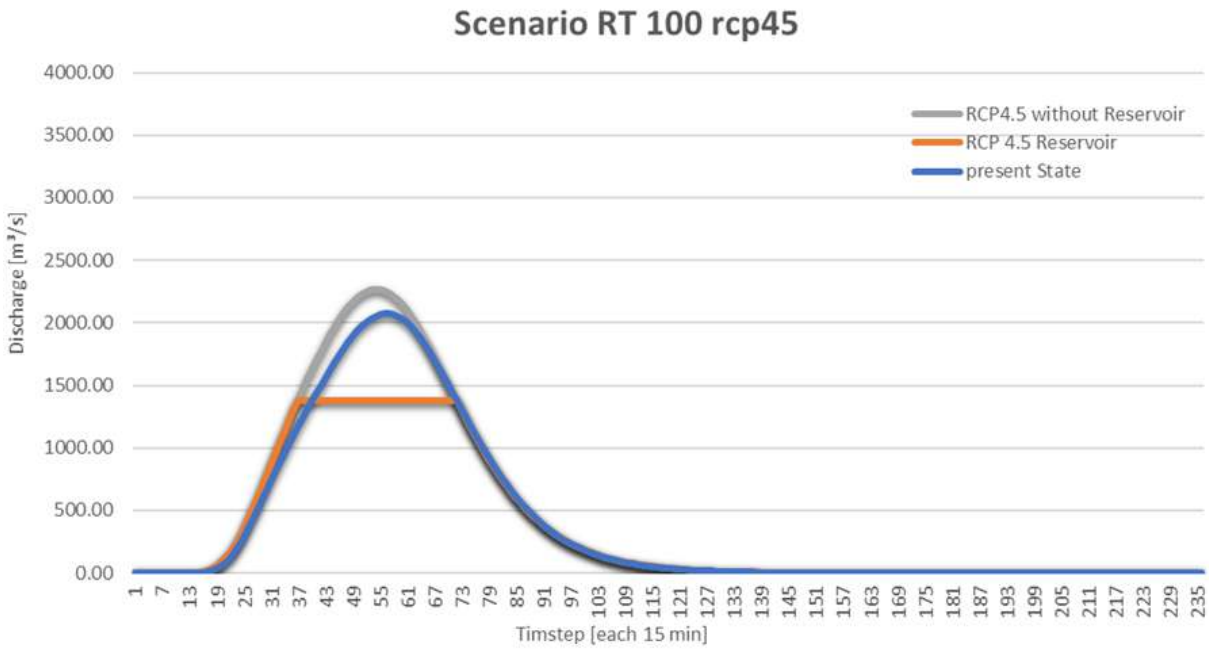


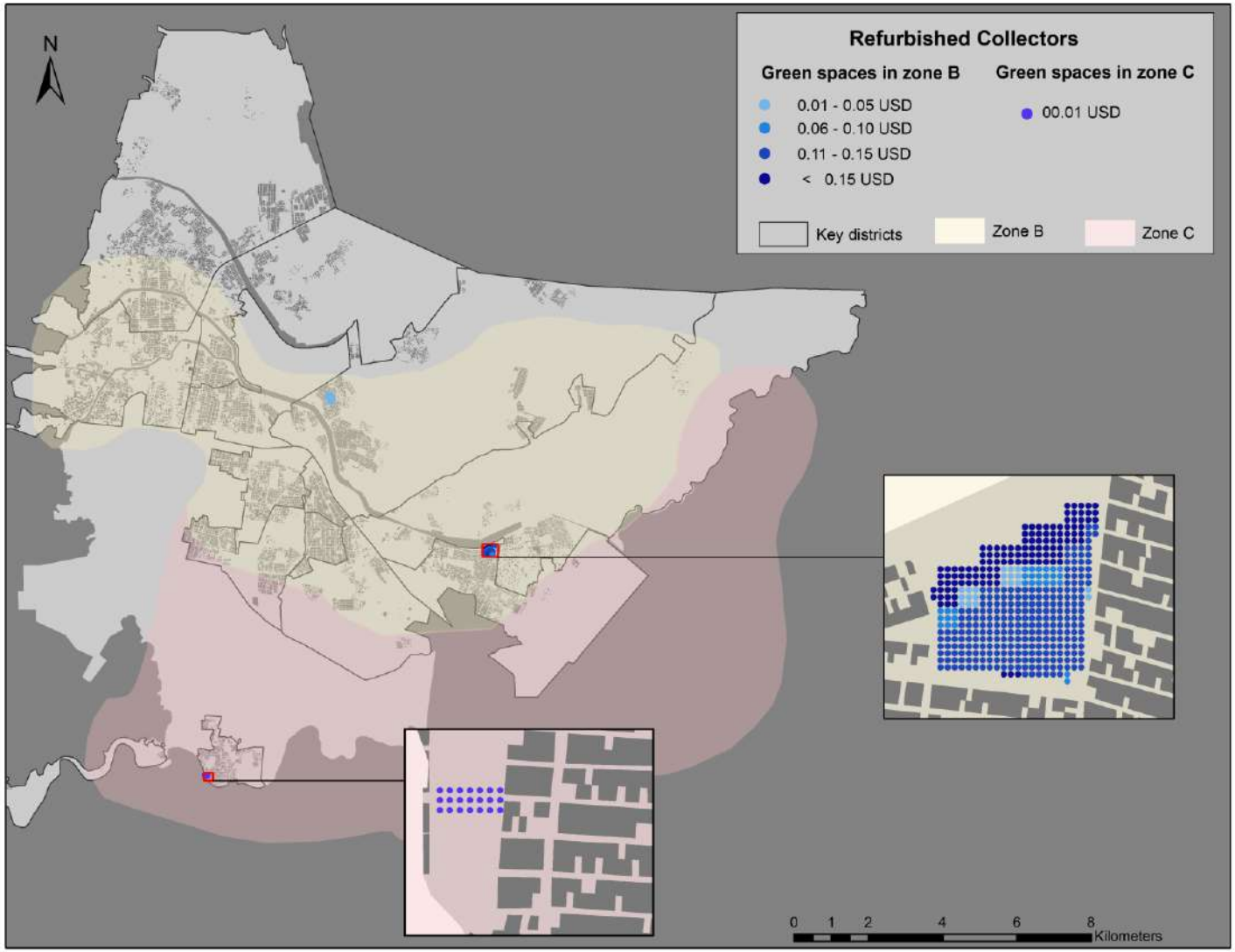
Figure 6 Simulation of Chamelecón River discharges return period 100 years RCP 8.5

Table 3 Peak values return period 100 years

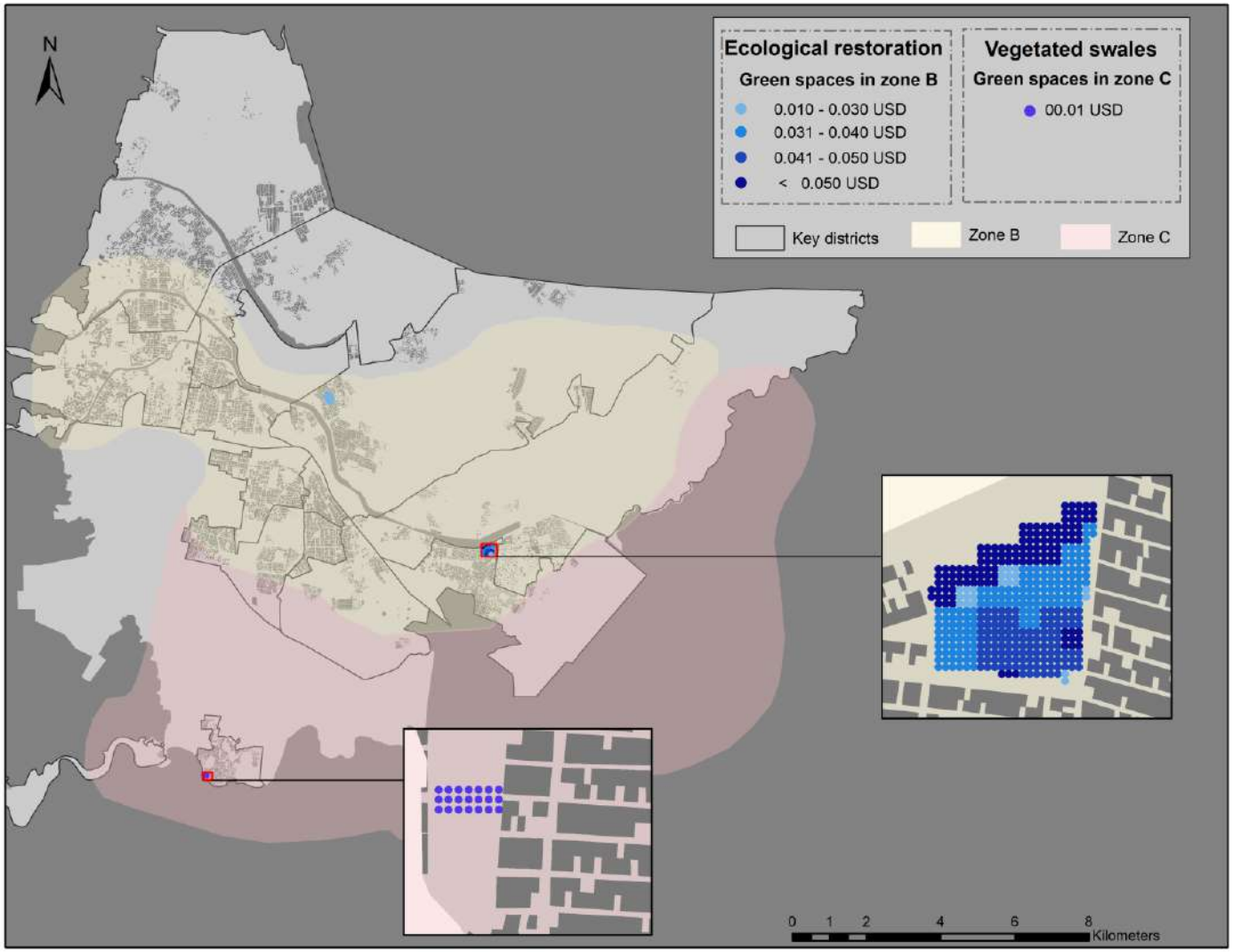
	Location: El Tablon Reservoir				**Location: Catchment / Model Outflow**	
	In Flow (without Res.)		**Outflow (Reservoir)**			
	Maximum [m³/s]	**Volume [m³]**	**Maximum [m³/s]**	**Volume [m³]**	**Maximum [m³/s]**	**Volume [m³]**
Present State	**2‘074.2**	82‘413‘720	%	%	2’108.0	115’286’580
RCP 4.5	**2‘268.7**	89‘488‘530	**1‘382.00**	71‘925‘390	2’213.0	117’554’196
RCP 8.5	**3‘797.2**	148‘626‘180	**2‘514.00**	125‘379‘8100	3’470.1	127’642’410

ANNEX 9

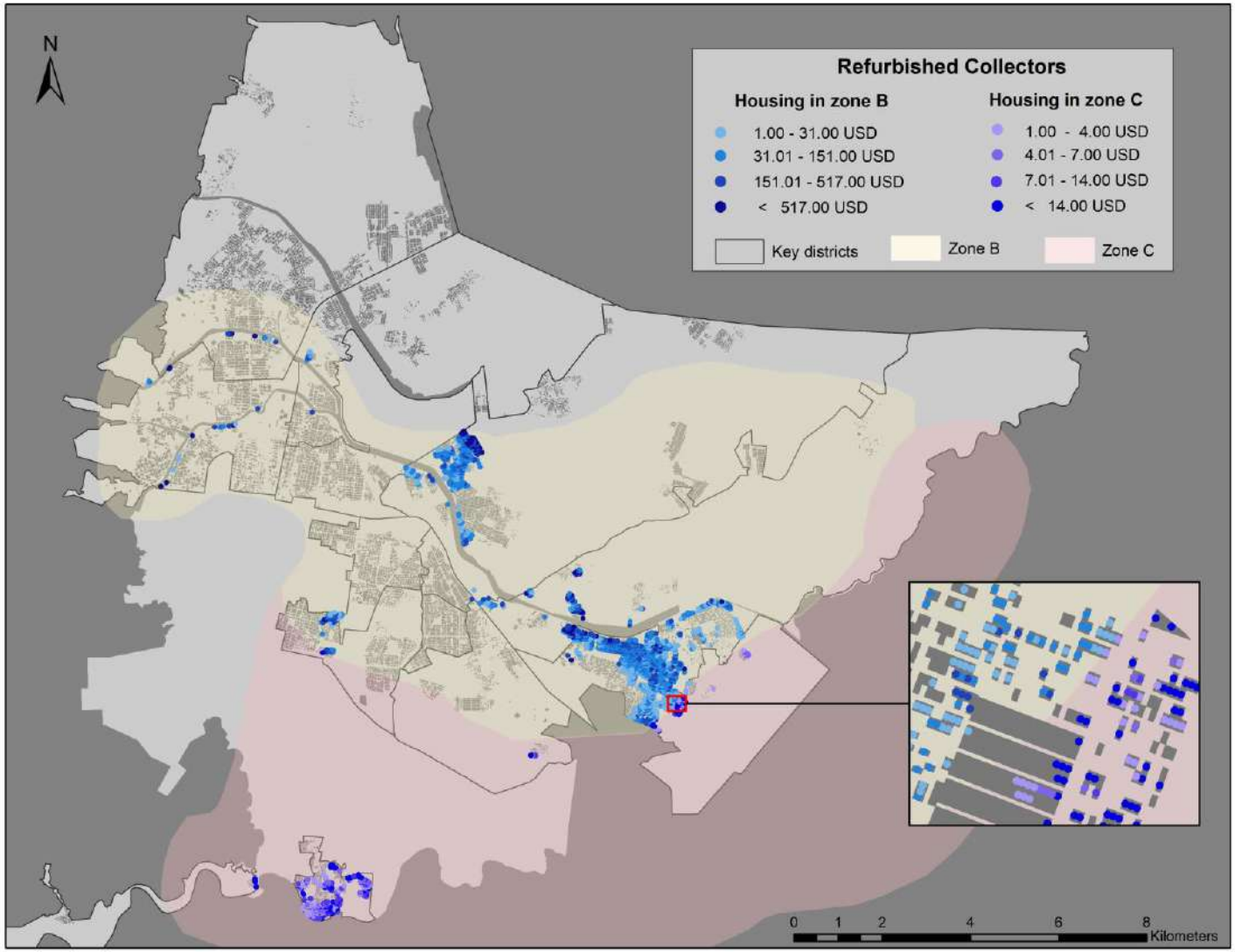
Geographical benefit distribution from the adaptation measures



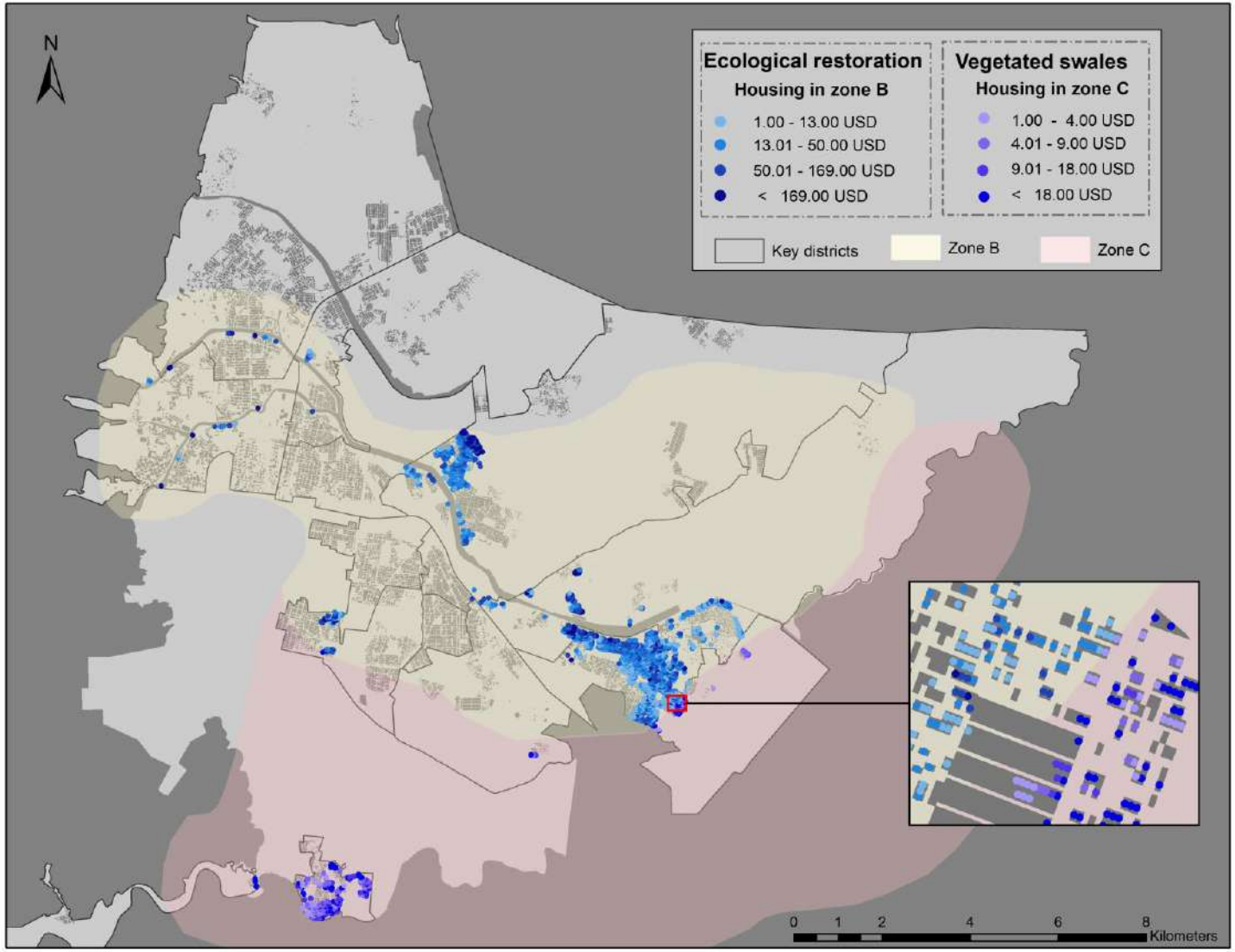
Benefits for Green Spaces with Refurbished Collectors under a mild Climate Scenario (RCP 4.5)



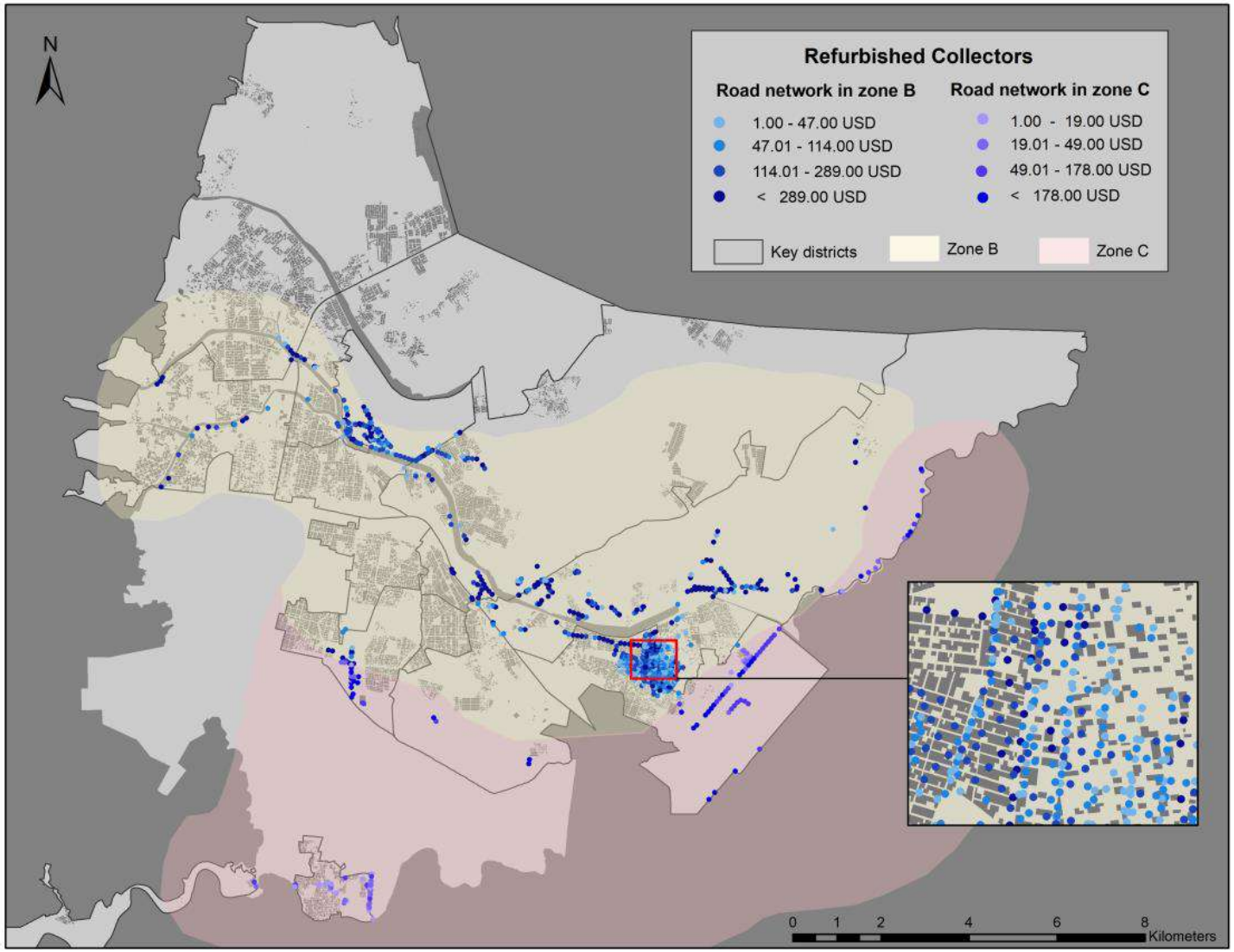
Benefits for Green Spaces with Ecological Restoration and Vegetated Swales under a mild Climate Scenario (RCP 4.5)



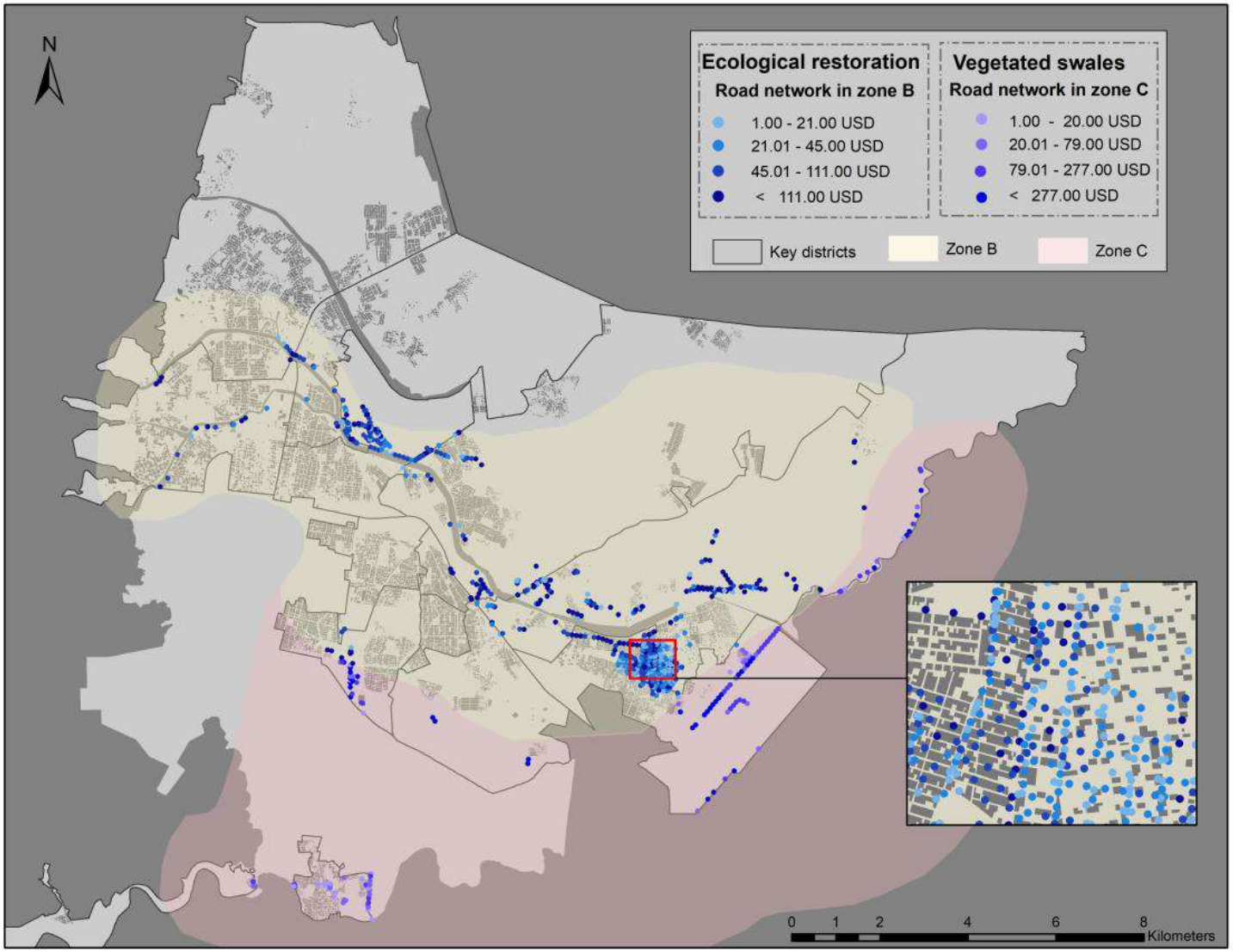
Benefits for Housing with Refurbished Collectors under a mild Climate Scenario (RCP 4.5)



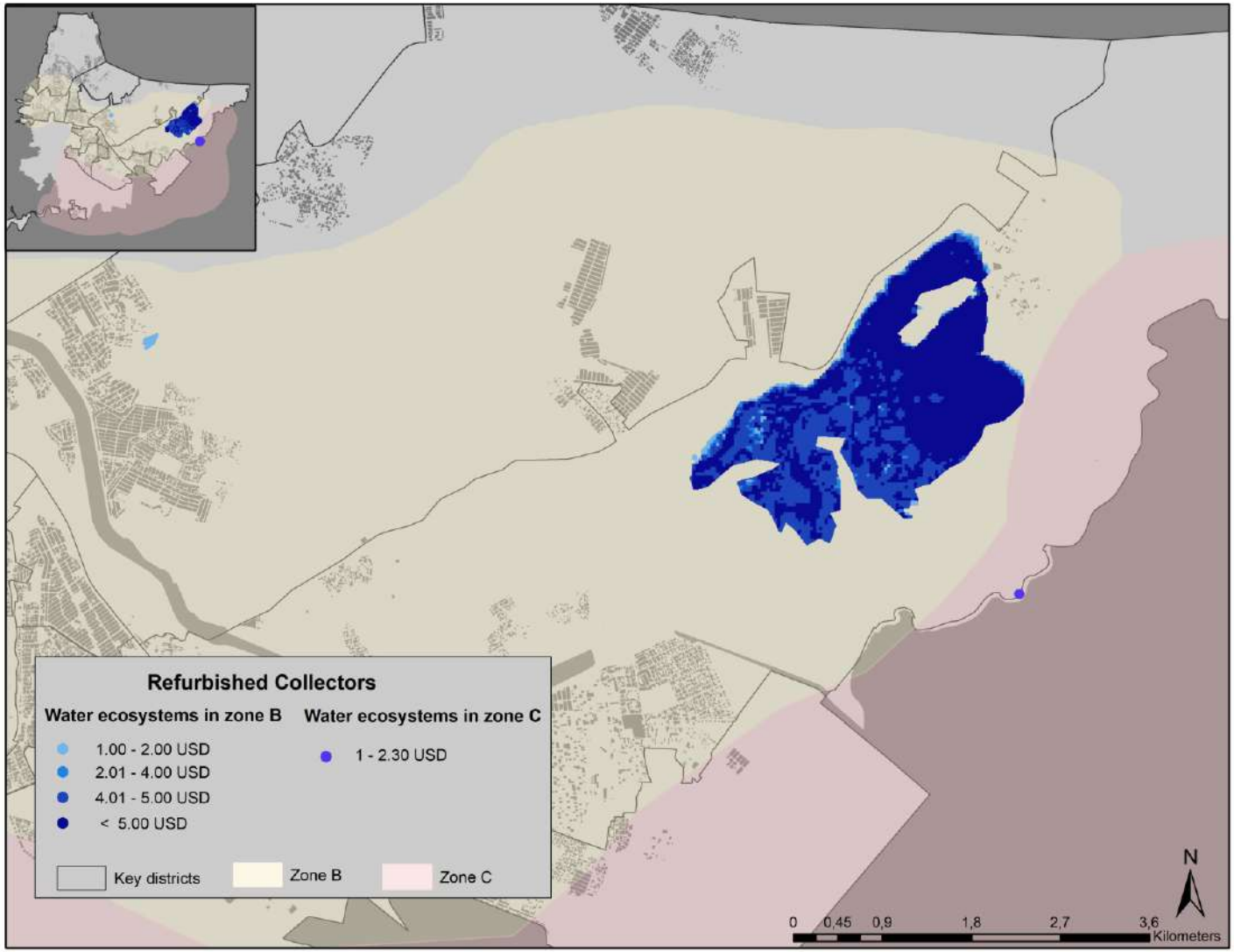
Benefits for Housing with Ecological Restoration and Vegetated Swales under a mild Climate Scenario (RCP 4.5)



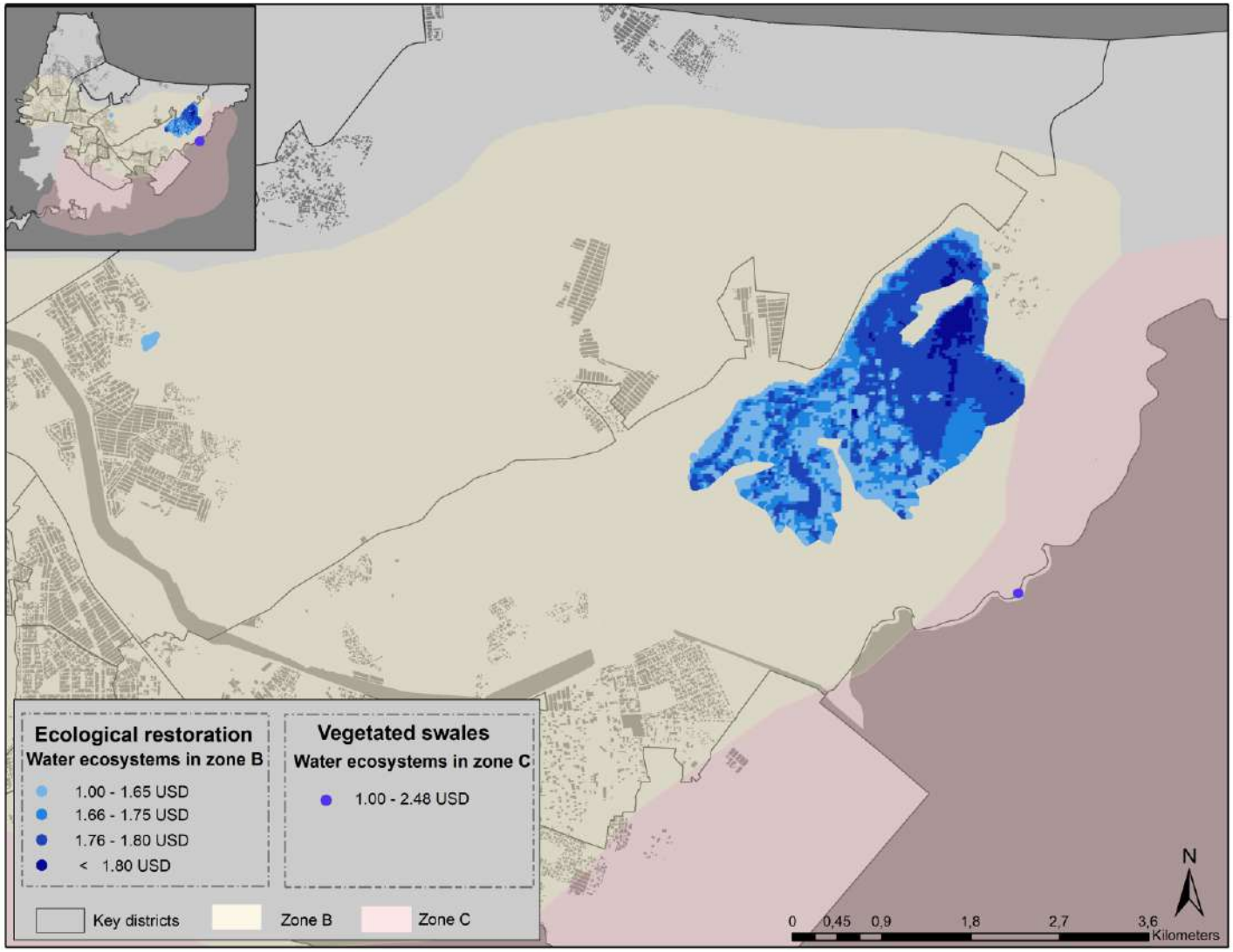
Benefits for Road Network with Refurbished Collectors under a mild Climate Scenario (RCP 4.5)



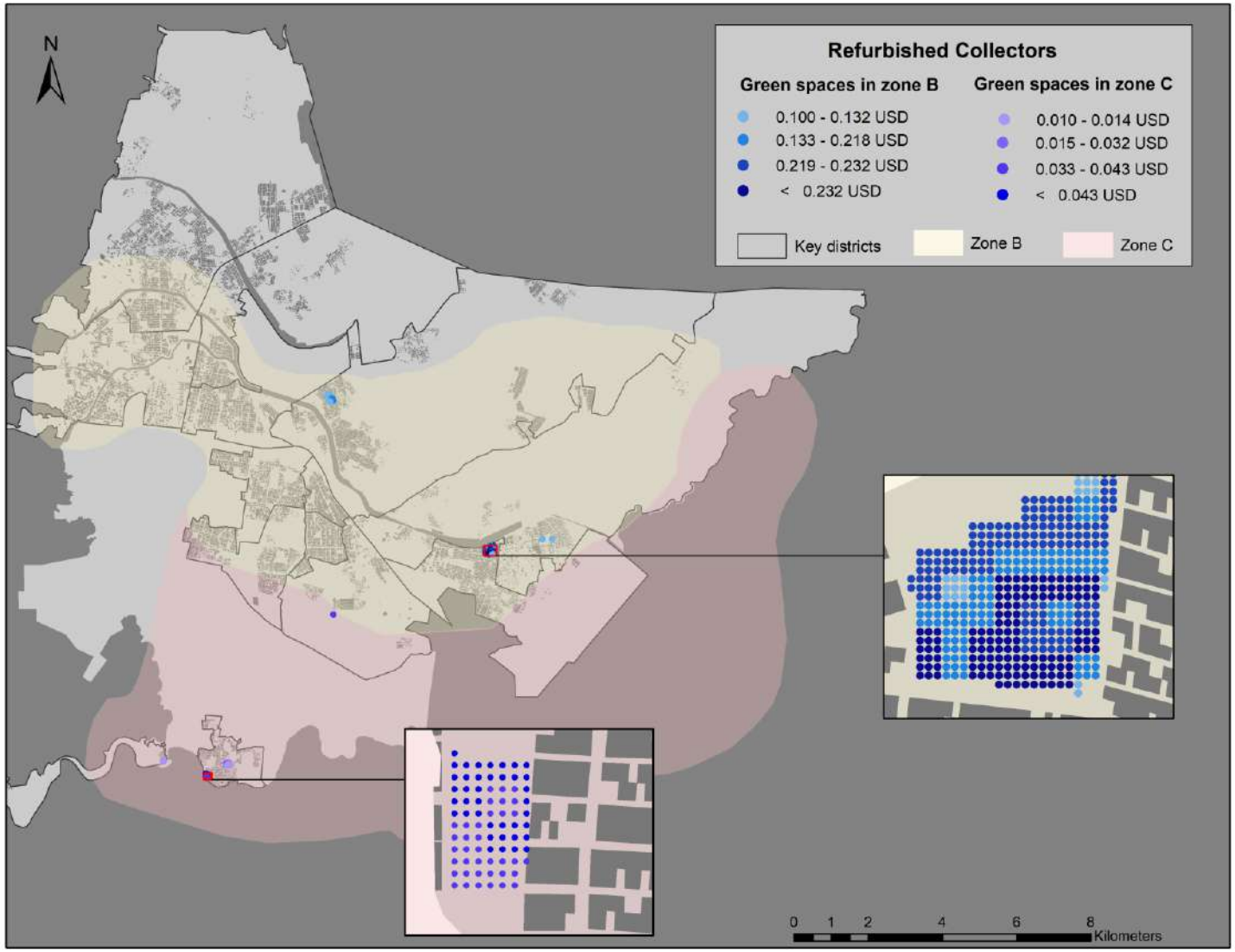
Benefits for Road Network with Ecological Restoration and Vegetated Swales under a mild Climate Scenario (RCP 4.5)



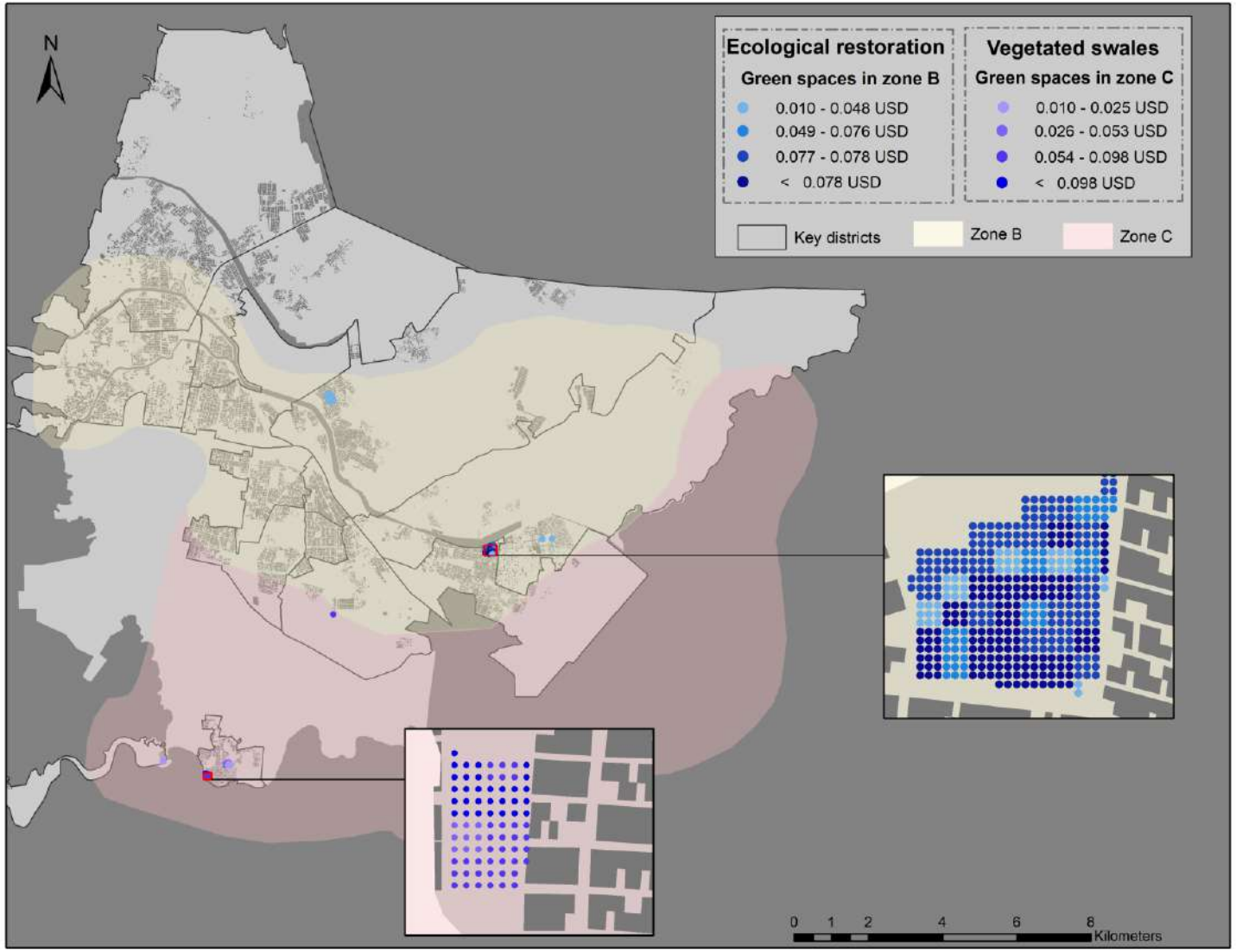
Benefits for Water Ecosystems with Refurbished Collectors under a mild Climate Scenario (RCP 4.5)



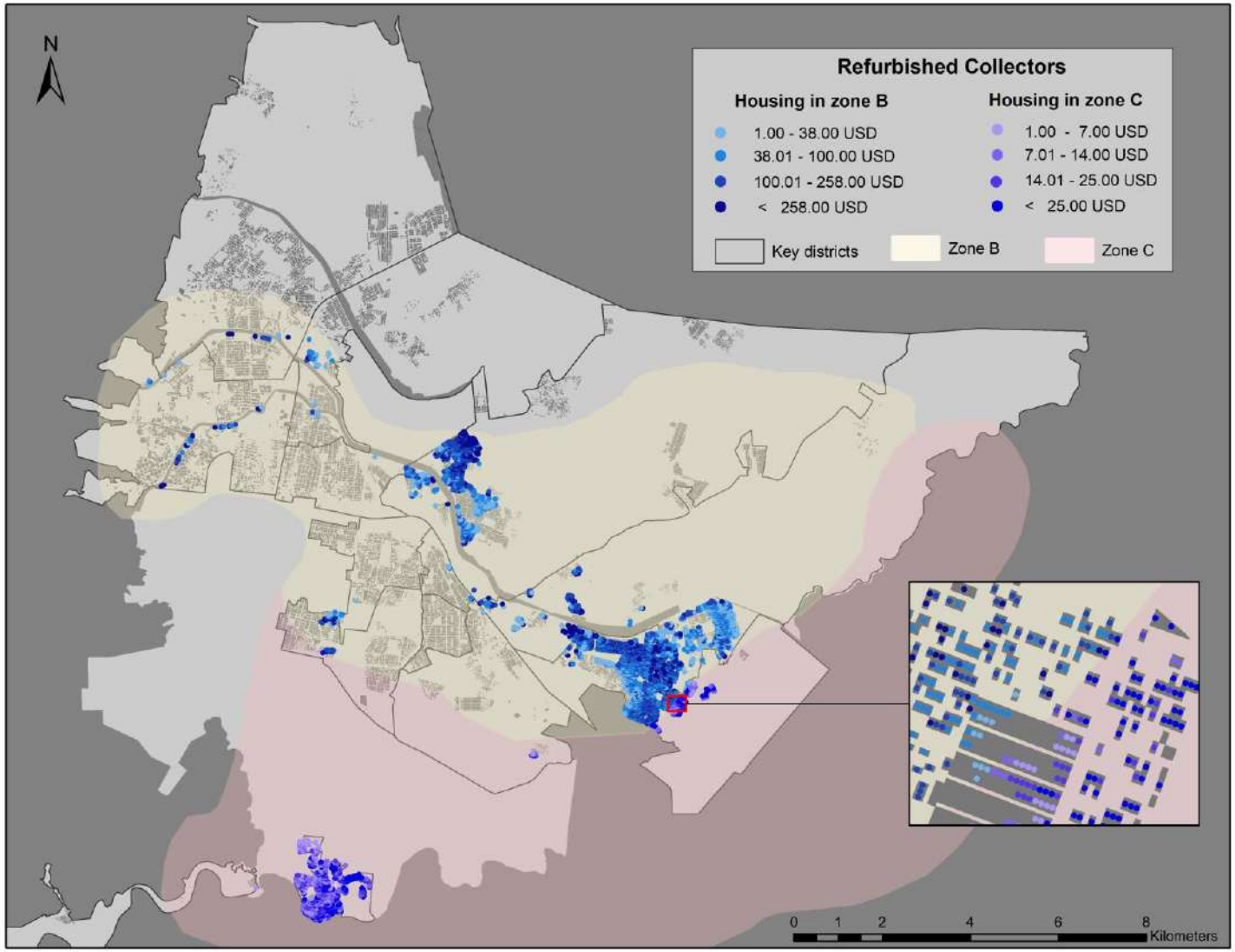
Benefits for Water Ecosystems with Ecological Restoration and Vegetated Swales under a mild Climate Scenario (RCP 4.5)



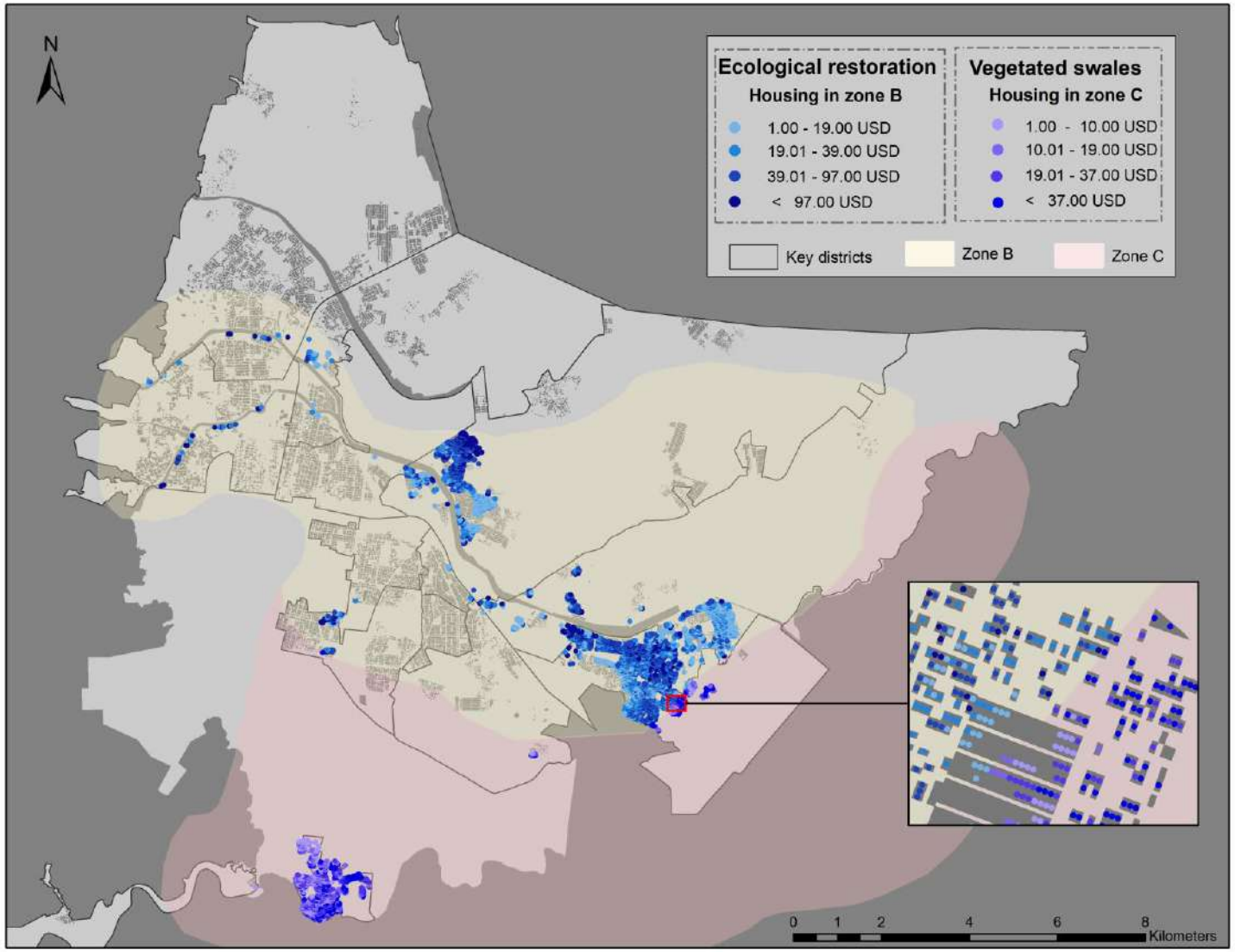
Benefits for Green Spaces with Refurbished Collectors under an extreme Climate Scenario (RCP 8.5)



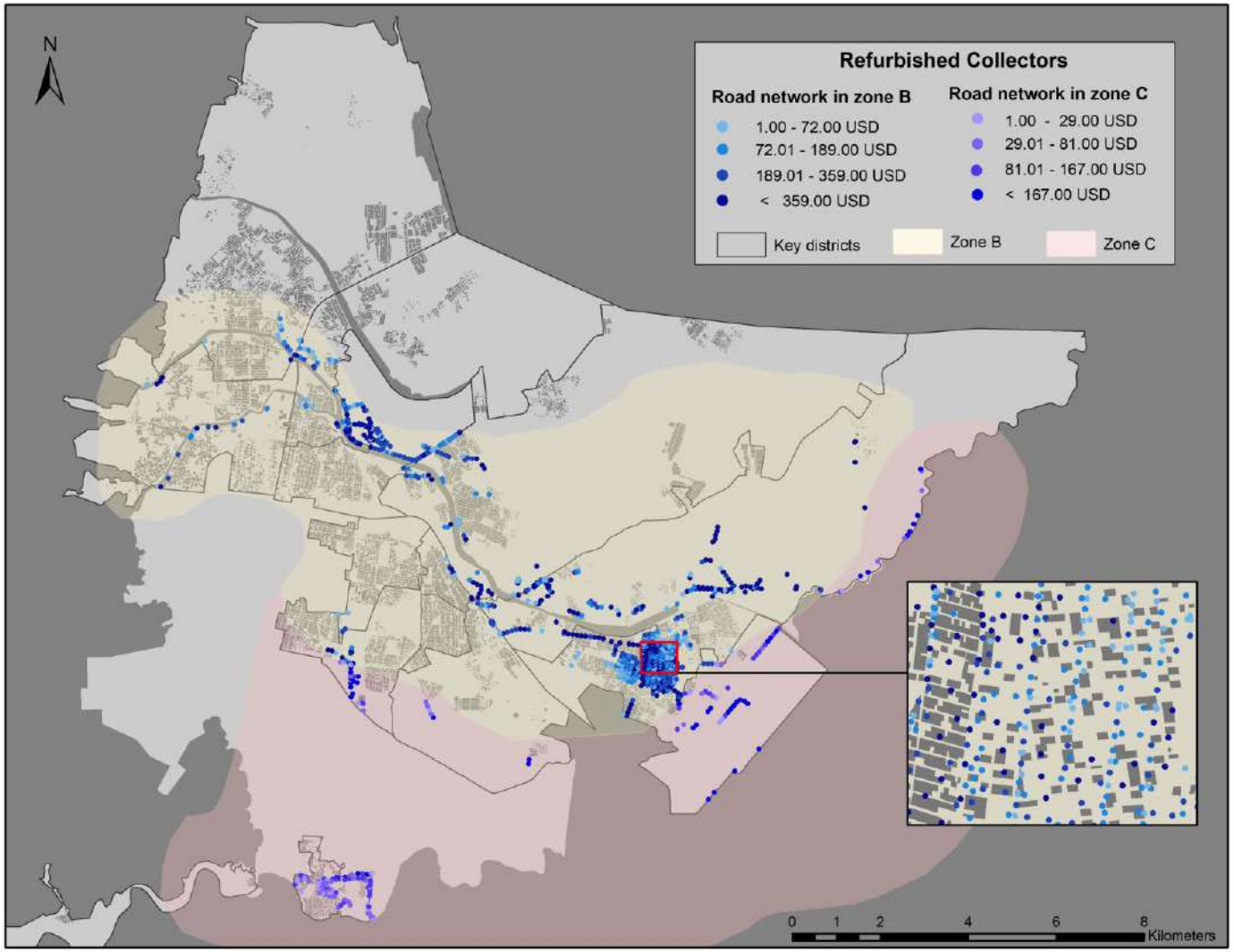
Benefits for Green Spaces with Ecological Restoration and Vegetated Swales under an extreme Climate Scenario (RCP 8.5)



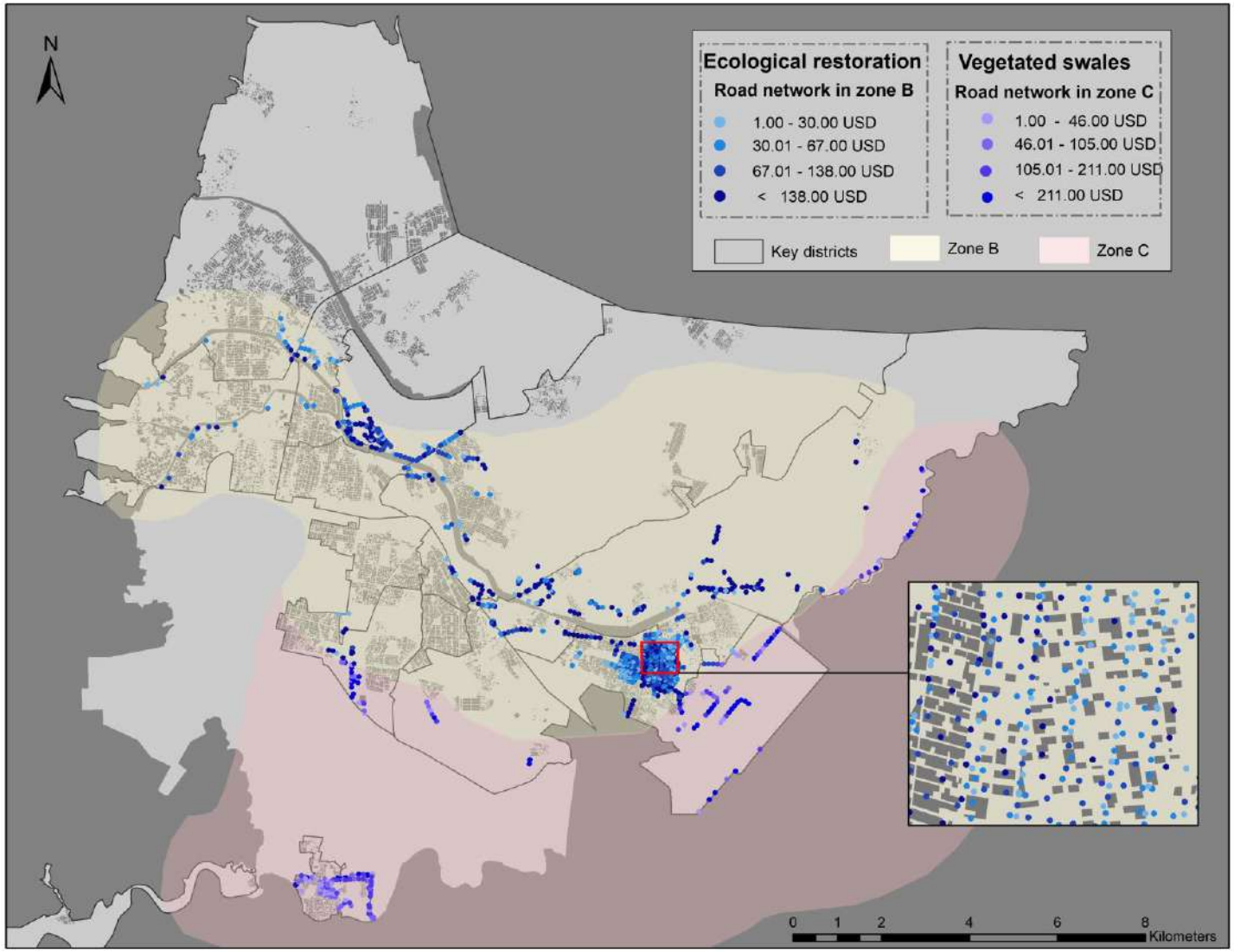
Benefits for Housing with Refurbished Collectors under an extreme Climate Scenario (RCP 8.5)



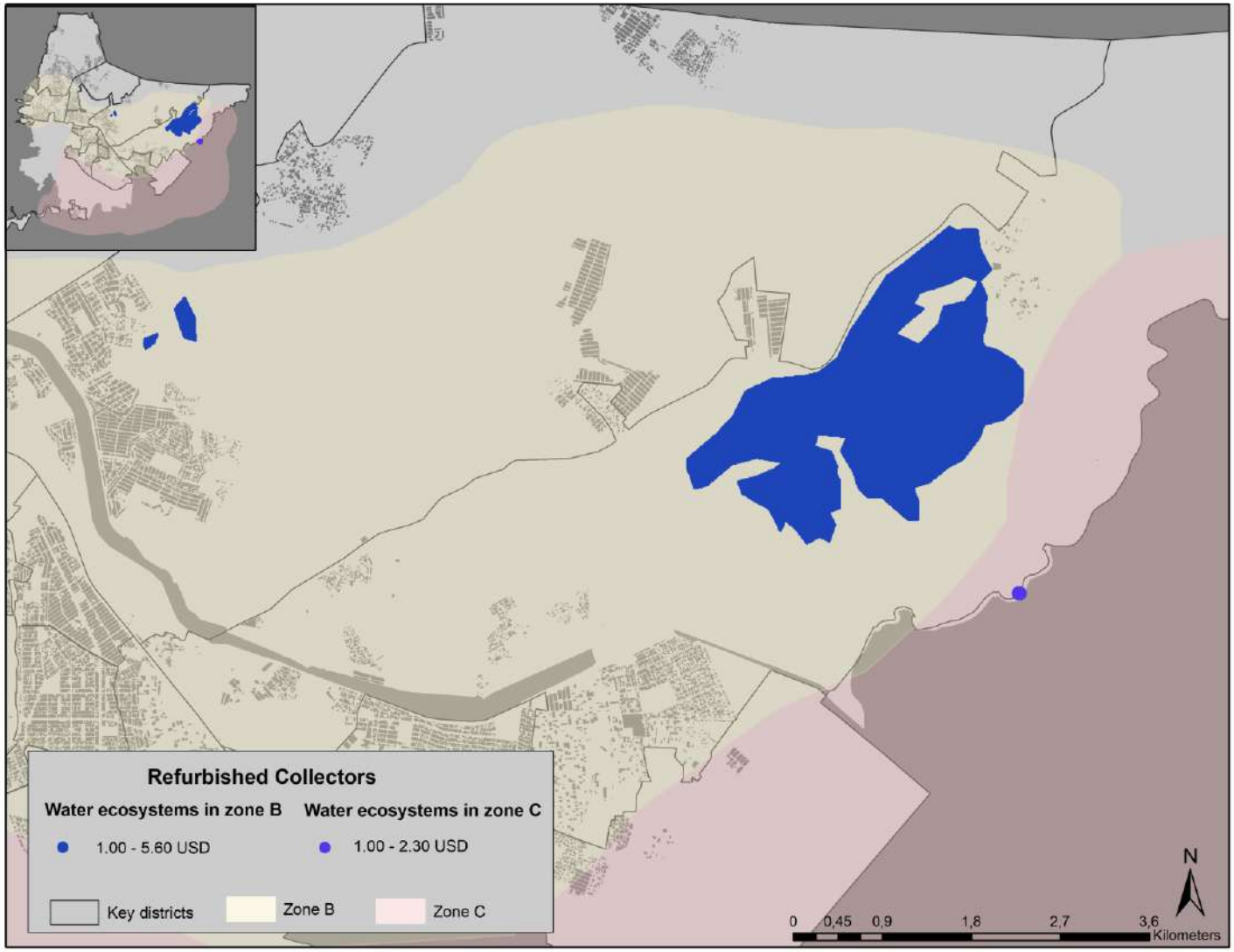
Benefits for Housing with Ecological Restoration and Vegetated Swales under an extreme Climate Scenario (RCP 8.5)



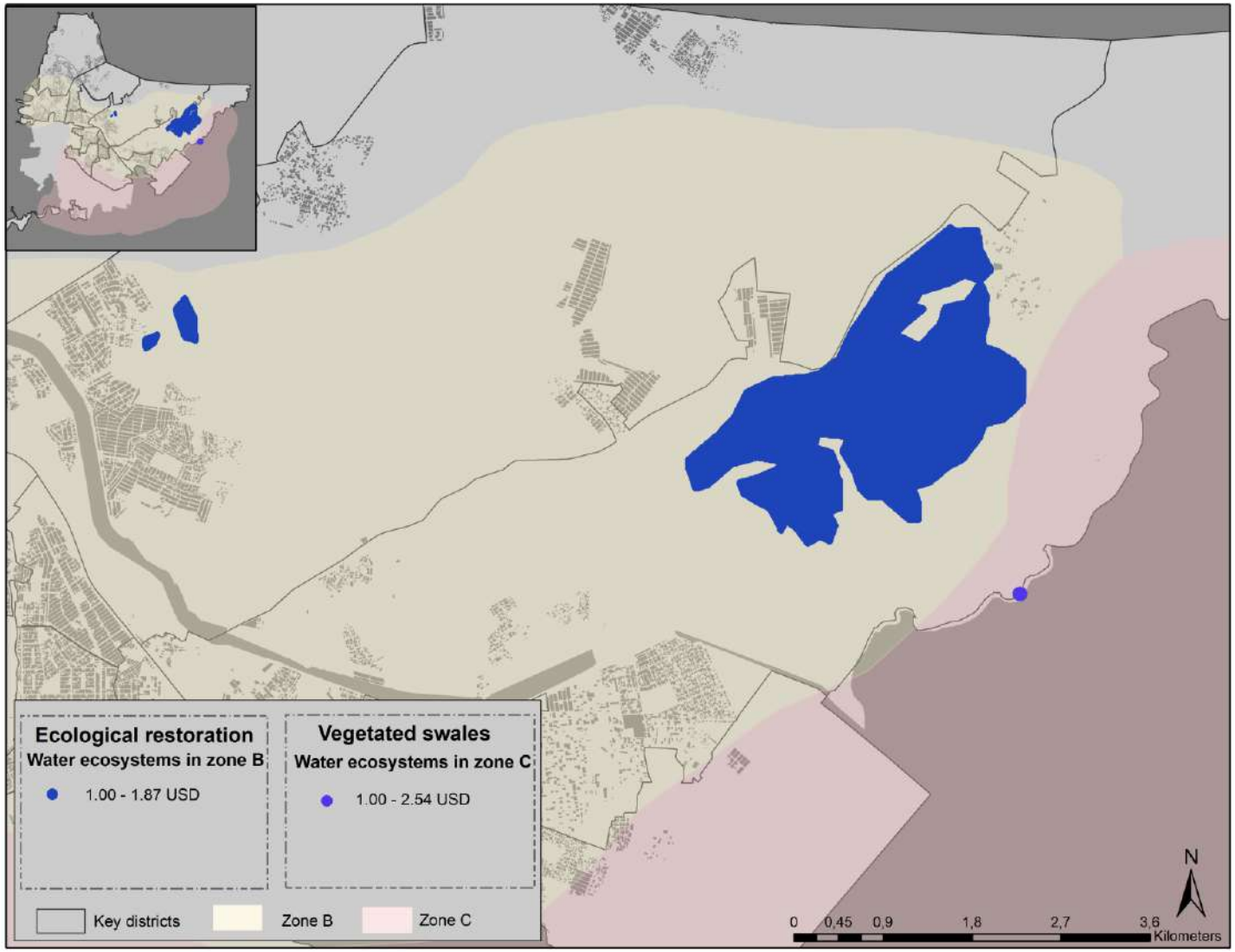
Benefits for Road Network with Refurbished Collectors under an extreme Climate Scenario (RCP 8.5)



Benefits for Road Network with Ecological Restoration and Vegetated Swales under an extreme Climate Scenario (RCP 8.5)



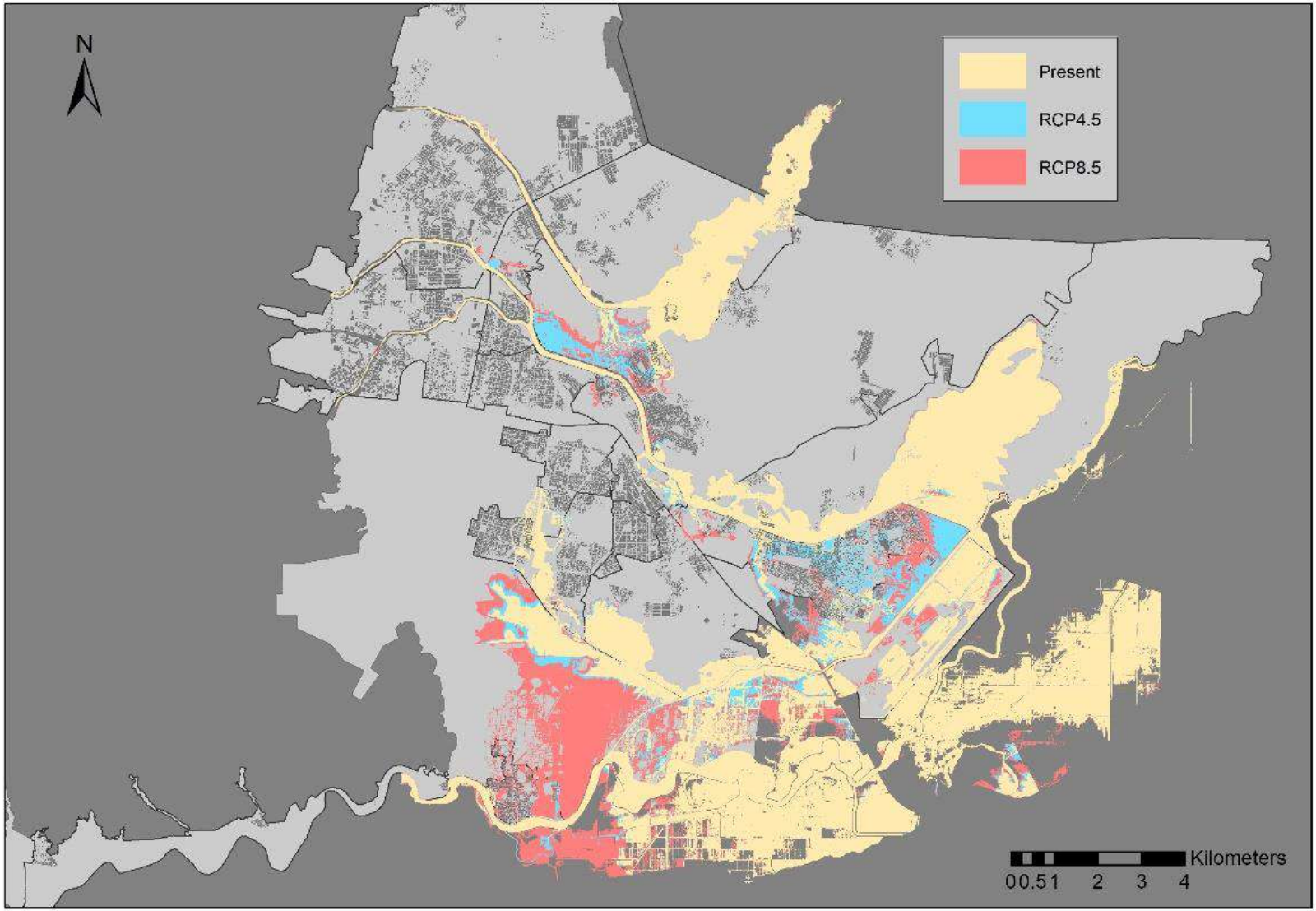
Benefits for Water Ecosystems with Refurbished Collectors under an extreme Climate Scenario (RCP 8.5)



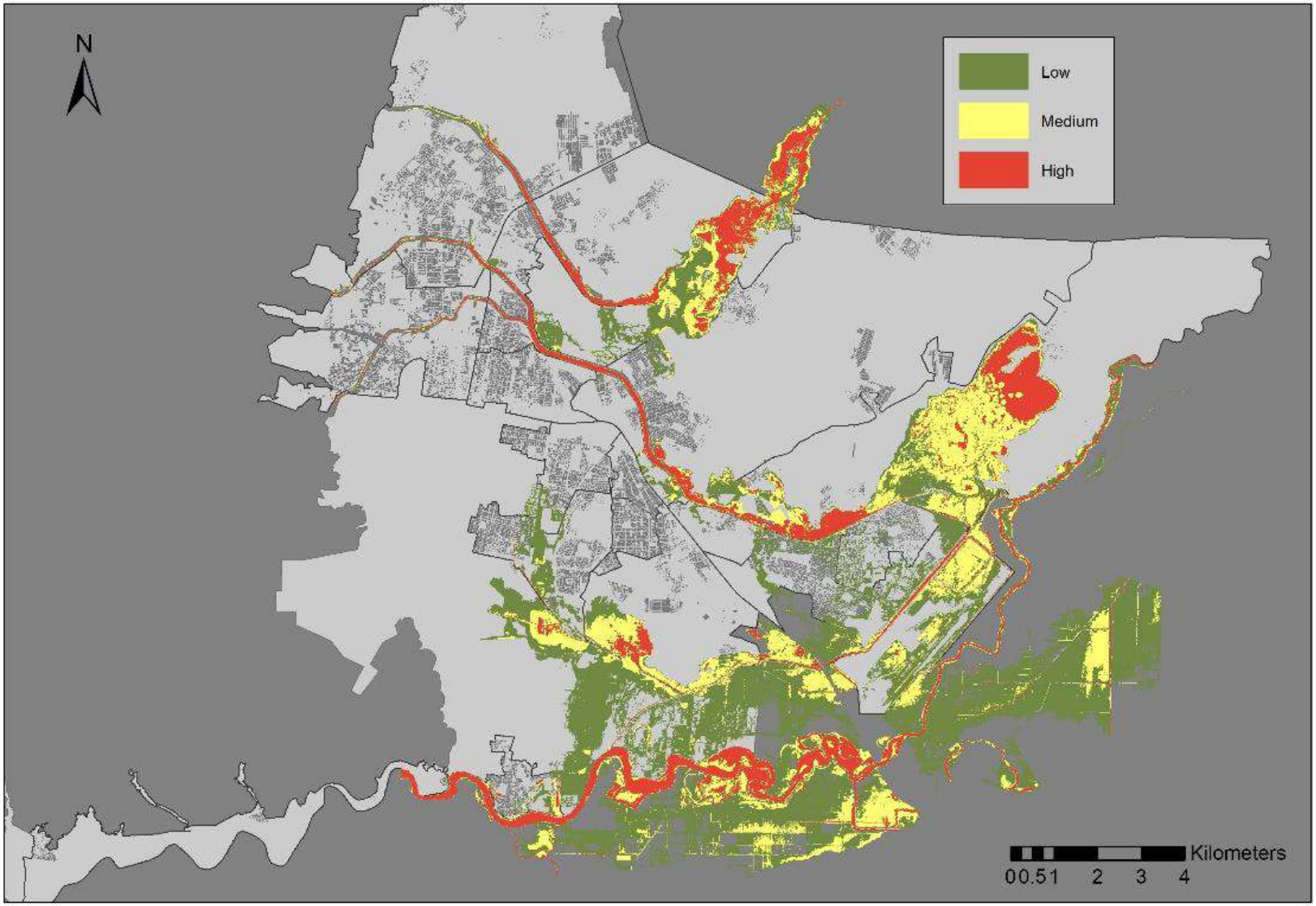
Benefits for Water Ecosystems with Ecological Restoration and Vegetated Swales under an extreme Climate Scenario (RCP 8.5)

ANNEX 10

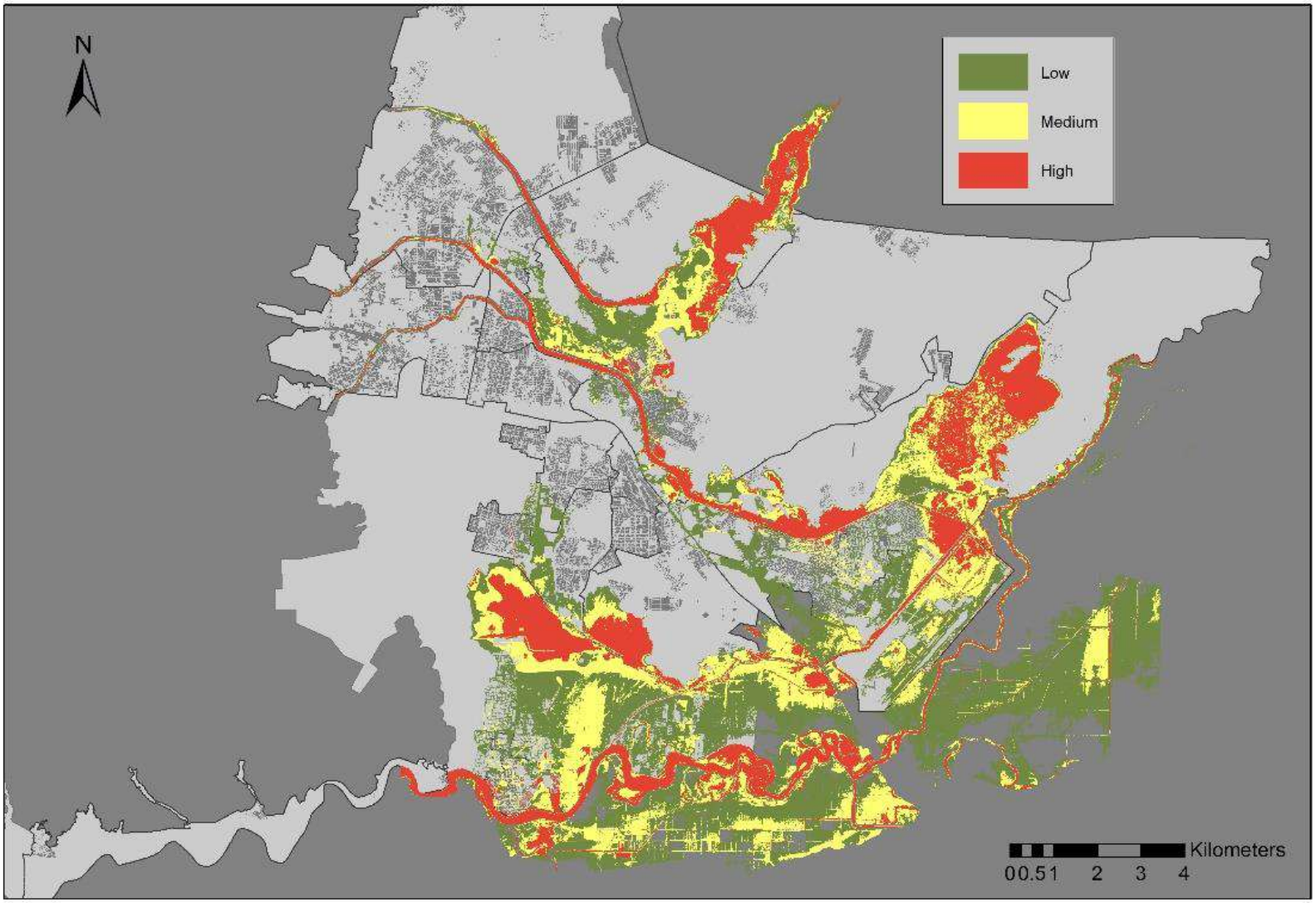
All maps from the report



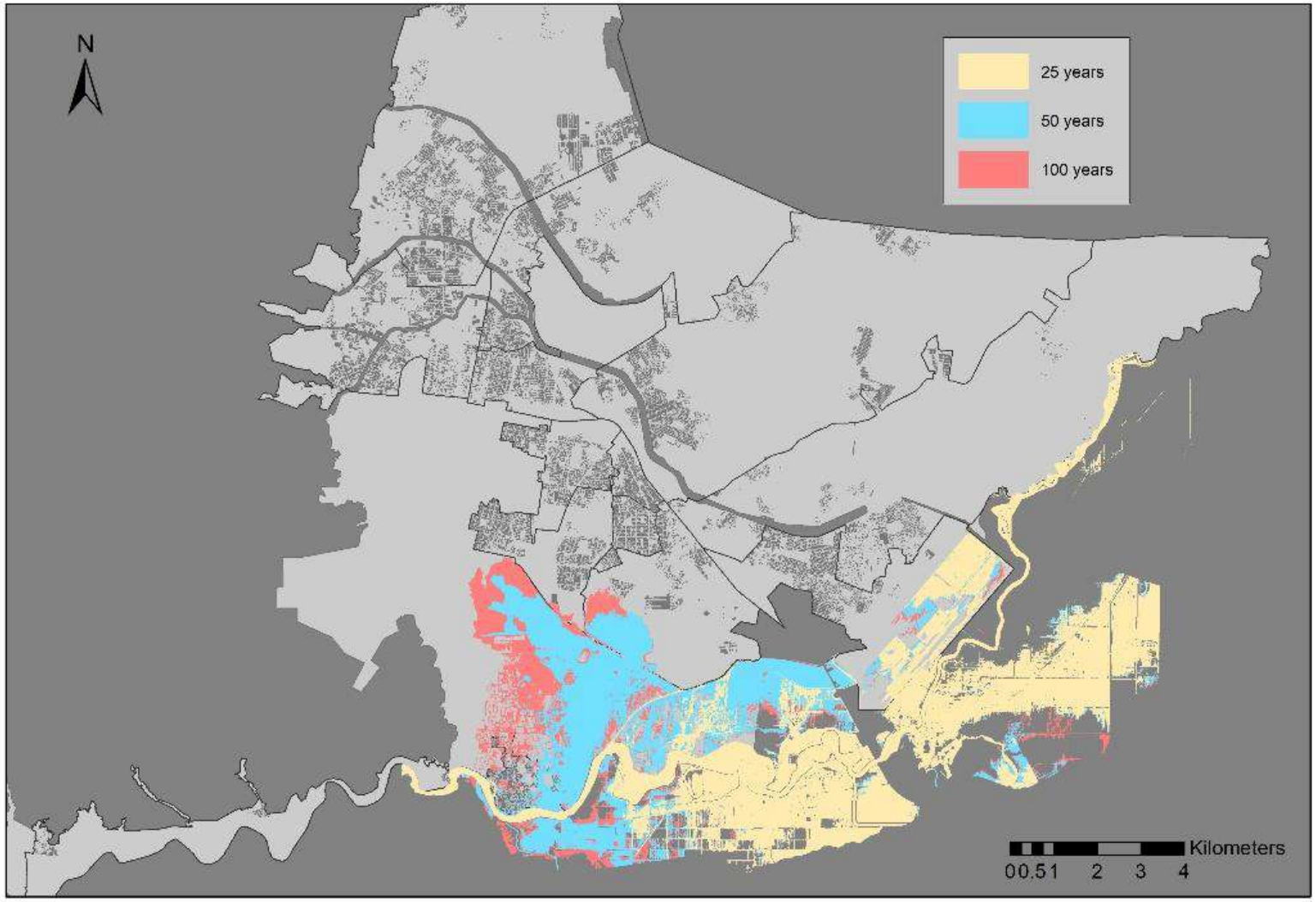
Flood extend for three different scenarios for the 100yr return period



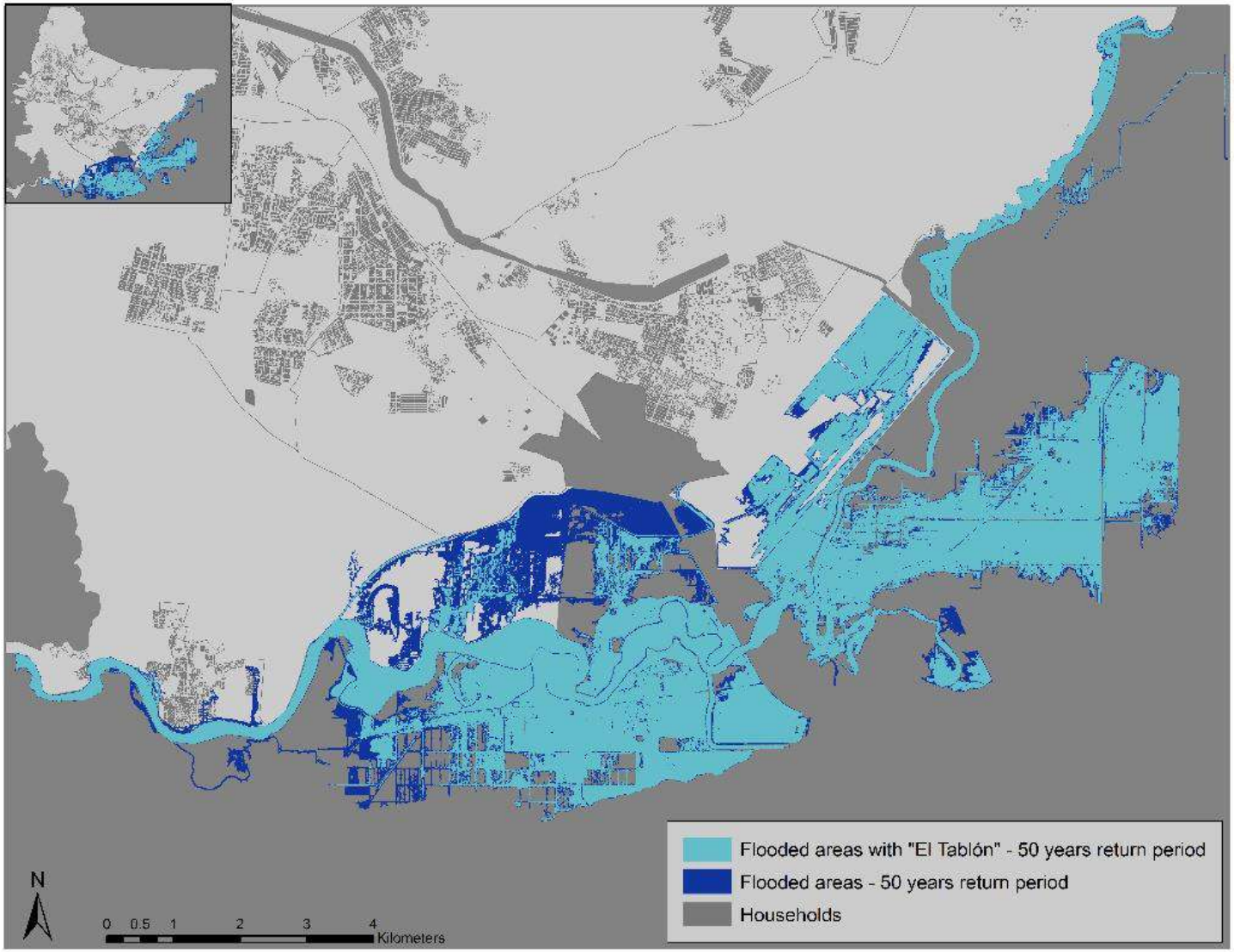
Maximum water depth for the present climate (100yr)



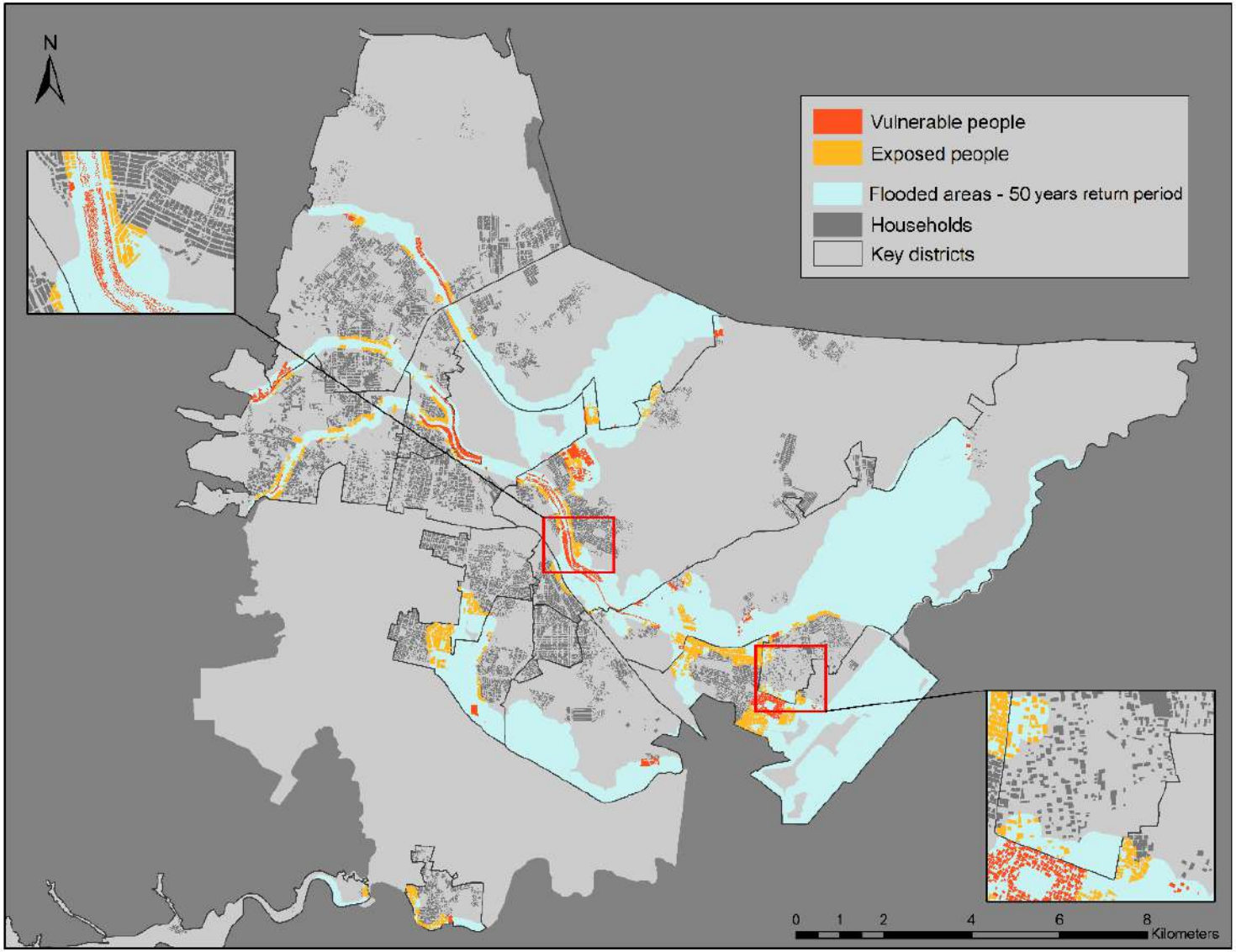
Maximum water depths for a strong future climate (100yr)



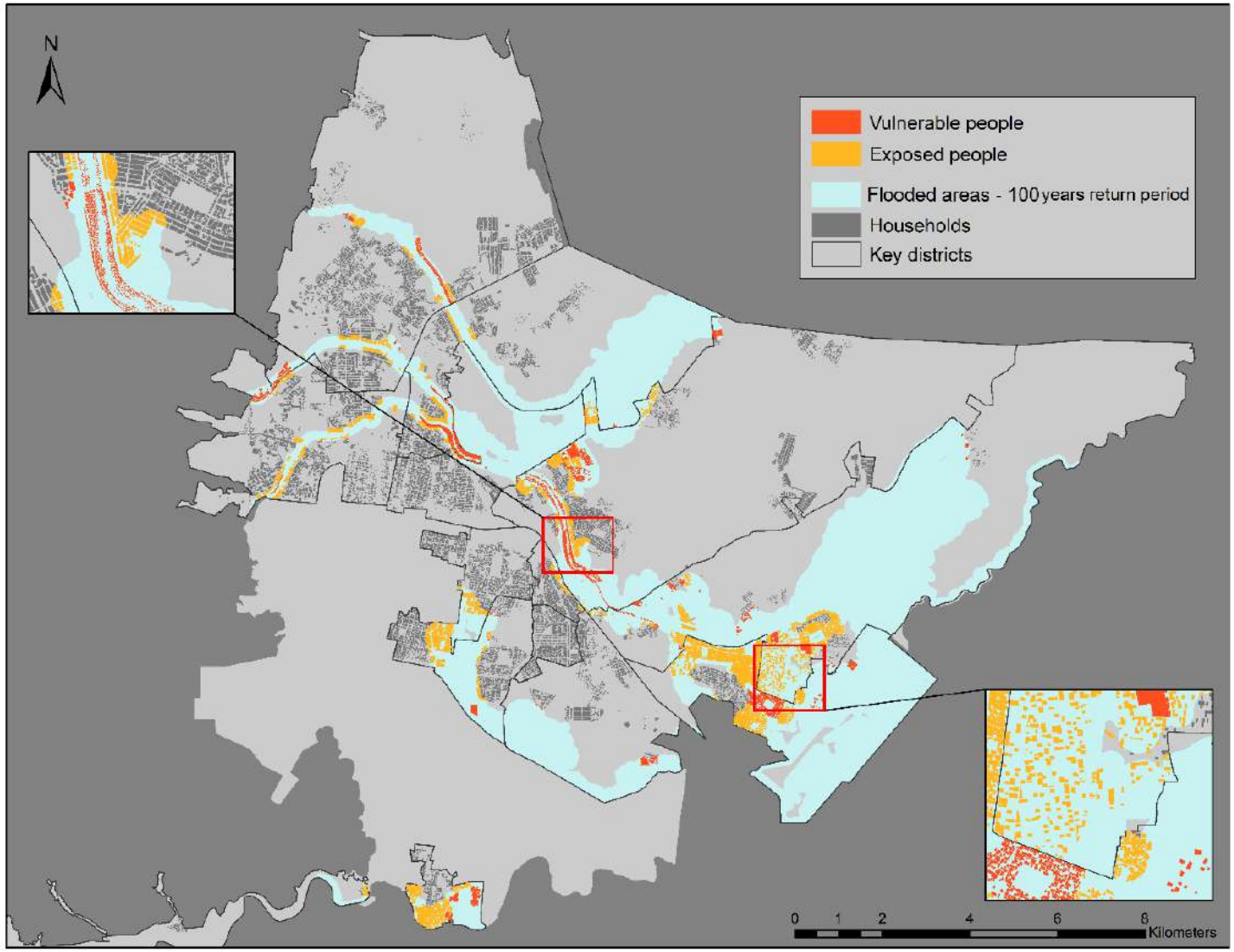
Impact of El Tablón Dam on flood extend for large flood in the Chamelecón sub-catchment



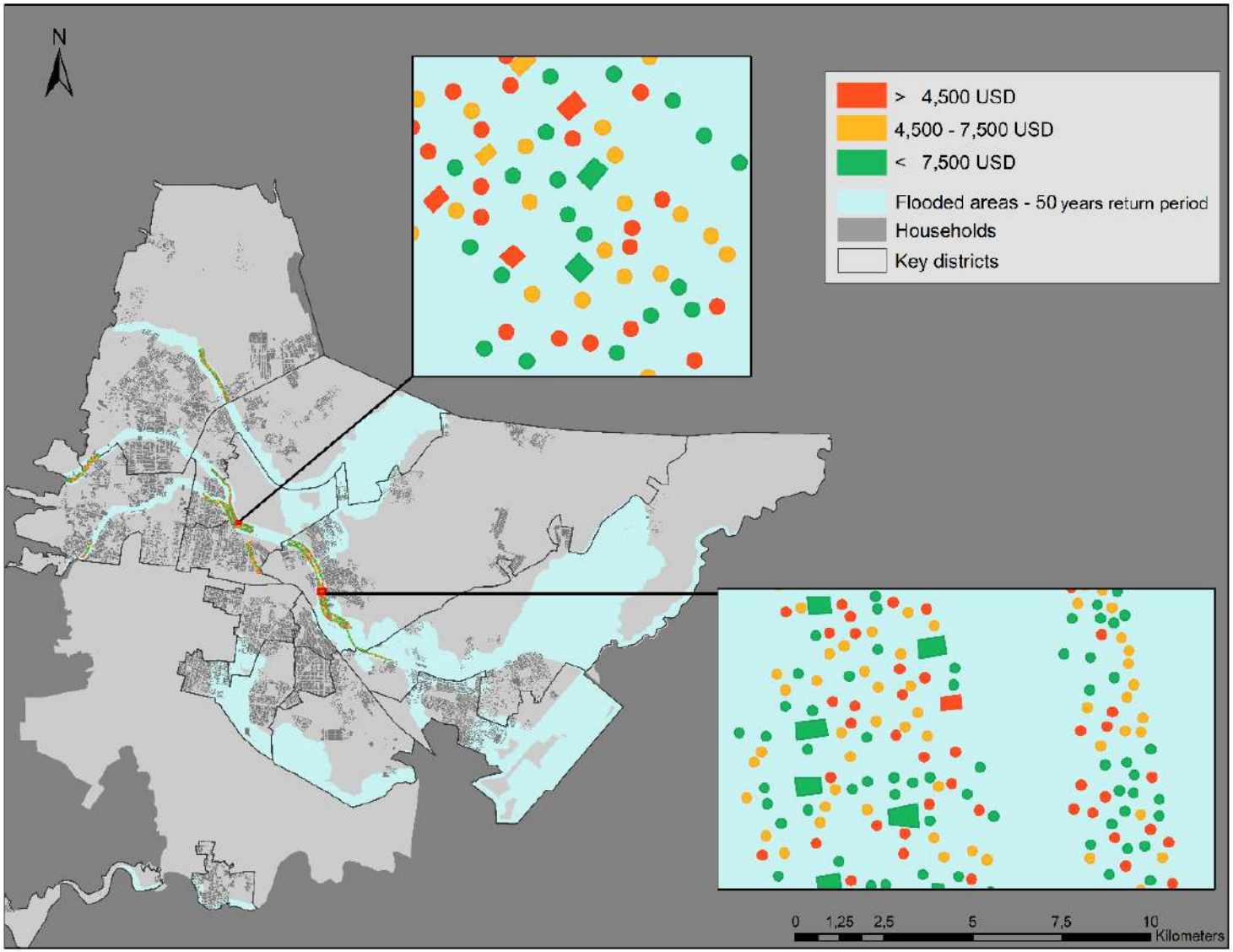
Impact of el Tablón Dam for the RCP4.5 future scenario (50Yr)



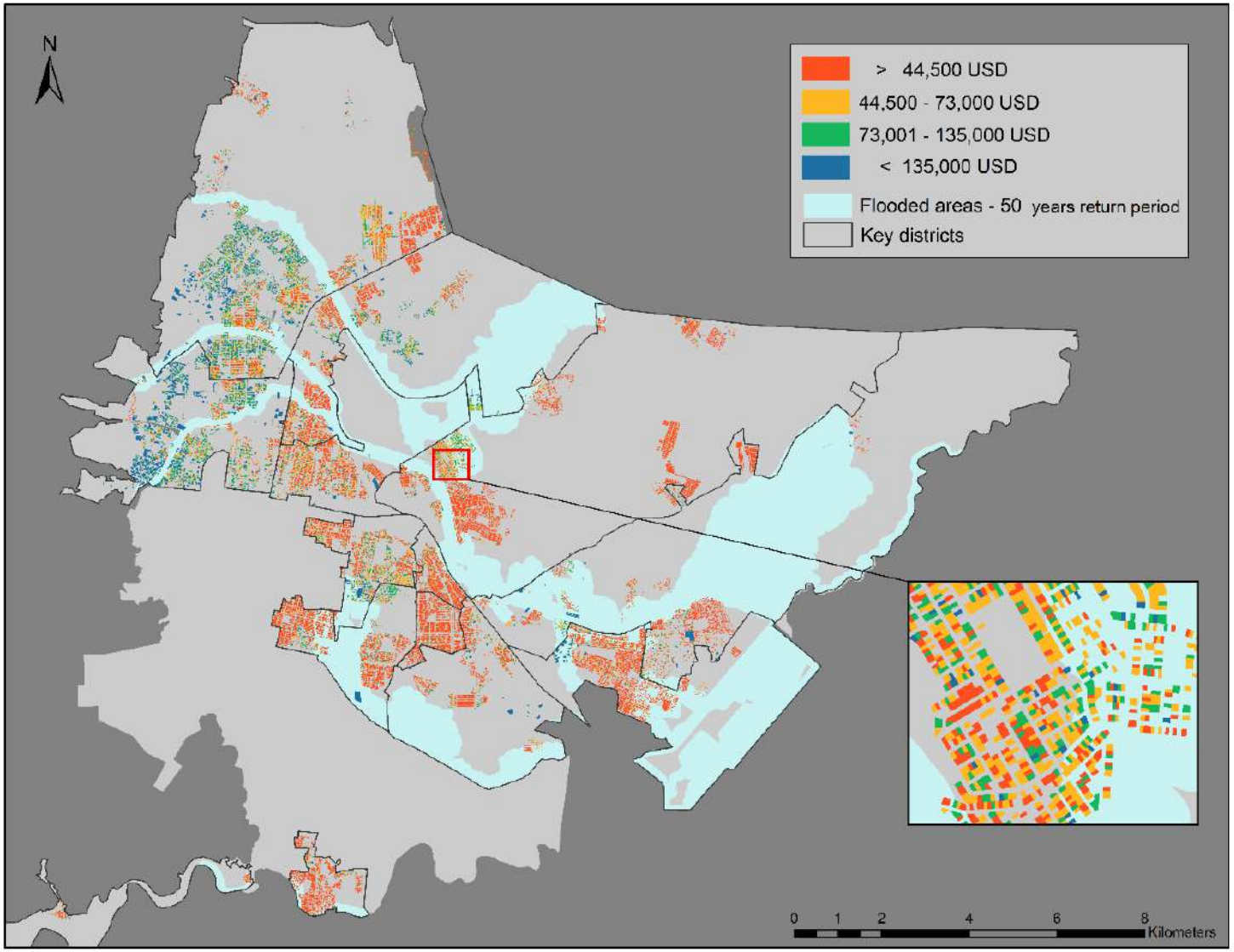
Households exposed to floods for a 50 years return period at the present scenario.



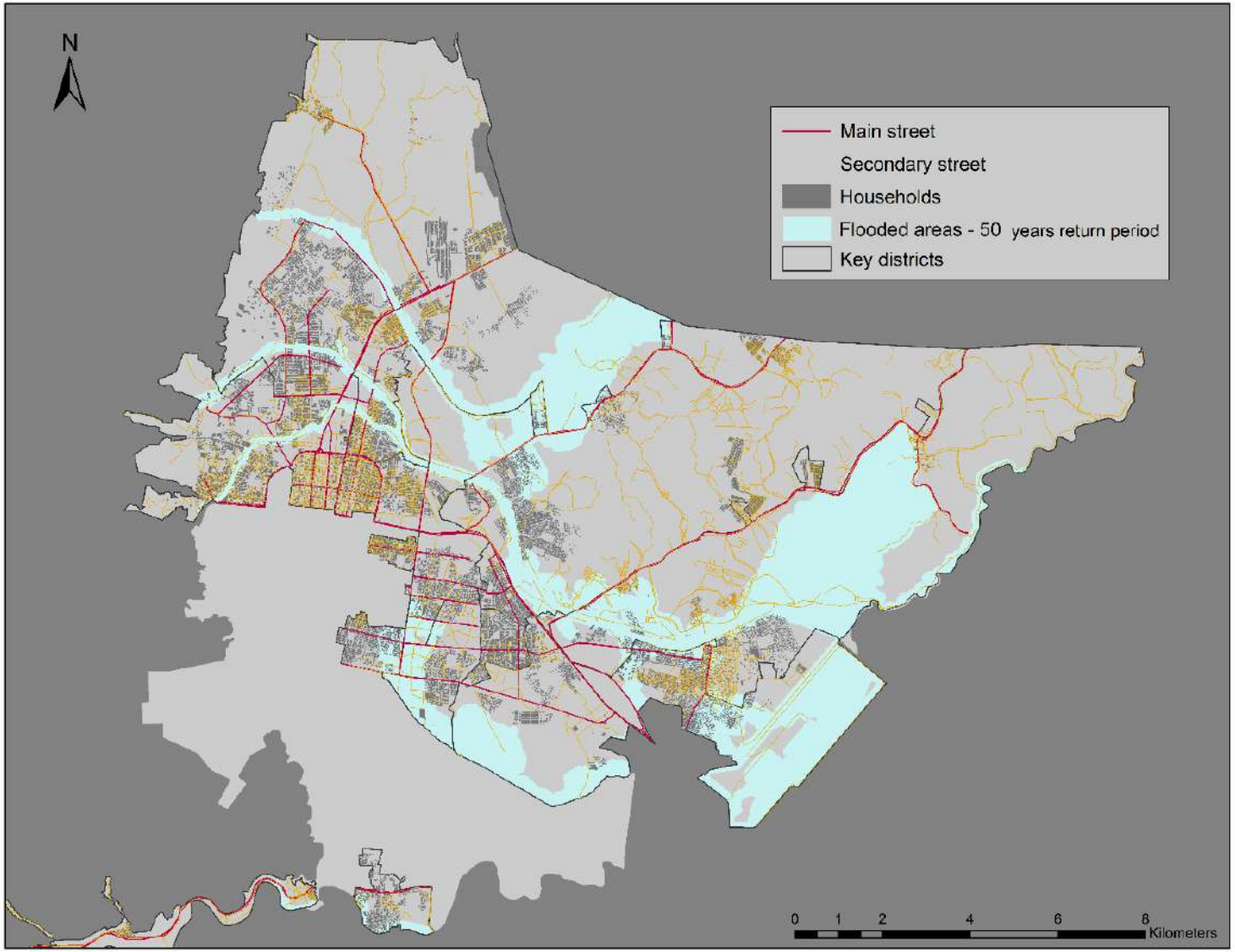
Households exposed to floods for a 100 years return period at the present scenario



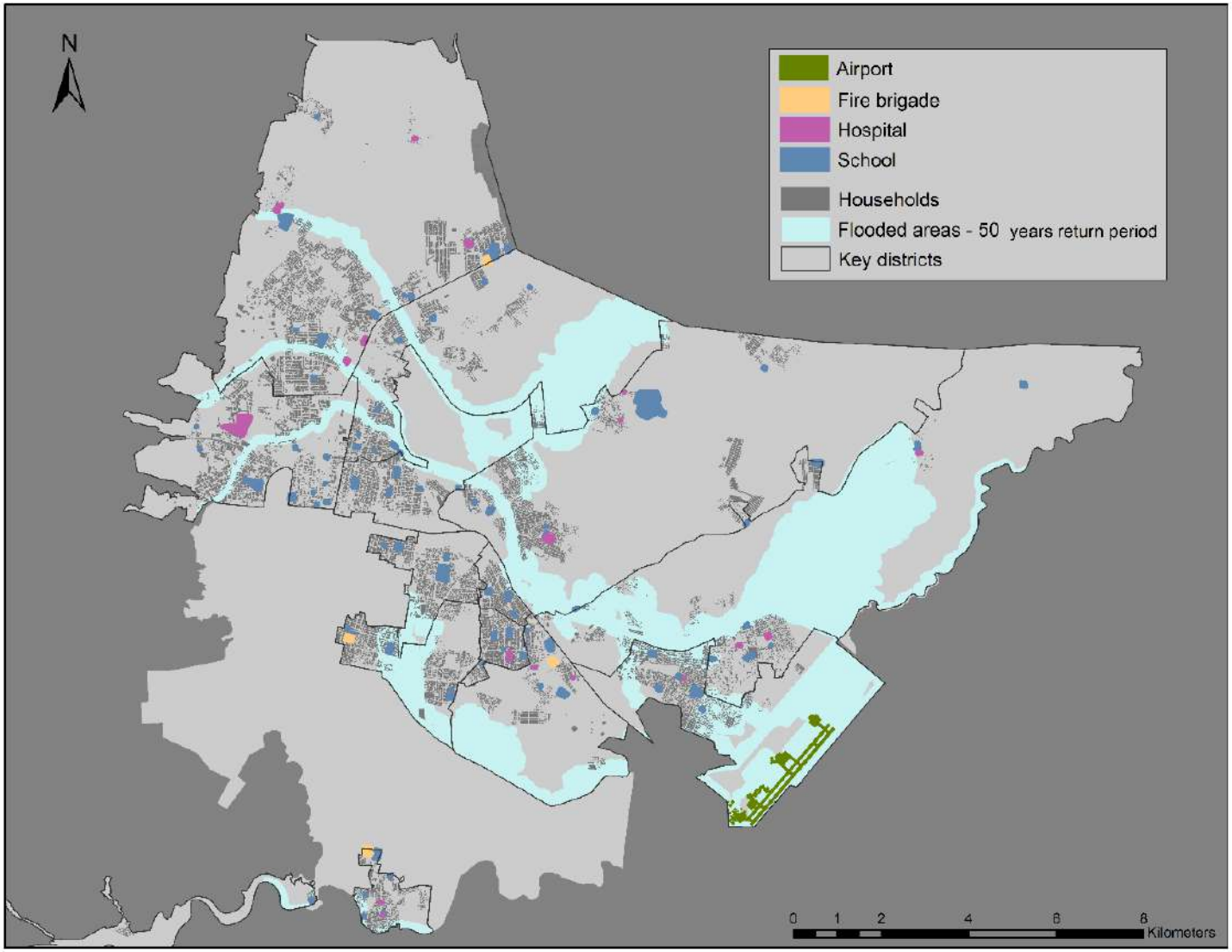
Location and value estimates of housing in Los Bordos



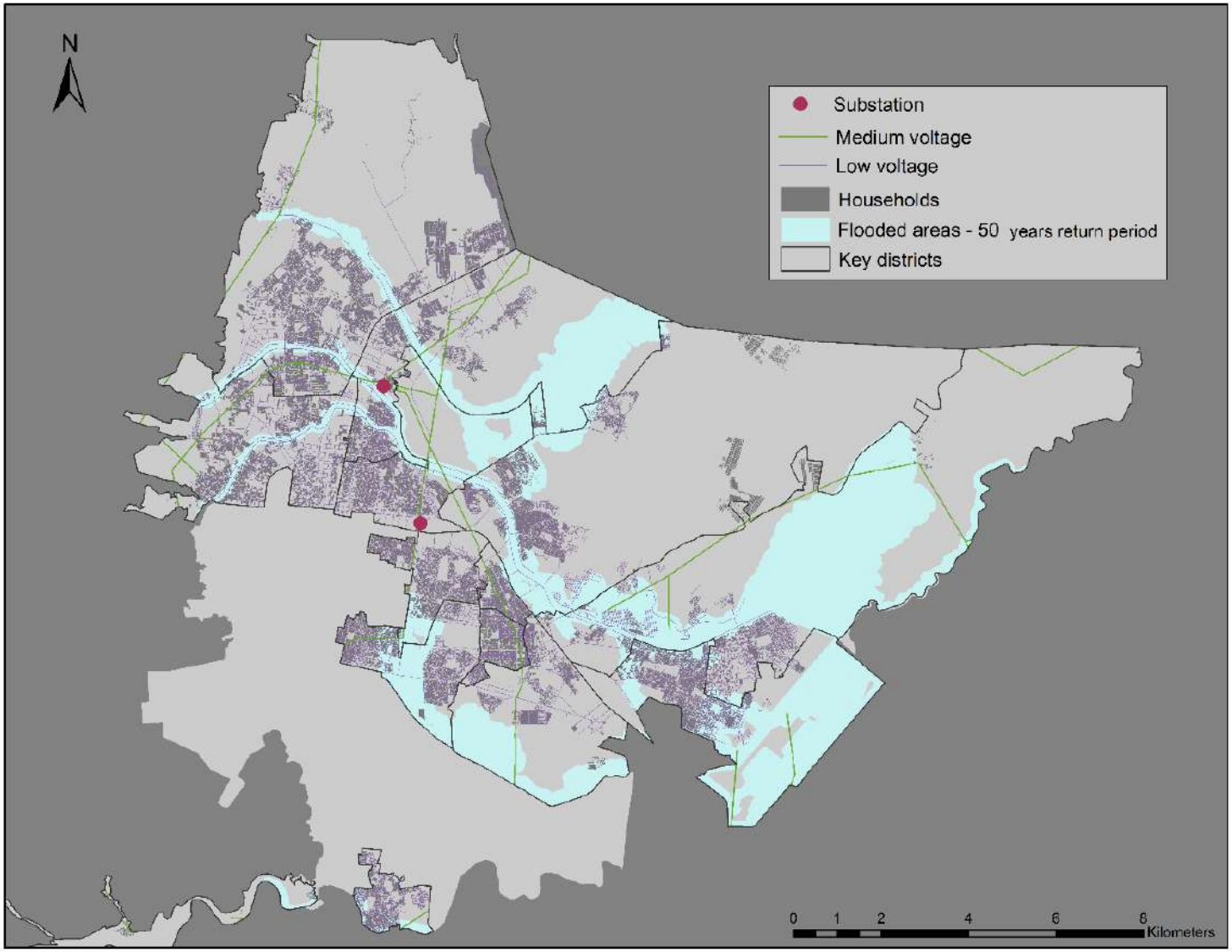
Estimated 2020 USD values for formal housing in San Pedro Sula.



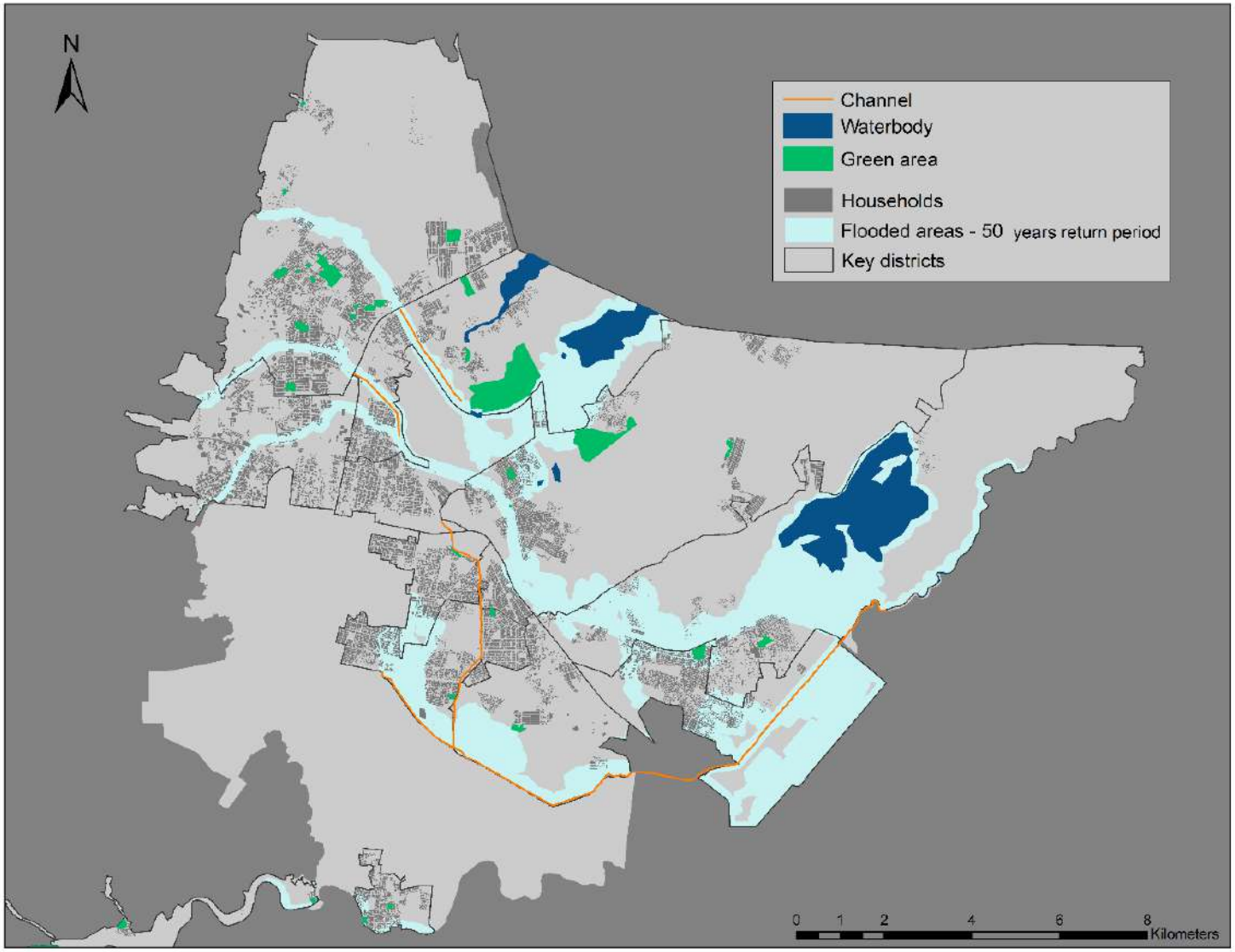
Considered road network. Red: Major roads. Yellow: Minor roads.



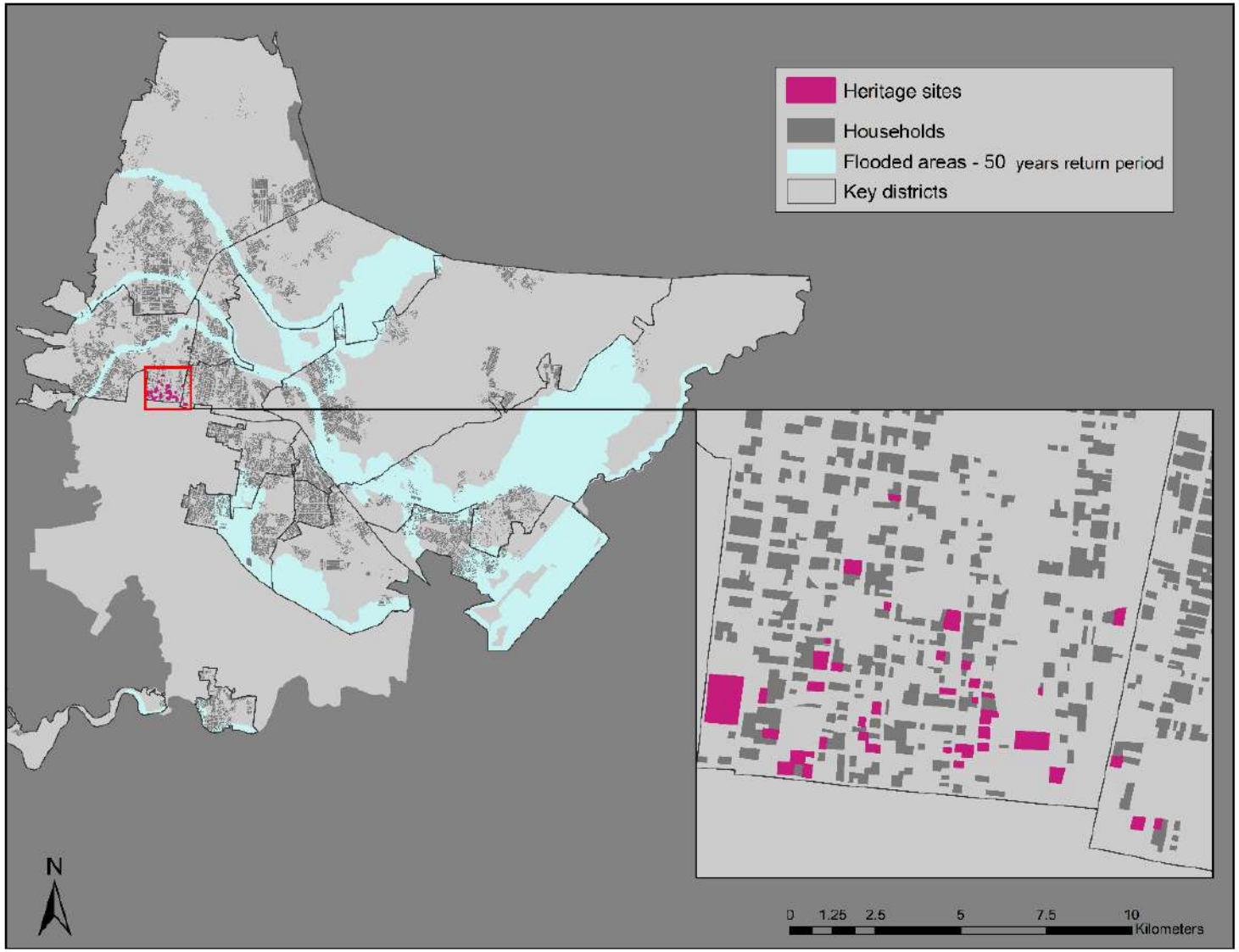
Location of public buildings studied.



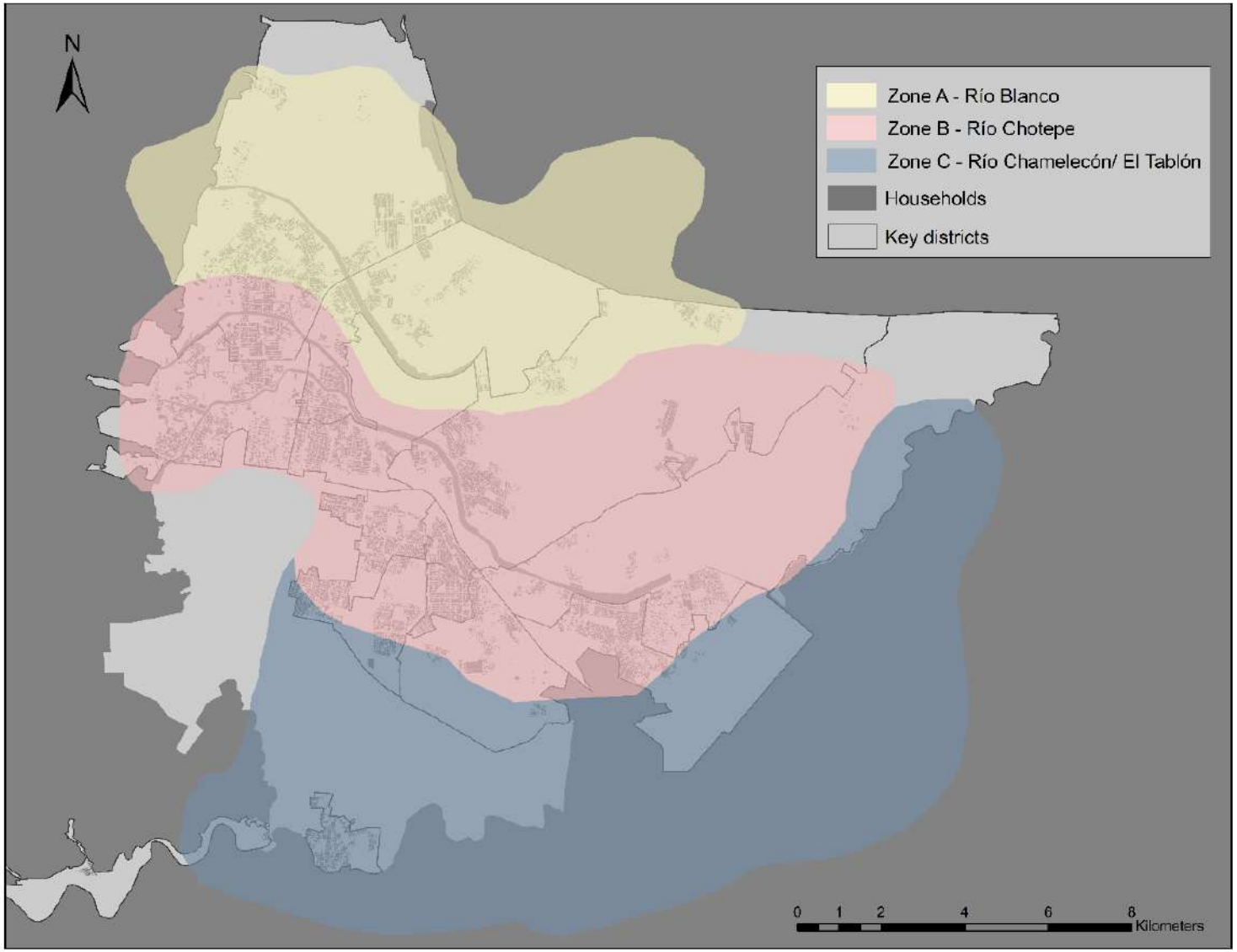
Electrical grid, incl. substations.



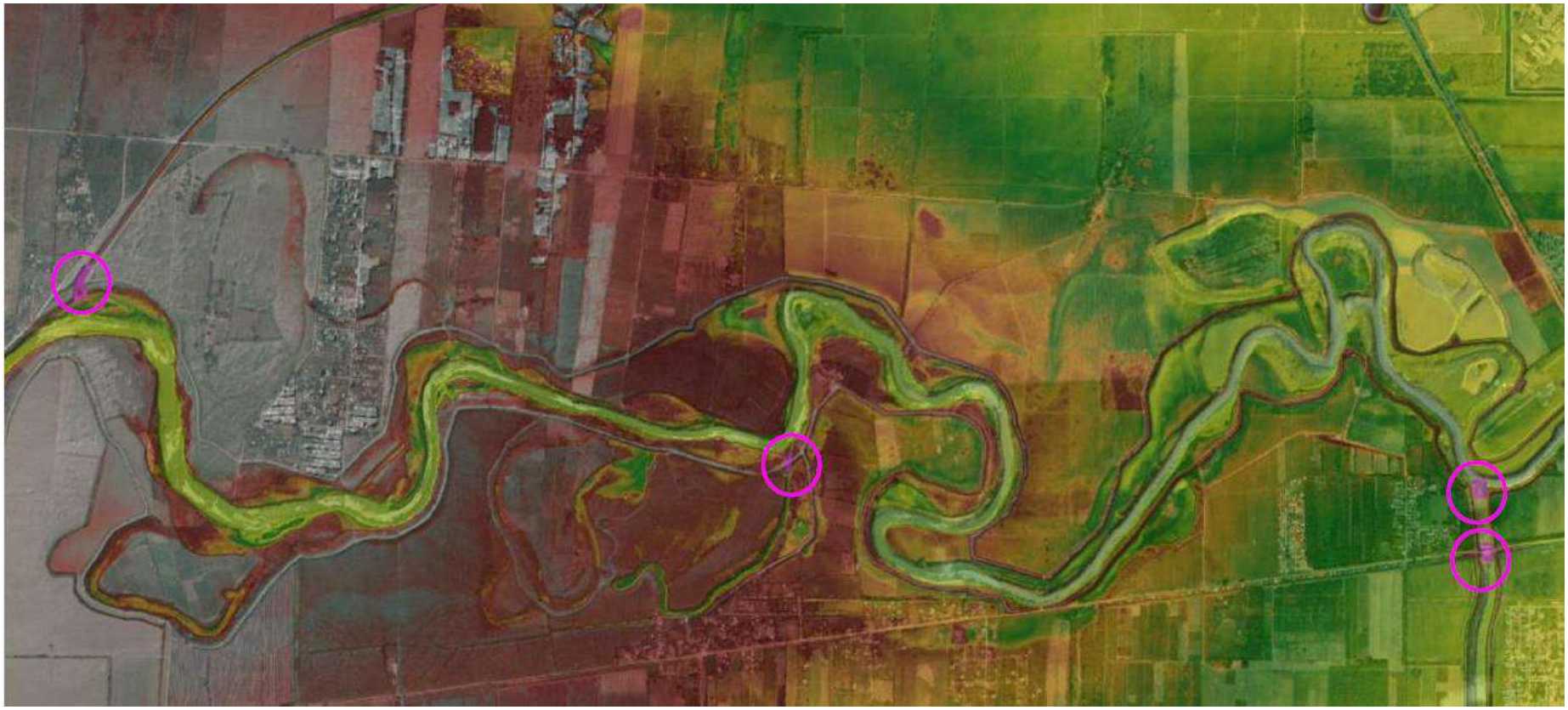
Drainage channels (orange), environmental assets (green), and water bodies (blue).



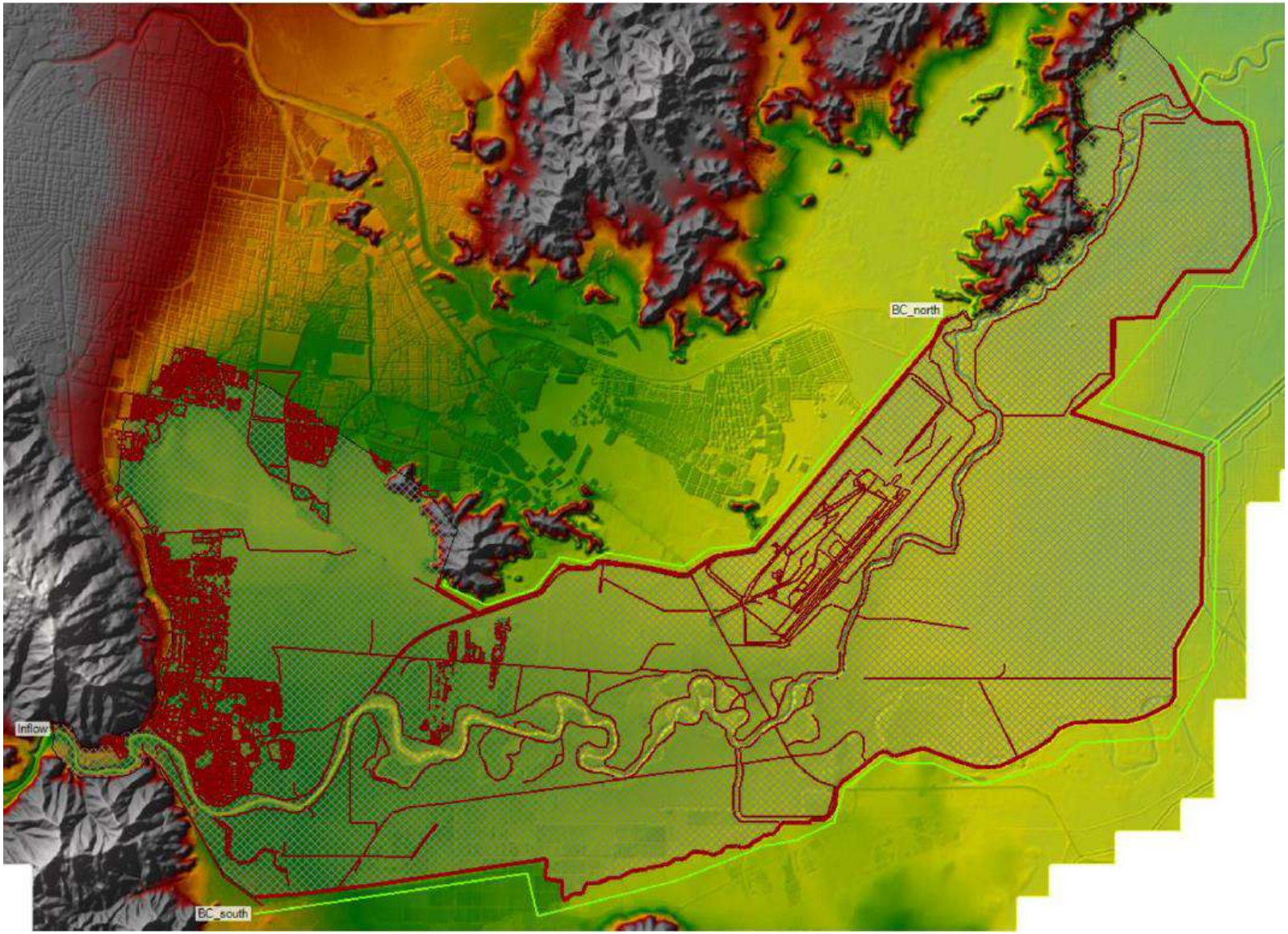
Heritage sites.



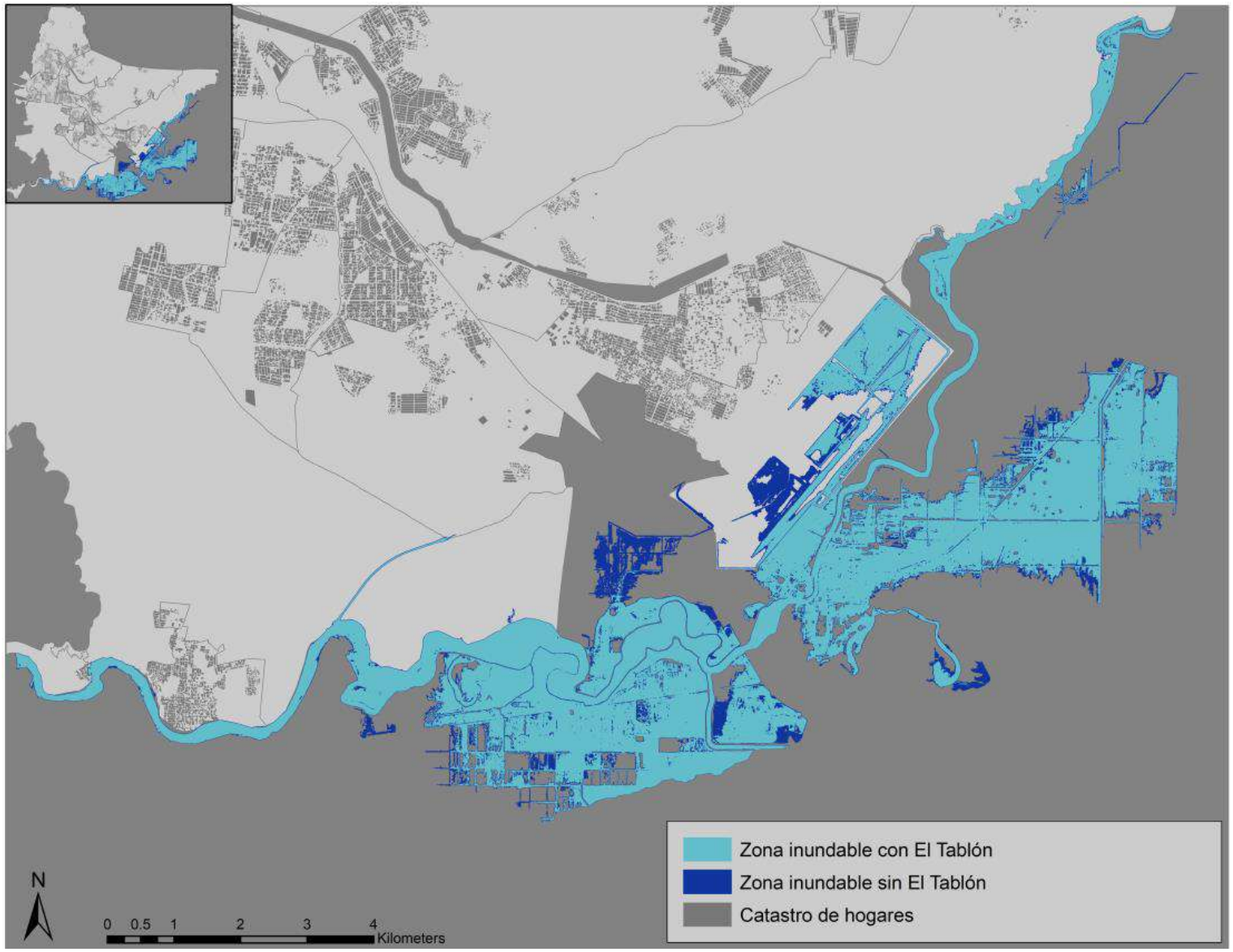
Zones for measures implementation in San Pedro Sula



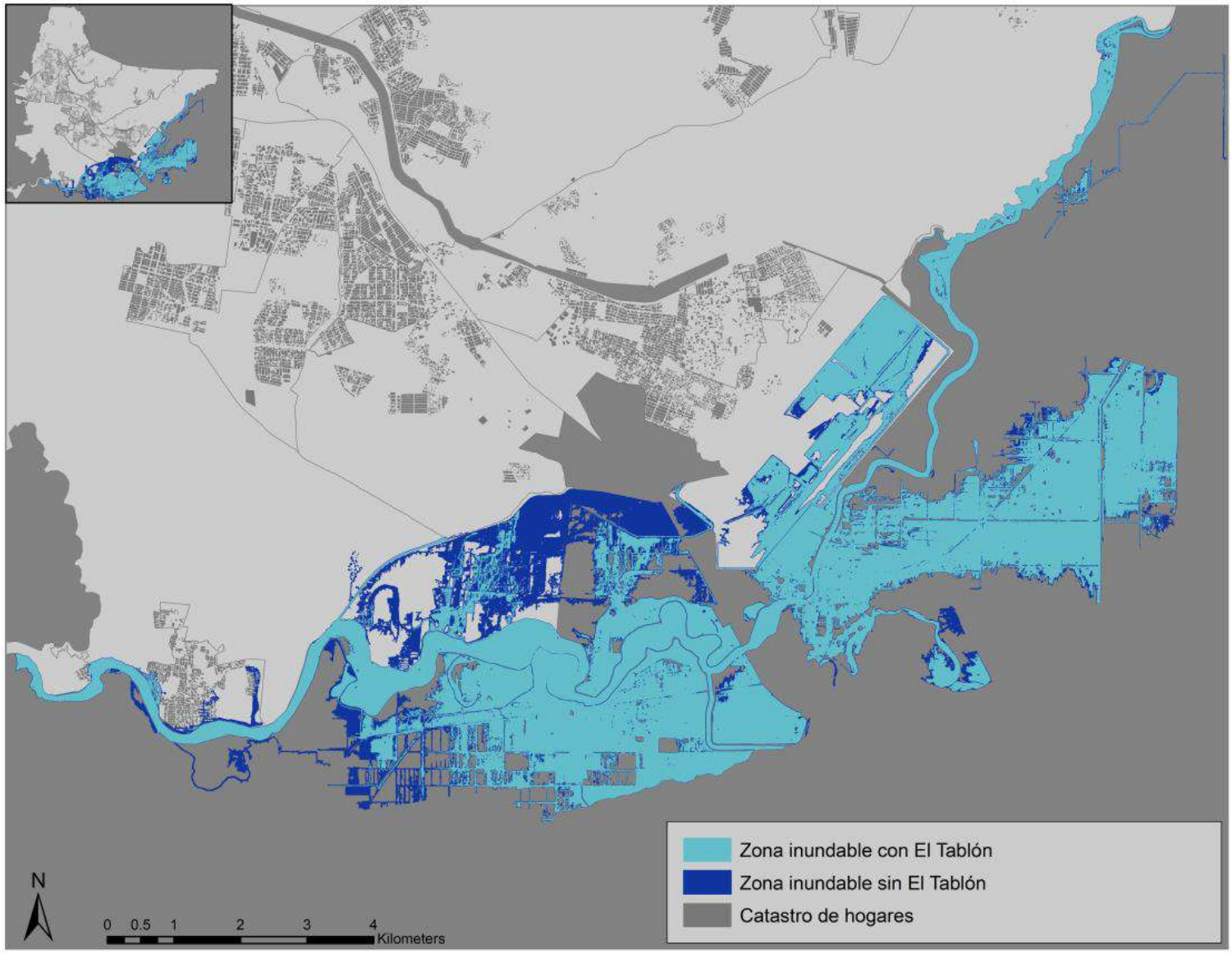
Modifications of the land model for the Chamelecón River



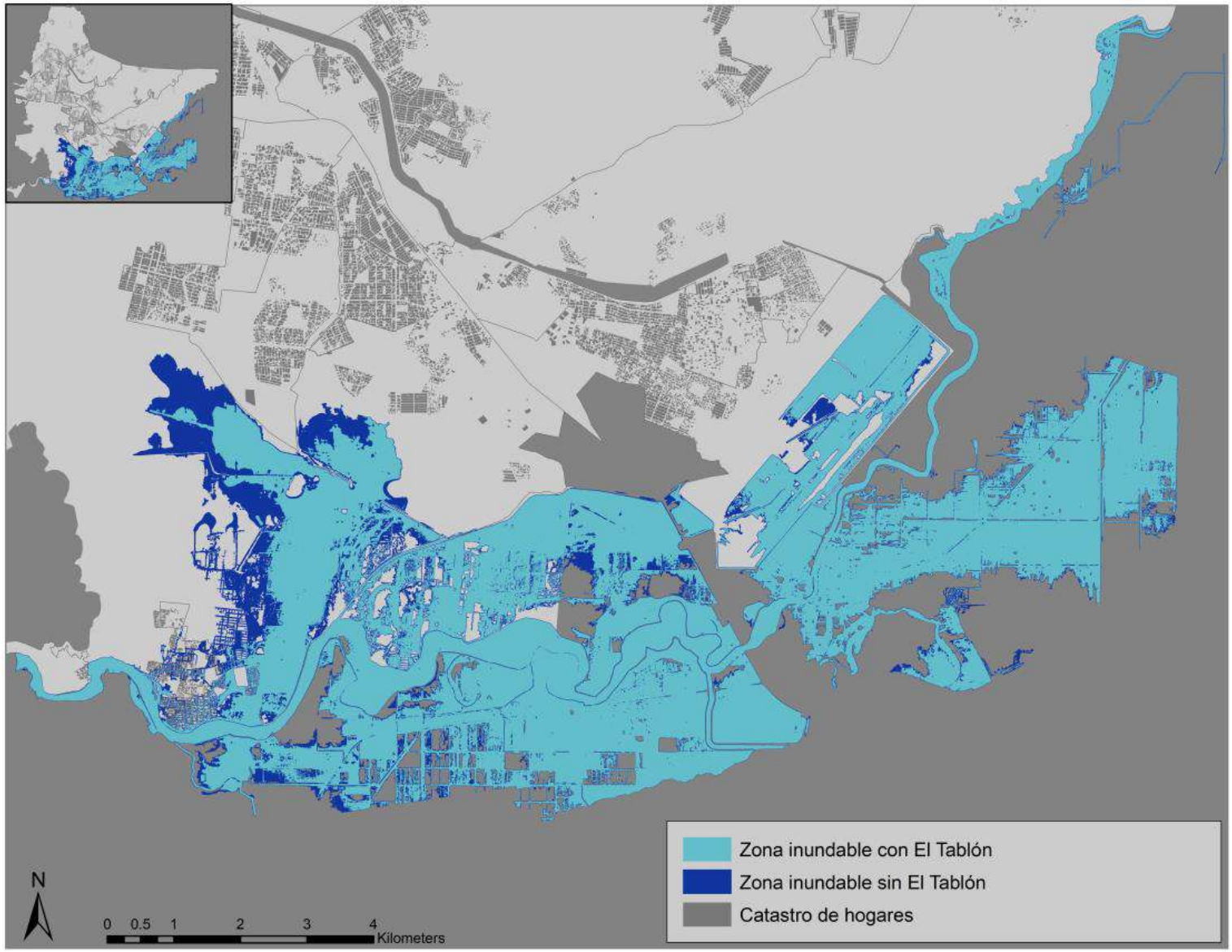
Configuration of the Chamelecon River model, including breaklines (red) and boundary conditions (green)



Floodable areas with and without the Tablón dam for a return period of 25 years



Floodable areas with and without the Tablón dam for a return period of 50 years



Floodable areas with and without the Tablón dam for a return period of 100 year