Mainstreaming Disaster Risk Management to Sustain Local Roads Infrastructure

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Acronyms and Abbreviations

DA	Department of Agriculture
DENR	Department of Environment and Natural Resources
DepEd	Department of Education
DET	Dutch Expert Team
DILG	Department of Interior and Local Government
DOH	Department of Health
DOST	Department of Science and Technology
DOT	Department of Tourism
DOTr	Department of Transport
DPWH	Department of Public Works and Highways
DRRM	Disaster Risk Reduction and Management
EO	Executive Order
GAA	General Appropriations Act
GDP	Gross Domestic Product
GIS	Geographic Information System
GOCC	Government Owned or Controlled Corporations
IA	Implementing Agreement
IDP	Infrastructure Development Preparation
IRR	Implementing Rules and Regulations
IWRM	Integrated Water Resources Management
JV	Joint Venture
MWB	Municipal Water Boundaries
MWWS	Metropolitan Waterworks and Sewerage System
NAMRIA	National Mapping and Resource Information Authority
NEDA	National Economic Development Authority
NGA	National Government Agency
NGO	Non-Government Organizations
NHA	National Housing Authority
NIA	National Irrigation Administration
NPC	National Power Corporation
NRDC	National Resources Defense Council
NWRB	National Water Resources Board
ODA	Official Development Assistance
OGA	Other Government Agencies
OIDCI	Orient Integrated Development Consultants, Inc.
OPMBCS	Operational Plan for the Manila Bay Coastal Strategy
PAMB	Protected Area Management Board
PAPs	Programs, Activities, Projects
PCG	Philippine Coast Guard
PDGs	Philippine Development Goals
PER	Project Evaluation Report
PfR	Partners for Resilience
PNP	Philippine National Police
PRB	Pampanga River Basin
PRBC	Pampanga River Basin Council
RBCO	River Basin Control Office
RDC	Regional Development Council
TOR	Terms of Reference
WPP	Water Partnership Program
WRS	Water Resource System

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1 Introduction

1.1 Introduction to the project

The 2017-2022 Philippine Development Plan recognizes that road infrastructure is a key point of convergence with productive sectors, but the quality remains inadequate. As of 2015, 97 percent (of 31,242 km) of national roads, 62 percent (of 15,377 km) of city roads, and 29 percent (of 31,075 km) of provincial roads were paved. The World Economic Forum-Global Competitiveness Report (WEF-GCR) 2015-2016 ranked the Philippines 97th out of 140 countries in terms of quality of road infrastructure, below neighbouring countries such as Indonesia, Vietnam, Cambodia and Laos.

The KALSADA-Conditional Matching Grant to Provinces (CMGP) program was developed by the national government to help Local Government Units (LGUs) improve the quality of provincial roads, which is significantly below that of national and city roads. This program positions the national government to support, but not supplant, the provincial governments in their responsibility to provide an efficient network of provincial roads which are currently inadequate to meet the need of the population for easier mobility within the provinces.

For sustainability, climate resilience considerations need to be better factored into local roads (provincial, city, municipal and barangay roads) planning and design, especially in the Philippine setting. Drainage on many local roads is frequently absent resulting in recurrent damages caused by runoffs and flooding. Even new roads are sometimes implemented without recourse to properly addressing drainage requirements, and thus the estimated funding requirements for local roads are likely underestimated. This is further exacerbated by the lack of comprehensive drainage plans in LGUs. For local roads, LGUs typically apply the adopted standards of the national roads agency, however how it is applied is largely up to the LGUs, as there is no supervision from national roads agency. Thus, there is a need to assess how road design standards relevant to climate resilience are interpreted and applied by LGUs in practice. Moreover, there are possible interventions by national agency for flood management in a specific area that could have significant implications on project identification and selection at the LGU level, but which otherwise will not be considered without proper linkage and coordination between the national agency and LGUs. How these various interventions are planned and the timing of their implementation to ensure sustainability and resilience of local roads is critical. This project aims to specifically increase the capacity of LGUs in dealing with climate and other risks affecting local roads, and enhance coordination with the national roads agency towards improving the resilience of local roads.

1.2 Scope of this report

Within the context described, the major objectives of the project can be described as:

- increase the capacity and knowledge of a selected LGU in dealing with climate/disaster risks faced by local transport infrastructure, and
- pilot an institutionalized coordination process with the national agencies to better inform local roads planning, using a learning-by-doing approach.

Moreover, the results of the TA must comply with good river basin planning practices based on an IWRM approach and should explicitly address the high levels of uncertainty.

The pilot project is executed within the Nueva Ecija province, in region 3, allowing for a case to apply the ‘learning by doing’ aspect of the objectives together with the LGU and local stakeholders. The results of the project will be directly usable for a wider dissemination to other LGUs.

The results of the project are discussed in two reports:

- Risk assessment report (Costa et al, 2019)
- Adaptive strategy building report (this report)

This Adaptive Strategy Building Report presents and discusses a proposed iterative methodology for adaptive strategy building, including the initial prioritization of interventions, the consideration of IWRM aspects, and the application of simplified quantitative analysis techniques for the provincial road network of Nueva Ecija. The implications of this approach for existing roads design standards are also presented.

1.3 Structure of the report

Following this introductory chapter, the report introduces the Province of Nueva Ecija in chapter 2. Chapter 3 presents and provides guidance for the proposed adaptive strategy building approach designed expressly for LGU application, which recognises the inherent uncertainties LGU planners must contend with in developing their plans. Chapter 4 then presents the results of the review of the existing Pampanga River Basin IWRM plan and its implications for LGU roads planning. Chapter 5 presents the results of a simplified, rapid flood modelling example assessment of the type LGU roads planners could seek to include in their roads planning processes, in order to take into consideration potential integrated flood impacts. Chapter 6 then presents the findings of our review of existing disaster risk management design standards and specifically how they incorporate climate risks.

Specific recommendations are provided at the conclusion of each chapter. Chapter 7 finalizes the report with summary conclusions.

2 Introduction to the province of Nueva Ecija, Central Luzon, Philippines

Nueva Ecija is a landlocked province in the Philippines located in the Central Luzon region, the largest island in the country (Figure 2.1). Covering a total area of 5,751.33 square kilometres, it is the largest province in Central Luzon. It is bounded by (north going clockwise) Aurora, Bulacan, Pampanga, Tarlac, Pangasinan, Nueva Vizcaya.

It is composed of 27 municipalities (Aliaga, Bongabon, Cabiao, Carranglan, Cuyapo, Gabaldon, General Natividad, General Tinio, Guimba, Jaen, Laur, Licab, Llanera, Lupao, Nampicuan, Pantabangan, Penaranda, Quezon, Rizal, San Antonio, San Isidro, San Leonardo, Santa Rosa, Santo Domingo, Talavera, Talugtug, Zaragoza) and 5 cities (Cabanatuan, Gapan, Munoz,

Figure 2.1. Location of Nueva Ecija

Palayan, San Jose) with a population of 2,151,461 people and a density of 370 inhabitants per square kilometre, as of the 2015 census. Currently, the province has 28 provincial government department/division heads namely Legal Officer, Budget Officer, Accountant, Treasurer, General Services Officer, Human Resource Management Officer, Planning and Development Coordinator, Social Welfare and Development Officer, Engineer, Assessor, Agriculturist, Veterinarian, Trade and Industry Officer, Environment and Natural Resources Officer, Provincial Information Officer, Acting Chief of Hospital, Personal Staff Head, Chief Administrative Officer, Station Manager, Warden, Sports and Manpower Development Services Chief Officer, Supervising Tourism Operations Officer, Manpower Training Center Officer, Civil Security Unit Chief, Disaster Risk Reduction and Management Officer, ELJMC Chief, and Cooperative Officer.

Nueva Ecija is also known for being Rice Granary of the Philippines since one its major industries is agriculture for rice, corn, and onions. Other industries include poultry and dairy farms, mining, and health services. It is one of the provinces that is traversed by Pampanga River. The river provides the province for irrigation, fishponds, and others. However, it also floods the province given extreme weather conditions.

The province is linked to the main highway system of Luzon, the Maharlika Highway, through a system of roads that interconnect the various municipalities. The road system makes Nueva Ecija easily accessible from all surrounding provinces and from Manila as well.

3 Adaptive strategy building

3.1 Introduction

This chapter presents an approach and results for initial adaptive strategy building for roads planning in Nueva Ecija responding to the risks identified in the risk assessment. The approach recognises the importance of planning for an uncertain future and is simple enough for provincial planners to apply independently. The analysis is provided at the level of generic archetypes in order to provide useful initial guidance to provincial planners when performing assessments for specific road sections in Nueva Ecija.

The chapter commences with a brief discussion of decision making under uncertainty (DMU) (section 3.2), before outlining in detail the analytical steps of the adaptive strategy building approach to be applied (section 3.3). There follows a description of the generic archetypes analysed (section 3.4), and a discussion of the key uncertainties impacting on the provincial roads network in Nueva Ecija(section 3.5). Measures for each archetype are then described (section 3.6), before the assessment at the level of the generic archetypes are presented (section 3.7). A discussion of preparing adaptation pathways for specific road sections is then provided, as well as a prototypical pathways map for one archetype (section 0). The chapter concludes with a brief account of the application of the approach with LGU representatives (section 3.9), summary remarks (section 3.10) and recommendations (section 3.11).

3.2 Decision making under uncertainty

Decision makers today face deep uncertainties about a myriad of external factors, such as climate change, population growth, new technologies, economic developments, as well as their impacts. For investments in transport infrastructure, where capital expenditures can be high and asset lifespans long, decision makers need to be confident the decisions they take today will continue to apply in the future. They also need to be confident that the planned infrastructure is designed to cope with the changing conditions. To meet this challenge, new methods and approaches have been developed to help decision makers identify and evaluate robust and adaptive strategies, and thereby make sound decisions in the face of these challenges.

One such approach is Deltares' Dynamic Adaptive Policy Pathways (DAPP) (Haasnoot et al., 2013). DAPP is an approach to decision making under uncertainty (DMU) which explicitly considers decision-making over time. At its essence is proactive and dynamic planning in response to how the future may unfold. It explores alternative sequences of decisions or interventions (i.e. adaptation pathways) under multiple futures, which help to illuminate any path-dependencies. The approach recognizes that policy interventions have uncertain design lives, and sooner or later may fail to achieve their objectives as conditions change or may not be feasibly implemented until certain conditions exist (i.e. they reach an adaptation tipping point). Interventions are sequenced into 'pathways', with each pathway ensuring that the specified policy objectives continue to be achieved as conditions change. DAPP supports planners to design dynamic adaptive plans that cover short-term actions, long-term options, and adaptation signals which identify when to implement actions or revisit decisions.

DAPP is most useful when there exists a high potential for 'regret' in terms of not taking action, taking action in the wrong direction, taking insufficient action, or over-investing. It is also most usefully applied in situations where the system is sensitive to the changing conditions, and/or where there exists path- or temporal-dependencies. That is, where one action precludes another from being taken, when switching from one action to another involves significant transfer costs, or when acting today has different consequences to acting in the future.

3.3 Approach

The approach (Figure 3.1) applied in this study adapts and contextualises DAPP and strategy building activities to the specifics of provincial roads planning in Nueva Ecija. We undertake a semi-quantitative assessment, whereby available data and expert judgement is combined in a procedure intended to be appropriate for provincial roads planners to implement independently. Given the large number of provincial road sections in Nueva Ecija, our analysis is presented at the level of generic archetypes, with the current and future performance of measures relevant to each archetype assessed via expert judgement. The impact of both climatic and socioeconomic uncertainties is included in the analysis, through examination of existing trends and projected developments in expected peak discharges and traffic demand. Robustness of individual measures is assessed across several plausible future scenarios via minimax analysis, with the measures ultimately prioritised and assessed semi-quantitatively by applying a flexible, weighted multi-criteria analysis framework. Prioritised measures can then be used to assemble initial relative adaptation pathways through consideration of the sequencing of options in the short-, medium- and long-terms. The following paragraphs outline each of these points in greater detail.

The intention of our archetypical approach is that it builds upon the previously reported risk assessment activities (Costa et al, 2019). Provincial roads planners would first determine key 'hotspot' locations for intervention from the risk assessment. For each hotspot, planners would then be able to select the appropriate archetype to provide an initial assessment of potential measures and their prioritisation. However, we would always encourage roads planners to update the figures used in the (archetypical) assessments to match the specific conditions of each hotspot. We also encourage roads planners to engage key stakeholders and decision makers in each of the assessment activities, in order to include a broad range of perspectives and improve transparency.

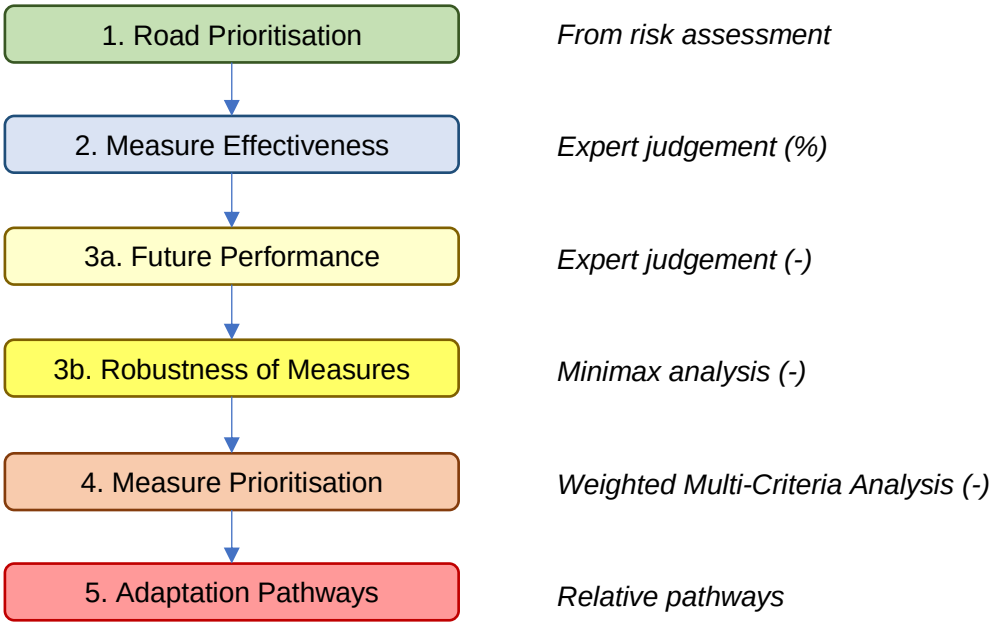


Figure 3.1: Strategy Building approach adopted in this study, with indication of methodology applied in each process step

3.3.1 Road Prioritisation

The final output from the risk assessment activities are the prioritisation maps for Nueva Ecija (e.g. Figure 3.2, refer to separate Risk Assessment Report: Costa et al, 2019). This map provides provincial roads planners with a quick, visual representation of the current status of each road section in the network, considering the five-category scales for both expected annual damages and losses (Figure 3.3).

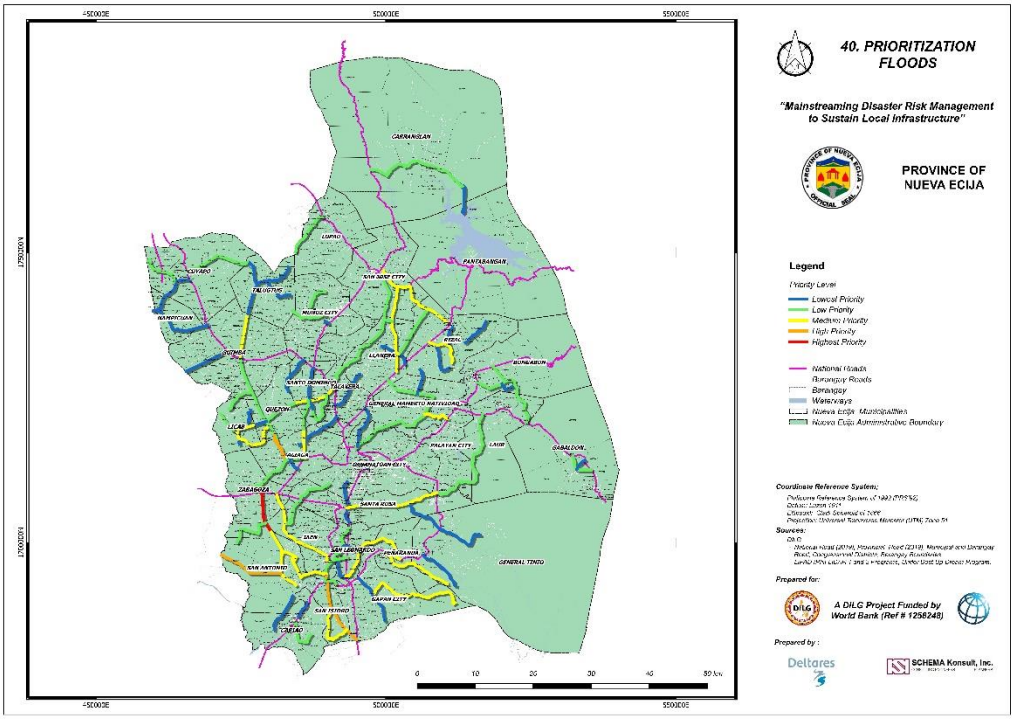


Figure 3.2: Prioritisation map for flood hazard

		Damage Category				
		C1	C2	C3	C4	C5
Losses Category	C1	1	1	2	2	3
	C2	2	2	3	3	4
	C3	3	3	3	4	4
	C4	3	4	4	5	5
	C5	4	4	5	5	5

Figure 3.3: Road prioritization matrix considering 5-category scales for both expected annual damages and losses

Borrowing from the DAPP approach, we apply the concept of adaptation tipping points to the 1-5 prioritisation scale (Figure 3.3). Provincial planners are free to determine at which point on the

scale they should implement measures; however, we recommend the following assessment rubric (Table 3.1). Action should be taken for any road sections falling into Prioritisation Category 3, as here the road is still mitigating hazard risks to an acceptable level but there should still be time enough to implement any measures before the road section 'tips' over into Category 4. Once a road sits within Categories 4 or 5, we consider it to be exhibiting unacceptable performance. The overarching objective for the roads planner is to attempt to have the entire road network residing in Categories 1-3 at any one time.

Table 3.1: Performance rubric for road sections

Prioritisation Category	Road section performance assessment
1	Acceptable performance of the road section
2	
3	Acceptable performance of the road section; adaptation tipping point is approaching
4	Unacceptable performance of the road section
5	

Once a road is prioritised and selected for upgrade, planners can then analyse the specific hazards/impacts/assets upon which they should focus from the damages and losses maps. From this analysis, the planner can then select the correct archetype (section 3.4) from which to base their assessment. Key questions to ask in this analysis are:

- Is unacceptable road performance due more to the damages or losses incurred?
- What are the specific hazard locations for this road sections?
- Which archetype(s) most closely match with these specific hazard locations?

3.3.2 Measure effectiveness

The effectiveness of the relevant measures for each archetype are then assessed in terms of their estimated relative risk reduction (%), by way of expert judgement. The presented scores were derived by the project consultant team based on previous experience in other road infrastructure projects (e.g. in Albania, Turkey, Paraguay, the Netherlands). A very effective measure scores 100%, while an ineffective measure scores 0%. For each archetype we have assessed each measure based upon its *theoretical* contribution to risk reduction were it to be implemented to its full potential. That is, we do not consider *any* restrictions that may limit the extent to which a measure may be applied. For a generic assessment this makes sense, however when conducting real-life assessments for specific road sections, we encourage planners to (together with stakeholders) update these effectiveness scores according to the realities of the situation on the ground. For example, some measures presently assessed as being highly 'effective' may not actually be possible to implement in all instances.

When updating the generic scores, LGU planners therefore need to think critically about the measure and anticipate its potential risk reduction impacts at the scale it is operating. Key questions to ask in this analysis are:

- What is the principle driver of risk for the specific road section (i.e. damages, losses, both)?
- How does the measure reduce risk (i.e. by mitigating damages, losses, both)?
- To what extent can this measure be implemented for this road section? (e.g. as much as is needed, or does its application need to be limited in some way?)
- Given the above, how effective do I believe this measure will be at mitigating existing risk for this road section (use the below figures to guide the assessment)?
    - Almost all risks mitigated 75-100%

- Many risks mitigated 50-75%
- Some risks mitigated 25-50%
- Considerable risk remains 0-25%

- Does my assessment make sense in comparison to the scores for the other options?

The assessment is naturally subjective. However, at this stage in the analysis this presents little issue, as the outcome is an initial strategic prioritisation (or ranking) of measures. This initial ranking can be further elaborated, improved and updated through later quantitative analysis (e.g. refer Chapter 5).

3.3.3 Future performance

The future performance of the road section in 2050 – both in its existing condition and with each measure applied – is then scored by applying a qualitative scoring rubric (Table 3.2) against each of the uncertain future scenarios. Informing the assessment are the (updated) effectiveness scores from the preceding step as well as consideration of the scenario impacts of climatic and traffic uncertainties on the development of risk (section 3.5). Note that these scores are qualitative in nature and are therefore should not be considered indicators of the absolute effectiveness of measures (refer preceding section). Also, measures with differing effectiveness scores may receive the same future performance score in different scenarios, depending on how each measure reduces risk. Expert judgement is again used to carry out the assessment, and we encourage planners to (together with stakeholders) update these according to the realities of the specific road section being analysed. When updating these scores, key questions to ask are:

- How will future risk for this road section grow given the projected scenario conditions? (i.e. derive approximate risk multiplier, refer section 3.5.4)
- How does the measure reduce risk (i.e. by mitigating damages, losses, both)?
- How effective is the measure under existing conditions (preceding step)?
- How will the measure therefore change my estimated projected risk multiplier?

Table 3.2: Scoring rubric for future performance of the road section

Score	Assessment of future performance
1	Extreme risk
2	Increased risk to present
3	Same risk as present
4	Decreased risk to present
5	Negligible risk

Note that the time horizon of 2050 was selected for several reasons. First, the period of approximately 30 years seems reasonable when considering the lifespan of many provincial road assets in Nueva Ecija. Second, it allows enough time for early climate change impacts to transpire, as it is anticipated that climate change will accelerate during the second half of the century. Third, it is not so far off into the future for future socioeconomic projections (and their relation to future traffic demand) to become meaningless to the present road network (refer section 3.5.4). Naturally a different time horizon could be selected, however we recommend selecting one that successfully balances the above three factors.

3.3.4 Robustness of measures

The preceding step results in each multiple scenario-dependent scores for each measure. Some measures may score highly in one scenario, while others may score highly in another. We undertake a minimax analysis (Savage, 1951) to establish the robustness of each measure across

the full range of potential future scenarios. The minimax analysis minimises the regret associated with taking a particular action (or measure) and assists planners in prioritising measures as close as possible to the optimal course.

In the proposed application of the minimax approach, the ratio of each measure's score in a particular scenario is calculated against the maximum possible score for that scenario. These ratios are then averaged for each measure across all the scenarios to derive an overall robustness score for each measure. A theoretical example calculation is provided below in Table 3.3. Example scores for future performance are provided for three measures and three scenarios in the first three columns. The next three columns provide the minimax analysis, and the final column averages these for each measure to determine its overall robustness score. In the example, Measure 1 emerges as the most robust measure, closely followed by Measure 3. Measure 2 appears to perform relatively poorly across the three scenarios.

Table 3.3: Example minimax analysis

	Scenario 1	Scenario 2	Scenario 3	Minimax Scn 1	Minimax Scn 2	Minimax Scn 3	Robustness Score
Measure 1	5	4	3	5/5 = 1.0	4/4 = 1.0	3/3 = 1.0	1.0
Measure 2	3	2	1	5/3 = 0.6	4/2 = 0.5	3/1 = 0.33	0.48
Measure 3	5	3	2	5/5 = 1.0	4/3 = 0.75	3/2 = 0.66	0.8

3.3.5 Measures prioritisation

The final measures prioritisation is formulated by applying a weighted multi-criteria analysis (MCA). Each criterion is weighted to establish its relative importance, with each measure then scored against the competing criteria on a scale of 1-10, with 1 reflecting poor performance, and 10 reflecting strong performance. The final MCA score is determined from the sum of the products of the weights and scores. For the purposes of the archetypical assessment, weights have been derived via expert judgement by the project team, before validation with local experts during the final project workshop (refer section 3.9). Measure scores have been similarly determined, however we encourage planners to further contextualise and update these both to the specific conditions and considerations for specific road sections together with stakeholders. Should stakeholders fundamentally disagree regarding weights and scores for the different measures, we would encourage planners to undertake multiple MCAs to encapsulate the breadth of SH opinion about how the measures should be prioritised, promote dialogue, and generate consensus.

The criteria considered in this assessment includes the six listed below. These were selected by the consultant team based on those prioritised during the EU INTACT project (www.intact-wiki.eu). However, this methodology has been kept intentionally flexible such that planners can add/remove criteria (e.g. environmental impact, social impact, etc.) should they (or stakeholders) choose to do so.

- Costs — *based on indicative cost estimates*
- Effectiveness — *derived from 'Measure effectiveness' score (Step 2)*
- Robustness — *derived from 'Robustness score' (Step 3b)*
- Flexibility — *ability to phase or further upgrade as conditions change*
- Ease of implementation — *availability of techniques/resources, lead time*
- Maintenance and Durability — *extent to which ongoing maintenance will be required*

3.3.6 Adaptation pathways

The measure prioritisation from Step 4 can then be used to construct relative adaptation pathways. Here we emphasise a consideration of how the various measures could logically be sequenced in time given the local conditions. Specific consideration is given to the following types of measures:

- Short term measures: those which are to be implemented in the immediate planning cycle
- Mid-term options: those measures which are preferred as the uncertain conditions develop and additional change is experienced
- Long-term options: those measures which are preferred should the uncertain conditions develop further, and large changes are experienced

Following the construction of the various possible pathways, these can also be qualitatively evaluated using scorecards against various criteria, and a preferred pathway selected.

3.4 Archetypes

For the purposes of this assessment, we identify seven (7) key archetypes relevant to the different hazards considered in this project. Where relevant, hazards are further split into multiple archetypes relevant to their key characteristics, such as flow direction, existing infrastructure, or geological conditions. The intention was to define generic road archetypes that would encompass all road locations, but which would not be too many to become unwieldy or too few to lack specificity. Table 3.4 presents these archetypes along with the visual symbology that will be applied for these archetypes in the remainder of this report.

For flooding, a total of four (4) archetypes are considered based on flow direction and existing infrastructure:

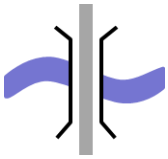
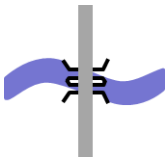
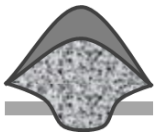
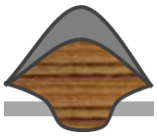
- **Perpendicular flow** refers to locations where rivers/tributaries/creeks/canals cross existing roads, with these crossings either being presently affected with existing **bridges**, **culverts**, or with **no drainage** provisions at all.
- **Parallel flow** refers to locations where the river runs along in a direction similar to that of the road, never crossing the road.

For landslides, two (2) further archetypes are considered according to geological conditions:

- **Rockfall** refers to road locations susceptible to falling rock.
- **Mud/debris flow** refers to locations more susceptible to upstream liquefaction and unstable soil slopes. It also refers to those locations vulnerable to flows of volcanic matter, such as lahars.

A single (1) additional archetype is identified for **seismic** hazards.

Table 3.4: Key road archetypes applied in this study

Hazard	Characteristics		Symbology
Flooding	Perpendicular Flow	Bridges	
		Culverts	
		No drainage	
	Parallel Flow		
Landslides	Rockfall		
	Mud/Debris flow		
Seismic	-		

3.5 Uncertainty scenarios

The Nueva Ecija road network is vulnerable to various flooding, landslide and seismic hazards. Disruption from these hazards to roads, bridges and culverts not only generates direct repair costs, but also leads to (often greater) indirect impacts due to service interruptions. Communities can be isolated; and trade and business operations can be disrupted as transport is deferred, delayed, or forced to seek alternative routes.

The driving forces behind these impacts encompass both inherently uncertain physical and socioeconomic factors. Table 3.5 presents key drivers identified for the Nueva Ecija road network with potentially the greatest impact on expected annual damages (EAD) and losses (EAL) for

national road assets. Physical drivers determine the magnitude of the hazard to be experienced (hence, both the damages and losses incurred), while the socioeconomic driver only influences the eventual impacts of the hazard in terms of (indirect) losses.

Table 3.5: Key physical and socioeconomic drivers of uncertainty relevant to the Nueva Ecija road network

Driver	Anticipated state change	Impact
Key Physical Drivers		
Climate change	Increased rainfall (duration & frequency)	Fluvial flooding Pluvial flooding Landslides
	Increased rainfall intensity	Fluvial flooding Pluvial flooding Landslides
Seismic activity	Ground acceleration	Earthquakes Landslides
Key Socioeconomic Drivers		
Economic Growth	Increased traffic flows	Increased losses (all hazards)

3.5.1 Climate change

Climate change is expected to lead to uncertain changes in rainfall in terms of duration, frequency and intensity that could lead to increased incidences of fluvial flooding or landslides that impact road assets. As outlined in the NEDA-Region III PRB IWRM plan update, the basin is expected to become wetter in the rainy season. Extreme daily rainfall is also anticipated to increase, with the number of extreme wet weather days (rainfall >200mm) projected to increase from an observed baseline of 9 days/year in the year 2000 to 13 days/year in 2020 and 17 days/year in 2050 under a medium-range emission scenario (NEDA, 2018, p.2-12). It must be noted, however, that these projections did not include for bias correction in the climate models used, such that we would not recommend drawing firm conclusions from them. Further detailed information from PAGASA on future scenario projections for extreme rainfall in PRB was not identified by the project team.

An alternative 2016 study (Ushiyama et al, 2016) presents longer-term climate projections for extreme rainfall in the PRB based on a dynamic downscaling and bias correction of Global Circulation Models (GCMs). The authors present an analysis examining potential changes in terms of annual maximum 2-day rainfall volume and likelihood in the period 2075-2099, based on the IPCC's RCP 8.5 global climate change scenario. Four different distributions of sea surface temperature (SST) were applied as boundary conditions to the Meteorological Research Institute-Atmospheric General Circulation Model (MRI-AGCM) version 3.2, namely multi-model ensemble (MME) and Clusters 1, 2 and 3 (Kitoh and Endo, 2016). Figure 3.4 re-presents partial results of this analysis. It demonstrates that future rainfall extremes and likelihoods may range under this scenario from almost equivalent to the present day (Cluster 1) to intensities much greater and more likely than today (Cluster 2).

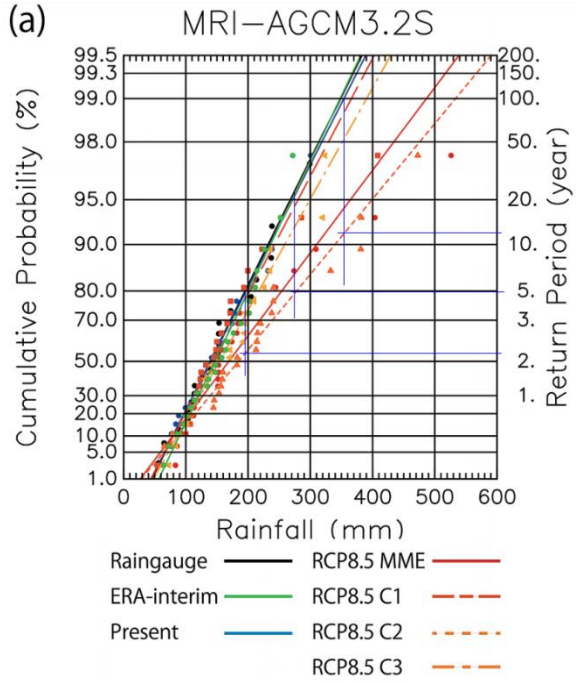


Figure 3.4: Frequency analysis of annual maximum 48 h rainfall from downscaling and bias corrected results of MRI-AGCM 3.2S (reproduced from Ushiyama et al, 2016, Figure 4).

This analysis presents a useful – albeit wide – range of plausible climate futures to inform the DMU approach for provincial roads planners and has been adopted for the remainder of this report. Figure 3.4 has been used to derive the range of plausible future projections (in 2100) for extreme rainfall likelihoods for flooding return periods presented in the earlier risk assessment (5, 25 and 100 year; Table 3.6), which were then used to directly inform scenario analyses for potential future expected annual damages and losses. For simplicity, we have taken the future projection in the study to refer to 2050 and have assumed a linear interpolation for the anticipated changes from the 2100 figures presented below. In our analysis, the Low Climate Change scenario refers to the Cluster 1 (C1) figures, while the High Climate Change scenario refers to Cluster 2 (C2).

Table 3.6: Plausible development in likelihood of extreme wet weather events to 2100, based on Ushiyama et al (2016)

Current Return Period	**New Return Period**	
	2050	**2100**
1 in 100 year		
Low CC	90	80
High CC	56	12
1 in 25 year		
Low CC	22.5	20
High CC	15	5
1 in 5 year		
Low CC	5	5
High CC	3.6	2.2

3.5.2 Seismic activity

As a DMU approach, DAPP is particularly useful to apply in situations where the driving conditions change in clearly identifiable trends over time. Seismic activity does not fit this category, as its effects are largely random and independent of time. In such situations, developing adaptation pathways for increasing levels of ground motion makes little sense. Conventional planning approaches that set earthquake construction standards for infrastructure according to the incidence probabilities for specified levels of ground acceleration will typically suffice. As such, any considerations of changing seismology have been removed from the DMU analysis.

3.5.3 Economic growth

Socioeconomic drivers of uncertainty for road networks relate most to factors influencing the amount of traffic using the road network. This project applies the GDP methodology to determine traffic demand projections, where GDP growth rates are multiplied with the elasticity of demand for vehicle travel (see below equation). Under this methodology, other socioeconomic effects (e.g. population growth) are not considered as separate drivers of traffic volume but are rather incorporated into the economic growth rate figure.

*Future Traffic Demand = Current Traffic Demand * (1 + GDP growth * Elasticity)*

Applying this methodology relies upon several assumptions. First, that ownership and use of vehicles is directly related to the degree of economic development and current intensity of the road network. An important driver in determining the degree by which the number of registered vehicles (and travelled distance) grows in relation to economic developments is the demand elasticity, which is normally is between 0.75 and 1.2 (Litman, 2019). This means that when the economic growth is 1% and the elasticity 0.75 the number of registered vehicles will increase by 0.75%; hence, by using the elasticity the (projected) growth in number of registered vehicles can be determined from the (projected) economic growth. Analysis of the increase in number of registered vehicles in the Philippines over the period 1985 – 2007 shows that the elasticity for registered vehicles is presently approximately 1.0, i.e. the number of registered vehicles will increase in parallel with the annual economic growth in GDP (see also Figure 3.5). Normally, elasticity is expected to decrease as the total number of registered vehicles grows; as more and more people privately own a car, less people are inclined to buy a car and increasing traffic congestion decreases ‘willingness’ to own a private car. For this study we assume a decreasing elasticity from 1.0 decreasing to 0.8 after 2030, depending on the selected economic growth scenario (Table 3.7).

To take into consideration future uncertainties in economic growth we apply the plausible range of growth to 2050 suggested in the Shared Socioeconomic Pathways (SSPs) (Riahi et al, 2017). These SSPs provide a bandwidth of global developments in the areas like economic growth, demographic developments and climate change, with SSP3 and SSP5 scenarios providing the extremes for economic development to 2050 in the Philippines. Figure 3.6 and Figure 3.7 present the economic growth projections and resulting development in number of vehicles (% multiplier) to 2050. This demonstrates that under the Low Traffic (SSP3) scenario, we assume a doubling of traffic by 2046 (210% by 2050) and under the High Traffic (SSP5) scenario, we assume a much earlier doubling of traffic in 2033 (360% in 2050) (Table 3.8).

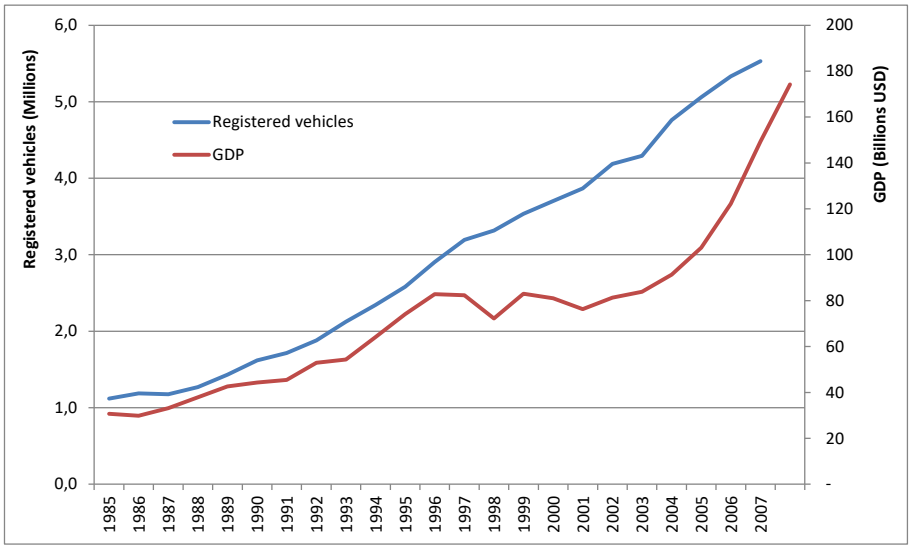


Figure 3.5: GDP growth and registered vehicles (ADB, 2011) in the Philippines (1985 – 2007)

Table 3.7: Elasticity used for determining number of registered vehicles in the Philippines (2019 – 2050)

	2019 - 25	2025 - 30	2030 - 35	2035 - 50
SSP3	1	1	0.9	0.9
SSP5	1	0.9	0.9	0.8

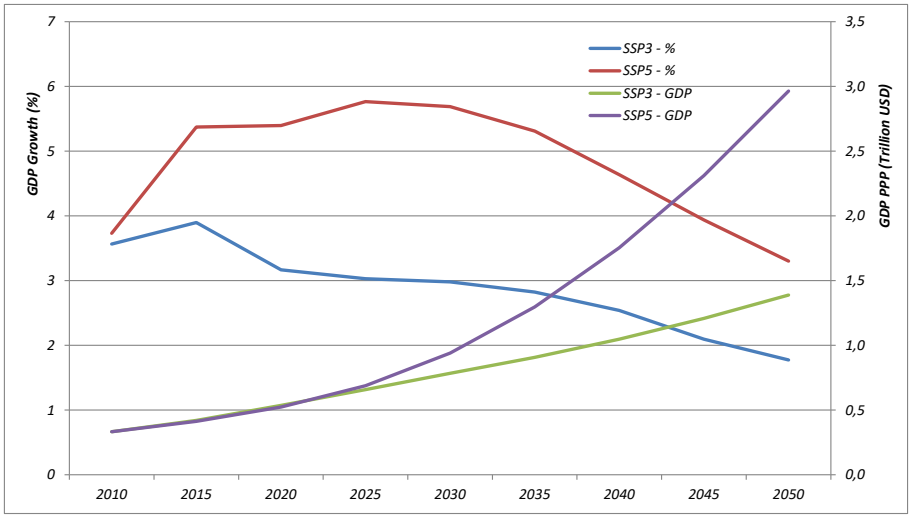


Figure 3.6: Projected economic growth and GDP in the Philippines under SSP3 and SSP5 scenarios (2010-2050) (Riahi et al, 2017)

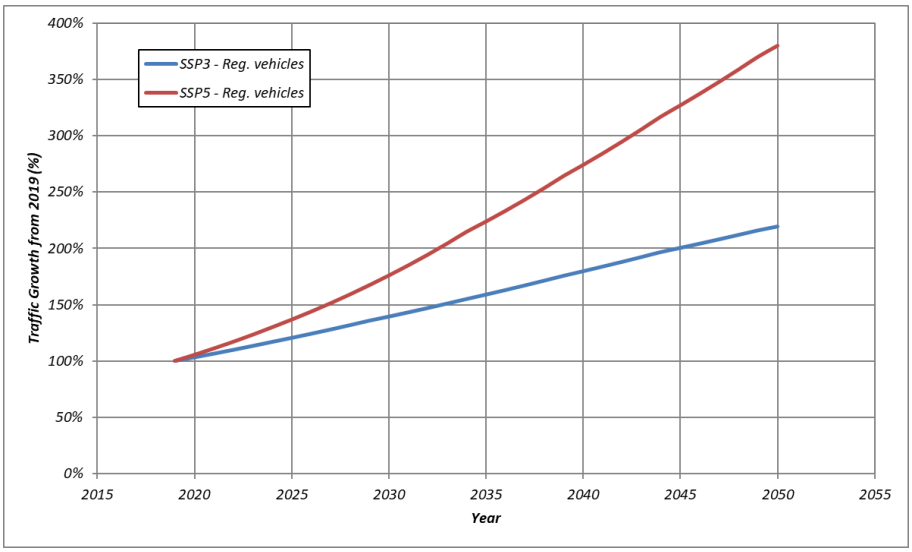


Figure 3.7: Indexed number of vehicles in the Philippines (2019 = 100) under SSP3 and SSP5 scenarios

Table 3.8: Future development in numbers of registered vehicles, based on GDP methodology

Scenario	Doubling (year)	2050 (multiplier)
Low Traffic (SSP3)	2046	x2.1
High Traffic (SSP5)	2033	x3.6

3.5.4 Future impacts of uncertainty scenarios

To ascertain future scenario impacts for the entire provincial road network in Nueva Ecija, we applied the above future climate and socioeconomic scenario inputs to previous calculations of the expected annual damages (EAD) and losses (EAL) from the risk assessment. In doing so, the intention is to provide provincial roads planners with an estimation of the orders of magnitude to which future system performance for the road archetypes and specific road sections may change under the uncertain conditions. Climate change impacts were analysed out to 2100, as these impacts become more significant towards the end of the century. The implications of the uncertainty in future traffic demands were only analysed to 2050, as the projected increased traffic flows (2.1-3.6 times the present day) will mean the road network will to be augmented in many locations via road widening, duplication and so forth by that time such that the system will have been fundamentally modified. A complete, comprehensive future traffic analysis is required to determine the necessary road design capacity requirements for each of the main transport corridors under these conditions. The climate resilience of any such asset augmentations would need to be assessed during their design, and adequate provisions made. Such an analysis of road network capacity falls beyond the scope of this project assessing the climate resilience of present network assets.

3.5.4.1 Change in Expected Annual Damages

To establish potential future EAD, we varied the return periods for the various hazards as per Table 3.6. Results of this analysis are presented below in Table 3.9 and Figure 3.8. These figures

demonstrate that future climate change could increase total flooding EAD across the province by up to approximately 40% by 2050 and up to approximately 110% in 2100 in the High CC scenario (based on the risk assessment data). Equally, however, total flooding EAD for both these time horizons may not increase much beyond present values (in the Low CC scenario). As mentioned previously, earthquake damages are not affected by the changing climate. Note also that estimations have not been presented for landslide damages, as the risk assessment was based upon qualitative susceptibility only and could not be calculated in the same manner as flooding and earthquake hazards (refer to the risk assessment report: Costa et al, 2019).

Table 3.9: Change in projected total EAD (PHP millions) for Nueva Ecija hazards under future climate scenarios

Hazard (Scenario)	Current	2050	2100
Flooding (Low CC)	534	535	537
Flooding (High CC)	534	740 (+139%)	1116 (+209%)
Earthquake	5.8	5.8	5.8

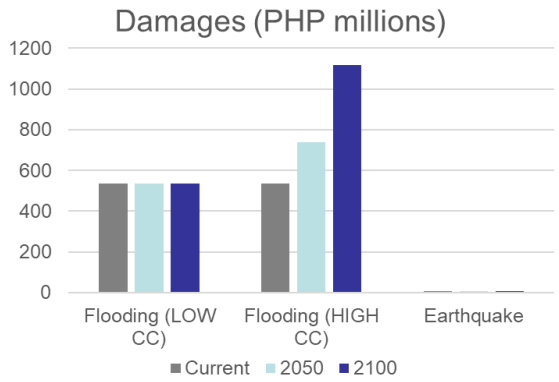


Figure 3.8: Change in projected total EAD (PHP millions) for Nueva Ecija hazards under future climate scenarios

3.5.4.2 Change in Expected Annual Losses

To establish potential future EAL, we varied the return periods for the various hazards as per Table 3.6 and Table 3.8. Results of this analysis are presented below in Table 3.10 and Figure 3.9. These demonstrate that the impacts of future traffic losses could become much more significant than they presently do by 2050. For flooding in a Low CC and Low Traffic scenario, total EAL could increase to more than 3 times its present levels, while in the High CC and High Traffic scenario, the multiplier could be in the order of 5 times present levels. Earthquake losses can also be seen to increase; from between 3.2-3.7 times present levels depending on how the future traffic demand develops. Again, estimations have not been presented for landslide losses, as the risk assessment was based upon qualitative susceptibility only and could not be calculated in the same manner as flooding and earthquake hazards (refer to the risk assessment report: Costa et al, 2019).

Table 3.10: Change in projected total EAL (PHP millions) for Nueva Ecija hazards under future climate & socioeconomic scenarios

Scenario	Current	2050	
		Low Traffic	High Traffic
Flooding (LOW CC)	111	352 (317%)	407 (367%)
Flooding (HIGH CC)	111	484 (436%)	560 (505%)
Earthquake	0.89	2.86 (321%)	3.31 (372%)

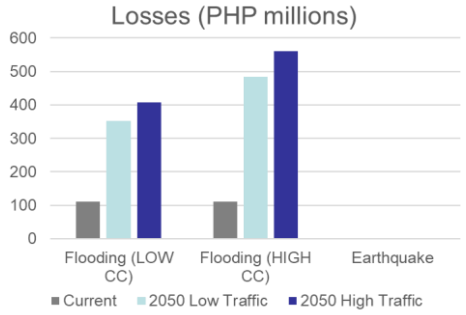


Figure 3.9: Change in projected total EAL (PHP millions) for Nueva Ecija hazards under future climate & socioeconomic scenarios

3.6 Identification of measures

The risk assessment demonstrated that the analysed hazards lead to significant impacts and risks, i.e. repair costs as well as losses from service interruption. Planning for and reducing the impact of a disaster is called disaster management. It often consists of a 'before the event' part, 'during the event' part and an 'after the event' part, and can be summarized in the Disaster Cycle (Figure 3.10).

Figure 3.10: Steps in the disaster cycle

Measures may therefore fall into the following steps of the disaster cycle:

- PRO-ACTION: activities in this stage aim to rule out the possibility of an extreme event e.g. flood defences to prevent flooding. The objective of this stage is to enable smooth and safe traffic.
- PREVENTION: activities in this stage aim to eliminate vulnerability, e.g. raising a road above the High-Water Level. The objective of this stage is to enable smooth and safe traffic.
- PREPARATION – In preparation of an extreme event: activities in this stage aim to reduce consequences, e.g. erosion proofing of a road. The objective of this stage is to support disaster consequence reduction.
- RESPONSE – During an extreme event: activities in this stage aim to minimize the loss of functions. This is often done by shutting down systems preventatively e.g. closing off roads at key junctions.
- RECONSTRUCTION – after an extreme event: activities in this stage aim to restore transport functionality, e.g. deployment of repairs. The objective of this stage is to provide access for recovery of affected areas.

For the purposes of this study, we identified potential measures by applying a simplified 'bow-tie' framework (Figure 3.11), consisting of:

- Measures to eliminate and prevent the cause of an event
- Measures to control the consequences and effects of an event

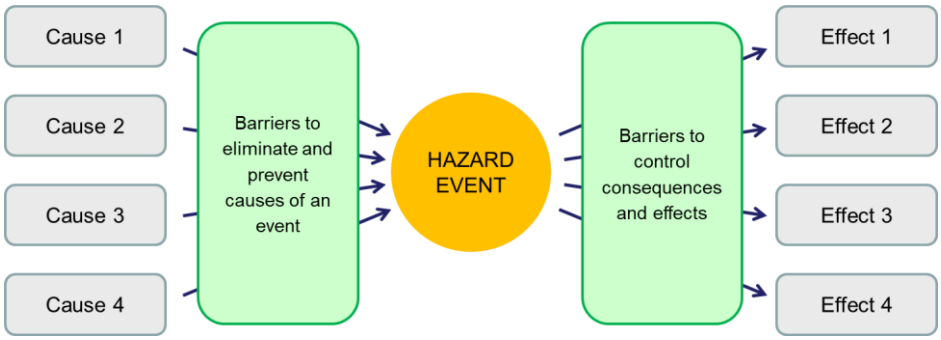


Figure 3.11: Simplified measures identification framework applied in this project

Using this framework, an inventory was made together with local experts to determine for each hazard and related archetype(s) which measures could be taken and are commonly used within the Nueva Ecija road network. This inventory is by no means exhaustive. The measures were selected on their applicability within the Philippines context and to show the principles of prioritizing measures using the presented strategy building approach for locally accepted measures.

3.6.1 Measures for flood hazard

For the flooding hazard, we considered several failure mechanisms and effects, depending on the archetype. For perpendicular flow archetypes, we considered the following:

- Failures where bridges, culverts or crossings do not have sufficient design capacity to handle potential peak flows
- Failures where bridges or culverts do not have sufficient capacity to convey peak flows, due to blockages from debris

- Failures due to erosion/scour of bridge and culvert foundations/abutments/embankments
- Failures due to the reduced carrying capacity of embankments
- Failures due to reduced structural integrity of structures (i.e. bridges)
- Failures due to the impassability of roads following a hazard event

For the parallel flow archetype, we considered the following failure mechanisms/effects:

- Failures where the river breaks its regular banks/levees due to high water
- Failures due to the reduced carrying capacity of embankments
- Failures due to placement of seasonal/agricultural retention basins close to roads

The following flood risk reduction measures have been identified (Table 3.11: Identified measures for flood risk reduction):

Table 3.11: Identified measures for flood risk reduction

Category	Flood risk reduction measure
Pro-action	- Retention basin or Flow diversion (e.g. green rivers) - Flood protection embankments/levees
Prevention	- Dredging river channels - Road elevation (with culverts, bridges, embankments, etc.) - Increase capacity culverts, bridges - Installation of upstream weirs to decrease flow velocity - (Improved) regular/ preventative maintenance (debris removal from under bridges, clearing culverts/debris screens) - Upgrading embankment designs to prevent structural failure - Integrated bridge monitoring (for structural integrity)
Preparation	- Erosion protection - Implementing submersible roads (roads designed to flood)
Response	- Improved traffic management (re-routing) (refer section 3.6.4) - Increase response capacity (refer section 3.6.4) - Increase road redundancy (improve barangay roads) (refer section 3.6.4) - Availability of Bailey Bridge material at critical locations
Reconstruction	- Increase repair capacity - Build back better based on improved/ updated design criteria and performance standards

Upstream retention basin or flow diversion

This reduces the peak flows at vulnerable road locations, e.g. river crossings or parallel flow locations where peak water levels approach or surpass the road elevation. Peak flow reduction is achieved by creating ‘man made’ retention facilities, e.g. retention ponds upstream of the asset or by increasing the concentration time (the time needed for water to flow from the most remote point in a catchment to the culvert/ bridge).

Retention facilities and diversions require substantial area, which is often not present. They also require sufficient local knowledge to determine if the necessary space is available. During the example flood modelling assessment, we did not readily identify such areas for the two assessed

locations (refer Chapter 5), however, this was not an exhaustive assessment and should not preclude its consideration in other locations.

Increase flood protection structures

In some instances, roads may be placed behind larger flood protection structures (e.g. levees, room for the river, etc.). In these cases, it may be preferred to increase the flood protections for a whole area. One must be sure that when implementing these types of measures, their effects on the whole river system are considered. Often, these measures may have the negative consequence of pushing or channelling floodwater further downstream (i.e. increasing flood peaks) or to other (unintended) locations.

Dredging river channels

Dredging river channels can have the effect of lowering water levels by increasing the conveyance capacity of the channel. Excess debris, silt and vegetation are removed using mechanical excavators. During peak events, the additional capacity in the river channel reduces risks of roads becoming submerged. However, dredging is a measure that comes with significant ongoing maintenance; once cleared, the dredged channel will gradually refill with fluvial matter washed down from upstream, which will require further dredging to remove. It also brings significant ecological and water quality impacts, as the removed material may include various plant and animal species important to maintaining river health. Furthermore, during the example flood modelling assessment, we also did not find that dredging channels would lead to sufficient reductions in water level (refer Chapter 5), such that it may not constitute are realistic option in many instances.

Elevating roads (with culverts/bridge/causeway/embankments)

This reduces road vulnerability by raising the elevation of the road surface at vulnerable locations. For perpendicular locations this needs to be achieved ensuring sufficient peak flow design capacity beneath the road surface, i.e. the bridge, culvert or causeway. For parallel flow locations, drainage provision is less important, unless the elevated road is intended to serve as a barrier preventing pluvial drainage to river channels. In these instances, the provision of adequate drainage is imperative to minimize the potential impacts of pluvial flooding.

New culvert design/add culverts

The provision of culverts to vulnerable road sections helps to increase the peak flow design capacity for any flow crossings, thereby reducing the likelihood that the water level banks up and surpasses the road elevation. As above, it can also be applied to parallel flow locations, to improve floodplain drainage to river channels through road embankments.

Maintenance provision for bridges/culverts

Maintaining the design flow capacity of any culverts or bridge crossings is imperative to ensuring that these infrastructures perform as designed and do not cause flood waters to back up upstream of the structure. Timely removal (i.e. before the wet season) of any debris blocking culverts or amassed at bridge supports helps to maintain flow capacities during peak events. Similarly, removing excess debris from upstream catchments prior to the wet season helps prevent this debris being washed down and causing blockages during flood events.

Integrated bridge monitoring (for structural integrity)

Monitoring the structural health of bridges is important to guarantee their safety. In doing so, roads engineers can ensure that these structures remain in compliance with the necessary construction standards and minimizes risks of failure during hazards. Visual inspections and periodic monitoring can achieve this to a certain extent, however for larger, more important bridges, integrated structural monitoring which employs electronic sensors, telemetry, databases and decision support systems assist roads engineers to receive improved, up-to-date assessments regarding the structural health of the bridge.

Upgrade embankments (e.g. impervious design)

Existing road embankments can fail due to the high-water content in the embankment itself, which reduces their carrying capacity. Upgrading these embankments with an impervious design or by providing sufficient drainage from the embankment itself can help mitigate these risks, by reducing the water content in the embankment during high water events, improving embankment stability.

Submersible road

Submersible roads do nothing to prevent causes of flooding but are intended to minimize flood effects and consequences. These are roads which are designed to flood during hazard events, but which incur minimal damage during the event to speed up the process of recovery. Submersible roads are constructed with durable road surfaces, along with erosion protection along road edges to prevent undermining.

Upstream weirs

Upstream weirs can be installed to reduce road vulnerability by broadening flows and decreasing flow velocities at river crossings. These can be particularly useful at ford locations but can also help reduce erosion of bridge abutments and culvert embankments.

Erosion protection

Erosion protection decreases the likelihood of road assets being damaged during flood events. That is, the road might still become unavailable due to flooding, however the subsequent damage may be (significantly) reduced. It is primarily achieved through the strategic placement of vegetation, synthetic geotextiles, gabions, concrete, etc. at vulnerable locations such as bridge and culvert abutments, or along the sides of embankments.

Bailey Bridge material available at critical locations

In particularly vulnerable bridge and other river/gully crossings, the provision and storage of materials to support the rapid installation of emergency Bailey Bridges in the immediate aftermath of a hazard will enable these routes to reopen more quickly. This will help to limit any losses as the longer rehabilitation works takes place.

3.6.2 Measures for landslide hazard

For the landslide hazard, we considered several failure mechanisms and effects, depending on the archetype. For mud/debris flow, we considered the following:

- Failures where volcanic eruptions or unstable former landslide deposits slip as a result of rainfall
- Failures due to erosion of existing (natural or engineered) slope supports
- Failures due to removal of stabilizing vegetation by wildfires

- Failures due to the impassability of roads following a hazard event

For rockfalls, we considered the following additional failure mechanisms/effects:

- Failures due to seismic activity
- Failures where rainfall reduces rockface stability
- Failures due to unfavourable structural geology (i.e. characteristics of any discontinuities in rock type)

The following landslide risk reduction measures have been identified (Table 3.12):

Table 3.12: Identified measures for landslide risk reduction

Category	Flood risk reduction measure
Pro-action	- Modify slope geometry
Prevention	- Drainage provisions - Maintain natural vegetation/prevent deforestation/catchment reforestation - Wildfire prevention - Erosion protection - Retaining structures - Rock anchors - Remove critical rock masses
Preparation	- Flow diversion channels/walls (e.g. for lahars) - Bridge over critical gullies - Rockfall galleries
Response	- Improved traffic management (re-routing) (refer section 3.6.4) - Increase response capacity (refer section 3.6.4) - Increase road redundancy (improve barangay roads) (refer section 3.6.4)
Reconstruction	- Increase repair capacity (refer section 3.6.4)

Flow diversion channels/walls

In locations where especially large landslide flows can be expected (e.g. due to volcanic eruption, lahars, etc), flow diversion walls may be installed to channel these flows away from vulnerable road sections.

Drainage provisions

Seepage of water into slopes and surface flows across rockfaces can reduce slope stability and dislodge rocks and boulders. The provision of adequate drainage to channel water away from susceptible slope sections and rockfaces can help minimize landslide risks resulting from these mechanisms.

Maintain natural vegetation/prevent deforestation/catchment reforestation

A well-developed forest cover minimizes the occurrence of shallow landslides on steep hillslopes. Landslides do not normally occur uniformly across a basin; typically, they are concentrated in critical areas of topography, soil and land use. It is argued that reforestation of only small parts of a basin, carefully targeted, can produce a disproportionately large reduction in landslide occurrence and sediment yield (Bathurst et al., 2009).

Wildfire prevention (forest management)

Similar to the above, the removal of vegetation by wildfires can leave steep hillslopes vulnerable to landslides until the vegetation is able to regenerate. Timely removal (i.e. before wildfire season) of targeted surface fuels (e.g. vegetation litter, undergrowth) in upland areas can help to reduce the spread and severity of fires, however such removal (typically achieved through 'burn off') must be carefully managed to maintain ecological balances, protect resources, and maintain slope stability.

Erosion protection (along critical river sections)

Erosion of river banks at the tow of landslide-susceptible slopes can undermine and/or erode the toe of the slope and facilitate landslides. Providing appropriate erosion protection along critical river sections can mitigate these risks. Banks can be protection with rip-rap, concrete, synthetics, or vegetation.

Modify slope geometry

Modification to the geometry of steep slopes helps to reduce the forces driving slope instability. Stepped sloped embankments are a common form and are effective in reducing the incidence of shallow failures and intercepting rock fall. They can be combined with gabions/ gabion walls. However, one must note that stepped slopes have little or no effect on potential deep-seated rock failures.

Bridge over critical gullies

For critical road crossings over steep gullies susceptible to channelling earthflows, bridges can be installed to keep roads elevated above the sliding matter in the event of a landslide. The bridge foundations and supports must be engineered to withstand the additional lateral forces exerted on them and must not themselves be placed on slopes susceptible to failure.

Retaining structures

Retaining structures are engineered to retain soil and/or rock. They are commonly used to accommodate changes in grade, provide increases in right-of-way and buttress the toe of slopes and gullies. In a broad sense, retaining structures can be classified according to their face inclination: if it is greater than 70 degrees, they are typically characterized as retaining walls, while slopes have face inclination flatter than 70 degrees. There are several types of retaining structures, including gabion walls, gravity, sheet pile, cantilever, and anchored earth/ mechanically stabilized earth (reinforced earth) walls and slopes (Exponent, 2019). Unless the structure is designed to retain water, it is important to have proper drainage behind the structure in order to limit the hydrostatic pressure behind.

Rock anchors

This is a type of internal slope reinforcement. Rock anchors can transmit an applied tensile load to the rock mass and may be used to reinforce rock slopes (Brown, 2015). The tensile load increases the friction force and thus increases the safety factor of the slope. This requires that the rock is not excessively fractured/ discontinuous. Wire mesh is added to prevent loose cobbles and boulders from falling onto the road. A gabion wall may also form the toe of the slope, to retain loose debris. In some cases, shotcrete may be used to prevent loose debris from detaching from the wall.

Rockfall galleries

Galleries are common structures to protect roads from rockfall hazards. They provide protection against high energy impacts as well as a suitable low maintenance solution for more frequent low energy events. Typical protection galleries consist of reinforced concrete slabs that are covered with a cushion layer to distribute contact stresses, reduce accelerations in the impacting body, and increase impact durations. However, more flexible barrier systems can also be installed, typically constructed from structural wire mesh.

Remove critical rock masses

Removal of critical rock masses from rock faces helps to prevent rockfalls before they occur by removing boulders and smaller rock matter prior to its failure. Weakened rock sections likely to fall first (through erosion, surface water flows, faults, etc.) are removed through hammering or controlled drilling and blasting.

3.6.3 Measures for seismic hazard

For the seismic hazard, we cannot mitigate or control the mechanism of the hazard (i.e. seismic activity). Hence, we can only take actions to reduce the consequences or effects of such events, including:

- Failures stemming from the impassability of roads following a hazard event
- Failures due to reduced structural integrity of structures (i.e. bridges)

The following seismic risk reduction measures have been identified (Table 3.13):

Table 3.13: Identified measures for earthquake risk reduction

Category	Earthquake risk reduction measure
Pro-action	- None
Prevention	- Seismic retrofitting existing infrastructure/replace the asset - Integrated bridge monitoring (for structural integrity)
Preparation	- None
Response	- Improved traffic management (re-routing) (refer section 3.6.4) - Increase response capacity (refer section 3.6.4) - Increase road redundancy (improve barangay roads) (refer section 3.6.4) - Availability of Bailey Bridge material at critical locations
Reconstruction	- Increase repair capacity (refer section 3.6.4) - Increase design standards / Build back better

Seismic retrofitting existing infrastructure/replace the asset

From the risk assessment, we see that damage and unavailability of roads due to seismic hazards only happens as a result of strong seismic events with a low probability (i.e. a high Return Period). Typical measures could be to rebuild the assets (primarily bridges) in a more robust manner. However, the EAD are quite low due to the low likelihood of an event, whereas installing a new bridge is (very) costly. This means that replacing a bridge on a provincial road will often not make economic sense. Hence, we would only recommend installing new bridges once the old ones need replacing, either due to old age/ unacceptable condition or due to seismic damage.

Retrofitting of bridges might make sense in some cases. However, determining where and what kind of retrofitting measures might be necessary, requires detailed, bridge-specific analysis, which falls outside the scope of this project.

Increase design standards/Build back better

To reduce downtime of the road, a bridge design based on updated building regulations/ standards could already be made beforehand to decrease the time taken during reconstruction efforts. As above, unless retrofitting makes specific sense, we would only recommend installing new bridges on provincial roads once the old ones need replacing, either due to old age/ unacceptable condition or due to seismic (or other hazard-induced) damage.

Integrated bridge monitoring (for structural integrity)

Monitoring the structural health of bridges is important to guarantee their safety. In doing so, roads engineers can ensure that these structures remain in compliance with the necessary construction standards and minimizes risks of failure during hazards. Visual inspections and periodic monitoring can achieve this to a certain extent, however for larger, more important bridges, integrated structural monitoring which employs electronic sensors, telemetry, databases and decision support systems assist roads engineers to receive improved, up-to-date assessments regarding the structural health of the bridge.

Bailey Bridge material available at critical locations

In particularly earthquake-prone bridge (and other) locations, the provision and storage of materials to support the rapid installation of emergency Bailey Bridges in the immediate aftermath of a hazard will enable these routes to reopen more quickly. This will help to limit any losses as the longer rehabilitation works take place.

3.6.4 Measures relevant to all hazards

Several measures are relevant to all hazard types. These particularly relate to those failures stemming from the consequences of hazard events, including:

- Failures due to the impassability of roads following a hazard event

The following more general risk reduction measures have been identified:

Traffic management (re-routing)

Traffic management does little to reduce damages from hazards but is more focused on limiting losses in the aftermath of an event. Once a road becomes impassable to traffic, the timely advice of the road closure can significantly reduce the detour losses incurred. Appropriate signage and detour route advisories can be placed at the beginning of any affected road sections, such that vehicles avoid being turned back and are guided to the most effective alternative route for their destination.

Increased response and recovery capacity

Another measure to reduce losses, being able to be back to business as usual quicker after a disaster also reduces the risk. This would, for example, require organizing such repairs more effectively i.e. streamlining the design-, build and contracting process. It also includes ensuring that the necessary materials, crews and equipment are available in the event of a hazard.

Increase redundancy (improve barangay roads)

Improving the redundancy of the road network through the improvement of barangay roads would help to reduce losses in the event the preferred road section became impassable. Our analysis assumes that the available detours consist of provincial roads only; should barangay roads be promoted, additional (shorter) routes may open. This would also have the additional benefit of reducing current and future traffic pressure on the existing provincial road network, as road users may choose to use the upgraded roads in place of existing routes.

3.7 Measures assessment and evaluation per archetype

The following paragraphs present the results of the assessment for each archetype following the approach presented in section 3.3.

3.7.1 Assessment and evaluation for flood archetypes

Table 3.14 presents the summary of measure effectiveness (expressed in terms of estimated risk reduction, %) determined by expert judgement for each of the four flood archetypes. It also specifies the relevant assumptions made when scoring each of the measures. The following paragraphs present the complete assessments for each flood archetype in turn.

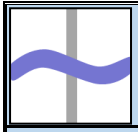
Table 3.14: Summary of effectiveness scores for measures for flood hazards

Applicable Flood archetypes				Measure	
Parallel flow	Perpendicular flow (bridge present)	Perpendicular flow (culverts present)	Perpendicular flow (no drainage)		
Effectiveness				Name	Assumptions
100%	100%	100%	100%	Upstream Retention Basin or Flow Diversion	- Capacity is sufficient to prevent any floods reaching the road
		80%	80%	Elevate roads (with culverts/ bridge/ causeway/ ford) (inc. erosion protection)	- Elevating existing embankments above peak flood level - Bridges/embankments may still be damaged during floods
30%			60%	Submersible road (inc. erosion protection)	- Road on river bed
		40%	40%	Install upstream weirs to decrease flow velocity	- Road/culverts may still flood, but with decreased velocity of flow
	60%	40%	60%	Erosion protection (vegetation, synthetics, gabions, concrete, etc.)	- Existing embankments protected - Permits faster recovery - Does nothing for flow capacity
20%	20%	20%	20%	Traffic management (re-routing)	- Only reduces losses
35%	35%	35%	35%	Increase response and recovery capacity (inc. crews, materials, equipment)	- Only reduces losses, but also decreases offline time
80%	80%	80%	80%	Increase redundancy (improve barangay road(s))	- Reduces losses by providing improved capacity of alternative routing
		70%		New culvert design/add culverts (inc. erosion protection)	- Improves flow conveyance capacity
50%		50%		Upgrade/new embankment design (impervious design, inc. erosion protection)	- Does nothing about existing flow conveyance capacity, could result in submersible road - Erosion protection permits faster recovery

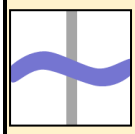
Applicable Flood archetypes				Measure	
Parallel flow	Perpendicular flow (bridge present)	Perpendicular flow (culverts present)	Perpendicular flow (no drainage)		
Effectiveness				Name	Assumptions
		70%		Adequate maintenance of culverts (maintaining max design capacity through screens, blockage removal, etc.)	- Identical capacity as new culvert - Capacity is sufficient
	90%			New bridge design (elevate)	- Elevation of bridge deck above peak flood levels
	50%			Debris removal from under bridge/supports (inc. debris screens for small bridges)	- Identical flow capacity as existing bridge
	40%			Bailey Bridge material availability at critical locations	- Reduces losses by limiting down time at critical crossing locations
	20%			Integrated bridge monitoring (for structural integrity)	- Provides early warning of potential bridge failure only
80%				Increase flood defence capacity (raise levees, etc)	- Road placed behind impermeable flood defences - Floodplain drainage to river not required (or achieved through pumping)
20%				Dredge river channel	- Realistic dredging volumes limited in comparison to needed water level reduction

3.7.1.1 Perpendicular Flow – No Drainage

Step 2 – Measures effectiveness

 **Measure**	**Risk reduction in Damages (D) or Losses (L)**	**Effectiveness (Risk reduction, %)**
Retention Basin or Flow Diversion	D,L	100%
Elevate roads (with culverts/bridge/causeway/ford) (inc. erosion protection)	D,L	80%
Submersible road (inc. erosion protection)	D	60%
Install upstream weirs to decrease flow velocity	D	40%
Erosion protection (vegetation, synthetics, gabions, concrete, etc.)	D,(L)	60%
Traffic management (re-routing)	L	20%
Increase response and recovery capacity (inc. crews, materials, equipment)	L	35%
Increase redundancy (improve barangay road(s))	L	80%

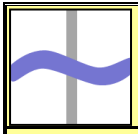
Step 3a – Future performance of measures

 Measure	Performance in 2050			
	High CC		Low CC	
	High Traffic	Low Traffic	High Traffic	Low Traffic
Current Situation (no measures)	*1*	*2*	*2*	*2*
Retention Basin or Flow Diversion	5	5	5	5
Elevate roads (with culverts/bridge/causeway/ford) (inc. erosion protection)	4	4	5	5
Submersible road (inc. erosion protection)	1	2	2	2
Install upstream weirs to decrease flow velocity	1	2	2	2
Erosion protection (vegetation, synthetics, gabions, concrete, etc.)	1	2	3	4
Traffic management (re-routing)	1	2	2	2
Increase response and recovery capacity (inc. crews, materials, equipment)	1	2	2	2
Increase redundancy (improve barangay road(s))	4	5	5	5

Notes: The above scores refer to the below qualitative rubric and are not indicators of absolute measure effectiveness (previous step).
Measures with different effectiveness scores may receive the same future performance score in different scenarios, depending on how each measure reduces risk.
For further explanation, refer section 3.3.3.

Score	Assessment of future performance
1	Extreme risk
2	Increased risk to present
3	Same risk as present
4	Decreased risk to present
5	Negligible risk

Step 3b – Robustness of measures

 Measure	High CC		Low CC		Robustness Score
	High Traffic	Low Traffic	High Traffic	Low Traffic	
Retention Basin or Flow Diversion	1.00	1.00	1.00	1.00	1.00
Elevate roads (with culverts/bridge/causeway/ford) (inc. erosion protection)	0.80	0.80	1.00	1.00	0.90
Submersible road (inc. erosion protection)	0.20	0.40	0.40	0.40	0.35
Install upstream weirs to decrease flow velocity	0.20	0.40	0.40	0.40	0.35
Erosion protection (vegetation, synthetics, gabions, concrete, etc.)	0.20	0.40	0.60	0.80	0.50
Traffic management (re-routing)	0.20	0.40	0.40	0.40	0.35
Increase response and recovery capacity (inc. crews, materials, equipment)	0.20	0.40	0.40	0.40	0.35
Increase redundancy (improve barangay road(s))	0.80	1.00	1.00	1.00	0.95

Note: For explanation of how these scores have been derived, refer section 3.3.4.

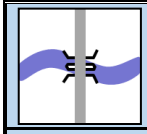
Step 4 – Measure prioritisation

Criterion / Weighting	Cost	Effectiveness	Robustness	Flexibility	Implement-ation	Maintenance	TOTAL
Weighting	*40%*	*30%*	*5%*	*5%*	*15%*	*5%*	
Retention Basin or Flow Diversion	1	10	10	8	1	4	4.7
Elevate roads (with culverts/bridge/causeway/ford) (inc. erosion protection)	3	8	9	6	4	7	5.3
Submersible road (inc. erosion protection)	6	6	4	8	7	8	6.2
Install upstream weirs to decrease flow velocity	4	4	4	7	6	8	4.6
Erosion protection (vegetation, synthetics, gabions, concrete, etc.)	5	6	5	9	8	8	6.1
Traffic management (re-routing)	10	2	4	10	9	10	7.1
Increase response and recovery capacity (inc. crews, materials, equipment)	8	3.5	4	10	8	8	6.5
Increase redundancy (improve barangay road(s))	1	8	10	8	2	5	4.2

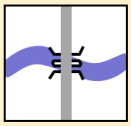
Notes: Each criterion is scored on a scale of 1-10, with 1 reflecting poor performance, and 10 reflecting strong performance.
Effectiveness score comes from Step 2 (multiplied by 10); Robustness score comes from Step 3b (multiplied by 10).
For further explanation, refer to section 3.3.5.

3.7.1.2 Perpendicular Flow – Culverts present

Step 2 – Measures effectiveness

 **Measure**	**Risk reduction in Damages (D) or Losses (L)**	**Effectiveness (Risk reduction, %)**
Retention Basin or Flow Diversion	D,L	100%
Elevate roads (further, on culverts/bridge)	D,L	80%
New culvert design/add culverts (inc. erosion protection)	D,L	70%
Upgrade/new embankment design (impervious design, inc. erosion protection)	D,L	50%
Install upstream weirs to decrease flow velocity	D	40%
Adequate maintenance of culverts (maintaining max design capacity through screens, blockage removal, etc.)	D,L	60%
Erosion protection (vegetation, synthetics, gabions, concrete, etc.)	D,(L)	40%
Traffic management (re-routing)	L	20%
Increase response and recovery capacity (inc. crews, materials, equipment)	L	35%
Increase redundancy (improve barangay road(s))	L	80%

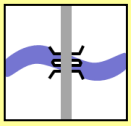
Step 3a – Future performance of measures

 Measure	Performance in 2050			
	High CC		Low CC	
	High Traffic	Low Traffic	High Traffic	Low Traffic
Current Situation (no measures)	*1*	*2*	*2*	*2*
Retention Basin or Flow Diversion	5	5	5	5
Elevate roads (further, on culverts/bridge)	4	4	5	5
New culvert design/add culverts (inc. erosion protection)	3	3	4	5
Upgrade/new embankment design (impervious design, inc. erosion protection)	2	2	4	5
Install upstream weirs to decrease flow velocity	1	2	2	2
Adequate maintenance of culverts (maintaining max design capacity through screens, blockage removal, etc.)	2	2	3	4
Erosion protection (vegetation, synthetics, gabions, concrete, etc.)	1	2	3	4
Traffic management (re-routing)	1	2	2	2
Increase response and recovery capacity (inc. crews, materials, equipment)	1	2	2	2
Increase redundancy (improve barangay road(s))	4	5	5	5

Notes: The above scores refer to the below qualitative rubric and are not indicators of absolute measure effectiveness (previous step).
Measures with different effectiveness scores may receive the same future performance score in different scenarios, depending on how each measure reduces risk.
For further explanation, refer section 3.3.3.

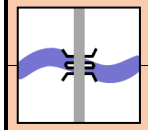
Score	Assessment of future performance
1	Extreme risk
2	Increased risk to present
3	Same risk as present
4	Decreased risk to present
5	Negligible risk

Step 3b – Robustness of measures

 Measure	High CC		Low CC		Robustness Score
	High Traffic	Low Traffic	High Traffic	Low Traffic	
Retention Basin or Flow Diversion	1.00	1.00	1.00	1.00	1.00
Elevate roads (further, on culverts/bridge)	0.80	0.80	1.00	1.00	0.90
New culvert design/add culverts (inc. erosion protection)	0.60	0.60	0.80	1.00	0.75
Upgrade/new embankment design (impervious design, inc. erosion protection)	0.40	0.40	0.80	1.00	0.65
Install upstream weirs to decrease flow velocity	0.20	0.40	0.40	0.40	0.35
Adequate maintenance of culverts (maintaining max design capacity through screens, blockage removal, etc.)	0.40	0.40	0.60	0.80	0.55
Erosion protection (vegetation, synthetics, gabions, concrete, etc.)	0.20	0.40	0.60	0.80	0.50
Traffic management (re-routing)	0.20	0.40	0.40	0.40	0.35
Increase response and recovery capacity (inc. crews, materials, equipment)	0.20	0.40	0.40	0.40	0.35
Increase redundancy (improve barangay road(s))	0.80	1.00	1.00	1.00	0.95

Note: For explanation of how these scores have been derived, refer section 3.3.4.

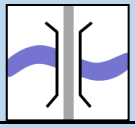
Step 4 – Measure prioritisation

 Criterion	Cost	Effectiveness	Robustness	Flexibility	Implement-ation	Maintenance	TOTAL
Weighting	*40%*	*30%*	*5%*	*5%*	*15%*	*5%*	
Retention Basin or Flow Diversion	1	10	10	8	1	4	4.7
Elevate roads (further, on culverts/bridge)	3	8	9	6	4	9	5.4
New culvert design/add culverts (inc. erosion protection)	5	7	8	5	6	7	6.0
Upgrade/new embankment design (impervious design, inc. erosion protection)	6	5	7	4	3	6	5.2
Install upstream weirs to decrease flow velocity	4	4	4	7	6	8	4.6
Adequate maintenance of culverts (maintaining max design capacity through screens, blockage removal, etc.)	10	6	6	10	9	3	8.1
Erosion protection (vegetation, synthetics, gabions, concrete, etc.)	5	4	5	9	8	8	5.5
Traffic management (re-routing)	10	2	4	10	9	10	7.1
Increase response and recovery capacity (inc. crews, materials, equipment)	8	3.5	4	10	8	8	6.5
Increase redundancy (improve barangay road(s))	1	8	10	8	2	5	4.2

Notes: Each criterion is scored on a scale of 1-10, with 1 reflecting poor performance, and 10 reflecting strong performance.
Effectiveness score comes from Step 2 (multiplied by 10); Robustness score comes from Step 3b (multiplied by 10).
For further explanation, refer to section 3.3.5.

3.7.1.3 Perpendicular Flow – Bridges present

Step 2 – Measures effectiveness

 **Measure**	**Risk reduction in Damages (D) or Losses (L)**	**Effectiveness (Risk reduction, %)**
Retention Basin or Flow Diversion	D,L	100%
New bridge design (elevate)	D,L	90%
Debris removal from under bridge/supports (inc. debris screens for small bridges)	D,L	50%
Erosion protection (vegetation, synthetics, gabions, concrete, etc.)	D,(L)	60%
Bailey Bridge material availability at critical locations	L	40%
Traffic management (re-routing)	L	20%
Increase response and recovery capacity (inc. crews, materials, equipment)	L	35%
Integrated bridge monitoring (for structural integrity)	L	20%
Increase redundancy (improve barangay road(s))	L	80%

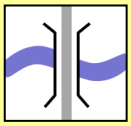
Step 3a – Future performance of measures

Measure	Performance in 2050			
	High CC		Low CC	
	High Traffic	Low Traffic	High Traffic	Low Traffic
Current Situation (no measures)	*1*	*2*	*2*	*2*
Retention Basin or Flow Diversion	5	5	5	5
New bridge design (elevate)	4	4	5	5
Debris removal from under bridge/supports (inc. debris scenes for small bridges)	2	2	3	4
Erosion protection (vegetation, synthetics, gabions, concrete, etc.)	2	2	3	4
Bailey Bridge material availability at critical locations	1	2	2	2
Traffic management (re-routing)	1	2	2	2
Increase response and recovery capacity (inc. crews, materials, equipment)	1	2	2	2
Integrated bridge monitoring (for structural integrity)	1	2	2	2
Increase redundancy (improve barangay road(s))	4	5	5	5

Notes: The above scores refer to the below qualitative rubric and are not indicators of absolute measure effectiveness (previous step).
Measures with different effectiveness scores may receive the same future performance score in different scenarios, depending on how each measure reduces risk.
For further explanation, refer section 3.3.3.

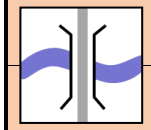
Score	Assessment of future performance
1	Extreme risk
2	Increased risk to present
3	Same risk as present
4	Decreased risk to present
5	Negligible risk

Step 3b – Robustness of measures

 Measure	High CC		Low CC		Robustness Score
	High Traffic	Low Traffic	High Traffic	Low Traffic	
Retention Basin or Flow Diversion	1.00	1.00	1.00	1.00	1.00
New bridge design (elevate)	0.80	0.80	1.00	1.00	0.90
Debris removal from under bridge/supports (inc. debris screens for small bridges)	0.40	0.40	0.60	0.80	0.55
Erosion protection (vegetation, synthetics, gabions, concrete, etc.)	0.40	0.40	0.60	0.80	0.55
Bailey Bridge material availability at critical locations	0.20	0.40	0.40	0.40	0.35
Traffic management (re-routing)	0.20	0.40	0.40	0.40	0.35
Increase response and recovery capacity (inc. crews, materials, equipment)	0.20	0.40	0.40	0.40	0.35
Integrated bridge monitoring (for structural integrity)	0.20	0.40	0.40	0.40	0.35
Increase redundancy (improve barangay road(s))	0.80	1.00	1.00	1.00	0.95

Note: For explanation of how these scores have been derived, refer section 3.3.4.

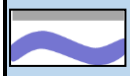
Step 4 – Measure prioritisation

 Criterion	Cost	Effectiveness	Robustness	Flexibility	Implement-ation	Maintenance	TOTAL
Weighting	*40%*	*30%*	*5%*	*5%*	*15%*	*5%*	
Retention Basin or Flow Diversion	1	10	10	8	1	4	4.7
New bridge design (elevate)	2	9	9	4	2	9	4.9
Debris removal from under bridge/supports (inc. debris scenes for small bridges)	10	5	6	10	9	3	7.8
Erosion protection (vegetation, synthetics, gabions, concrete, etc.)	5	6	6	9	8	8	6.1
Bailey Bridge material availability at critical locations	4	4	4	10	4	8	4.5
Traffic management (re-routing)	10	2	4	10	9	10	7.1
Increase response and recovery capacity (inc. crews, materials, equipment)	8	3.5	4	10	8	8	6.5
Integrated bridge monitoring (for structural integrity)	7	2	4	10	5	6	5.1
Increase redundancy (improve barangay road(s))	1	8	10	8	2	5	4.2

Notes: Each criterion is scored on a scale of 1-10, with 1 reflecting poor performance, and 10 reflecting strong performance.
Effectiveness score comes from Step 2 (multiplied by 10); Robustness score comes from Step 3b (multiplied by 10).
For further explanation, refer to section 3.3.5.

3.7.1.4 Parallel Flow

Step 2 – Measures effectiveness

 **Measure**	**Risk reduction in Damages (D) or Losses (L)**	**Effectiveness (Risk reduction, %)**
Retention Basin or Flow Diversion	D,L	100%
Increase flood defence capacity (raise levees, elevate road, etc)	D,L	80%
Dredge river channel	D,L	20%
Upgrade/new embankment design (inc. erosion protection & drainage)	D,L	50%
Submersible roads (inc. erosion protection)	D	30%
Traffic management (re-routing)	L	20%
Increase response and recovery capacity (inc. crews, materials, equipment)	L	35%
Increase redundancy (improve barangay road(s))	L	80%

Step 3a – Future performance of measures

Measure	Performance in 2050			
	High CC		Low CC	
	High Traffic	Low Traffic	High Traffic	Low Traffic
Current Situation (no measures)	*1*	*2*	*2*	*2*
Retention Basin or Flow Diversion	5	5	5	5
Increase flood defence capacity (raise levees, elevate road, etc)	4	4	5	5
Dredge river channel	1	2	3	3
Upgrade/new embankment design (inc. erosion protection & drainage)	2	2	4	5
Submersible roads (inc. erosion protection)	1	2	3	4
Traffic management (re-routing)	1	2	2	2
Increase response and recovery capacity (inc. crews, materials, equipment)	1	2	2	2
Increase redundancy (improve barangay road(s))	4	5	5	5

Notes: The above scores refer to the below qualitative rubric and are not indicators of absolute measure effectiveness (previous step).
Measures with different effectiveness scores may receive the same future performance score in different scenarios, depending on how each measure reduces risk.
For further explanation, refer section 3.3.3.

Score	Assessment of future performance
1	Extreme risk
2	Increased risk to present
3	Same risk as present
4	Decreased risk to present
5	Negligible risk

Step 3b – Robustness of measures

Measure	High CC		Low CC		Robustness Score
	High Traffic	Low Traffic	High Traffic	Low Traffic	
Retention Basin or Flow Diversion	1.00	1.00	1.00	1.00	1.00
Increase flood defence capacity (raise levees, elevate road, etc)	0.80	0.80	1.00	1.00	0.90
Dredge river channel	0.20	0.40	0.60	0.60	0.45
Upgrade/new embankment design (inc. erosion protection & drainage)	0.40	0.40	0.80	1.00	0.65
Submersible roads (inc. erosion protection)	0.20	0.40	0.60	0.80	0.50
Traffic management (re-routing)	0.20	0.40	0.40	0.40	0.35
Increase response and recovery capacity (inc. crews, materials, equipment)	0.20	0.40	0.40	0.40	0.35
Increase redundancy (improve barangay road(s))	0.80	1.00	1.00	1.00	0.95

Note: For explanation of how these scores have been derived, refer section 3.3.4.

Step 4 – Measure prioritisation

Criterion	Cost	Effectiveness	Robustness	Flexibility	Implement-ation	Maintenance	TOTAL
Weighting	*40%*	*30%*	*5%*	*5%*	*15%*	*5%*	
Retention Basin or Flow Diversion	1	10	10	8	1	4	4.7
Increase flood defence capacity (raise levees, elevate road, etc)	3	8	9	6	4	9	5.4
Dredge river channel	5	2	5	8	4	1	3.9
Upgrade/new embankment design (inc. erosion protection & drainage)	3	5	7	6	3	9	4.2
Submersible roads (inc. erosion protection)	5	3	5	8	7	8	5.0
Traffic management (re-routing)	10	2	4	10	9	10	7.1
Increase response and recovery capacity (inc. crews, materials, equipment)	8	3.5	4	10	8	8	6.5
Increase redundancy (improve barangay road(s))	1	8	10	8	2	5	4.2

Notes: Each criterion is scored on a scale of 1-10, with 1 reflecting poor performance, and 10 reflecting strong performance.
Effectiveness score comes from Step 2 (multiplied by 10); Robustness score comes from Step 3b (multiplied by 10).
For further explanation, refer to section 3.3.5.

3.7.2 Assessment and evaluation for landslide archetypes

Table 3.15 presents the summary of measure effectiveness (expressed in terms of estimated risk reduction, %) determined by expert judgement for each of the two landslide archetypes. It also specifies the relevant assumptions made when scoring each of the measures. The following paragraphs present the complete assessments for each landslide archetype in turn.

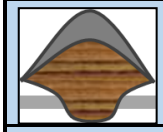
Table 3.15: Summary of effectiveness scores for measures for landslide hazards

Applicable Landslide Archetypes		Measure	
Mud and debris flows	Rockfall		
Effectiveness		**Description**	**Assumptions**
50%		Install drainage in critical areas to prevent seepage	- Slopes only become waterlogged via direct infiltration
60%		Build flow diversion channels/walls (for volcanic eruption matter/lahars)	- Only relevant in volcanic locations - Topography permits matter to be channelled away from road sections
50%	50%	Maintain natural vegetation/prevent deforestation/catchment reforestation	- No competition for resources use in upland areas
60%		Erosion protection along critical river sections (vegetation, synthetics, gabions, concrete, etc.)	- Existing embankments protected - Permits faster recovery - Does nothing for flow capacity
70%	70%	Modify slope geometry (e.g. stepped embankments)	- Sufficient area exists in road easement to modify topography to minimize incidence of slips
80%		Install retaining structures in gullies (e.g. barriers)	- Works mostly for roads at base of slopes; not for roads on slopes
80%		Install bridge over critical areas/gullies	- Bridge designed to withstand lateral forces - Foundations not placed on landslide-susceptible slopes
50%		Wildfire prevention through improved forest management	- Maintains adequate level of forest cover to maintain existing slope stability
20%	20%	Traffic management (re-routing)	- Only reduces losses
45%	35%	Increase response and recovery capacity (inc. crews, materials, equipment)	- Only reduces losses, but also decreases offline time
80%	80%	Increase redundancy (improve barangay road(s))	- Reduces losses by providing improved capacity of alternative routing
	50%	Install drainage above critical rock masses to prevent surface flows	- Reduces rocks becoming dislodged
	70%	Remove loose/critical rock masses	- Reduces amount of rock matter falling on roads
	80%	Install retaining structures (e.g. retaining walls, gabion walls, netting, etc.)	- Retaining structures well designed - Drainage to reduce hydrostatic pressure build up installed
	80%	Internal slope reinforcement (e.g. rock bolts)	- Reduces rockfalls from occurring

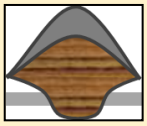
Applicable Landslide Archetypes		Measure	
Mud and debris flows	Rockfall		
Effectiveness		**Description**	**Assumptions**
	50%	Install rockfall galleries	- Rockfalls still occur, but galleries limit impacts

3.7.2.1 Mud/Debris flow

Step 2 – Measures effectiveness

 **Measure**	**Risk reduction in Damages (D) or Losses (L)**	**Effectiveness (Risk reduction, %)**
Install drainage in critical areas to prevent seepage	D,L	50%
Build flow diversion channels/walls (for volcanic eruption matter/lahars)	D,L	60%
Maintain natural vegetation/prevent deforestation/catchment reforestation	D,L	50%
Erosion protection along critical river sections (vegetation, synthetics, gabions, concrete, etc.)	D,L	60%
Modify slope geometry (e.g. stepped embankments)	D,L	70%
Install retaining structures in gullies (e.g. barriers)	D,L	80%
Install bridge over critical areas/gullies	D,L	80%
Wildfire prevention through improved forest management	D,L	50%
Traffic management (re-routing)	L	20%
Increase response and recovery capacity (inc. crews, materials, equipment)	L	45%
Increase redundancy (improve barangay road(s))	L	80%

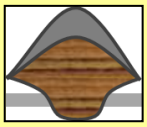
Step 3a – Future performance of measures

 Measure	Performance in 2050			
	High CC		Low CC	
	High Traffic	Low Traffic	High Traffic	Low Traffic
Current Situation (no measures)	*1*	*2*	*2*	*2*
Install drainage in critical areas to prevent seepage	2	2	3	4
Build flow diversion channels/walls (for Vulcanic eruption matter/lahars)	2	2	3	4
Maintain natural vegetation/prevent deforestation/catchment reforestation	2	2	3	4
Erosion protection along critical river sections (vegetation, synthetics, gabions, concrete, etc.)	2	2	3	4
Modify slope geometry (e.g. stepped embankments)	4	4	4	5
Install retaining structures in gullies (e.g. barriers)	3	4	4	5
Install bridge over critical areas/gullies	3	4	4	5
Wildfire prevention through improved forest management	1	2	3	4
Traffic management (re-routing)	1	2	2	2
Increase response and recovery capacity (inc. crews, materials, equipment)	1	2	2	2
Increase redundancy (improve barangay road(s))	4	5	5	5

Notes: The above scores refer to the below qualitative rubric and are not indicators of absolute measure effectiveness (previous step).
Measures with different effectiveness scores may receive the same future performance score in different scenarios, depending on how each measure reduces risk.
For further explanation, refer section 3.3.3.

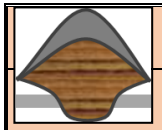
Score	Assessment of future performance
1	Extreme risk
2	Increased risk to present
3	Same risk as present
4	Decreased risk to present
5	Negligible risk

Step 3b – Robustness of measures

 Measure	High CC		Low CC		Robustness Score
	High Traffic	Low Traffic	High Traffic	Low Traffic	
Install drainage in critical areas to prevent seepage	0.50	0.40	0.60	0.80	0.58
Build flow diversion channels/walls (for volcanic eruption matter/lahars)	0.50	0.40	0.60	0.80	0.58
Maintain natural vegetation/prevent deforestation/catchment reforestation	0.50	0.40	0.60	0.80	0.58
Erosion protection along critical river sections (vegetation, synthetics, gabions, concrete, etc.)	0.50	0.40	0.60	0.80	0.58
Modify slope geometry (e.g. stepped embankments)	1.00	0.80	0.80	1.00	0.90
Install retaining structures in gullies (e.g. barriers)	0.75	0.80	0.80	1.00	0.84
Install bridge over critical areas/gullies	0.75	0.80	0.80	1.00	0.84
Wildfire prevention through improved forest management	0.25	0.40	0.60	0.80	0.51
Traffic management (re-routing)	0.25	0.40	0.40	0.40	0.36
Increase response and recovery capacity (inc. crews, materials, equipment)	0.25	0.40	0.40	0.40	0.36
Increase redundancy (improve barangay road(s))	1.00	1.00	1.00	1.00	1.00

Note: For explanation of how these scores have been derived, refer section 3.3.4.

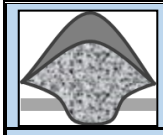
Step 4 – Measure prioritisation

 Criterion	Cost	Effectiveness	Robustness	Flexibility	Implement-ation	Maintenance	TOTAL
Weighting	*40%*	*30%*	*5%*	*5%*	*15%*	*5%*	
Install drainage in critical areas to prevent seepage	7	5	6	10	7	3	6.3
Build flow diversion channels/walls (for Vulcanic eruption matter/lahars)	1	6	6	8	1	4	3.2
Maintain natural vegetation/prevent deforestation/catchment reforestation	6	5	6	10	8	8	6.3
Erosion protection along critical river sections (vegetation, synthetics, gabions, concrete, etc.)	5	6	6	8	8	7	6.0
Modify slope geometry (e.g. stepped embankments)	2	7	9	6	2	8	4.4
Install retaining structures in gullies (e.g. barriers)	3	8	8	8	6	5	5.6
Install bridge over critical areas/gullies	2	8	8	8	3	9	4.9
Wildfire prevention through improved forest management	7	5	5	10	8	2	6.4
Traffic management (re-routing)	10	2	4	10	9	10	7.1
Increase response and recovery capacity (inc. crews, materials, equipment)	8	4.5	4	10	8	8	6.8
Increase redundancy (improve barangay road(s))	1	8	10	8	2	5	4.3

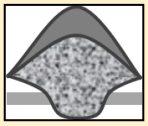
Notes: Each criterion is scored on a scale of 1-10, with 1 reflecting poor performance, and 10 reflecting strong performance.
Effectiveness score comes from Step 2 (multiplied by 10); Robustness score comes from Step 3b (multiplied by 10).
For further explanation, refer to section 3.3.5.

3.7.2.2 Rockfall

Step 2 – Measures effectiveness

 **Measure**	**Risk reduction in Damages (D) or Losses (L)**	**Effectiveness (Risk reduction, %)**
Install drainage above critical rock masses	D,L	50%
Maintain natural vegetation/prevent deforestation/catchment reforestation	D,L	30%
Remove loose/critical rock masses	D,L	70%
Install retaining structures (e.g. retaining walls, gabion walls, netting, etc.)	D,L	80%
Internal slope reinforcement (e.g. rock bolts)	D,L	80%
Install rockfall galleries	D,L	90%
Traffic management (re-routing)	L	20%
Increase response and recovery capacity (inc. crews, materials, equipment)	L	45%
Increase redundancy (improve barangay road(s))	L	80%

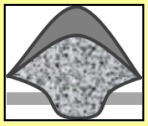
Step 3a – Future performance of measures

 Measure	Performance in 2050			
	High CC		Low CC	
	High Traffic	Low Traffic	High Traffic	Low Traffic
Current Situation (no measures)	*1*	*2*	*2*	*2*
Install drainage above critical rock masses	2	2	3	4
Maintain natural vegetation/prevent deforestation/catchment reforestation	2	2	3	4
Remove loose/critical rock masses	3	4	4	5
Install retaining structures (e.g. retaining walls, gabion walls, netting, etc.)	4	4	5	5
Internal slope reinforcement (e.g. rock bolts)	4	4	5	5
Install rockfall galleries	4	5	5	5
Traffic management (re-routing)	1	2	2	2
Increase response and recovery capacity (inc. crews, materials, equipment)	1	2	2	2
Increase redundancy (improve barangay road(s))	4	5	5	5

Notes: The above scores refer to the below qualitative rubric and are not indicators of absolute measure effectiveness (previous step).
Measures with different effectiveness scores may receive the same future performance score in different scenarios, depending on how each measure reduces risk.
For further explanation, refer section 3.3.3.

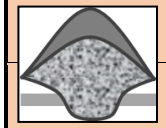
Score	Assessment of future performance
1	Extreme risk
2	Increased risk to present
3	Same risk as present
4	Decreased risk to present
5	Negligible risk

Step 3b – Robustness of measures

 Measure	High CC		Low CC		Robustness Score
	High Traffic	Low Traffic	High Traffic	Low Traffic	
Install drainage above critical rock masses	0.50	0.40	0.60	0.80	0.58
Maintain natural vegetation/prevent deforestation/catchment reforestation	0.50	0.40	0.60	0.80	0.58
Remove loose/critical rock masses	0.75	0.80	0.80	1.00	0.84
Install retaining structures (e.g. retaining walls, gabion walls, netting, etc.)	1.00	0.80	1.00	1.00	0.95
Internal slope reinforcement (e.g. rock bolts)	1.00	0.80	1.00	1.00	0.95
Install rockfall galleries	1.00	1.00	1.00	1.00	1.00
Traffic management (re-routing)	0.25	0.40	0.40	0.40	0.36
Increase response and recovery capacity (inc. crews, materials, equipment)	0.25	0.40	0.40	0.40	0.36
Increase redundancy (improve barangay road(s))	1.00	1.00	1.00	1.00	1.00

Note: For explanation of how these scores have been derived, refer section 3.3.4.

Step 4 – Measure prioritisation

 Criterion	Cost	Effectiveness	Robustness	Flexibility	Implement-ation	Maintenance	TOTAL
Weighting	*40%*	*30%*	*5%*	*5%*	*15%*	*5%*	
Install drainage above critical rock masses	7	5	6	10	8	3	6.4
Maintain natural vegetation/prevent deforestation/catchment reforestation	9	3	6	10	9	8	7.0
Remove loose/critical rock masses	5	7	8	10	6	5	6.2
Install retaining structures (e.g. retaining walls, gabion walls, netting, etc.)	5	8	10	8	6	7	6.5
Internal slope reinforcement (e.g. rock bolts)	4	8	10	10	6	8	6.3
Install rockfall galleries	2	9	10	8	5	7	5.5
Traffic management (re-routing)	10	2	4	10	9	10	7.1
Increase response and recovery capacity (inc. crews, materials, equipment)	8	4.5	4	10	8	8	6.8
Increase redundancy (improve barangay road(s))	1	8	10	8	2	5	4.3

Notes: Each criterion is scored on a scale of 1-10, with 1 reflecting poor performance, and 10 reflecting strong performance.
Effectiveness score comes from Step 2 (multiplied by 10); Robustness score comes from Step 3b (multiplied by 10).
For further explanation, refer to section 3.3.5.

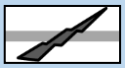
3.7.3 Assessment and evaluation for seismic archetype

Table 3.16 presents the summary of measure effectiveness (expressed in terms of estimated risk reduction, %) determined by expert judgement for the seismic archetype. It also specifies the relevant assumptions made when scoring each of the measures. Thereafter follow the complete assessment tables.

Table 3.16: Summary of effectiveness scores for measures for seismic hazards

Applicable Seismic Archetypes	Measure	
Earthquakes		
Effectiveness	**Name**	**Assumptions**
70%	Increase design standards for roads/bridges/culverts/embankments	- Existing infrastructure is replaced per regular asset management cycles (Build Back Better)
80%	Seismic retrofit/strengthen current road infrastructure (mostly bridges)	- Existing infrastructure is proactively upgraded
20%	Monitoring equipment to investigate structural integrity of infrastructure (mostly bridges)	- Provides early warning of potential bridge failure only
60%	Bailey Bridge material availability at critical locations	- Reduces losses by limiting down time at critical crossing locations
20%	Traffic management (re-routing)	- Only reduces losses
35%	Increase response and recovery capacity (inc. crews, materials, equipment, rebuild better)	- Only reduces losses, but also decreases offline time
80%	Increase redundancy (improve barangay road(s))	- Reduces losses by providing improved capacity of alternative routing
70%	Increase design standards for roads/bridges/culverts/embankments	- Existing infrastructure is replaced per regular asset management cycles (Build Back Better)

Step 2 – Measures effectiveness

 **Measure**	**Risk reduction in Damages (D) or Losses (L)**	**Effectiveness (Risk reduction, %)**
Increase design standards for roads/bridges/culverts/embankments	D,L	70%
Refurbish/strengthen current road infrastructure (mostly bridges)	D,L	80%
Monitoring equipment to investigate structural integrity of infrastructure (mostly bridges)	D,L	20%
Bailey Bridge material availability at critical locations	L	60%
Traffic management (re-routing)	L	20%
Increase response and recovery capacity (inc. crews, materials, equipment, rebuild better)	L	35%
Increase redundancy (improve barangay road(s))	L	80%

Step 3a – Future performance of measures

Measure	Performance in 2050	
	High Traffic	Low Traffic
Current Situation (no measures)	*2*	*2*
Increase design standards for roads/bridges/culverts/embankments	4	5
Refurbish/strengthen current road infrastructure (mostly bridges)	4	5
Monitoring equipment to investigate structural integrity of infrastructure (mostly bridges)	2	2
Bailey Bridge material availability at critical locations	4	4
Traffic management (re-routing)	2	2
Increase response and recovery capacity (inc. crews, materials, equipment, rebuild better)	2	2
Increase redundancy (improve barangay road(s))	4	5

Notes: The above scores refer to the below qualitative rubric and are not indicators of absolute measure effectiveness (previous step).
Measures with different effectiveness scores may receive the same future performance score in different scenarios, depending on how each measure reduces risk.
For further explanation, refer section 3.3.3.

Score	Assessment of future performance
1	Extreme risk
2	Increased risk to present
3	Same risk as present
4	Decreased risk to present
5	Negligible risk

Step 3b – Robustness of measures

Measure	High Traffic	Low Traffic	Robustness Score
Increase design standards for roads/bridges/culverts/embankments	1.00	1.00	1.00
Refurbish/strengthen current road infrastructure (mostly bridges)	1.00	1.00	1.00
Monitoring equipment to investigate structural integrity of infrastructure (mostly bridges)	0.50	0.40	0.45
Bailey Bridge material availability at critical locations	1.00	0.80	0.90
Traffic management (re-routing)	0.50	0.40	0.45
Increase response and recovery capacity (inc. crews, materials, equipment, rebuild better)	0.50	0.40	0.45
Increase redundancy (improve barangay road(s))	1.00	1.00	1.00

Note: For explanation of how these scores have been derived, refer section 3.3.4.

Step 4 – Measure prioritisation

Criterion	Cost	Effectiveness	Robustness	Flexibility	Implement-ation	Maintenance	TOTAL
Weighting	*40%*	*30%*	*5%*	*5%*	*15%*	*5%*	
Increase design standards for roads/bridges/culverts/embankments	9	7	10	10	8	9	8.4
Refurbish/strengthen current road infrastructure (mostly bridges)	2	8	10	4	3	9	4.8
Monitoring equipment to investigate structural integrity of infrastructure (mostly bridges)	4	2	5	10	5	6	4.0
Bailey Bridge material availability at critical locations	4	6	9	10	4	8	5.4
Traffic management (re-routing)	10	2	5	10	9	10	7.2
Increase response and recovery capacity (inc. crews, materials, equipment, rebuild better)	8	3.5	5	10	8	8	6.6
Increase redundancy (improve barangay road(s))	1	8	10	8	2	5	4.3

Notes: Each criterion is scored on a scale of 1-10, with 1 reflecting poor performance, and 10 reflecting strong performance.
Effectiveness score comes from Step 2 (multiplied by 10); Robustness score comes from Step 3b (multiplied by 10).
For further explanation, refer to section 3.3.5.

3.8 Adaptation Pathways

As indicated in section 3.3.6, the preceding archetype prioritisations can serve as a basis for constructing relative adaptation pathways, consisting of initial sequences of short- mid- and long-term actions.

Note that the prioritisation tables do not automatically generate the preferred sequencing for adaptation pathways. Rather, they provide guidance as to which measures are more preferred over others in the MCA. Another important consideration regarding measures selection is the preferred type of measure to be implemented (Pro-action, Prevention, Preparation, Response, Reconstruction); or alternatively, whether the priority for the road section is to reduce damages or losses (or both). In each of the 'Measure effectiveness' tables we have indicated whether a measure is targeted more towards damages or losses reduction. In many instances it may be appropriate (and preferred) to implement the most favourable losses reduction measures in parallel with the most favourable damage reduction measures. We recommend roads planners consider the specific objectives of risk reduction for each road section when ultimately selecting their preferred measures for implementation.

Unfortunately given the variability of the different contexts and wide variety of potential interventions available for specific road sections, it makes little sense to develop *generic* adaptation pathways for each archetype. For each specific underperforming road section, some effectiveness and future performance scores for different measures may need to be varied, other measures may need to be considered, while even others may need to be removed from the analysis entirely. For example, although we treat retention basins/flow diversions as particularly successful measures for flooding in this assessment, in many locations there will not be suitable upstream locations for basin construction. Similarly – as above – some road sections may need to prioritise the implementation of measures targeting losses mitigation, while others will need to prioritise damage mitigation measures.

Nevertheless, by way of example, Figure 3.12 presents an initial adaptation pathways map for a *fictitious* road section in Nueva Ecija that is vulnerable to perpendicular flooding due to its complete lack of drainage (i.e. relevant archetype: Perpendicular Flow – No Drainage). For this fictitious road section, we have assumed that the crossing does not occur in a steep gully but is rather a broad shallow crossing. We have also assumed that the scores and assessment provided in section 3.7.1.1 apply. The specific policy objective for this road section is to effectively mitigate both damages and losses into the future.

The adaptation pathways map has effectively been split in two parts: the top half is dominated by measures targeting damage reduction, while the bottom half includes those measures focussed solely on reducing losses. The relative performance of each of the measures are based upon each measure's effectiveness score, and the projected impacts of the climate and socio-economic uncertainties have been used to inform the extreme 'high' and 'low' relative scenario axes. One can clearly see that the robust retention basin/flow diversion is effective in all scenarios, while the other measures have reduced effectiveness. The road elevation measure has also been split into sub-actions to reflect its flexibility of application. That is, the road could be gradually elevated as peak flood levels increased due to climate change. The map does not show every conceivable possible pathway but illustrates those deemed the most logical; for example, if one started with elevating the road or installing a submersible road.

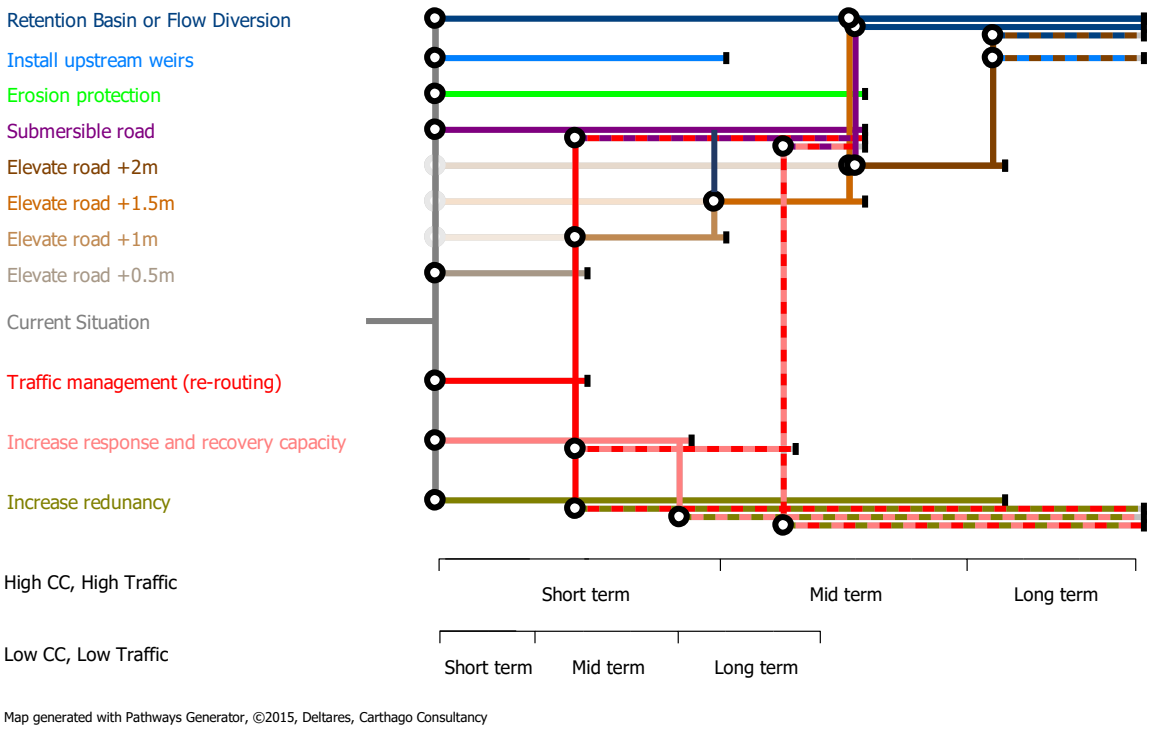


Figure 3.12: Example adaptation pathways map developed for a fictitious road section of the Perpendicular Flow – No Drainage archetype

From the measure prioritisation table (section 3.7.1.1), one can see that the most preferred measure targeting damages reduction is the submersible road, followed by erosion protection and road elevation (which also mitigates losses). The installation of upstream weirs and the construction of a retention basin – although effective in the latter case – are least preferred. For losses-only reduction, improved traffic management is the most preferred solution (also for all measures), followed by increasing the response and recovery capacity and finally increasing the number of alternative routes through barangay road improvement.

Hence, a preferred pathway targeting both damages and losses reduction could be to initially keep allowing the road to flood by installing a submersible road and improving traffic management and response and recovery capacity in the short to medium-term. As preventing the flooded road from occurring becomes more important, planners could then transition to elevating the road with a culverted causeway to convey river flows (including regular maintenance to maintain conveyance capacity). Should peak flows increase with climate change, the road could be elevated further (with additional culverts) and ultimately an upstream retention basin or flow diversion installed if required. Figure 3.13 illustrates this preferred pathway (dark red dashed lines) while Table 3.17 summarises the key actions and timing involved in this example.

Note that provincial roads planners may find it difficult to construct formal adaptation pathways maps in the style of Figure 3.13. In which case, producing simplified pathways in the form of a table like Table 3.17 will suffice in many instances. What is important is that roads planners consider their decision making in time and in the long term, such that they explore alternative pathways of prioritised measures to achieve the specified objectives into the uncertain future. Thinking about the sequencing of options as conditions change will help planners to identify

potential path-dependencies, where one measure logically cannot be implemented prior to another, or lock-in situations, where future choices become constrained to due to previous decisions (e.g. bridge construction) or result in considerable investment losses. Doing so will assist planners to keep their options open for as long as possible to flexibly adapt to the changing conditions as they emerge.

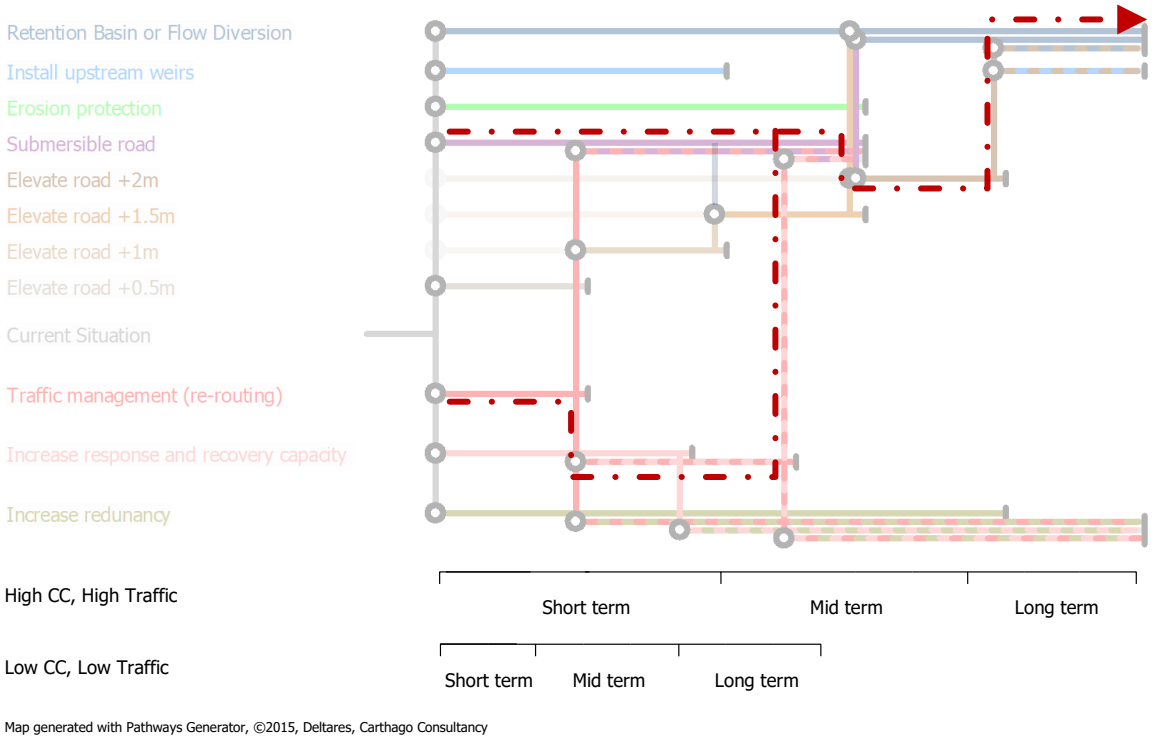


Figure 3.13: Preferred adaptation pathway for the fictitious road section

Table 3.17: Example preferred pathway for the fictitious road section

Short-term actions	Mid-term options	Long-term options
- Submersible road (D) - Traffic Management (L) - Improve response & recovery capacity (L)	- Elevate road on culverted causeway (include erosion protection an ongoing maintenance) (D, L)	- Elevate road further (D, L) - Install upstream retention or flow diversion (D, L)

3.9 LGU application of the approach

The preceding approach was applied together with representatives from Nueva Ecija and selected national agencies during a 2-day workshop in Cabanatuan City on 18-19 July 2019. Following practical application of the risk assessment outputs, provincial roads planners then selected a prioritised road to upgrade and stepped through the adaptive strategy building approach using the relevant archetype assessment as a foundation. Irrelevant measures were removed, effectiveness and future performance scores updated, minimax analyses implemented, multi-criteria analyses performed (including validation of criteria weights), and simplified adaptation pathways formulated.

Workshop participants were all able to successfully apply the proposed strategy building methodology during the workshop. Many of the participants were surprised to learn that softer measures (e.g. maintenance, traffic management, recovery crews, etc.) often emerged as the most preferred short-term solutions, even when updated (non-archetypical) scores were applied. Many of the analytical techniques presented in the methodology were new to participants, and their feedback suggested they found the inclusion of multi-criteria analysis their most useful and significant learning.

Figure 3.14:LGU application of the risk assessment and strategy building approaches during final project workshop

3.10 Concluding remarks

Decision makers today face deep uncertainties about future conditions. They need to be confident the decisions they take today will continue to apply in the future. To meet this challenge, new methods and approaches have been developed to help decision makers identify and evaluate robust and adaptive strategies, and thereby make sound decisions in the face of these challenges. The adaptive strategy building approach we have presented in this chapter contextualises Deltares' DAPP DMU approach to the specifics of provincial roads planning in Nueva Ecija. The proposed semi-quantitative approach builds upon the previously reported outputs from the risk assessment, and combines available data, expert judgement and simplified analytical methodologies in a procedure that provincial roads planners should find appropriate to implement independently.

Due to the large number of roads in Nueva Ecija, our analysis has been presented at the level of seven generic archetypes that encompass all potential road locations but permit planners to focus on those measures of relevance to the specific archetypes. However, these assessments must be seen as a starting point, rather than the definitive solution. The generic assessment tables should be adapted and contextualised to the specific local conditions of each road section, as the presented assessments score measures according to their maximum theoretical application. We encourage roads planners to therefore update these tables with scores (and/or additional measures) more appropriate to the conditions of the specific road section as and if required.

We have simplified the analysis down to a consideration of only two key drivers of uncertainty: the effects of climate change on future peak river flows and potential growth in traffic demands. Our analysis of these uncertainties reveals a large plausible range of both future climate impacts and traffic demands in 2050, with these leading to potential increases in damages and losses respectively between 0-40% and 200-400% above present levels. Roads planning must therefore be flexible enough to adapt to whichever conditions emerge. Our analysis also indicates that although provincial roads damages presently outweigh losses in a ratio of 5:1, this balance could shift significantly by 2050 to 1.3-1.5:1.

When formulating long-term adaptive strategies, roads planners must also keep in mind the overall policy objectives for each road section. That is, is the primary objective to reduce damages, losses, or both? Moreover, is this objective at all likely to change in the future given the uncertain developments? The presented approach demonstrates the advantages of taking an anticipatory, future-focussed perspective towards provincial roads planning in Nueva Ecija. By considering decision making in time and exploring long term alternative pathways of prioritised measures, the specified objectives for specific road sections may continue to be achieved into the uncertain future.

3.11 Recommendations for roads planning

The outcomes of the preceding adaptive strategy building assessment inform the following recommendations:

1. LGU roads planners should apply the presented adaptive strategy building approach in their future roads planning. The semi-quantitative approach offers an easy means for planners to better account for future uncertainties in their planning. DILG should ensure that supported application and capacity building is carried out with targeted LGUs already planning to upgrade their local roads infrastructure, supported by consultants as necessary. This could be followed up by a wider DILG-coordinated capacity building program for all remaining LGUs to support wider approach roll-out and build confidence in approach application. Local consultants could be included in capacity building activities to ensure adequate support exists for the LGUs in the future.

2. An important aspect of the approach is the contextualisation of the generic archetypical assessments to the specific local conditions for each vulnerable road section. The assessment tables and approach have been designed with flexibility in mind: values can be changed, and new measures may be introduced, or others omitted. We recommend that LGU planners and local consultants familiarise themselves with the approach such that independent contextualisation is not seen as a barrier to its application. The capacity building approach outlined in the preceding recommendation should therefore include a focus on this integral element of the approach.

3. When formulating long-term adaptive strategies, LGU roads planners must also determine and keep in mind the overall policy objectives for each road section. Again, the proposed capacity building approach should focus on how LGU practitioners can best do this given locally available information.

4 IWRM Review

4.1 Introduction

This chapter presents the results of the review of the existing Pampanga River Basin IWRM plan and its implications for LGU roads planning.

Integrated Water Resources Management (IWRM) promotes the coordinated development and management of water, land, and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (GWP, 2000). The ultimate goal of IWRM is to achieve 'water security for all,' which is the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human wellbeing, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability (UN Water, 2003).

The Philippines recently adopted guidelines for IWRM planning to be implemented in the river basins in the country. These were prepared under the 2015-16 World Bank project, *'Philippines: Establishing Integrated Water Resources Management Planning Tools and Guidance, and Capacity Building.'* The guidelines are currently in the process of being adopted in individual river basins, with an important part of this process being capacity development of Local Government Unit (LGU) officials regarding their application.

The purpose of this review is to ascertain the compliance of present IWRM plans for the Pampanga River Basin (PRB) with the planning framework presented in these guidelines. The ultimate aim of the review is to provide recommendations to LGU and other government agencies on any updates or improvements which may need to be made to the plans in order to bring them in line with the framework. Given the vulnerability of road infrastructure to flood impacts in Nueva Ecija (Figure 4.1), the review focuses most on those aspects of the PRB IWRM plans relating to Flood Risk Management (FRM) and considers the impacts of the plans for the road network. In principle, the FRM measures included in the IWRM plans should not have the unintended consequence of exacerbating potential flood damage or interruptions to the road network; rather they should mitigate these risks.

The chapter is structured as follows. Section 4.2 introduces the recently adopted IWRM planning guidelines. Section 4.3 introduces the relevant PRB IWRM planning documents that were studied as part of the review, before Section 4.4 examines the compliance of the existing PRB IWRM plan with the guidelines. Section 4.5 then examines any implications of the plan for LGU roads planners. Section 4.6 provides recommendations to LGUs regarding improving the PRB IWRM plan, mainstreaming IWRM into sectoral planning processes and increasing LGU involvement in future IWRM planning process in the PRB.

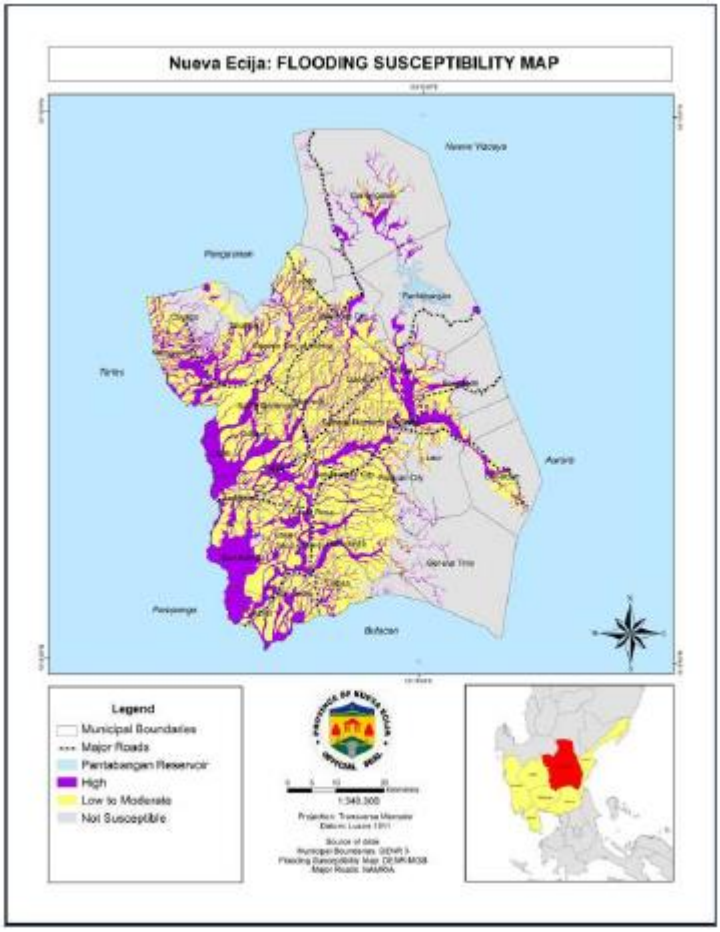


Figure 4.1 - Nueva Ecija Flooding Susceptibility Map (DENR-MGB)

4.2 National IWRM Planning Framework

The new National IWRM Planning Framework (DPWH, 2016) refers to an iterative, cyclic process in which a set of logical sequence phases are driven and supported by a continuous management support and stakeholder involvement events. The expected outcome of the process is an IWRM plan, which is endorsed and implemented by the government (i.e. decision-makers) and stakeholders. Throughout the process, decision makers and stakeholders gain insight in the system and its performance, as well as on the importance and benefits from jointly addressing sustainable development of water resources.

The guidelines refer to five main steps of IWRM planning. Each step consists of several activities, with these illustrated in (Figure 4.2):

I. **Inception** – sets the boundary conditions for the analysis. The four main activities are (i) creating the enabling conditions for the IWRM planning exercise, i.e. 'organize' the planning exercise, (ii) setting-up the stakeholder involvement process, (iii) defining the analysis conditions, and (iv) defining the objectives that the water resource developments should support.

II. **Situation analysis** – describes the present and future water resources problems. It shows the uniqueness of the Water Resources System (WRS) of the river basin. It contains a

complete description of all elements of a water resources system, including the natural resources, socio-economic and institutional systems. Major problems and issues in terms of WRM faced by the national and regional authorities and stakeholders are extensively described for the present situation (base case) and future situation(s) (reference case(s)). As the future situation is unknown, uncertainties are addressed by defining alternative scenarios that describe possible future conditions. A collection of potential measures is formulated based on the results of the description of the WRS, the problem analysis, and the scenario analysis. A supporting computational framework is typically applied to assess WRS vulnerabilities in each of the base and reference cases.

III. **Strategy building** – develops alternative strategies for decision making. Strategy design is the development of coherent combinations of potential measures to satisfy the objectives defined in Step I, via impact assessment. Intensive interaction with the decision makers and stakeholders is needed to develop strategies that are supported. The outcome of the strategy design is several alternative strategies from which the decision makers and stakeholders can select their preferred strategy. Principles of adaptive management should also be applied during this step for the proposed strategies to account for future uncertain impacts of scenario drivers and to make the strategies dynamic. The computational framework is again applied in order to assess the impacts of the different strategies. Figure 4.3 further elaborates the specific activities and process steps which should feature during the strategy building step.

IV. **Action planning** – prepares the schedule of implementation and investment plans, by translating the preferred strategy into a concrete action plan. The action plan has an ‘open’ and ‘rolling’ character, meaning that it is not static or prescriptive, and leaves room for individual decision-makers to further elaborate upon in relation to their own responsibilities. It includes the provision of any required feasibility studies or environmental impact assessments, detailed technical designs, monitoring and evaluation plans, and promotion activities. It should assign clear responsibilities for identified actors; clear timelines and clear budget allocations towards any capital and operational expenses.

V. **Implementation** – refers to the actual implementation of the action plan, including its monitoring and evaluation. An implementation framework applies for both Steps IV (Action Planning) and V (Implementation) (Figure 4.4).

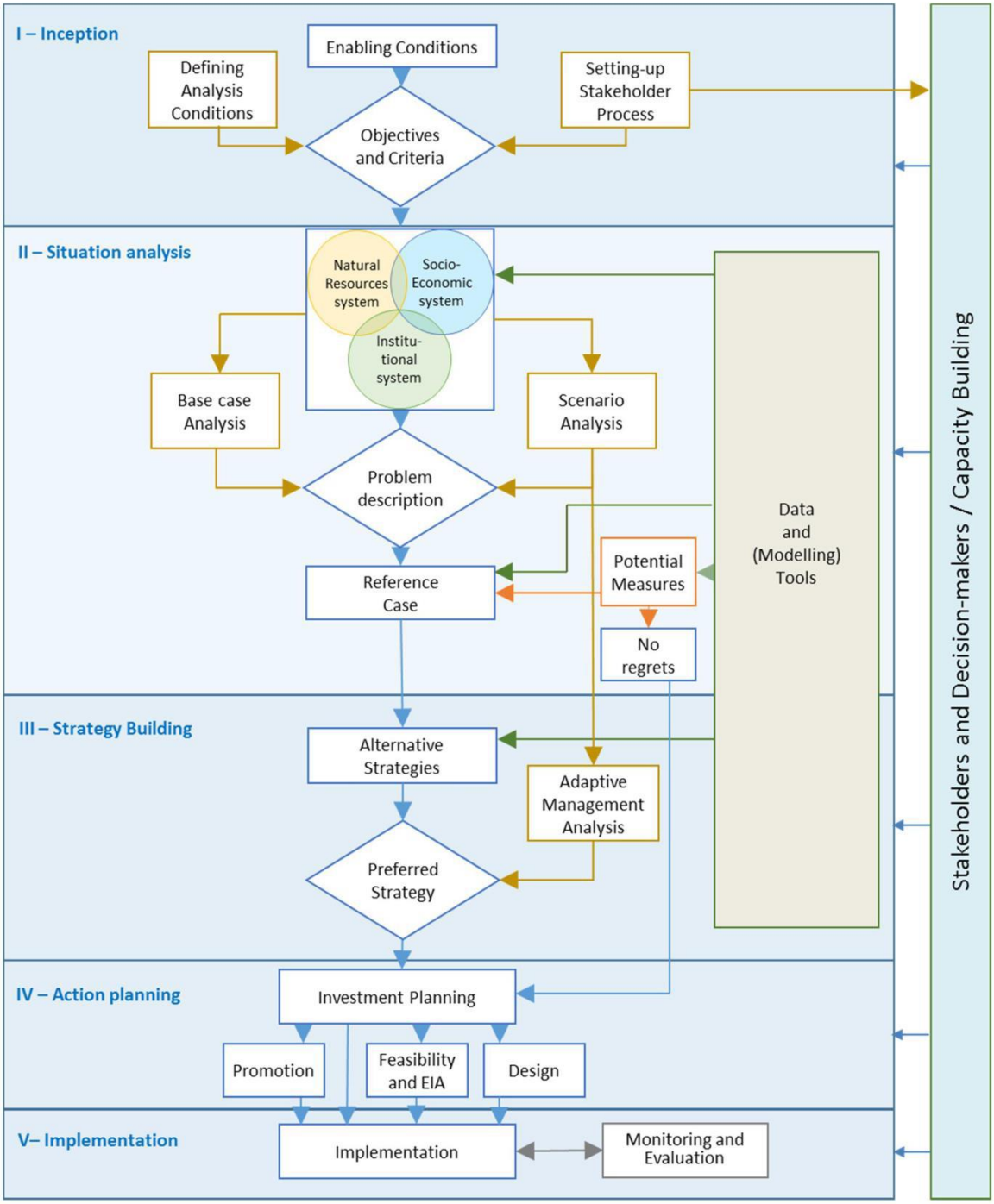


Figure 4.2 - National IWRM Planning Framework (DPWH, 2016)

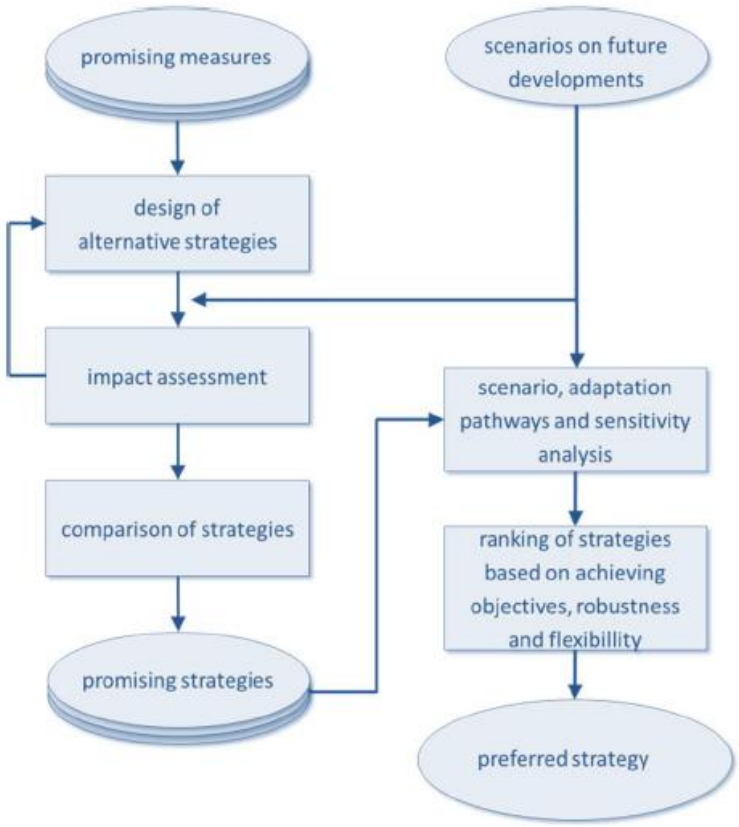


Figure 4.3 - Development of alternative strategies and selection of preferred strategy

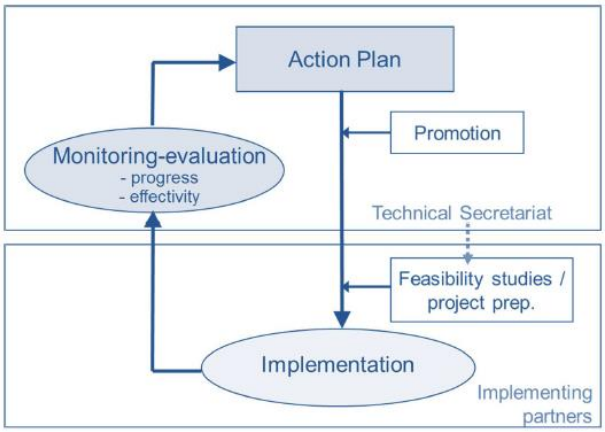


Figure 4.4 - Implementation Framework

4.3 Existing IWRM Plans

The project team has identified two existing plans of relevance to assess against the new IWRM planning framework for Nueva Ecija and the purposes of this study:

- 2011 Study on Integrated Water Resources Management for Poverty Alleviation and Economic Development in Pampanga River Basin (NWRB, 2011; hereafter JICA Study)
- 2018 NEDA Region 3 update to the above plan: Climate Responsive Integrated Master Plan for the Pampanga River Basin (NEDA, 2018; hereafter NEDA 3 Study).

The original IWRM plan (JICA study) was prepared and completed for the Pampanga River Basin with the dual objectives of formulating an initial IWRM Plan for the Pampanga River Basin and to transfer relevant skills and technologies on IWRM to personnel of NWRB and other relevant organizations. It had the principal visions of 'poverty alleviation and economic development' and considered national/regional development policies in the study area.

The plan proposes a total of 84 projects distributed to six different sectors as components of the IWRM Plan to be implemented for the short term (2011 to 2015), medium term (2018 to 2020) and long term (2021 to 2025), 10 of which are related to the sector Flood and Sediment Disasters. Out of the total 84 projects, 36 are on-going, 18 are proposed and 30 are still in the conceptual stage. The projects have been divided into two groups (Group A and B) in order to facilitate the programming of the project development scenarios and the project implementation schedule/investment program.

This original IWRM plan has since been updated by NEDA Region 3 to consider and address specific potential impacts of climate change (NEDA 3 Study). This study was completed in 2018 and covers the years 2016–2030. It has been aligned with present national and regional development policies and implementation programs, projects, and activities geared towards achieving high, inclusive and sustainable growth. In addition to other measures, it recommends the establishment of a relevant authority empowered with specific functions to advocate and implement the IWRM Plan, and to monitor water rights, water quality, and ecosystem services, and to provide vital operations and maintenance for all flood control facilities.

The NEDA 3 Study reassessed the original 84 projects from the JICA Study, subjecting these to a further round of consultation. As a result, an updated total of 97 projects are now identified and included in the Pampanga Basin IWRM plan, with 40 projects falling under the thematic area of flood mitigation, hazard management and climate adaptation.

In addition to these two river basin plans, the study team consulted with both national and regional DPWH and local government agencies regarding other planned disaster risk reduction measures which may not have been documented in either of the two studies. Only one further plan, the Nueva Ecija PDRRMP was identified. This has been formulated following the National DRRM Framework, National DRRM Plan and the Regional DRRM Plan, with further planning guidance from the Office of the Civil Defense. The plan covers the four NDRRMP thematic areas, namely: (1) Disaster Prevention and Mitigation; (2) Disaster Preparedness; (3) Disaster Response; and (4) Disaster Rehabilitation and Recovery. A review of this plan revealed that the proposed measures were all non-structural in nature, with little impact for the Nueva Ecija road network. Hence, they have not been considered further in this study.

4.4 Existing plan compliance with national framework

The existing IWRM plans prepared by JICA and updated by NEDA 3 were reviewed to ascertain compliance with the recently adopted National IWRM Planning Framework (section 4.2). These findings are presented fully in Appendix I.

Although each of the two planning documents do not fully comply with the new guidelines, they did undertake many of the required activities presented in the updated analytical framework. Future updates to the plans would benefit from more structured, quantitative analysis procedures including the development of an appropriate computational framework and specification of measurable performance criteria and indicators against which the formulation and performance of the plan may be assessed. Similarly, scenario analyses and adaptive planning principles should be incorporated to account for the plausible range of future long-term (>50 years) climatic and socioeconomic uncertainties, and to serve as a basis for the reference case analyses, measures assessment and adaptive strategy formulation. Alternative strategies should also be developed, from which a preferred strategy can be selected and elaborated in consultation with stakeholders. And the plan should be elaborated with the inclusion of a formal monitoring framework to monitor the overall performance of the plan against the specified performance criteria.

4.5 Implications from the plans for the road network in Nueva Ecija

The vision for the PRB (including Nueva Ecija) as formulated in the JICA Study and updated during the NEDA 3 Study is that 'PRB shall become the most economically advanced and resilient river basin in the country that shall attain the lowest incidence of poverty, fully restored watershed and ecosystems, properly utilized and managed water resources, adequately provided modern infrastructure facilities, and an empowered citizenry in partnership with transparent, accountable, and development oriented leaders'. The overall development master plan framework for the PRB (Figure 4.5) illustrates how the PRB vision (pink box) contributes to regional and national development goals through five thematic area/sector outcomes, namely: water resources; watershed management; wetland management; flood mitigation, hazard management and climate adaptation; and institutional management.

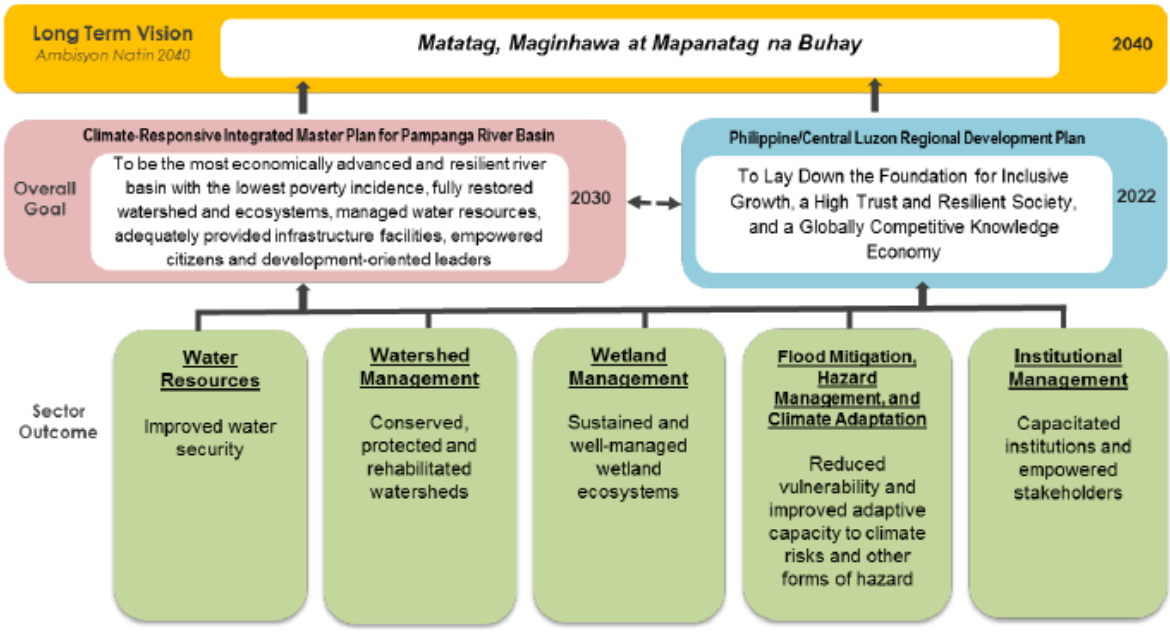


Figure 4.5 - Overall Master Plan Framework of PRB (NEDA, 2018)

As indicated previously, the five thematic areas have collectively identified 97 projects for the PRB, all of which are intended to be implemented by 2040. Forty of these projects (equivalent to 83.5 percent of total investment costs) belong to the fourth thematic area: flood mitigation, hazard management, and climate adaptation. These are mainly composed of flood mitigation and road improvement infrastructure, including projects to increase levels of redundancy in the road network to better mitigate impacts of future hazards. In combination, these projects are intended to reduce vulnerabilities and improve the adaptive capacity of the system to climatic risks and other forms of hazards. Specific sub-sector outcomes include: strengthening preparedness and disaster mitigation efforts; improving response early recovery and rehabilitation interventions; and improving the adaptive capacity to climatic and geologic hazards.

Appendix II lists all flood mitigation, hazard management and climate adaptation identified in the two planning documents. In general, most of the structural measures identified in the JICA study are in the downstream areas of the PRB, with only two projects targeting flood control maintenance works for the Rio Chico branch. In the NEDA 3 update, additional structural measures have been identified of relevance to Nueva Ecija, including:

- Rehabilitation and strengthening of ring levees (e.g. in Arayat-Cabiao)
- Dredging and widening of critical river sections, construction of river training works, dikes and flood levees (e.g. for Rio Chico)
- River training works and slope stabilization of other rivers (e.g. Coronell, Talavera)
- Construction of segments of the North Luzon East Expressway and other highways
- Road widening and embankment heightening, provision of drainage systems for existing expressways and other roads

The schedule of projects (Appendix II) illustrates that flooding is a serious concern in Nueva Ecija. Unfortunately, additional information on each of these measures beyond (very) brief project descriptions included in the JICA and NEDA 3 studies was not made available to the project team. That is, little information appears to exist regarding proposed locations, dimensioning, or the intended impacts or consequences of these measures to facilitate a proper review or further assessment. Figure 4.6 presents locations of proposed measures for which location information was available in the two studies, overlaid onto the 100-year flood hazard map and provincial road network.

Generally, flood control projects that propose installing flood control structures, or dredging, widening and training river channels are intended to lower water levels at vulnerable locations. In many instances these locations are at or near road crossings, or where rivers flow parallel to vulnerable road sections. As such, they hold implications for the performance of the road network during peak flow events. Similarly, dike and levee construction/rehabilitation are intended to protect presently vulnerable areas from future incidences of flooding. These areas can also include vital road corridors, or roads may even be placed atop these embankments.

Conversely, flood control and road improvement projects such as the construction of new roads, widening existing roads or elevating them on embankments, installing bridges, fords and the like will inevitably impact flow patterns throughout the floodplain. Elevating roads on embankments where previously water could flood unimpeded often merely shifts the impacts of flooding elsewhere. This can be very effective if the locations of these new structures have been well thought through and subjected to rigorous social and environmental impact assessment. However, in the absence of such analyses, these actions can lead to unintended negative consequences.

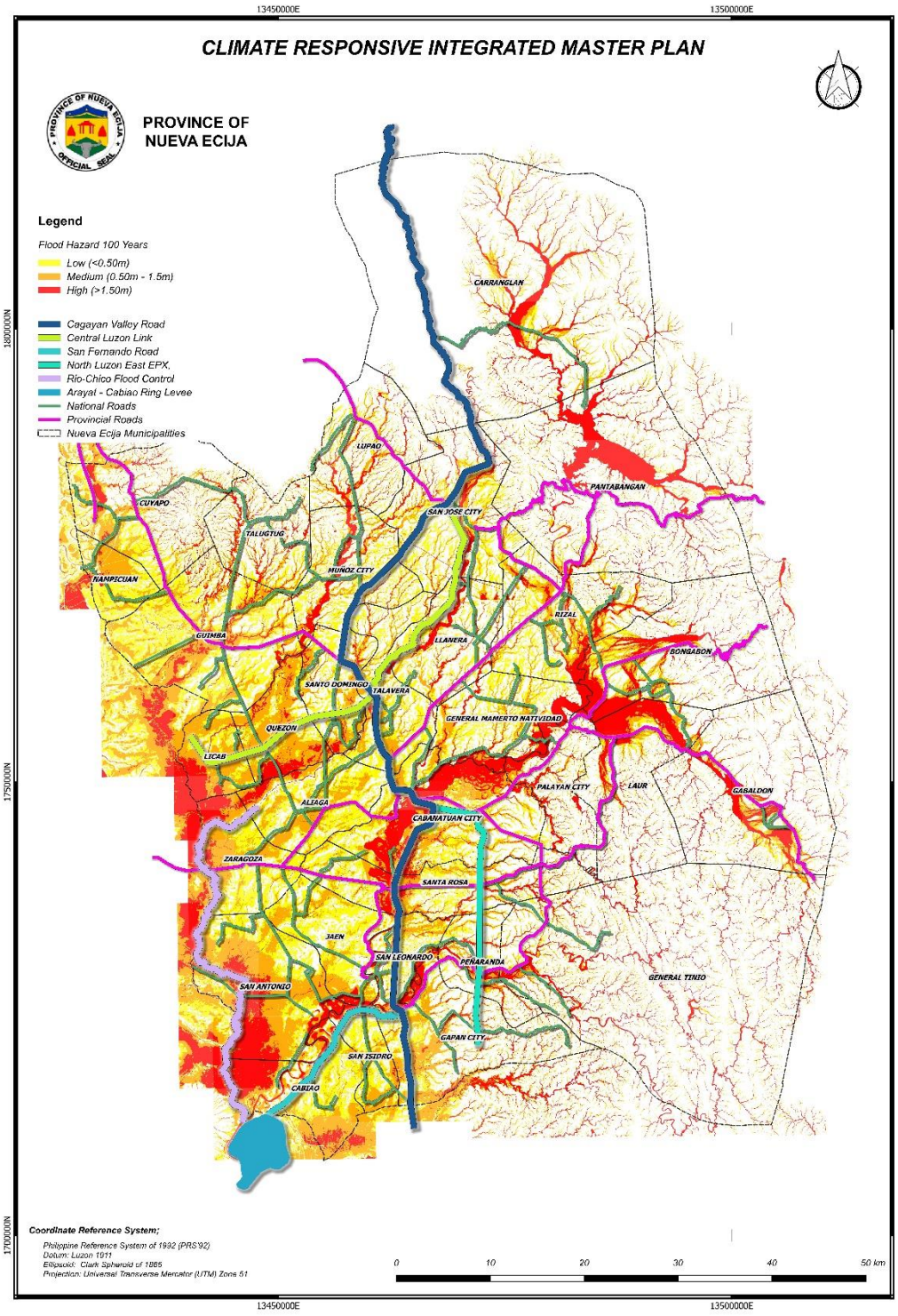


Figure 4.6: Map showing some of the proposed IWRM measures listed in the Neda 3 Study

Furthermore, in making these investments, policy makers will want to be sure that they continue to function as intended for the life of each project. It is broadly recognised that climate change has the potential to increase flood hazards in the Philippines in the future (PAGASA, 2011; PAGASA, 2018). Policy makers want to be sure that the actions they take today will still apply under future conditions. This is one of the reasons behind the adoption of the National IWRM Planning

Framework. The structured analytical process it recommends – including quantitative impact assessment, scenario analysis and integration of adaptive planning principles – is intended to mitigate the risks of over- and under- investment in, among others, flood mitigation and hazard management.

Undertaking an integrated, quantitative assessment of the impacts of current and future flood mitigation and road infrastructure projects in Nueva Ecija is an important mechanism by which to help achieve the goals expressed in the vision for the PRB outlined previously. Such studies need not be resource-intensive but can be performed relatively quickly and simply using available information and analytical techniques. We recommend an iterative process, whereby initial coarser studies are first undertaken to ascertain strategic directions and impacts, before further detailed analyses provide more precise information on the selected options. The next chapter (Chapter 5) provides an example of how such a quantitative strategic level assessment may be carried out for two example systems in Nueva Ecija.

4.6 Recommendations for improvements to current IWRM plans

Based on our preceding assessment and consultations with project stakeholders during this TA, the project team has identified the following nine (9) recommendations to improve the current status of the IWRM plans for the PRB, bring them into line with the National IWRM planning guidelines and improve the resilience of provincial road network in Nueva Ecija.

1. DPWH and DENR should further disseminate and promote the National IWRM Planning framework across relevant sectoral agencies at national, provincial and local levels of government, to ensure common understanding and a commitment to adopt and integrate IWRM into roads and other sectoral planning processes. This should be accompanied by comprehensive and targeted capacity development activities, to equip agencies with the necessary skills and tools to undertake these types of analyses.

2. Roads planning agencies at all levels of government must advocate for, adopt and integrate IWRM into roads and other sector planning processes. This integration will likely involve the creation and coordination of new relationships between different sector agencies and other stakeholders, as appropriate. DPWH, DILG and RBCO can support these processes through the establishment of coordination committees at the basin scale, including all relevant sectoral and local government agencies. As indicated by the existing PRB IWRM plan, water-related challenges hold implications for a wide variety of sectors, including roads planning. The traditional approach currently practised is sectoral/project focused; only takes into consideration sector-specific needs and benefits; fails to resolve conflicts between competing users of resources (including space); and has limited stakeholder participation. The IWRM approach recognises, considers and seeks to integrate the needs of interrelated sectors, resolves conflicts between users and includes broad stakeholder engagement. Its adoption will improve provincial roads resilience through the realisation of synergies between different sector needs and benefits. For example, larger flood protection works by other actors may mean other measures to reduce localised road flood impacts are no longer required.

3. Roads plans at all levels of government must be aligned with one another to facilitate coordination and commonality of purpose. DPWH should formally engage LGUs in its FRM, DRR and roads planning processes to ensure proposals will enhance provincial development objectives. LGUs must ensure that their roads plans reinforce existing regional and national priorities and comply with the overall objectives of the PRB IWRM

plan. DPWH and LGUs must take joint strategic decisions based on an assessment of the comparative integrated impacts of different actions.

4. NWDB, and NEDA should coordinate to update the existing PRB IWRM plan to address the shortcomings identified as a result of this review. An improved structured quantitative analysis procedure should be carried out, including the specification of measurable performance criteria and indicators against which the formulation and performance of the plan can be assessed. Quantitative base and reference case analyses should be conducted against these criteria, in addition to a comparative quantitative impact assessment of potential measures and strategies. Scenario analyses should be elaborated to account for the plausible range of future climatic and socioeconomic uncertainties, and to serve as a basis for the reference case analyses, measures assessment and strategy formulation. Alternative strategies should be developed, from which a preferred strategy can be selected and elaborated in consultation with stakeholders. LGU planners must ensure they are involved in these processes to ensure that metrics and measures to assess and improve provincial roads resilience are included in the plans. Appropriate consultants should be engaged to support these processes as and when required, with terms of reference including requirements for comprehensive capacity transfer to local organisations.

5. To support quantitative analysis, an appropriate computational framework for IWRM planning should be developed and maintained by appropriate government agencies (e.g. NWRB, NEDA). This could comprise a fast, integrated system model (e.g. metamodel) or be comprised of individual sector-specific models at fit-for-purpose resolutions to permit rapid integrated assessment of many options and strategies under the plausible range of future conditions. The developed models should generate information of relevance to the performance criteria. End-users (including LGU officials) should be involved in the development of these tools to ensure model transparency and build trust and ownership. Sufficient training should be provided to end-users to develop confidence in the application of these tools for IWRM (and associated roads) planning. Appropriate consultants should be engaged to develop (and use) these tools where required, with terms of reference including requirements for comprehensive capacity transfer to local organisations.

6. NWRB and NEDA must ensure that any update to the PRB IWRM plan should take into consideration the potential longer-term (>50 years) impacts of the uncertainty drivers to help minimise risks of mal-adaptation. Other adaptive planning principles should be similarly applied, in order to develop plans and strategies which are both flexible and robust to the uncertain future conditions and prevent over- and under-investment in (road) infrastructure. LGU planners should apply similar principles for their own roads planning (refer Chapter 3).

7. NWRB and NEDA must ensure that any update to the PRB IWRM plan should be elaborated with the inclusion of a formal monitoring framework for not only project implementation, but for monitoring the overall performance of the plan against the specified performance criteria (refer recommendation 4). The monitoring framework should also specify the key signals and triggers to assess over the life of the plan to ascertain the direction and magnitude of the uncertainty drivers and determine when (or whether) LGUs and others need to take further action to improve (road) resilience. The framework should assign roles to the relevant national/regional agencies (e.g. NIA, NEC, UP-NHRC, DPWH, LGUs, etc.) to monitor the relevant signals, with coordination provided by NWRB/NEDA.

8. NWRB and NEDA must ensure that any update to the PRB IWRM plan follows the action planning and implementation framework (Figure 4.4). The implementation plan should specify not only the implementing agencies, but also the mechanisms by which the various projects will be financed. Operational and risk management plans should also be included, as well as the consideration of communication, public awareness and gender-related issues.

9. Given the relative paucity of information regarding the proposed measures included in the IWRM plan (refer section 4.5), LGU roads planners must liaise and coordinate with DPWH to obtain additional information pertaining to these measures' locations, likely dimensions, intended impacts, etc. Should this information not yet exist, LGU planners should request to be involved in future planning activities relating to these measures in which such information will be determined/become available. This will allow LGUs to better incorporate the intended impacts of these measures into their own planning activities and facilitate improved LGU investment prioritisations to improve the resilience of the provincial road network as an integrated whole. DILG and DPWH have a significant role to play in facilitating and coordinating LGU involvement in these processes.

5 Example flood assessment

5.1 Introduction

The previous chapter noted the importance of taking IWRM issues into account when undertaking provincial roads planning. It outlined the contents of the current IWRM plan for Nueva Ecija and described the implications of the plan for provincial road infrastructure. It focussed attention on the relevant planned flood hazard mitigation actions and national roads improvement actions in the plan. Due to lack of detail regarding the proposed measures in the plan, the assessment remained qualitative in nature, and broadly recommended that provincial roads planners become more involved in the planning procedures for both these specific measures and for the IWRM planning process in general.

In this chapter, we investigate the potential and provide guidance for LGU planners to undertake simplified, rapid, quantitative analyses of the vulnerability of provincial roads to flood hazards, so that LGU planners may be better informed regarding any implications for their own planning. The intention of this work is not to provide definitive advice for the specific measures contained in the plans, but rather to demonstrate the benefits of including simplified, quantitative, impact analyses in processes for resilient roads planning. This is achieved by investigating the potential for simplified flood models at multiple scales, populated with readily available local and/or global data to support LGU strategic roads planning. We apply simplified metrics – the anticipated depth of flow and velocities acting on affected road sections – to ascertain the impacts of example strategic options for hazard mitigation under various current and future peak discharge conditions.

Both the risk assessment (Costa et al, 2019) and the review of the IWRM plans for the Pampanga River Basin reveal the complexity of the river system in Nueva Ecija (Figure 5.1). Several larger rivers are fed by many tributaries and smaller creeks, with these all ultimately contributing to the main Pampanga channel flow. Moreover, the system is punctuated by many smaller irrigation canals and drainage channels, which take and return water to the river/tributary system. When overlaid with the provincial road network, one also sees that many provincial road assets are vulnerable to flooding not from the main river channels, but rather the smaller creeks, tributaries and canals.

Simplifying such a complex system into a single basin-wide flood model for the purposes of roads planning was not possible within the resources and scope of this assignment. Hence, an assessment of two example systems operating at two different scales is presented. A discussion of the challenges encountered in undertaking the assessment at both scales is included to inform and provide guidance to LGU planners regarding how to conduct similar assessments in the future.

The chapter is structured as follows. Section 5.2 introduces the modelling approach applied in this study, before section 5.3 provides a description of the two different systems that have been analysed. Section 5.4 then discusses the specific data requirements for the models and provides guidance regarding where such data can be found. Section 5.5 presents the results of the flood assessment for each of the two systems, before section 5.6 places these results in context and discusses the challenges encountered in modelling the two systems using simplified processes. The section concludes with a summary of recommendations (section 5.7) for future roads planning.

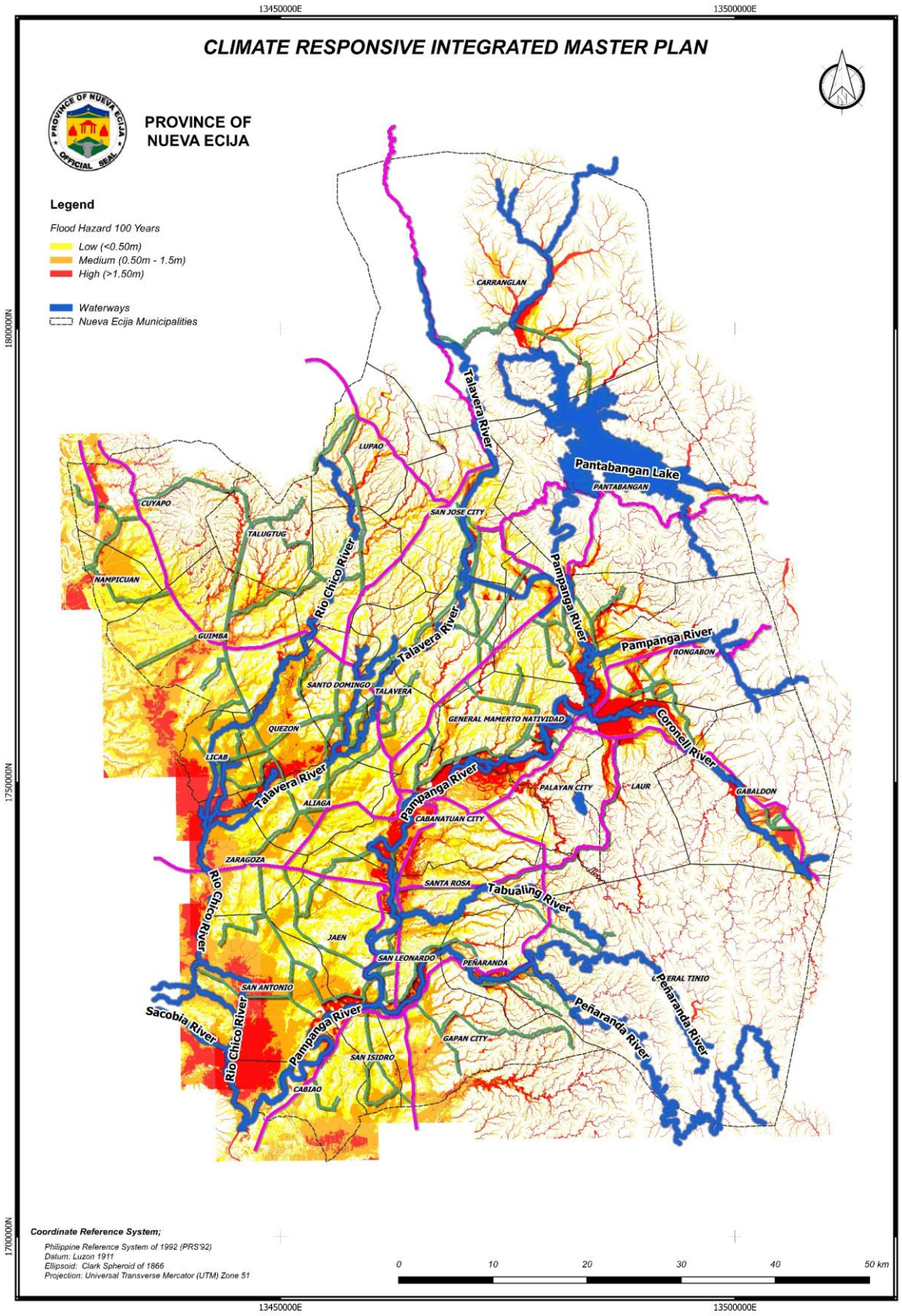

CLIMATE RESPONSIVE INTEGRATED MASTER PLAN
PROVINCE OF NUEVA ECIJA
Legend
Flood Hazard 100 Years
Low (<0.50m)
Medium (0.50m - 1.5m)
High (>1.50m)
Waterways
Nueva Ecija Municipalities
13450000E
13500000E
1800000N
1750000N
1700000N
CARRANGLAN
Talavera River
Pantabangan Lake
PANTABANGAN
LUPAO
SAN JOSE CITY
CUYAPO
TALUGTUG
NAMPICUAN
Rio Chico River
Pampanga River
GUIMBA
Talavera River
Pampanga River
BONGABON
SANTO DOMINGO
TALAVERA
GENERAL MAMERTO NATIVIDAD
Coronel River
QUEZON
LICAB
Talavera River
PALAYAN CITY
LAUR
GABALDON
ALIAGA
Pampanga River
CABANATUAN CITY
ZARAGOZA
SANTA ROSA
Tabualing River
Rio Chico River
JAEN
SAN LEONARDO
PEÑARANDA
GENERAL TINIO
Peñaranda River
SAN ANTONIO
Sacobia River
Rio Chico River
Pampanga River
Peñaranda River
GAPAN CITY
SAN ISIDRO
CABIAO
Coordinate Reference System;
Philippine Reference System of 1992 (PRS'92)
Datum: Luzon 1911
Ellipsoid: Clark Spheroid of 1866
Projection: Universal Transverse Mercator (UTM) Zone 51
0
10
20
30
40
50 km

Figure 5.1: Nueva Ecija 1:100-year Flood Hazard Map, provincial roads overlaid and indicated in pink

5.2 Modelling approach

A simplified flood modelling was performed for two example systems operating at two different scales to reflect flood hazards operating at these scales and to ascertain the appropriateness or otherwise of modelling the system in this way to determine potential impacts to provincial road assets. The two types of systems assessed were:

- Small creek/tributary system: Tabualing River
- Major river system: Pampanga River (from Pantabangan Dam to the junction with the Penaranda River)

One-dimensional steady state analyses of peak flows for various return periods were undertaken for each of the systems, with flood depths and velocities analysed at those road locations identified from the risk assessment as being most vulnerable to flooding. For the purposes of this demonstration analysis, we analysed the impacts of peak flows with return periods of 5, 10, 50 and 100 years, due to data availability. These results are presented for completeness; however, the first step of any policy analysis should be to determine appropriate performance objectives/design criteria for each provincial road section. For provincial roads, designing these to withstand impacts from 1:10 year events may prove sufficient and should be determined in close consultation with stakeholders.

The river systems were modelled as simplified single channels, removing smaller tributaries from the analyses. Discharge information was derived from that published in the IWRM plan, to minimise requirements for data collection and eliminate the need to build rainfall-runoff models. Vulnerable locations were taken directly from the earlier risk assessment (Costa et al, 2019), specifically the exposure maps (e.g. Figure 5.3).

Each of the two systems was modelled under the following conditions:

- Existing system conditions, with model performance calibrated against the 100-year flood hazard map (Figure 5.2)
- Future conditions, with peak flows estimated for both 2050 and 2100 time horizons, to ascertain potential impacts of climate change for vulnerable road assets
- Example measure assessments under each of the existing and future flow conditions, to ascertain the potential climate resilience of the example measures applied

Both systems were modelled using the Hydrologic Engineering Center's River Analysis System (HEC-RAS) river modelling software package. HEC-RAS was developed at Hydrologic Engineering Center (HEC), which is a division of the Institute of Water Resources (IWR), U.S. Army Corps of Engineers (USACE). It is a software that allows the user to perform one-dimensional steady flow hydraulics; one and two-dimensional unsteady flow river hydraulics calculations; quasi unsteady and full unsteady flow sediment transport-mobile bed modelling; water temperature analysis; and generalized water quality modelling (nutrient fate and transport). It is public domain that is also used for flood modelling internationally, including the Philippines.

As indicated in section 4.5, minimal information was made available regarding any of the proposed measures included in the IWRM planning documents in order to model them. Furthermore, for those few measures for which location information was available, most of these did not impact the two selected river systems to be modelled. For these reasons, three example measures have been applied at each vulnerable road location instead, in order to demonstrate orders of magnitude of flood depth reduction these types of measures could realistically deliver for river systems at the two scales. In a real assessment, however, additional details relating to the proposed IWRM

measures and their indicative dimensioning would need to be sought from the appropriate agencies (e.g. DPWH).

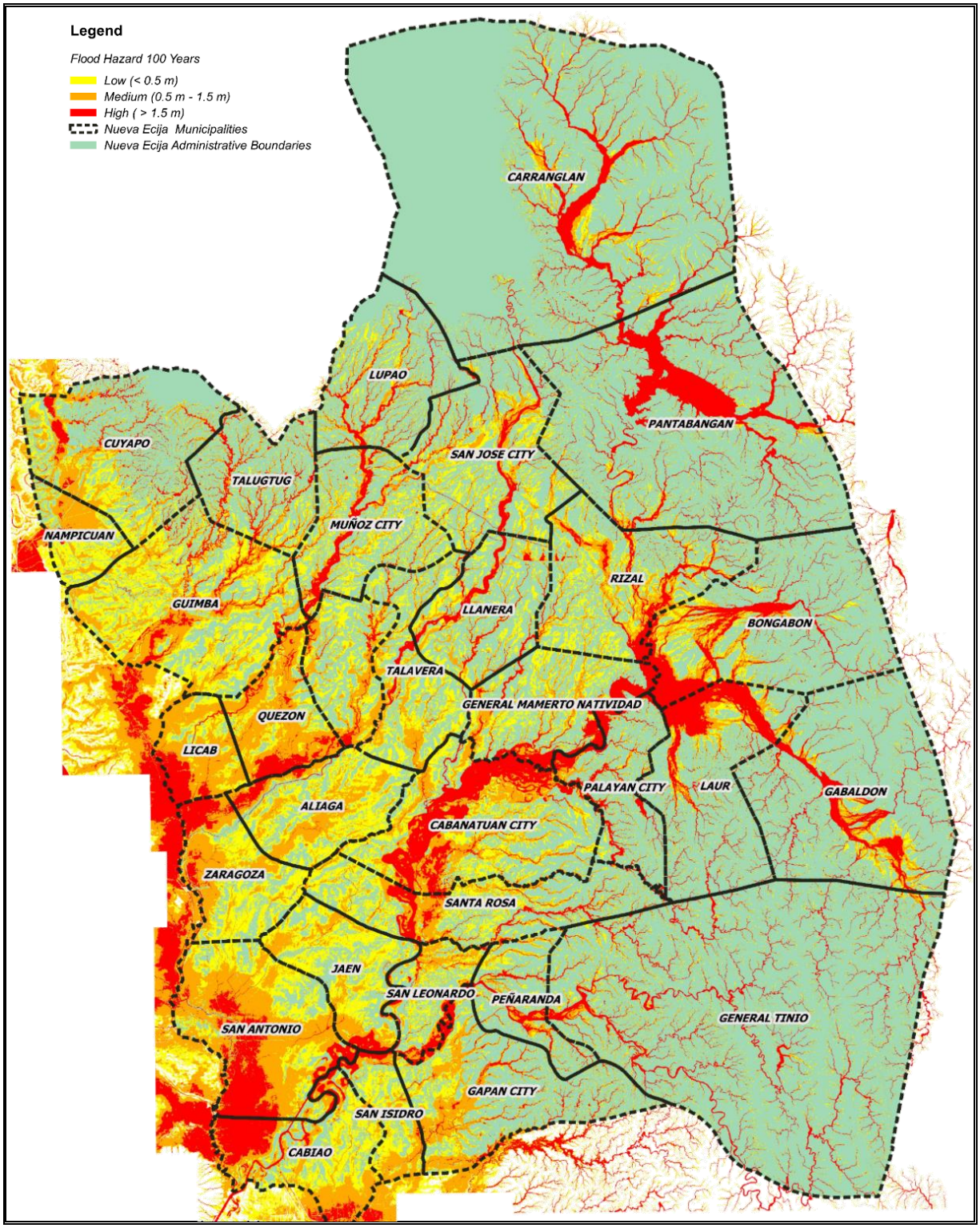


Figure 5.2: Nueva Ecija 1:100-year Flood Hazard Map

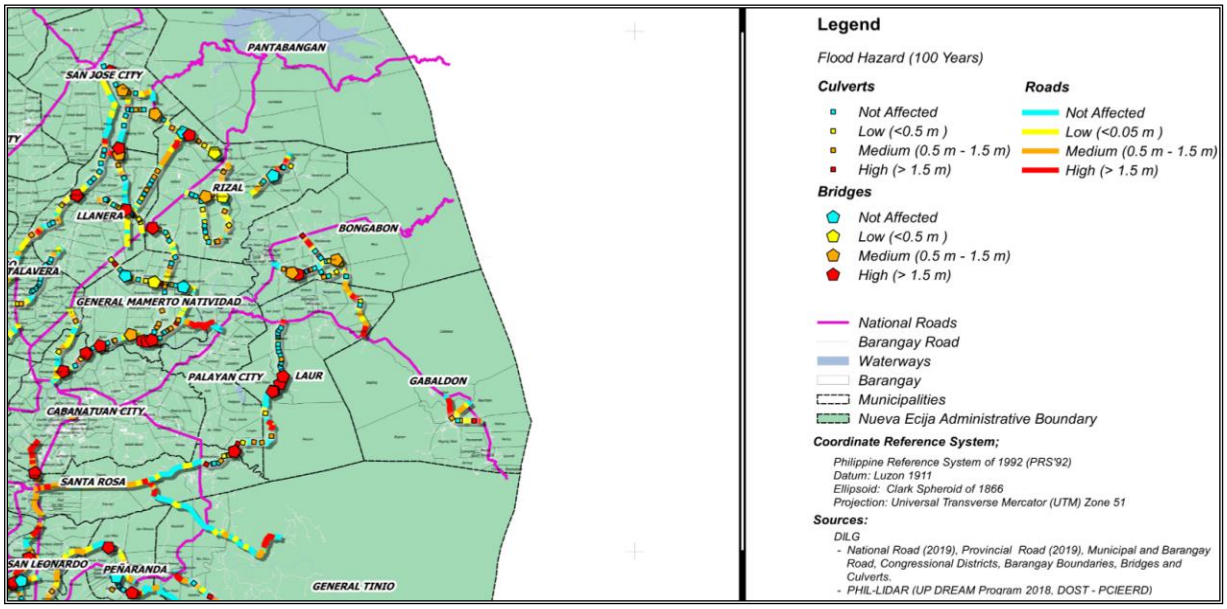


Figure 5.3: Nueva Ecija 1:100-year Flood Exposure Map excerpt covering the analysed systems, illustrating vulnerable locations.

The three example measures modelled include:

- Road elevation
- River channel dredging
- Upstream retention

Each of the measures was implemented in the model via modification to the Digital Terrain Model (DTM) (road elevation, dredging), or modification to the peak flow discharges (retention).

We must emphasise that the example analysis presented in this section is for demonstration purposes only. The three measures included should be considered to be neither exhaustive nor to constitute a recommended strategy. They have been included only to indicate the type of quantitative information modelling exercises such as these could generate. When conducting real assessments, LGU planners will of course be able to model other measures such as those presented in section 3.6, as required. This could also encompass non-structural measures (e.g. identification of alternative routes/re-routing), however measuring the comparative impacts of these types of measures would likely require the application of different modelling tools.

We must also stress that in any comparison of measures, the scales at which those measures are operating must also be taken into consideration. In this example we consider upstream retention as an option. This measure operates on a much greater scale than the other two alternatives. As such, it could lead to potential water level reductions in multiple downstream 'hotspot' locations. Any subsequent evaluation of this (likely expensive) measure against (likely cheaper) more localised solutions would therefore also need to take into consideration its integrated impacts for the rest of the downstream river system.

5.3 System descriptions

5.3.1 Tabualing River System (small creek/tributary)

The Tabualing River System (Figure 5.4, blue line) serves as the small river/tributary system for the purposes of this demonstrative modelling study. It is itself fed by a number of smaller tributaries prior to joining the main Pampanga River channel near Santa Rosa. Figure 5.4 demonstrates that

provincial roads are specifically vulnerable to flooding from this river at two key locations (indicated by the dark blue circles); one location parallel to the flow of the river, and a perpendicular crossing of the river. Further upstream a national road (green line) also crosses the river, but this has not been included in our assessment. The flood exposure map (excerpt, Figure 5.5) verifies these observations, however also suggests the Santa Rosa-Liwayway-Mapalad road may be vulnerable to flood impacts not originating from the Tabualing river (e.g. exposure in the central sections of the road). The satellite image (Figure 5.6) indicates that the road runs through an agricultural area, which may provide an explanation for these additional impacts (e.g. presence of irrigation canals, etc.). From Figure 4.6 we can also see that the location circled left in Figure 5.4 coincides with the planned river crossing for the proposed North Luzon East Expressway.

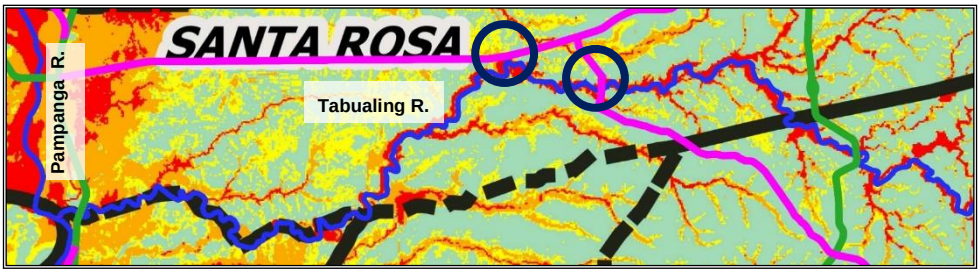


Figure 5.4: Tabualing River System, downstream flow from right to left.
Blue lines: rivers, Pink lines: provincial roads, Green lines: national roads

Figure 5.5: Santa Rosa – Liwayway – Mapalad Road flood exposure map (1:100 year).
Refer to risk assessment report for map legend (Costa et al, 2019).

Figure 5.6: Satellite image of Santa Rosa – Liwayway – Mapalad Road and Tabualing River (Google Earth)

5.3.2 Pampanga River System

The Pampanga River system in Nueva Ecija (Figure 5.7) serves as the major river/tributary system for the purposes of this demonstrative modelling study. The flood hazard map underlay in Figure 5.7 demonstrates the Pampanga River has the potential to cause serious flooding impacts in many locations in Nueva Ecija. For the purposes of this assessment, we have focussed on four key locations/areas below the junction with the Coronell River where these impacts appear to coincide with the provincial road network (indicated by the dark blue circles). The flood exposure map (Figure 5.8) again verifies these observations, however, both maps also suggest that some flood impacts may again not originate from the river, but from the smaller tributaries excluded from the analysis. From Figure 4.6 we can also see that the vulnerable provincial road sections located near Santa Rosa and Cabanatuan will interact with the proposed Cagayan Valley Road improvement works.

Given the size and complexity of the Pampanga River System, a number of simplifications have been made for the purposes of this assessment. We have borrowed from the river system schematic presented in the 2011 IWRM plan (NWRB, 2011), in order to focus on the primary channel flows and exclude all other tributaries. The control points we focus on are illustrated in Figure 5.9. This includes upstream sections of the Pampanga River from Pantabangan Dam to its junction with the Peñaranda (P4-P9) and the Coronell River tributary (P18). Pantabangan Dam has been modelled simply and under worst-case flood-full level, to eliminate the need to include operation rules in the analysis.

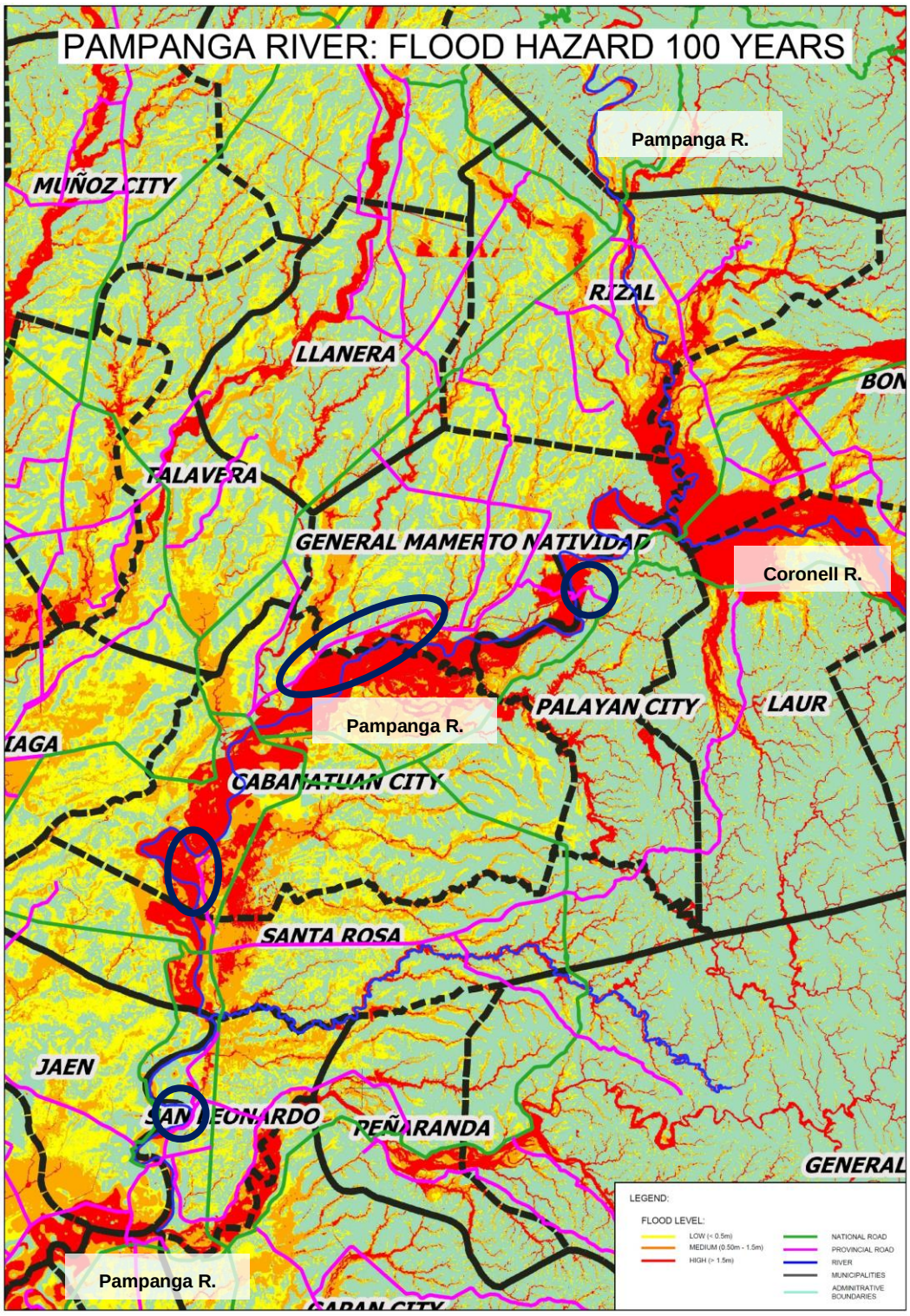


Figure 5.7: Pampanga River System, downstream flow from top-right to bottom-left. Blue lines: rivers, Pink lines: provincial roads, Green lines: national roads

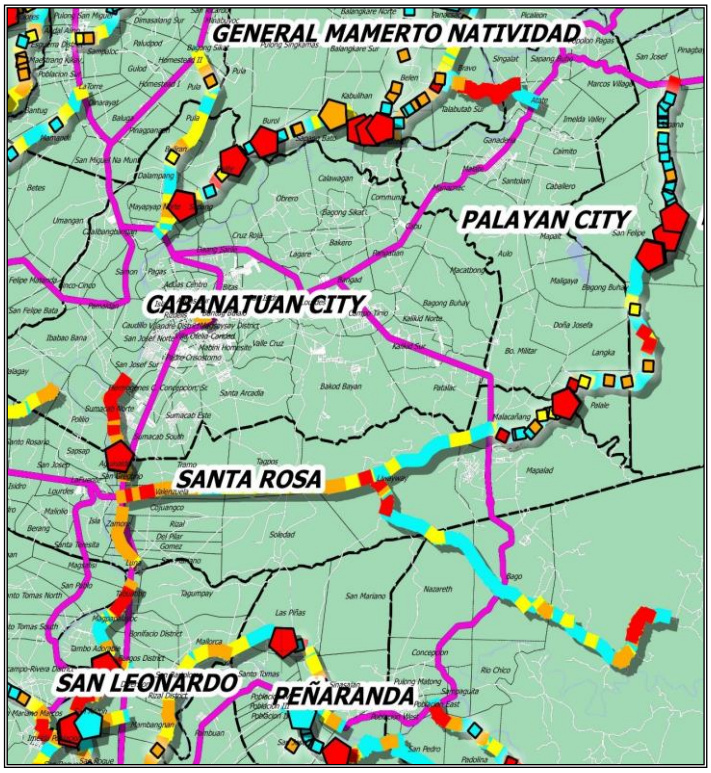


Figure 5.8: Flood exposure map (1:100 year) for the targeted areas (for complete map see risk assessment, Costa et al, 2019)

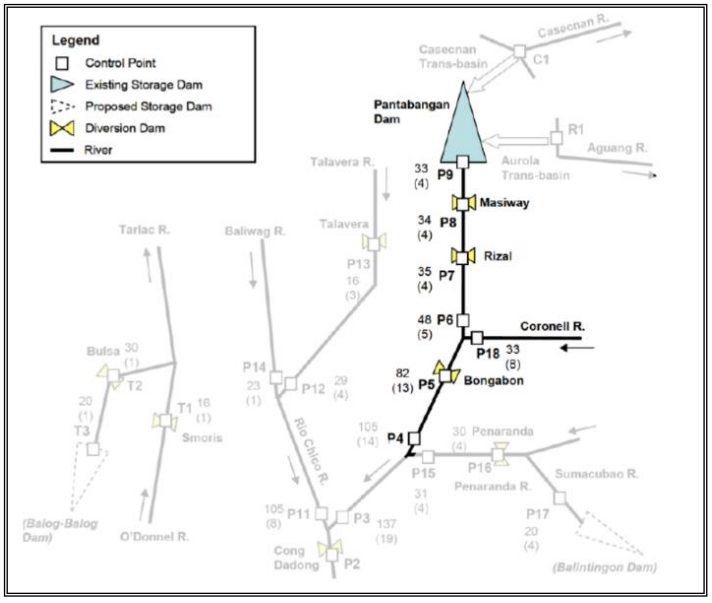


Figure 5.9: Pampanga River System control points included in this analysis (adapted from NWRB, 2011)

5.4 Flood modelling data

5.4.1 Data needs

To be able to carry out the assessment the following input data are needed, with the potential sources of this data indicated (Table 5.1):

Table 5.1: Input data needs, with potential data sources

Data needed	Potential sources
Digital Terrain Model (for model channel and floodplain cross sections)	- NAMRIA (local) - STRM (global) - Google Earth (global)
Steady-state peak discharges (for various return periods)	- IWRM plan (NWRB, 2011), specific discharge tables - PAGASA (local), for rainfall data and climate projections
Assumed floodplain/channel roughness (Manning's n)	- Literature (e.g. Chow, 1959)
Structure locations and dimensions (e.g. roads, irrigation, bridges, etc.)	- NIA (local) - RBIS (local)
Proposed measure dimensions	- IWRM plan (NWRB, 2011; NEDA, 2018) - Relevant agencies

Note that in simplifying the modelling requirements, we have also tried to minimise the need to perform extensive data collection and pre-processing but have rather relied upon information that should be readily available within the Philippines.

5.4.2 Data repositories in the Philippines

Potential data sources within the Philippines include the following agencies:

National Mapping and Resource Information Authority

National Mapping and Resource Information Authority (NAMRIA) is mandated to provide the public with map making services and to act as the central mapping agency, depository, and distribution facility for natural resources data in the form of maps, charts, texts, and statistics. (source: www.namria.gov.ph)

Philippine Atmospheric, Geophysical, and Astronomical Services Administration

Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAG-ASA) is an agency under Department of Science and Technology that among other things maintains a nationwide network pertaining to observation and forecasting of current and future climate, weather and flood and other conditions affecting national safety, welfare and economy. (source: bagong.pagasa.dost.gov.ph)

National Irrigation Administration

National Irrigation Administration (NIA) is a government-owned and controlled corporation primarily responsible for irrigation development and management. (source: www.nia.gov.ph)

Roads and Bridges Information System

Roads and Bridges Information System (RBIS) is a system developed by Department of Interior and Local Government (DILG) which showcases information of infrastructures in provincial level. It is regularly updated by the Provincial Engineering Office (PEO).

5.4.3 Data collection

5.4.3.1 Digital Terrain Model

As indicated in Table 5.1, digital elevation information has a number of potential sources including NAMRIA, as well as global datasets from the Shuttle Radar Topography Mission (SRTM) and Google Earth. NAMRIA is the official mapping agency of the Philippines, hence it was the preferred source for DTM data for this study. Access to this data either requires purchase or a formal Memorandum of Understanding (MOU) between the agency and the requesting party (here DILG). Unfortunately, an MOU between DILG and NAMRIA was not able to be concluded in time for this data to be applied in this study.[1] Hence, global data sources were used in its place.

SRTM data (1 Arc-Second Global: USGS, 2018) was initially explored. Although it was observed to reproduce hilly areas quite well, its performance in the Pampanga river floodplain was less satisfactory. It simply did not reproduce any river channel locations to sufficient detail to be applied in the study.

Elevation data from Google Earth (Google, 2018) was then examined. Although this also did not appear to be of sufficiently high resolution in floodplain areas, it nevertheless included greater detail than the SRTM data set. Consequently, it was selected for application in the study. The generated DTMs for the two systems being analysed are presented below in Figure 5.10 and Figure 5.11.

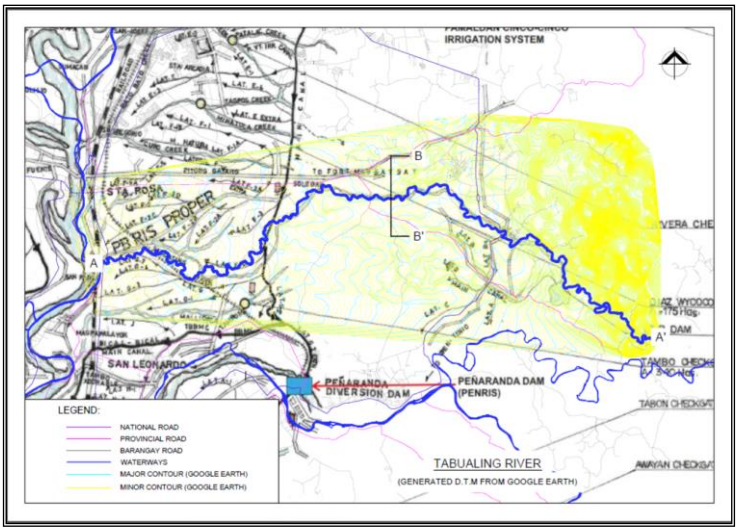


Figure 5.10: Generated Digital Terrain Model from Google Earth for Tabualing River System

[1] *The data was eventually made available in June, 2019. When compared to the dataset applied (Google Earth), the NAMRIA data was seen to underperform in floodplain areas, similar to the STRM data. Refer sections 5.5.1.2 and 5.5.2.1.*

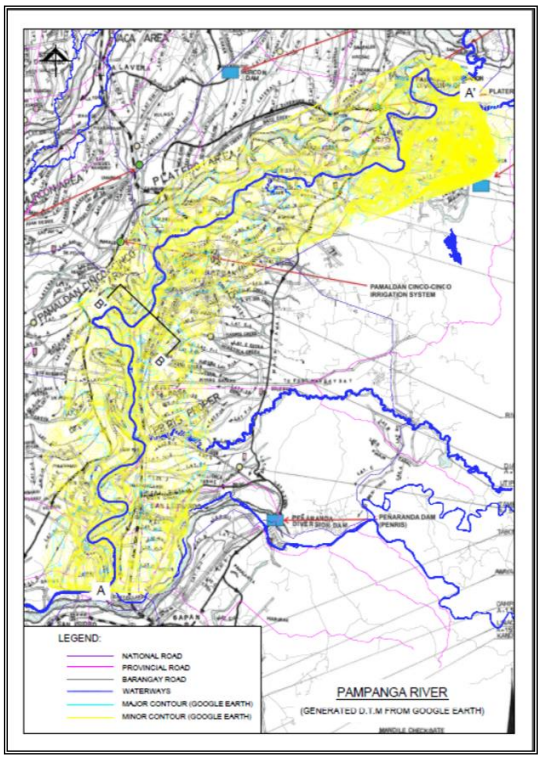


Figure 5.11: Generated Digital Terrain Model from Google Earth for Pampanga River System

Further analysis of this data during the modelling exercise revealed that in some locations extremely wide topographical cross sections were required to perform the HEC-RAS modelling for the Pampanga River System. The Pampanga floodplain is so flat and broad that in some places river cross sections >8km were needed before elevations were reached that could contain floodwaters (typical cross sections were 2-3km). To keep computational times reasonable, it was assumed that for sections wider than 2km, gradients were extended at the edge of the cross section to their intersection with the 100-year peak climate change flood level in 2100. The gradient extended was whichever was greater for each relevant section: the existing gradient or 1:1000.

5.4.3.2 Discharge data

Current Flow Conditions

Discharge data is obtained directly from the 2011 PRB IWRM plan documentation (NWRB, 2011). Here we applied the specific discharge curves included in that study to determine the design peak discharges presented in Table 5.2. Relevant sub-catchment areas were derived from the technical tables presented in the IWRM plan (Annex-T A.7.5.3, NWRB, 2011). Figure 5.12, Figure 5.13, Figure 5.14, Figure 5.15 reproduce the specific discharge curves from the IWRM planning study (Annex-F A.4.3.5, NWRB, 2011). By inspection, we used the Mindanao curve to derive river discharges for return periods of 1:5 year and 1:10 year, while for higher return periods (1:50 year and 1:100 year) we applied the Visayas curve. In most instances, it is observed that these curves will slightly overestimate stream flows in the basin, with errors largest for the lower return periods.

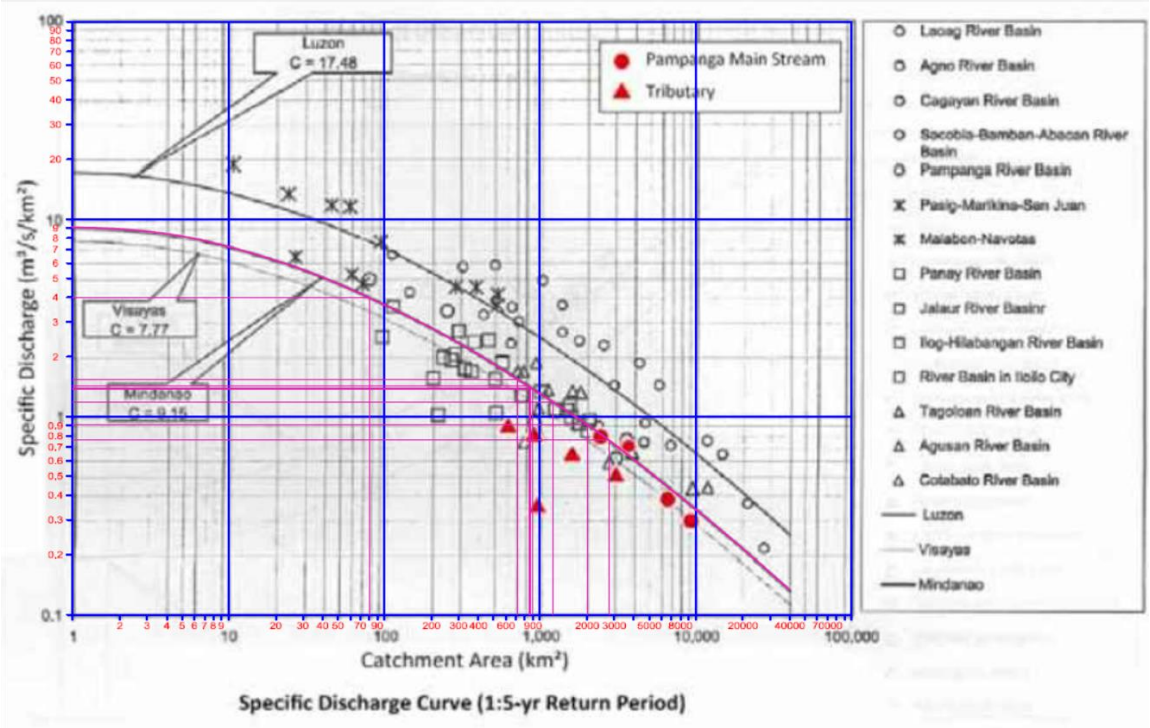


Figure 5.12: Specific Discharge Curve (1:5-year return period)

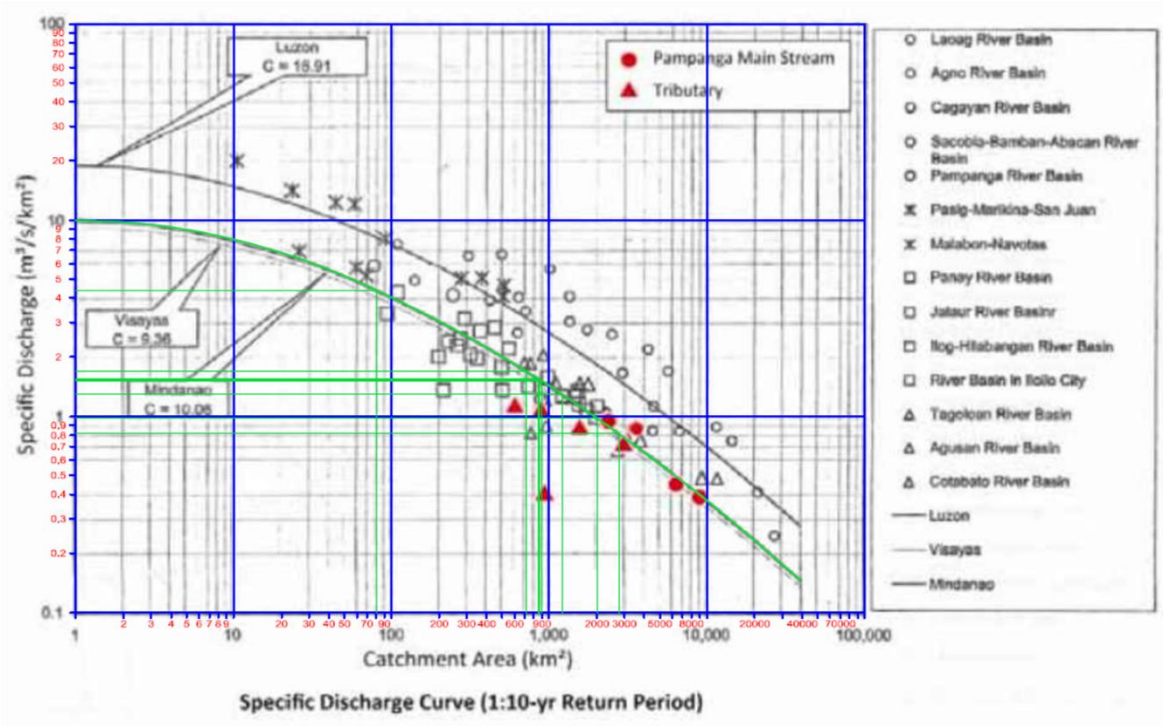


Figure 5.13: Specific Discharge Curve (1:10-year return period)

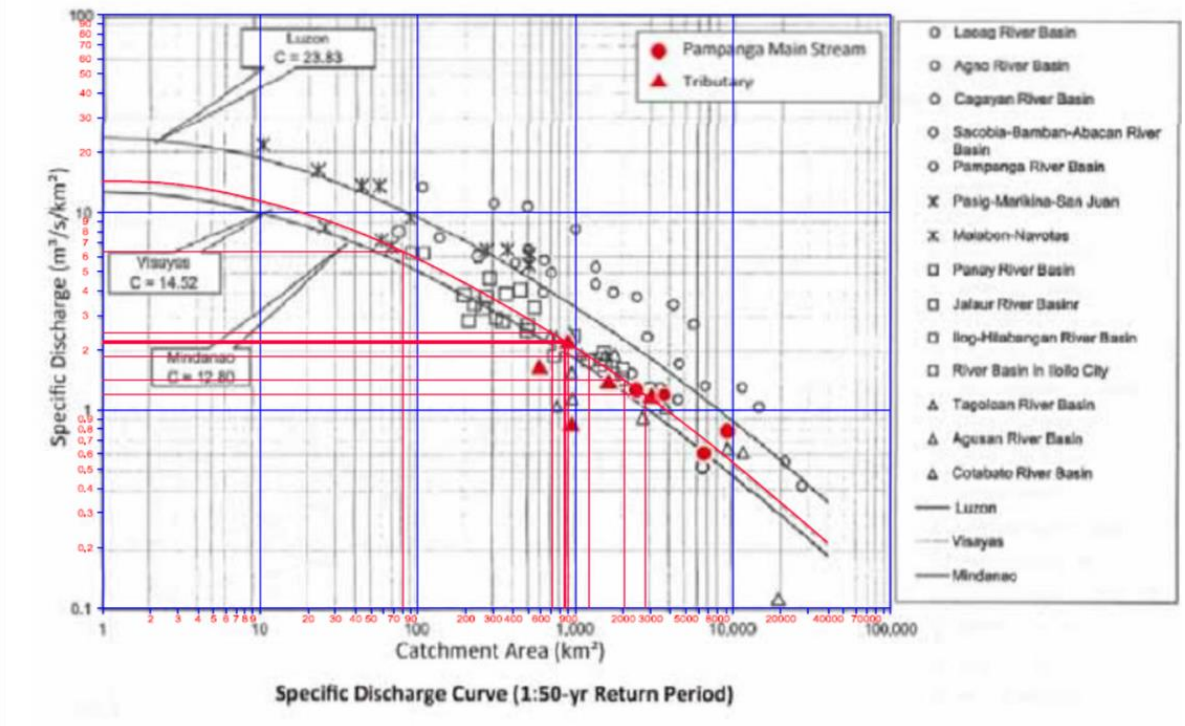


Figure 5.14: Specific Discharge Curve (1:50-year return period)

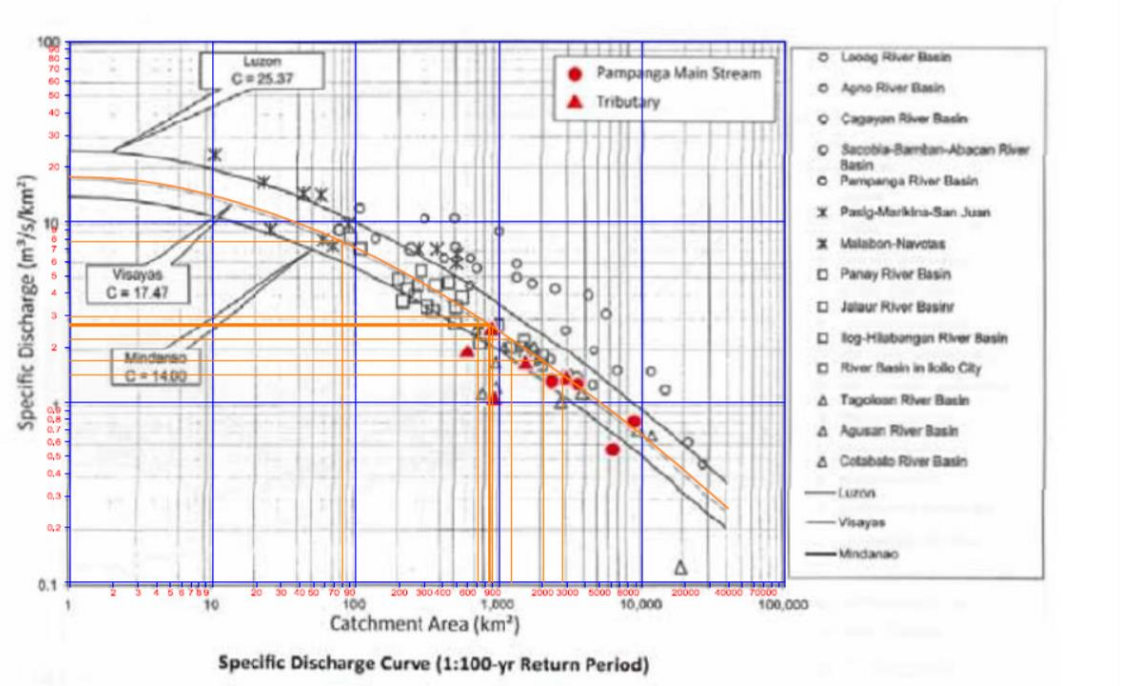


Figure 5.15: Specific Discharge Curve (1:100-year return period)

Table 5.2: Discharge data applied in the modelling study

River System	Control Point	Drainage Area (km^2)	Specific Discharge ($m^3/s/km^2$)				Current Discharge (m^3/s)			
			5-yr	10-yr	50-yr	100-yr	5-yr	10-yr	50-yr	100-yr
Pampanga	P2	870	1.4	1.54	2.22	2.67	1218	1339	1932	2325
	P3	901	1.37	1.51	2.18	2.62	1239	1362	1966	2365
	P4	1286	1.14	1.25	1.81	2.18	1467	1613	2328	2801
	P6	2026	0.89	0.98	1.41	1.7	1802	1981	2860	3441
	P8	2797	0.74	0.81	1.18	1.41	2071	2277	3287	3955
Coronell	P5	712	1.55	1.7	2.46	2.96	1103	1213	1750	2106
Tabualing	P7	81	3.97	4.36	6.3	7.57	321	353	510	614

Future Flow Conditions Subject to Climate Change

As discussed in section 3.5.1, climate change is expected to modify future rainfall in terms of its duration, frequency and intensity that could lead to increases in peak discharges. Published PAGASA data indicates that extreme daily rainfall in the PRB is anticipated to increase, with the number of extreme wet weather days (rainfall >200mm) projected to increase from an observed baseline of 9 days/year in the year 2000 to 13 days/year in 2020 and 17 days/year in 2050 under a medium-range emission scenario (NEDA, 2018: p.2-12). Further detailed information from PAGASA on future scenario projections for extreme rainfall in PRB was not identified by the project team.

An alternative study (Ushiyama et al, 2016) presents longer-term (to 2100) climate projections for extreme rainfall in the PRB based on a dynamic downscaling and bias correction of Global Circulation Models (GCMs). The project team applied this study for the purposes of the flood modelling exercise, to derive potential worst-case increases in peak flood discharges for the two river systems. Figure 3.4 was applied by inspection to derive potential increases in rainfall intensity in the basin for two time-horizons (2050 and 2100), assuming a linear interpolation from the 2100 figures. Peak discharges in Table 5.3 were then multiplied by these increases to derive the future peak discharges presented in Table 5.4. Naturally, this assumes a direct increase in rainfall intensity will result in a commensurate increase in peak discharge, which will not necessarily be the case as this depends upon the specific characteristics of the basin (soils, vegetation, topography). However, in the absence of a rainfall-runoff model, this assumption is acceptable for the present strategic planning purposes.

Table 5.3: Future (worst-case) changes in rainfall intensity in the Pampanga River Basin (from Ushiyama et al, 2016)

Return Period	Current Intensity (mm)	Future rainfall intensity (mm)		Intensity multiplier (%)	
		2050	2100	2050	2100
1 in 100 year	350	440	530	126%	151%
1 in 50 year	320	400	480	125%	150%
1 in 10 year	230	285	340	124%	148%
1 in 5 year	200	240	280	120%	140%

Table 5.4: Future (worst-case) peak discharges for the studied river sections applied in the modelling study

River System	Control Point	Drainage Area (km^2)	2050 Peak Discharge (m^3/s)				2100 Peak Discharge (m^3/s)			
			5-yr	10-yr	50-yr	100-yr	5-yr	10-yr	50-yr	100-yr
Pampanga	P2	870	1462	1659	2415	2923	1705	1979	2898	3521
	P3	901	1487	1688	2458	2973	1735	2013	2949	3581
	P4	1286	1760	1999	2910	3521	2054	2384	3492	4242
	P6	2026	2162	2455	3575	4326	2523	2928	4290	5211
	P8	2797	2485	2822	4109	4972	2899	3366	4931	5989
Coronell	P5	712	1324	1503	2188	2648	1544	1793	2625	3189
Tabualing	P7	81	385	437	638	772	449	522	765	930

5.4.3.3 Channel roughness

Channel roughness is the measure of the amount of frictional resistance water experiences when passing over land and channel features. Flow velocity is strongly dependent on the resistance to flow. An increase in roughness will cause a decrease in the velocity of water flowing across a surface. An extensively used roughness coefficient is Manning's n-value. It is highly variable and depends on number of factors including: surface roughness, vegetation, channel irregularities, channel alignment, scour and deposition, obstructions, size and shape of the channel, stage and discharge, seasonal changes, temperature, and suspended material and bedload. Widely used values for Manning's n are published in Chow (1959), and we have applied the values listed in Table 5.5 for the purposes of this modelling study.

Table 5.5: Manning's n values for channel roughness applied in this study

Feature	Description	Manning's n (roughness)
River Channel	Clean, straight, full stage, no rifts or deep pools	0.030
Floodplain and overbank areas	Mix of mature field crops and scattered brush, heavy weeds	0.045

5.4.3.4 Irrigation structures

A number of irrigation control structures (i.e. diversion dams) are present along the two river systems (e.g. refer Figure 5.9), which need to be taken into account due to their impacts on water levels along the river systems. NIA was consulted regarding the location and dimensions of these structures, and the project team was supplied with the information on Irrigation Structures (dams and canals) from the NIA-Upper Pampanga River Integrated Irrigation System (NIA-UPRIIS). This file served as reference to estimate the dimension and location for these dams and irrigation canals along the studied river sections (presented in Figure 5.16, Figure 5.17 and Figure 5.18).

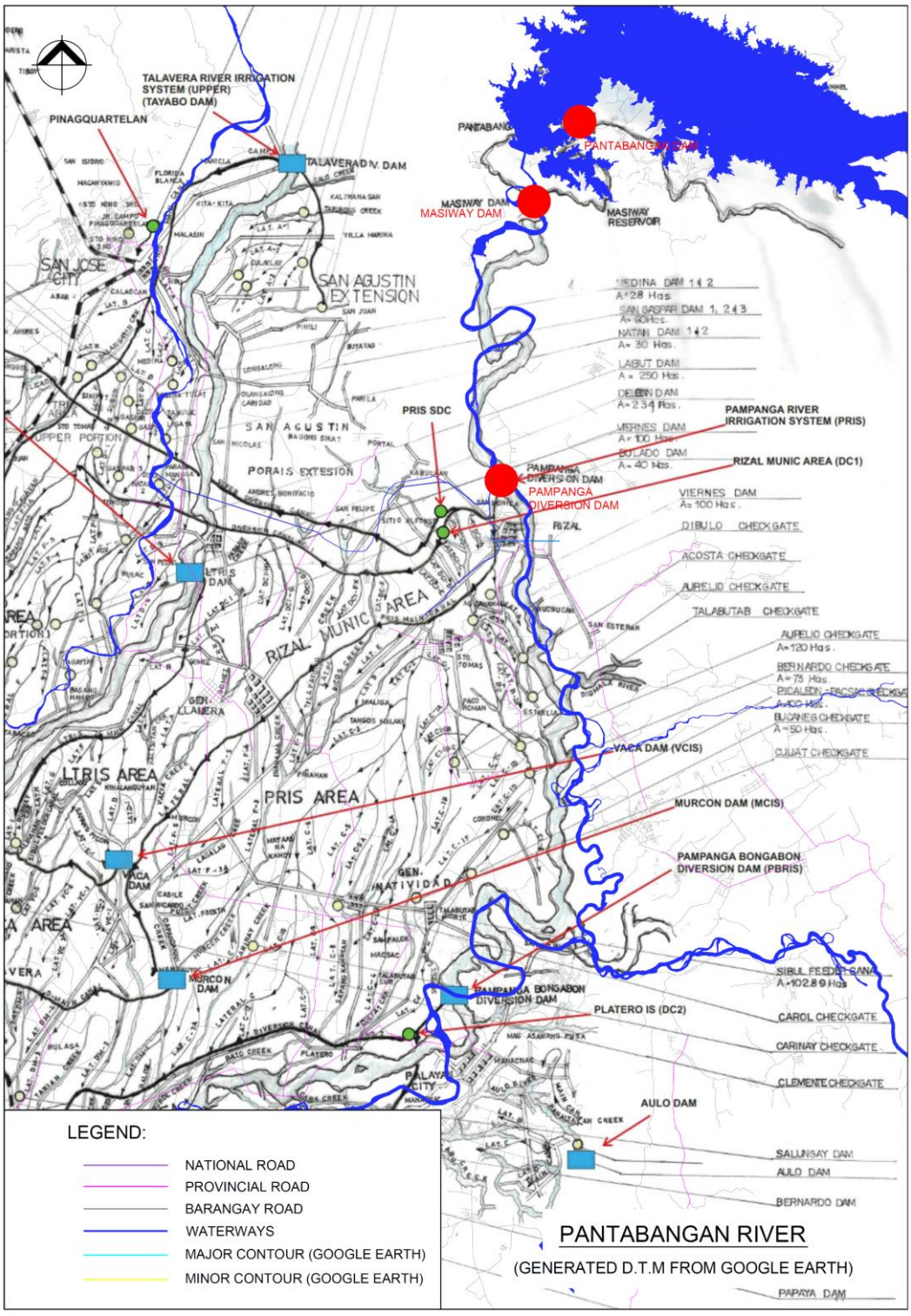


Figure 5.16: Irrigation Structures Layout Map in Nueva Ecija (1/3)

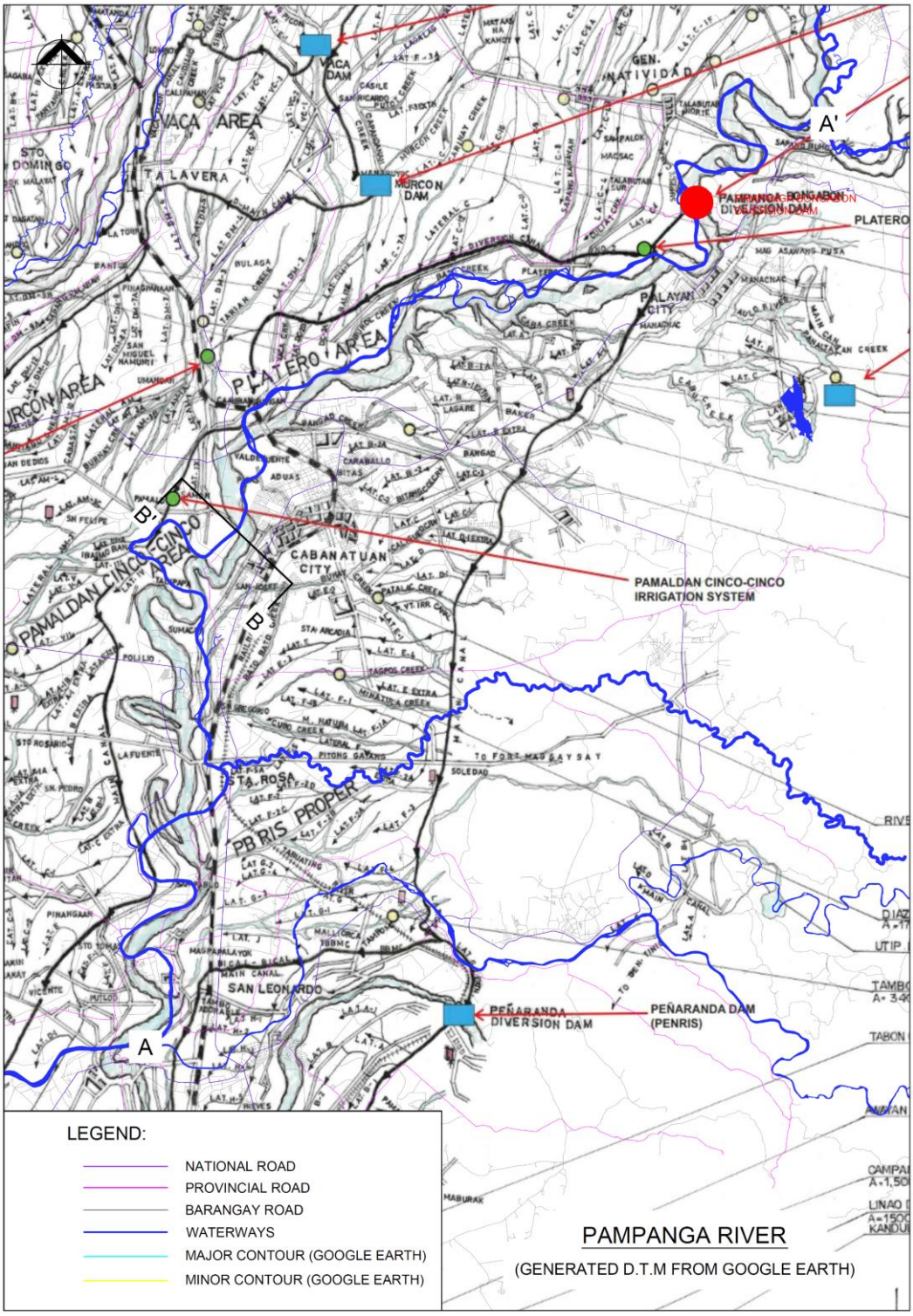


Figure 5.17: Irrigation Structures Layout Map in Nueva Ecija (2/3)

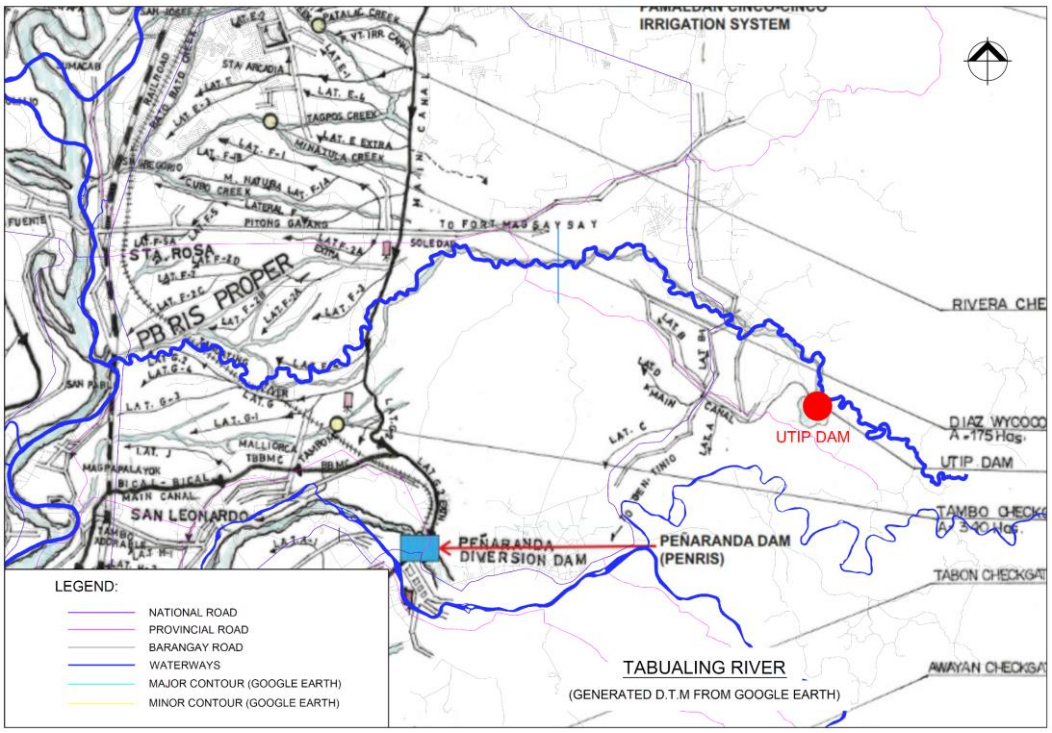


Figure 5.18: Irrigation Structures Layout Map in Nueva Ecija (3/3)

5.4.3.5 Example structural measures

As outlined previously in section 5.2, example flood mitigation measures were selected for each of the river sections to demonstrate orders of magnitude in terms of flood depth and velocity reduction these types of measures could deliver for river systems at the two scales. These are by no means the only measures that could have been assessed using the presented modelling approach but are intended to provide an indication of the type of analysis such modelling can support.

For the **road elevation** measure, it was assumed that roads traversing floodplains would simply be raised 1m, as this reflects present-day practices in Nueva Ecija. For vulnerable river crossings, bridges were to be installed to a level necessary to convey peak flows.

For **dredging**, an assumed dredged channel depth of 0.5m was applied along the length of the critical river section, for a width commensurate with the existing channel width.

For **upstream retention**, the available upstream area was analysed used CAD software to determine potential storage volumes at favourable locations. These were then used to derive assumed average reductions in peak flows based on a 12-hour design storm for each return period.
Table 5.6 presents the modified discharge data for the two systems applied in the study.

Input data for each of the measures identified for Tabualing and Pampanga River systems are summarised in Table 5.7.

Table 5.6: Adjusted peak discharges for upstream retention measures for the two river systems

Return Period	Tabualing River Peak Discharges (m^3/s) (P5)				Pampanga River Peak Discharges (m^3/s) (P6)			
	Detained discharge	Current	2050	2100	Detained discharge	Current	2050	2100
5-year	43	278	342	406	351	1450	1810	2171
10-year	43	310	394	479	351	1629	2103	2576
50-year	43	467	595	722	351	2508	3223	3938
100-year	43	571	729	887	351	3089	3974	4859

Table 5.7: Input data for example structural flood risk reduction measures implemented in the model

Measure	Tabualing River System	Pampanga River System
Road elevation	+1m for roads in floodplains As appropriate for river crossings	+1m for roads in floodplains As appropriate for river crossings
River channel dredging	Depth: 0.5m Width: 40m Length: as appropriate	Depth: 0.5m Width: 100m Length: as appropriate
Upstream retention	1,867,785 m^3 P5 discharges as per Table 5.6	15,194,725 m^3 P6 discharges as per Table 5.6

5.5 Flood Assessment

5.5.1 Tabualing River System

The Tabualing river was modelled considering the two vulnerable road locations (Figure 5.19). Location 1 will impact the road running adjacent to the river while Location 2 will impact the road crossing the river.

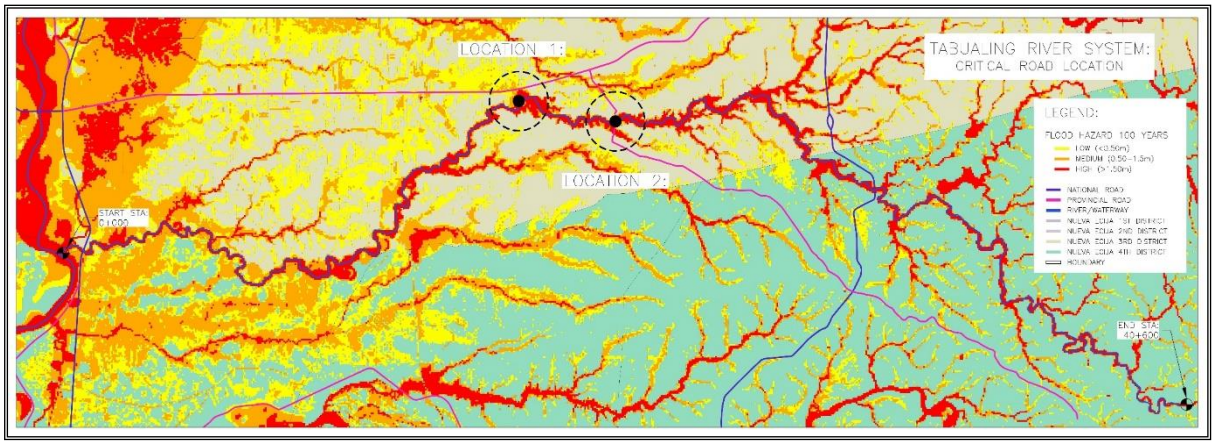


Figure 5.19: Tabualing River Vulnerable Locations

5.5.1.1 Location 1: Parallel flow

Figure 5.20 presents the analysed cross sections analysed for Location 1, indicating their stations. Table 5.8 then presents the summarized results of our analysis for the most vulnerable 16600 location for the existing system and the system with each of the example measures applied. Results for both current climate conditions and with the system subjected to future (worst-case) climate change in 2050 and 2100 are also presented. Complete HEC-RAS output figures for each of these modelling runs are provided in Appendix III.

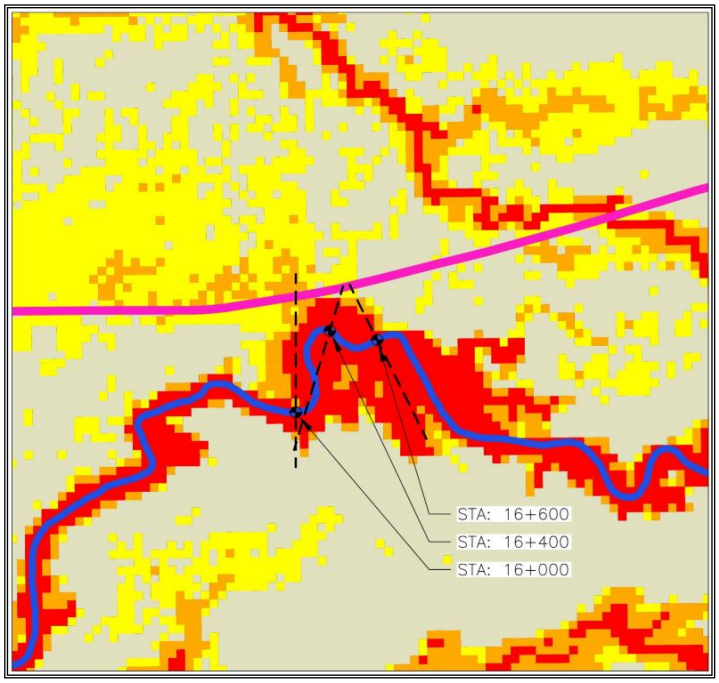


Figure 5.20: Tabualing River Location 1 most vulnerable cross sections

The results indicate that at this location, the road is presently only vulnerable to floods with the highest return periods (1:50 and 1:100 year). Should climate change increase peak discharges, by 2050 the road will only have 0.1m freeboard even under 1:10 year conditions, and by 2100, its present level will only just be able to withstand 1:5 year floods. Velocities remain below critical 1 m/s levels in all instances.

The results also illustrate that elevating the road by simply 1m would suffice for all return periods in all potential futures. Even elevating the road 0.5m would suffice for all but the heaviest floods. Dredging reduces water levels minimally (<15cm), while the upstream retention measure is even less effective (<10cm). This indicates that unless dredging or available retention volumes were able to be increased dramatically beyond those modelled, then these two measures do not present realistic options for this location.

Table 5.8: Tabualing River Location 1 HEC-RAS summarised modelling results for most vulnerable road location

Flow Data	River Station (Vulnerable Road Location)	Flood Profile	Discharge (m^3/s)	Difference in Level* (m) (Road to Water Level)				Critical Velocity (m/s)			
				Existing Condition	Elevate Road	Dredging	Retention	Existing Condition	Elevate Road	Dredging	Retention
No Climate Change	16600	5-YR	321	0.37	1.37	0.53	0.48	0.83	0.83	0.73	0.83
		10-YR	353	0.29	1.29	0.45	0.39	0.84	0.84	0.75	0.83
		50-YR	510	-0.06	0.94	0.07	0.03	0.79	0.84	0.75	0.8
		100-YR	614	-0.24	0.76	-0.12	-0.17	0.78	0.88	0.75	0.79
With Climate Change: 2050	16600	5-YR	385	0.22	1.22	0.37	0.31	0.84	0.84	0.76	0.84
		10-YR	437	0.1	1.1	0.25	0.2	0.82	0.82	0.77	0.83
		50-YR	638	-0.29	0.72	-0.16	-0.21	0.77	0.88	0.75	0.79
		100-YR	772	-0.46	0.54	-0.34	-0.4	0.78	0.96	0.74	0.78
With Climate Change: 2100	16600	5-YR	449	0.07	1.07	0.22	0.17	0.81	0.82	0.77	0.83
		10-YR	522	-0.08	0.92	0.05	0	0.79	0.84	0.75	0.8
		50-YR	765	-0.45	0.55	-0.33	-0.39	0.78	0.95	0.74	0.78
		100-YR	930	-0.67	0.33	-0.56	-0.62	0.8	1.01	0.76	0.79

*Negative water depths indicate the depth to which water is flowing over the road surface.
Positive water depths indicate that the road elevation is greater than the elevation of the water surface.

5.5.1.2 Location 2: Perpendicular river crossing

Figure 5.21 presents the analysed cross sections analysed for Location 2, indicating their stations. A preliminary examination of the topographic data for this crossing suggested that the topographic information may not be sufficiently detailed enough to reproduce the realistic conditions. The applied (Google Earth) data suggested a very shallow river channel (to a depth of ~3m) and a location of the bridge section on or very close to the ground surface (Figure 5.22). Eventual comparison with the NAMRIA data set demonstrated that the latter performed even more poorly, with no indication whatsoever of a river channel being present. Inspection of the satellite imagery for this location (Figure 5.23) and physical site visit (Figure 5.24), revealed a deep river channel, with the bridge located approximately 8m above the water surface.

Consequently, it was decided to remove this location from the analysis as the available topographic information would not support a meaningful assessment of measures. Preliminary examination of these outputs suggested that even under existing conditions, the model indicated flooding of the bridge at far more regular occurrences than would presently occur. It also suggested the elevation of the bridge would need to be raised far beyond current (and practical) levels. We would therefore recommend redoing this analysis with improved topographic information for this location, either obtained through coarse physical surveying of the affected area or improved remote sensing (e.g. LiDAR).

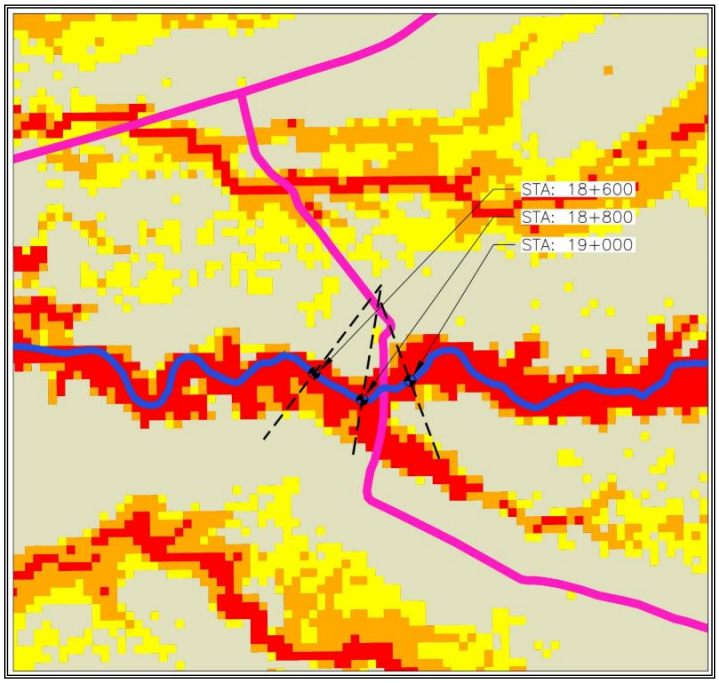


Figure 5.21: Tabualing River Location 2 most vulnerable cross sections

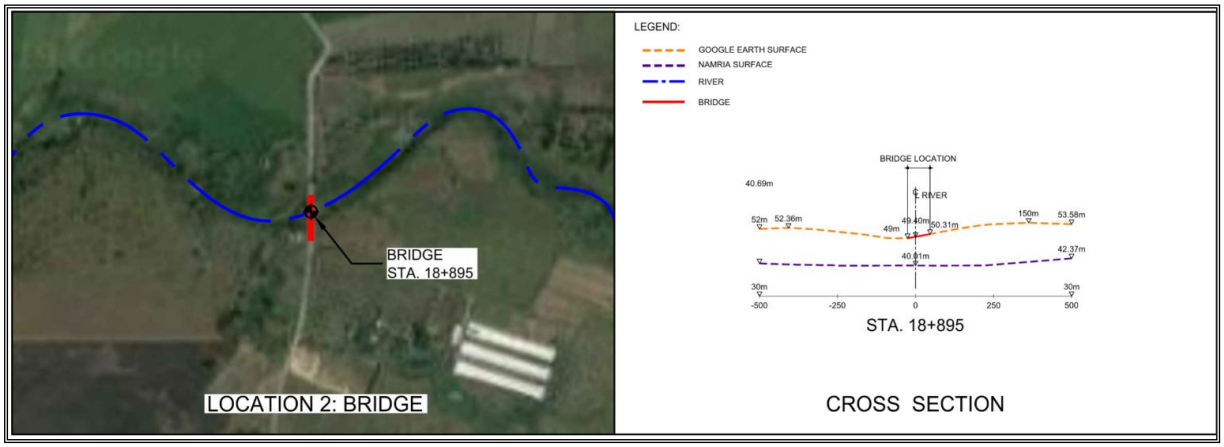


Figure 5.22: Plan and Section at Tabualing River Location 2 (Bridge)

Figure 5.23: Satellite imagery at Tabauling River Location 2 indicating presence of a deep channel

Figure 5.24: Photos of river channel and bridge at Tabauling River Location 2

5.5.1.3 Discussion of Tabualing Results

Location 1

The modelling results indicated that simply elevating the road could offer a realistic option to mitigate future flood risks in this location. Conducting a field visit to this site, however, revealed additional complexity relating to flood hazards at this location. Figure 5.25 presents a photo of this location, with the river located to the right of the photo. The photo illustrates that the road has already been somewhat elevated (~0.5m) during its initial construction, and that to the north (left) flooded agricultural fields (paddy) are present. Floodplain drainage from these fields to the river beneath the road surface is provided via infrequent small culverts (~0.3m diameter) (Figure 5.26). This suggests that during heavy rainfall events, the existing road acts to retain water in the fields, releasing it gradually to the river through the culverts. Local inhabitants confirmed this behaviour and indicated that during heavy rain events water banks up on the upstream (left-hand) side of the road, even sometimes overtopping the road surface. Consequently, although continuing to raise the road surface to mitigate future extreme fluvial flood impacts may be required, this would have to balance needs to provide adequate retention and drainage to the river to prevent pluvial flooding from the paddy fields during these extreme wet weather events. Moreover, the road embankment would need to be well constructed to prevent water-logging, such that the embankment is prevented from collapsing through structural failure. Finally, consideration must also be given to how to protect any roadside properties, as these too will be affected by any current and future flood impacts.

Figure 5.25: Photo of affected road at Tabauling River Location 1

Figure 5.26: Photo of provided drainage at Tabualing River Location 1

Location 2

The limitations of the topographic information presented in section 5.5.1.2 prevented the analysis from being undertaken at this location. However, this also raises questions about the veracity of the results presented for Location 1. Given there is no channel present at Location 2, the model likely underestimates that channel depth along its entire length, which may mean that peak water levels do not reach as high as indicated in our Location 1 results. This is likely to be the case, however given the distance of the river from the affected road section, we do not anticipate that the additional flow area provided by the deeper channel would reduce peak water levels greatly (c.f. dredging results). Although the Location 1 results would no doubt be improved with improved topographic information, we expect that the substance of our conclusions would not change.

Further inspection of Figure 5.21 indicates two additional locations of vulnerability for these road sections, that have not been captured by our simplified model. There appears to be a small creek in the vicinity of the provincial road intersection that also has the potential to significantly flood both roads. Simplifying the entire Tabualing river system down to its minimal components as we have done here has its limitations. It may be preferred to rather focus on all vulnerable locations for a particular road section and then construct a model that encapsulates the relevant hazards. That is, instead of starting at the scale of the river and applying the road network as we have done here, it may be preferred to start with the roads and then add the relevant rivers/creeks to be modelled using simplified, rapid modelling processes like those presented here.

5.5.2 Pampanga River system

There are four vulnerable road locations that were identified in the Pampanga river system (Figure 5.27). Location 1 impacts the road crossing (and its related approaches), while locations 2-4 impact the roads running parallel to the main river channel.

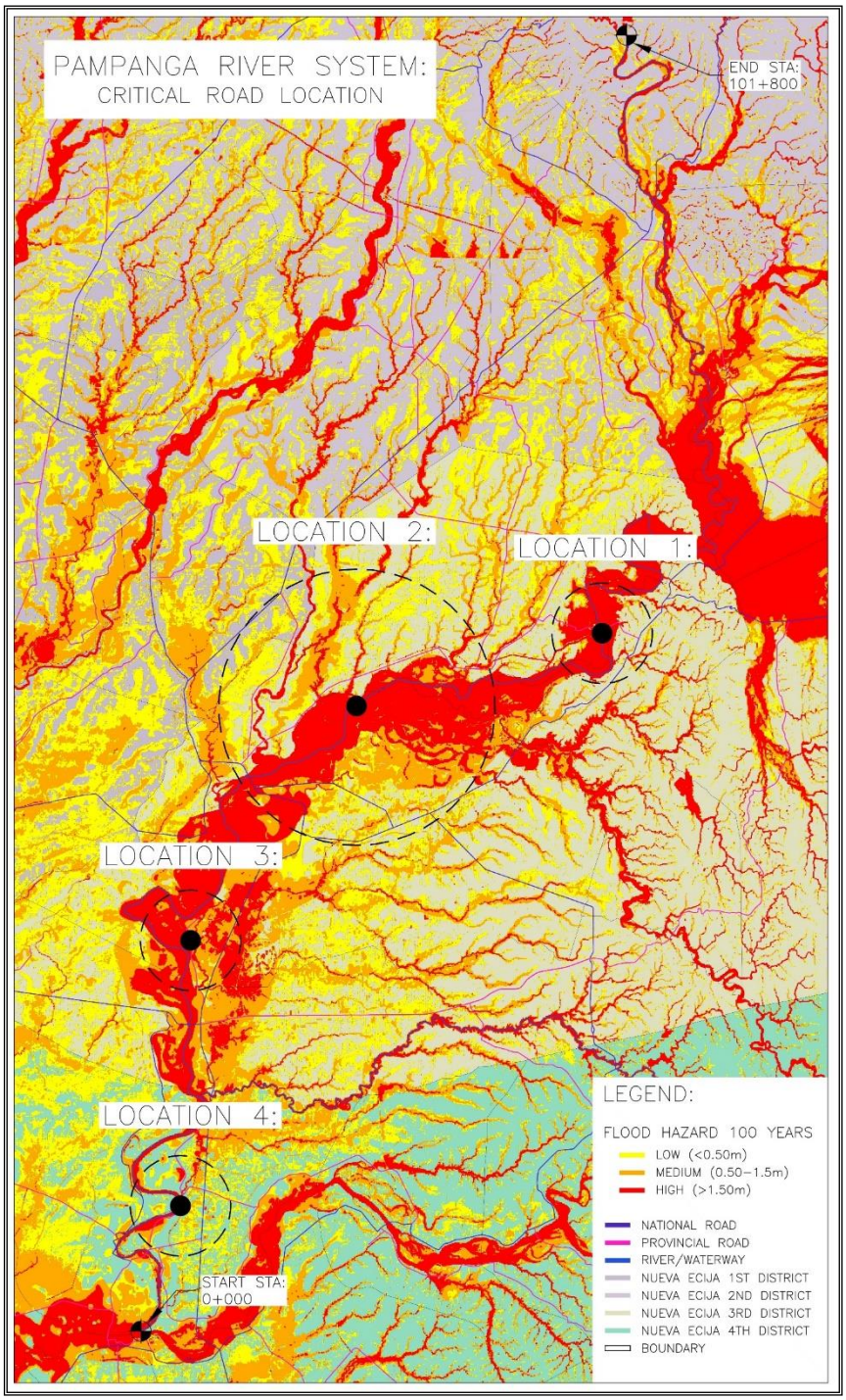


Figure 5.27: Pampanga River Vulnerable Locations Modelled in this study

5.5.2.1 Location 1: Perpendicular river crossing

Figure 5.28 presents the analysed cross section analysed for Location 1, indicating its stations. The river crossing (located slightly downstream of the analysed section) occurs along the Talabutab-Platera Road. A preliminary examination of the topographic data for this crossing suggested that the topographic information may not be sufficiently detailed enough to reproduce the realistic conditions. The applied (Google Earth) data suggested a negligible river channel and

a location of the bridge section on or very close to the ground surface (Figure 5.29). Eventual comparison with the NAMRIA data set demonstrated that the latter performed similarly poorly, with no indication whatsoever of a river channel being present. Inspection of the satellite imagery for this location (Figure 5.30) revealed a complex location, where the river crossing (on a potentially very high, 220m long bridge) occurs downstream of an irrigation flow diversion structure channelling water to agricultural areas via a canal to the west (left) of the diversion dam. Figure 5.28 also indicates potential flooding of the river crossing approaching road sections to a distance of up to 1.5km from the main river channel. Inspection of the 1:25 year and 1:5 year flood hazard maps from the risk assessment suggests that many of these broader impacts are not presently avoided for even the lowest return period events. Mitigating flood impacts to keep the entire road section open during extreme floods would require significantly larger infrastructure than is presently in place, as the entire 2.5km length of road would need to be elevated further on an even taller bridge, which may not be practical or economically feasible. An alternative solution would be to install a submersible road and smaller bridge (designed to flood) to minimise any damages and recovery time after extreme weather events, but with the ability to keep the road passable during regular operation. The latter measure, however, has not been included in our modelling study.

It was consequently decided not to analyse this location any further as the available topographic information would not support meaningful assessment of measures. Moreover, the results to be derived from the modelling activities would not have added anything further to the preceding qualitative assessment at this stage. We would therefore recommend performing an analysis with improved topographic information for this location, either obtained through coarse physical surveying of the affected area or improved remote sensing (e.g. LiDAR).

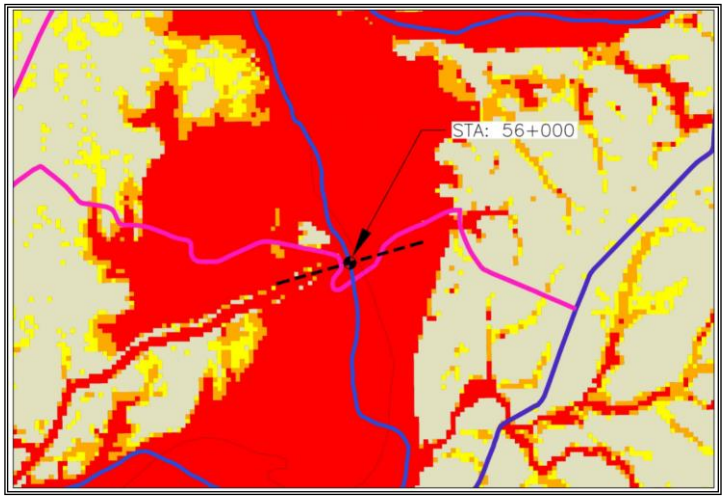


Figure 5.28: Pampanga River Location 1 most vulnerable cross section

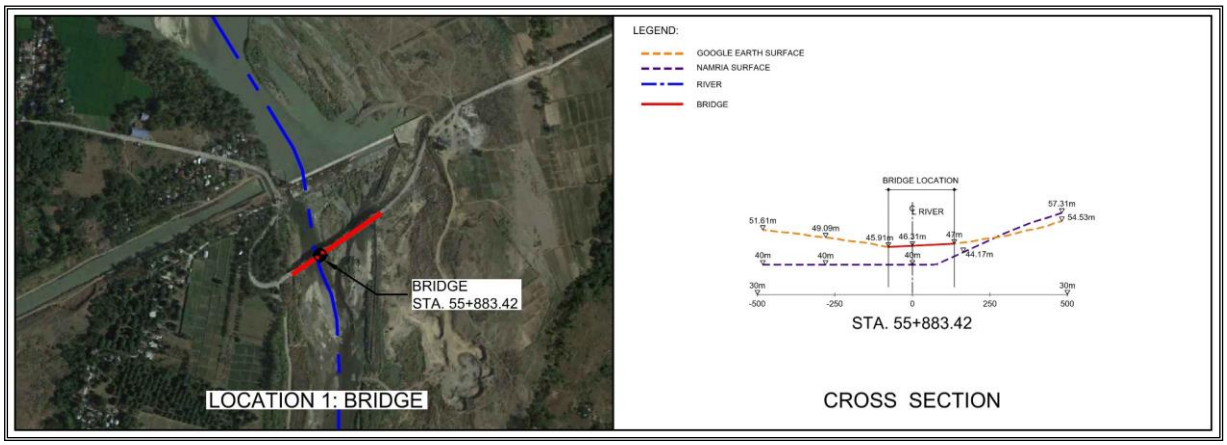


Figure 5.29: Plan and Section at Pampanga River Location 1 (Bridge)

Figure 5.30: Satellite imagery at Pampanga River Location 1 indicating presence of tall bridge (inset)

5.5.2.2 Location 2: Parallel flow

Figure 5.31 presents the analysed cross sections for Location 2, indicating their station. These sections occur along the Mayapayap-Gen. Malvar Natividad Road. Table 5.9 presents the summarized results of our analysis for the most vulnerable locations (46800, 44400, 44200, 41800, 41600) for the existing system and the system with each of the example measures applied. Results for both current climate conditions and with the system subjected to future (worst-case) climate change in 2050 and 2100 are also presented (Table 5.10 and Table 5.11). Complete HEC-RAS output figures for each of these modelling runs are provided in Appendix IV.

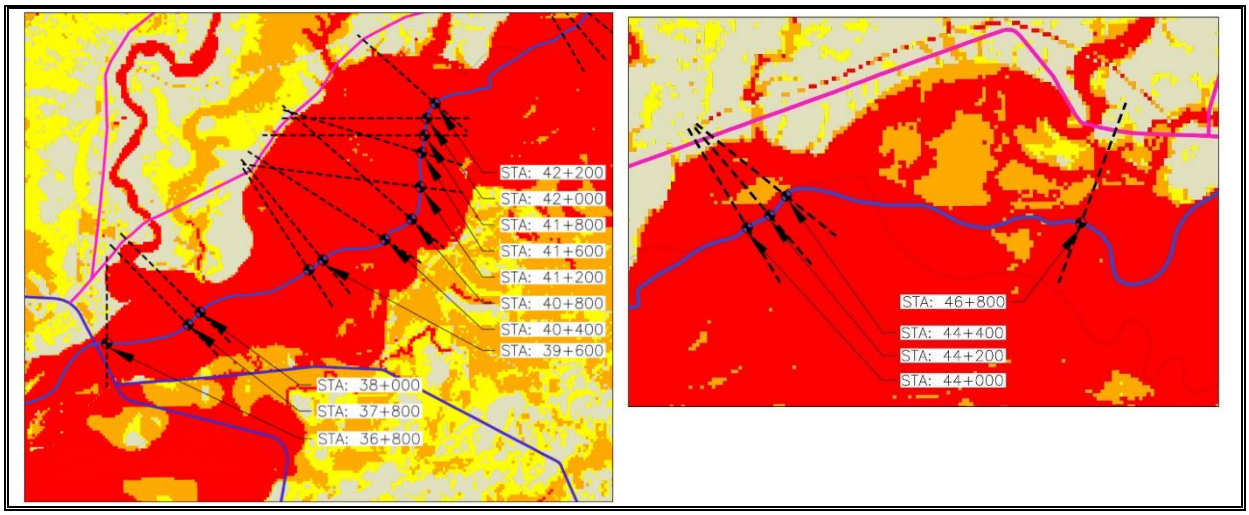


Figure 5.31: Pampanga River Location 2 cross sections.
Most vulnerable sections at stations 41600, 41800, 44200, 44400 and 46800

The results indicate that at this location, the road is presently only vulnerable to flooding at station 46800, and then only for the most extreme 1:100 year event. Under climate change, gradually additional stations become submerged, but again mainly for only the most extreme events. Stations 44200 and 41600 do exhibit high flow velocities in all runs, however, which suggests that bank erosion could become an issue for this road section and that erosion protection may be required.

Furthermore, like the results obtained for Location 1 for the Tabualing River System, the results indicate that elevating the road by 1m would suffice for all return periods in all potential futures, although this would do nothing to address bank erosion. The results again also illustrate the limitations of the dredging and retention measures. Even the considerable (100m wide) dredging we are applying here only reduces water levels minimally (<10cm), while the upstream retention measure is slightly more effective (<15cm). This indicates that unless dredging or available retention volumes were able to be increased dramatically beyond those modelled, then these two measures again do not present realistic options for this location.

Table 5.9: Pampanga River Location 2 HEC-RAS summarised modelling results for most vulnerable road locations – No Climate Change

River Station (Vulnerable Road Location)	**Profile**	**Discharge** (m^3/s)	**Difference in Level*** (m)				**Critical Velocity** (m/s)			
			Existing Condition	Elevate Road	Dredging	Retention	Existing Condition	Elevate Road	Dredging	Retention
46800	5-YR	1802	0.51	1.51	0.58	0.72	0.45	0.45	0.39	0.39
	10-YR	1981	0.45	1.42	0.5	0.6	0.46	0.47	0.42	0.42
	50-YR	2860	0.02	1.02	0.09	0.18	0.59	0.59	0.54	0.55
	100-YR	3441	-0.22	0.79	-0.15	-0.07	0.66	0.67	0.60	0.62
44400	5-YR	1802	0.49	1.49	0.55	0.68	0.68	0.68	0.63	0.69
	10-YR	1981	0.49	1.48	0.45	0.6	0.73	0.74	0.63	0.7
	50-YR	2860	0.2	1.2	0.21	0.29	0.81	0.81	0.74	0.77
	100-YR	3441	0.04	1.04	0.1	0.13	0.86	0.86	0.82	0.82
44200	5-YR	1802	1.3	2.3	1.39	1.47	1.85	1.85	1.43	1.69
	10-YR	1981	1.16	2.11	1.34	1.4	1.63	1.58	1.52	1.75
	50-YR	2860	0.53	1.53	0.71	0.71	1.25	1.25	1.33	1.39
	100-YR	3441	0.29	1.29	0.49	0.37	1.17	1.17	1.26	1.13
41800	5-YR	1802	0.96	1.96	1.07	1.21	0.6	0.6	0.52	0.6
	10-YR	1981	0.9	1.87	0.98	1.05	0.61	0.62	0.56	0.57
	50-YR	2860	0.45	1.45	0.62	0.64	0.68	0.68	0.65	0.67
	100-YR	3441	0.25	1.25	0.35	0.38	0.73	0.73	0.68	0.7
41600	5-YR	1802	1.89	2.89	2.14	2.14	1.38	1.38	1.22	1.41
	10-YR	1981	1.85	2.82	2.07	2.03	1.41	1.42	1.28	1.42
	50-YR	2860	1.41	2.41	1.65	1.59	1.26	1.26	1.38	1.44
	100-YR	3441	1.1	2.1	1.3	1.29	1.21	1.21	1.15	1.25

*Negative water depths indicate the depth to which water is flowing over the road surface.
Positive water depths indicate that the road elevation is greater than the elevation of the water surface.

Table 5.10: Pampanga River Location 2 HEC-RAS summarised modelling results for most vulnerable road locations – Climate Change to 2050

River Station (Vulnerable Road Location)	**Profile**	**Discharge** (m^3/s)	**Difference in Level*** (m)				**Critical Velocity** (m/s)			
			Existing Condition	Elevate Road	Dredging	Retention	Existing Condition	Elevate Road	Dredging	Retention
46800	5-YR	2162	0.33	2.1	0.41	0.5	0.5	0.85	0.45	0.45
	10-YR	2455	0.2	1.95	0.27	0.36	0.54	0.95	0.49	0.49
	50-YR	3575	-0.27	1.47	-0.2	-0.13	0.67	1.14	0.62	0.63
	100-YR	4326	-0.54	1.19	-0.48	-0.41	0.74	1.22	0.68	0.71
44400	5-YR	2162	0.43	1.43	0.46	0.5	0.77	0.77	0.69	0.69
	10-YR	2455	0.3	1.3	0.36	0.45	0.76	0.76	0.72	0.76
	50-YR	3575	0.01	1.01	0.07	0.09	0.87	0.87	0.84	0.83
	100-YR	4326	-0.17	0.83	-0.11	-0.08	0.93	0.95	0.89	0.9
44200	5-YR	2162	0.98	1.98	1.05	1.26	1.47	1.47	1.28	1.77
	10-YR	2455	0.74	1.74	0.97	1.02	1.41	1.41	1.35	1.49
	50-YR	3575	0.25	1.25	0.42	0.34	1.17	1.17	1.22	1.17
	100-YR	4326	0.03	1.03	0.14	0.14	1.13	1.13	1.14	1.15
41800	5-YR	2162	0.79	1.79	0.9	0.95	0.63	0.63	0.57	0.61
	10-YR	2455	0.67	1.67	0.76	0.82	0.67	0.67	0.6	0.63
	50-YR	3575	0.19	1.19	0.3	0.33	0.73	0.73	0.69	0.71
	100-YR	4326	-0.11	0.89	0.0	0.03	0.75	0.75	0.72	0.74
41600	5-YR	2162	1.75	2.75	2	1.89	1.45	1.45	1.33	1.38
	10-YR	2455	1.61	2.61	1.9	1.77	1.45	1.45	1.42	1.44
	50-YR	3575	1.01	2.01	1.21	1.22	1.19	1.19	1.14	1.23
	100-YR	4326	0.62	1.62	0.75	0.79	1.14	1.14	1.07	1.15

*Negative water depths indicate the depth to which water is flowing over the road surface.
Positive water depths indicate that the road elevation is greater than the elevation of the water surface.

Table 5.11: Pampanga River Location 2 HEC-RAS summarised modelling results for most vulnerable road locations – Climate Change to 2100

River Station (Vulnerable Road Location)	**Profile**	**Discharge** (m^3/s)	**Difference in Level*** (m)				**Critical Velocity** (m/s)			
			Existing Condition	Elevate Road	Dredging	Retention	Existing Condition	Elevate Road	Dredging	Retention
46800	5-YR	2523	0.17	1.17	0.24	0.33	0.55	0.55	0.49	0.5
	10-YR	2928	-0.01	1.00	0.07	0.15	0.6	0.6	0.54	0.55
	50-YR	4290	-0.52	0.48	-0.46	-0.4	0.73	0.76	0.68	0.7
	100-YR	5211	-0.83	0.18	-0.77	-0.71	0.8	0.85	0.74	0.77
44400	5-YR	2523	0.28	1.28	0.34	0.43	0.77	0.77	0.72	0.77
	10-YR	2928	0.18	1.18	0.19	0.27	0.82	0.82	0.75	0.78
	50-YR	4290	-0.16	0.84	-0.1	-0.08	0.92	0.94	0.89	0.9
	100-YR	5211	-0.38	0.63	-0.32	-0.3	0.97	1.01	0.94	0.95
44200	5-YR	2523	0.71	1.71	0.96	0.98	1.38	1.38	1.37	1.46
	10-YR	2928	0.49	1.49	0.69	0.68	1.21	1.21	1.32	1.36
	50-YR	4290	0.04	1.04	0.15	0.15	1.13	1.13	1.15	1.15
	100-YR	5211	-0.22	0.78	-0.15	-0.12	1.09	1.12	1.08	1.11
41800	5-YR	2523	0.64	1.64	0.74	0.79	0.67	0.67	0.61	0.64
	10-YR	2928	0.43	1.43	0.59	0.62	0.69	0.69	0.66	0.68
	50-YR	4290	-0.1	0.91	0.01	0.04	0.75	0.75	0.72	0.74
	100-YR	5211	-0.47	0.54	-0.37	-0.32	0.76	0.78	0.74	0.76
41600	5-YR	2523	1.58	2.58	1.87	1.74	1.44	1.44	1.42	1.45
	10-YR	2928	1.37	2.37	1.61	1.55	1.26	1.26	1.37	1.43
	50-YR	4290	0.64	1.64	0.77	0.81	1.14	1.14	1.07	1.16
	100-YR	5211	0.2	1.2	0.3	0.36	1.1	1.1	1.05	1.12

*Negative water depths indicate the depth to which water is flowing over the road surface.
Positive water depths indicate that the road elevation is greater than the elevation of the water surface.

5.5.2.3 Location 3: Parallel flow

Figure 5.32 presents the analysed cross sections for Location 3, indicating their station. These sections occur along the Bonifacio-Sumacab Road. Table 5.12 presents the summarized results of our analysis for the most vulnerable locations (29400, 22200, 20600) for the existing system and the system with each of the example measures applied. Results for both current climate conditions and with the system subjected to future (worst-case) climate change in 2050 and 2100 are also presented (Table 5.13 and Table 5.14). Complete HEC-RAS output figures for each of these modelling runs are provided in Appendix IV.

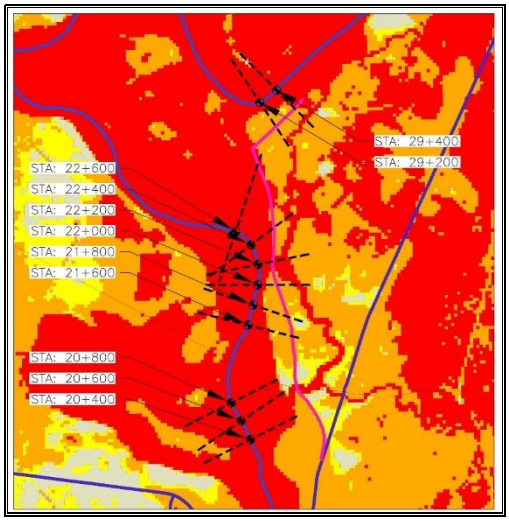


Figure 5.32: Pampanga River Location 3 cross sections. Most vulnerable sections at stations 29400, 22200 and 20600

The results indicate that this road section presents considerable challenges to planners. It is presently highly vulnerable to extreme floods, and in places is submerged every five years by up to 2.5m of water, rising to nearly 4m for the most extreme events. Climate change will only exacerbate these effects further. The dredging measure again does little to reduce these impacts, while the retention measure reduces flow depths by 30-40cm; still insufficient to mitigate the majority of impacts.

Elevating the road again offers a potential solution, however, the road would need to be elevated significantly higher than the 1m modelled in this study. To protect even against 1:10 year events, the road would need to be elevated approximately 2-3m when the impacts of future climate change are taken into consideration. Alternatively, a submersible road could be installed which is designed to flood during these peak events, but which minimises any damages and recovery times in their aftermath. Or the road could be relocated to a less vulnerable alignment. These latter measures, however, have not been included in our modelling study.

Table 5.12: Pampanga River Location 3 HEC-RAS summarised modelling results for most vulnerable road locations – No Climate Change

River Station (Vulnerable Road Location)	**Profile**	**Discharge** (m^3/s)	**Difference in Level*** (m)				**Critical Velocity** (m/s)			
			Existing Condition	Elevate Road	Dredging	Retention	Existing Condition	Elevate Road	Dredging	Retention
29400	5-YR	1802	-0.67	0.33	-0.66	-0.36	0.24	0.35	0.21	0.25
	10-YR	1981	-0.77	0.18	-0.81	-0.52	0.24	0.37	0.2	0.25
	50-YR	2860	-1.49	-0.48	-1.48	-1.23	0.21	0.47	0.19	0.19
	100-YR	3441	-1.89	-0.88	-1.88	-1.65	0.23	0.53	0.22	0.22
22200	5-YR	1802	-2.54	-1.53	-2.51	-2.16	0.27	0.56	0.22	0.37
	10-YR	1981	-2.64	-1.69	-2.66	-2.35	0.25	0.58	0.21	0.38
	50-YR	2860	-3.42	-2.4	-3.38	-3.15	0.24	0.66	0.21	0.24
	100-YR	3441	-3.83	-2.82	-3.8	-3.59	0.24	0.68	0.22	0.24
20600	5-YR	1802	-1.04	-0.04	-1.03	-0.68	0.28	0.29	0.25	0.25
	10-YR	1981	-1.13	-0.18	-1.18	-0.86	0.29	0.31	0.27	0.26
	50-YR	2860	-1.87	-0.88	-1.87	-1.61	0.32	0.4	0.32	0.33
	100-YR	3441	-2.28	-1.29	-2.27	-2.04	0.32	0.45	0.29	0.32

*Negative water depths indicate the depth to which water is flowing over the road surface.
Positive water depths indicate that the road elevation is greater than the elevation of the water surface.

Table 5.13: Pampanga River Location 3 HEC-RAS summarised modelling results for most vulnerable road locations – Climate Change to 2050

River Station (Vulnerable Road Location)	**Profile**	**Discharge** (m^3/s)	**Difference in Level*** (m)				**Critical Velocity** (m/s)			
			Existing Condition	Elevate Road	Dredging	Retention	Existing Condition	Elevate Road	Dredging	Retention
29400	5-YR	2162	-0.96	0.04	-0.96	-0.68	0.17	0.45	0.16	0.24
	10-YR	2455	-1.19	-0.19	-1.18	-0.92	0.19	0.48	0.17	0.17
	50-YR	3575	-1.98	-0.97	-1.97	-1.74	0.24	0.57	0.22	0.23
	100-YR	4326	-2.46	-1.45	-2.45	-2.24	0.26	0.61	0.24	0.25
22200	5-YR	2162	-2.85	-1.85	-2.81	-2.55	0.24	0.6	0.2	0.27
	10-YR	2455	-3.1	-2.09	-3.06	-2.8	0.24	0.63	0.2	0.24
	50-YR	3575	-3.92	-2.91	-3.89	-3.68	0.25	0.68	0.22	0.24
	100-YR	4326	-4.4	-3.39	-4.36	-4.18	0.25	0.7	0.23	0.25
20600	5-YR	2162	-1.33	-0.33	-1.33	-1.04	0.31	0.33	0.28	0.28
	10-YR	2455	-1.57	-0.57	-1.56	-1.28	0.33	0.36	0.3	0.3
	50-YR	3575	-2.37	-1.38	-2.36	-2.13	0.32	0.47	0.3	0.32
	100-YR	4326	-2.83	-1.85	-2.82	-2.62	0.35	0.56	0.33	0.34

*Negative water depths indicate the depth to which water is flowing over the road surface.
Positive water depths indicate that the road elevation is greater than the elevation of the water surface.

Table 5.14: Pampanga River Location 3 HEC-RAS summarised modelling results for most vulnerable road locations – Climate Change to 2100

River Station (Vulnerable Road Location)	**Profile**	**Discharge** (m^3/s)	**Difference in Level*** (m)				**Critical Velocity** (m/s)			
			Existing Condition	Elevate Road	Dredging	Retention	Existing Condition	Elevate Road	Dredging	Retention
29400	5-YR	2523	-1.24	-0.24	-1.24	-0.97	0.19	0.43	0.18	0.17
	10-YR	2928	-1.54	-0.53	-1.53	-1.28	0.21	0.48	0.2	0.2
	50-YR	4290	-2.43	-1.43	-2.43	-2.21	0.26	0.61	0.24	0.25
	100-YR	5211	-2.97	-1.97	-2.97	-2.77	0.28	0.68	0.26	0.27
22200	5-YR	2523	-3.16	-2.14	-3.12	-2.86	0.24	0.35	0.2	0.24
	10-YR	2928	-3.47	-2.45	-3.43	-3.21	0.24	0.36	0.21	0.24
	50-YR	4290	-4.37	-3.37	-4.34	-4.16	0.25	0.37	0.23	0.25
	100-YR	5211	-4.9	-3.91	-4.87	-4.7	0.25	0.38	0.23	0.25
20600	5-YR	2523	-1.62	-0.62	-1.61	-1.34	0.33	0.32	0.31	0.31
	10-YR	2928	-1.92	-0.93	-1.91	-1.67	0.32	0.35	0.29	0.33
	50-YR	4290	-2.81	-1.83	-2.8	-2.6	0.35	0.35	0.32	0.34
	100-YR	5211	-3.35	-2.38	-3.34	-3.15	0.37	0.34	0.34	0.36

*Negative water depths indicate the depth to which water is flowing over the road surface.
Positive water depths indicate that the road elevation is greater than the elevation of the water surface.

5.5.2.4 Location 4: Parallel flow

Figure 5.32 presents the analysed cross sections for Location 4, indicating their station. These sections occur along the Jaen-Sta. Rosa East Road. Table 5.12 presents the summarized results of our analysis for the most vulnerable locations (7600 and 7400) for the existing system and the system with each of the example measures applied. Results for both current climate conditions and with the system subjected to future (worst-case) climate change in 2050 and 2100 are also presented. Complete HEC-RAS output figures for each of these modelling runs are provided in Appendix IV.

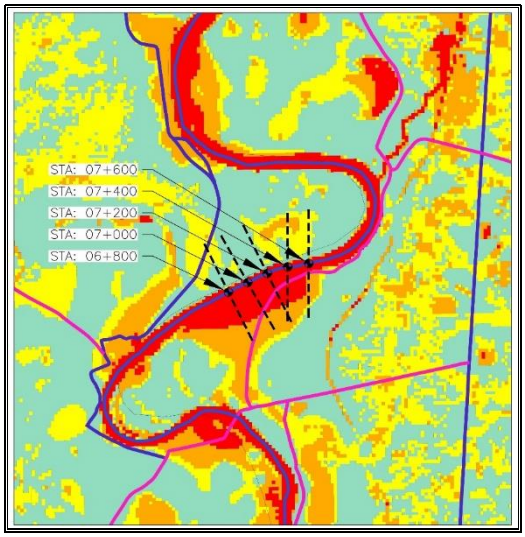


Figure 5.33: Pampanga River Location 4 cross sections. Most vulnerable sections at stations 7600 and 7400

As with location 3, the results indicate that this road section presents considerable challenges to planners. It is presently highly vulnerable to extreme floods, and in places is submerged every five years by up to 2.6m of water, rising to nearly 4m for the most extreme events. Climate change will only exacerbate these effects further. The dredging measure again does little to reduce these impacts (<15cm), while the retention measure reduces flow depths by 20-40cm; still insufficient to mitigate the majority of impacts.

Elevating the road again offers a potential solution, however, as with location 3 the road would need to be elevated significantly higher than the 1m modelled in this study. To protect even against 1:10 year events, the road would need to be elevated approximately 3-4m when the impacts of future climate change are taken into consideration. Potentially high flow velocities will also need to be accounted for, such that extensive erosion protection is required. Alternatively, a submersible road could be installed which is designed to flood during these peak events, but which minimises any damages and recovery times in their aftermath. Or the road could be relocated to a less vulnerable alignment. These latter measures, however, have not been included in our modelling study.

Table 5.15: Pampanga River Location 4 HEC-RAS summarised modelling results for most vulnerable road locations

Flow Data	**River Station** (Vulnerable Road Location)	**Profile**	**Discharge** (m^3/s)	**Difference in Level*** (m)				**Critical Velocity** (m/s)			
				Existing Condition	Elevate Road	Dredging	Retention	Existing Condition	Elevate Road	Dredging	Retention
No Climate Change	7600	5-YR	1802	-2.49	-1.39	-2.26	-2.05	0.76	1.84	0.7	0.81
		10-YR	1981	-2.65	-1.56	-2.45	-2.29	0.72	1.95	0.68	0.78
		50-YR	2860	-3.47	-2.38	-3.31	-3.23	0.58	1.88	0.56	0.61
		100-YR	3441	-3.84	-2.86	-3.74	-3.63	0.54	1.7	0.52	0.56
	7400	5-YR	1802	-2.59	-1.54	-2.42	-2.15	0.72	1.29	0.63	0.79
		10-YR	1981	-2.75	-1.72	-2.61	-2.39	0.69	1.34	0.62	0.74
		50-YR	2860	-3.54	-2.47	-3.41	-3.3	0.6	1.58	0.52	0.6
		100-YR	3441	-3.93	-2.87	-3.85	-3.71	0.61	1.73	0.53	0.6
With Climate Change: 2050	7600	5-YR	2162	-2.9	-1.75	-2.66	-2.52	0.67	1.09	0.65	0.75
		10-YR	2455	-3.18	-2.04	-2.97	-2.88	0.62	1	0.6	0.67
		50-YR	3575	-3.93	-2.95	-3.83	-3.71	0.53	0.83	0.51	0.55
		100-YR	4326	-4.36	-3.46	-4.3	-4.17	0.49	0.77	0.47	0.5
	7400	5-YR	2162	-2.98	-1.91	-2.81	-2.62	0.65	1.02	0.55	0.71
		10-YR	2455	-3.24	-2.17	-3.08	-2.97	0.61	1.08	0.52	0.64
		50-YR	3575	-4.02	-2.95	-3.95	-3.79	0.6	1.29	0.53	0.6
		100-YR	4326	-4.49	-3.39	-4.44	-4.29	0.6	1.4	0.54	0.6
With Climate Change: 2100	7600	5-YR	2523	-3.23	-2.1	-3.03	-2.92	0.61	0.99	0.6	0.66
		10-YR	2928	-3.52	-2.43	-3.37	-3.28	0.58	0.93	0.56	0.6
		50-YR	4290	-4.34	-3.44	-4.28	-4.15	0.49	0.77	0.47	0.51
		100-YR	5211	-4.83	-4	-4.78	-4.65	0.45	0.72	0.44	0.47
	7400	5-YR	2523	-3.3	-2.23	-3.14	-3	0.61	1.09	0.52	0.64
		10-YR	2928	-3.59	-2.52	-3.47	-3.35	0.6	1.17	0.52	0.6
		50-YR	4290	-4.47	-3.37	-4.42	-4.27	0.6	1.4	0.54	0.6
		100-YR	5211	-4.98	-3.85	-4.95	-4.81	0.63	1.48	0.56	0.6

5.5.2.5 Discussion of Pampanga Results

Location 1

No further discussion to that presented in section 5.5.2.1.

Location 2

The modelling results indicated very limited vulnerability to flooding at this location, which did not completely agree with the results of the risk assessment (Figure 5.8). Subsequent site inspection of this location (Figure 5.34) illustrates that the road is already largely elevated (1-1.5m) above rice paddy fields along both sides, and that an elevated irrigation canal is present and running parallel to the north of the road (Figure 5.35). Further inspection of the exposure, hazard and satellite data suggests that most flooding vulnerabilities are located at points where smaller tributaries and the irrigation canal cross the road, and that flooding from the main Pampanga channel causes few issues for this road section. Without including for these additional streamflows, the model cannot be used to analyse these specific vulnerabilities.

Figure 5.34: Photos of Pampanga River Location 2 (station 44400): (top left) box culvert under road; (top right) agricultural fields downstream of culvert, Pampanga River at line of trees in horizon; (bottom) agricultural fields upstream of culvert, irrigation canal embankment at horizon line.

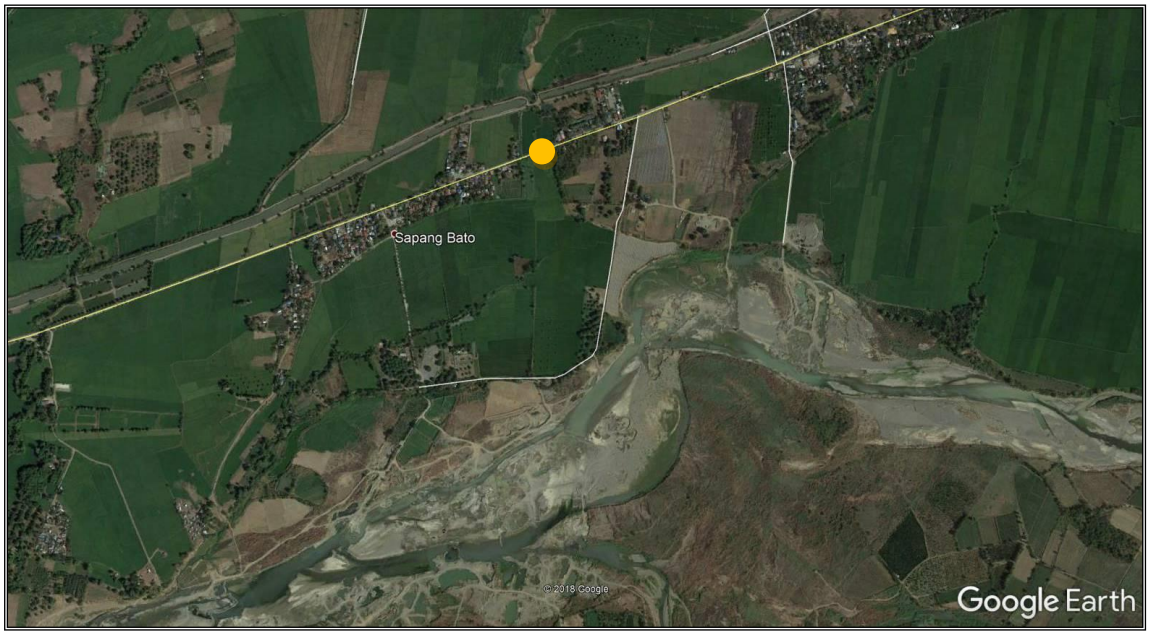


Figure 5.35: Satellite imagery of Pampanga River Location 2 (Station 44400). Pampanga river at bottom, provincial road indicated in yellow and irrigation canal to the north. Photos location indicated by yellow dot.

Location 3 & Location 4

The modelling results indicated that both these locations are highly vulnerable to regular, severe flooding of 2.5m-4m for extreme events. Site inspection of these locations (Figure 5.36, Figure 5.38) along with anecdotal interview with inhabitants confirmed these observations. Residents indicated that they experience waist-high flooding multiple times every year, and many more recent houses were observed to have constructed ground floor levels above this height.

The roads were both also observed to have been made of durable concrete construction; and residents commented that any damage to the road surface or downtime in the wake of a flood was minimal once floodwaters had subsided (typically 1-2 days). Hence, what is presently in place could be considered to constitute submersible roads. However, the addition of erosion protection – particularly along the river bank at Location 3 – would minimize existing vulnerabilities as the bank was observed to be actively eroding in the direction of properties. Whether more can be done to reduce damage to residential properties in the areas remains a point of discussion. This could be achieved, for example, through the construction of large flood protection structures (e.g. levees) along the river banks, or relocation (including of road assets) to permit the implementation of room for the river measures. Naturally these types of measures would involve significant environmental and social impacts, as inhabitants would either become disconnected from the river behind large levees or need to be relocated. Moreover, the impact of such large measures on broader flood patterns for the river system and floodplain would need to be investigated. Such investigations fall beyond the scope of the present study.

Figure 5.36: Photos of Pampanga River Location 3 (Station 22200): (left-right) View to the river from the bank, from riverside properties, from barangay road, towards provincial road. (Bottom left) Bank erosion.

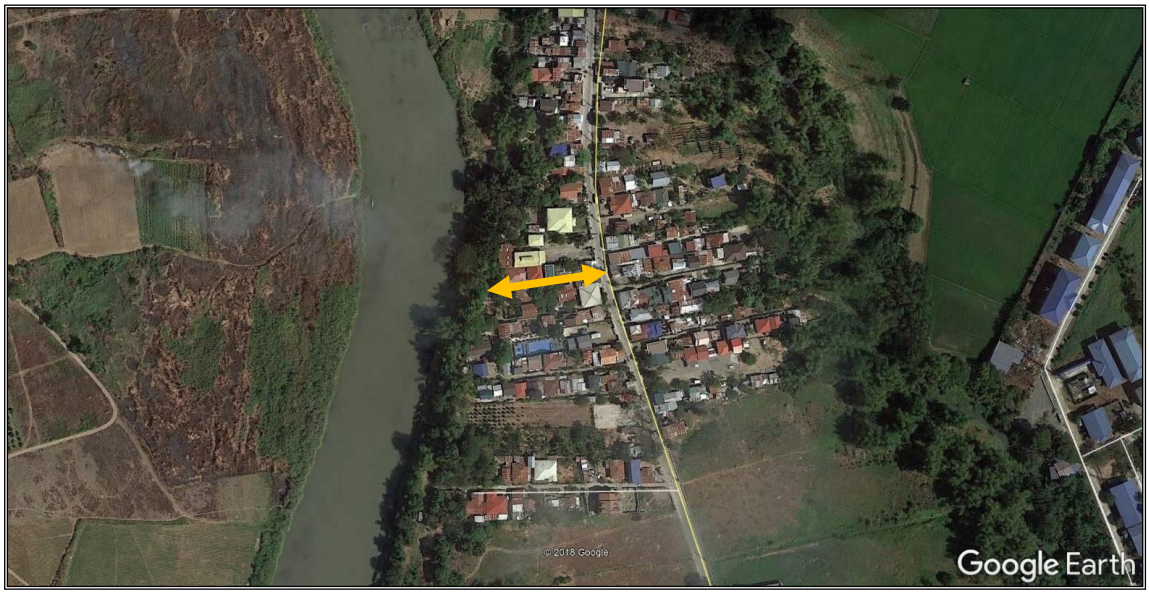


Figure 5.37: Satellite image of Pampanga River Location 3 (Station 22200). Photo locations indicated by yellow arrow.

Figure 5.38: Panoramic photo of Pampanga River Location 4 (Station 7600)

Figure 5.39: Satellite image of Pampanga River Location 4. Photo location indicated by yellow dot.

5.6 Discussion

The preceding discussion notwithstanding, the modelling study indicates the value of undertaking simplified, rapid quantitative analyses to investigate flood impacts to support LGU strategic roads planning provided that the analytical boundary conditions and input data are sufficiently reliable. These types of models can be effectively used to demonstrate orders of magnitude for the relative mitigation effects of a variety of strategic options relevant to roads planners. Moreover, potential future flood impacts resulting from climate change can be quickly assessed to ensure that any LGU interventions are made robust and resilient to the uncertain future. However, we would like to stress such analyses must be informed by the selection of appropriate performance objectives and design criteria relevant to the problem being addressed. We presented results for each of the locations for flood events up to and including 1:100 year events. We recognise that lower protection levels may be more appropriate for many vulnerable provincial road locations.

With the simplified analysis we have presented here, some very general conclusions may be drawn by roads planners. In the first instance, dredging river channels offers very limited benefits in these types of systems in terms of reduction in peak flow water levels. When one also considers the significant environmental and ongoing maintenance costs such a measure would involve, it is unlikely this would ever be a preferred measure to reduce flood impacts for roads. Second, upstream retention as modelled here also offers limited benefits, however this is entirely dependent upon the volume of retention available. A comprehensive study of potential retention areas in the basin was not undertaken for the purposes of this demonstrative study, in which case there may be additional retention volume which could increase the potential retention volumes considerably. This is particularly the case if one considers application of distributed retention throughout the basin in rice paddy fields during extreme wet weather events, like that which appears to be being applied in Location 1 in the Tabualing River System. Third, elevating roads always offers a potentially effective solution, but one must consider to what extent (i.e. what elevation) is both realistically practical and acceptable within the floodplain context. One must also consider the broader, integrated aspects of road elevation; e.g. how to deal with roadside properties, how to facilitate floodplain drainage to rivers, etc. And fourth, in some locations (e.g. Pampanga Location

3 & 4), the investigation of larger flood protection measures or perhaps even road relocation may be necessary to mitigate already severe impacts, which will demand coordination with other government agencies (i.e. DPWH).

However, two limitations of conducting these types of rapid analyses have also been revealed. First, the limitations of the topographic data meant that locations where having more accurate information was necessary (i.e. perpendicular river crossings) could not be effectively analysed. Second, the removal of smaller tributaries, creeks and canals was often seen to exclude several causes of vulnerability from the simplified analysis (e.g. Tabualing Location 2; Pampanga Location 2). This raises the issue of fit-for-purpose modelling. There is nothing wrong per se with an approach to simplify modelling processes to support rapid strategic assessments. However, the models constructed must nevertheless be fit-for-purpose. This means they must operate at the scale(s) of the processes driving vulnerability as well as the measures to combat these. For assessment of larger-scale measures – e.g. large flood protection structures, room for the river, system-wide retention – all of which operate at the scale of the main river system – the simplified models developed in this study are appropriate to assess orders of magnitude of potential impacts. But these models are less suited to assessing impacts of smaller measures for specific road locations (i.e. hotspots) vulnerable to flooding. For measures acting at the hotspot-scale (e.g. road elevation, drainage provision, smaller bridge crossings, etc.), it may be preferable to construct a series of smaller hotspot(s) system models which include all the relevant roads, rivers/tributaries/creeks, irrigation and drainage canals in the affected area. These could be informed by the results of the larger system model to provide boundary conditions. That being said, hotspot-system models would require additional input data to that applied in this study. For example, irrigation flow data from NIA, and rainfall data from PAGASA (e.g. IDF curves) and sub-catchment areas to derive peak sub-catchment discharges for smaller tributaries/canals. Improved topographic data would also be imperative for these models.

A final point worth emphasising is the fact that analyses for several of the studied locations were supported by physical site visits. These helped reveal the above two analytical limitations and more fully demonstrated the complexities of the issues to be addressed at each location. The adaptive strategy building approach presented in Chapter 3 will provide an initial screening of potential measures for each hotspot location. However, once the policy analysis progresses to the next level of analysis and modelling is required, this should be informed by information gained during physical site visits to guarantee that a complete picture of the challenges needing to be addressed is obtained.

5.7 Recommendations for future roads planning

The outcomes of the preceding flood modelling assessment inform the following recommendations:

1. LGU roads planners must consider integrated (e.g. flood-related) impacts during their strategic roads planning studies. Roads are in places extremely vulnerable to these hazards, and assessing their effects will assist LGU planners implement measures which are more robust and resilient to these impacts both under present-day and uncertain future conditions. This can be achieved through the implementation of an IWRM planning approach (refer Chapter 3), that includes coordination with national and other sectoral agencies and key stakeholders.

2. LGUs should (engage others to) undertake fit-for-purpose, rapid, quantitative analyses of the integrated impacts of their plans to support the planning process. These provide an effective demonstration of the orders of magnitude of the impacts of hazards and measures to mitigate these. Note that fit-for-purpose modelling is imperative. This means modelling

must be performed at the appropriate scale and resolution for the hazard and the mitigation measures that need to be represented. Such analyses also need to be followed up with more detailed studies at higher levels of detail in an iterative assessment and design process. Appropriate consultants should be engaged to support these analyses as and when required.

3. Quantitative modelling studies should be informed by physical site visits to vulnerable locations to guarantee a complete picture of the challenges to be addressed is obtained. The type of data to be collected is location-specific, but with respect to roads flooding could include: the current condition of road assets, their existing elevation in relation to the surrounding area, a qualitative assessment of area hydrology (likely flow/drainage paths), other drivers of vulnerabilities, and other such information. We recommend LGUs (or their engaged consultants) carry out these inspections at the time of the assessment, to ensure that up-to-date information can be incorporated into the modelling analyses.

4. A critical piece of information informing flood modelling studies is the accuracy of the topographic data applied. The local and global data sets applied in this study were of insufficient resolution to permit meaningful analyses of all vulnerable road locations (e.g. perpendicular river crossings). We recommend DILG, in consultation with NAMRIA and MGB, identify improved sources of topographic information for LGUs, which could be obtained either through coarse physical surveying of affected areas or improved remote sensing (e.g. LiDAR). As much as possible, existing structures like roads, irrigation canals, bridges, culverts and houses should be included in the data to enable them to be considered in the modelling. The project team has recently learned that the Philippines Mines and Geosciences Bureau (MGB) may have access to such improved topographic information. DILG should explore this avenue should it wish to support LGUs to conduct these types of assessments in the future.

6 Standards in relation to Disaster Risk Management

6.1 Introduction

The availability of design and construction standards for local roads and drainage facilities, and how they are being applied by LGU engineers and contractors, is of key importance to be able to improve the disaster risk management for local infrastructure. This chapter provides an initial overview on the available design and construction standards and the way these are being applied and understood at the local level. It concludes with several recommendations on how the capacity of LGUs and local contractors can be enhanced in this respect.

6.2 Current standards

6.2.1 Overview of available standards

"The Department of Public Works and Highways (DPWH) functions as the engineering and construction arm of the Government tasked to continuously develop its technology for the purpose of ensuring the safety of all infrastructure facilities and securing for all public works and highways the highest efficiency and quality in construction. DPWH is currently responsible for the planning, design, construction and maintenance of infrastructure, especially the national highways, flood control and water resources development system, and other public works in accordance with national development objectives." (source: http://www.dpwh.gov.ph)

The DPWH, then, sets the standards for design and construction that the consultants, contractors, and LGUs follow for building infrastructures in the country. DPWH Design Guidelines, Criteria and Standards (DGCS) are the main documents for design of roads. It is divided in 6 different volumes; each with a different topic. The volumes related to road design are mentioned below.

DPWH Design Guidelines, Criteria and Standards

- Volume 1 Introduction and Overview
  Defines the scope, purpose and overview of the six volumes and considers design for emergency response, safety, resiliency, environment, gender and provisions for accessibility for Persons with Disability (PWD).

- Volume 2A Geohazard Assessment
  Describes the nature of geohazards in the Philippines, the information required to assess their likelihood at a site, and a procedure for preparing a preliminary assessment.

- Volume 3 Water Engineering Projects
  Provides basic requirements and essential tools in the design preparation of water engineering projects, specifically for flood control, water supply, coastal facilities and urban drainage structures.

- Volume 4 Highway Design
  Covers design of all types of highways, including geometry, intersections, pavement, highway drainage, facilities and lighting.

- Volume 5 Bridge Design
  Covers the General Requirement and the Load and Resistance Factor Design (LRFD) approach in design for construction, alteration, repair and retrofitting of highway bridges and other related highway structures.

DPWH Procurement Manual
The DPM aims to put together a coherent set of clear, complete, up-to-date, streamlined, and simple operational rules and procedures, to serve as common reference and guide for DPWH and private contractors, consultants, and suppliers in the procurement of contractors for infrastructure, consulting services, and goods, consistent with RA 9184 and its IRR.

DPWH Blue Book
Volume II Standard Specifications for Highways, Bridges and Airports includes specifications for new construction materials and technologies that have been adopted and/or prescribed through Department Order issuances since 2004. Likewise, amendments to the 2004 Edition have been incorporated in this revised edition, thereby providing an updated standard reference material to be used in the implementation of our infrastructure projects.

National Structural Code of the Philippines
The structural code established minimum requirements for building structural systems using prescriptive and performance-based provisions. It is founded on broad-based principles that make possible the use of new materials and new building designs. Also, this code reflects the latest seismic design practice for earthquake resistant structures.

6.2.2 Disaster Risk Management and climate change in design and construction standards
To be more specific regarding the design in relation to disaster risk, the following requirements for flooding are used for the design of roads and its assets, as lifted from Volume 3 – Water Engineering Projects Manual:

Table 6-1 Minimum Capacity of Drainage Infrastructure

Land-use (Note 1)	Minor System		Major Drainage System Drainage Capacity (Note 2)
	Design Capacity	Check Capacity	
Drainage Pipes	15 year flood	25 year flood	100 year flood
Culverts (Note 1)	25 year flood	50 year flood	
Esteros/ creeks/ drainage channels	15 year flood	25 year flood	

Note 1. Refer to Volume 4 for highway cross drainage structure capacities
Note 2. Freeboards for buildings are detailed in Volume 6: Public Buildings and Other Related Structures.

Since climate change may cause higher hazard intensities, it has been investigated how climate change is being taken into account. For flooding this is discussed in Chapter 9 of Design Guidelines, Criteria and Standards Volume 3 – Water Projects Design. There are 2 approaches (general and alternative) suggested:

Approach	Recommendation
General Approach	Incorporate a 10% increase in rainfall intensity in the design. For example, a 100 year rainfall intensity is increased by 10%.
Alternative Approach	This sensitivity analysis should consider increases in rainfall intensities of 10%, and determine the likely impact on the proposed hydraulic design. In some situations, there will be minimal impacts, while in others the differences in flood levels will be more significant. Where the cost implications are significant, then consideration for a Planned Upgrade approach should be considered, as identified in Section 9.2.3.

For landslides, only minimal information is available in the standards on incorporation of disaster risk and climate change into design. The DGCS were published in 2015 and developments regarding incorporating climate change in design are proceeding quickly. This is backed up by a text from Volume 2A Geohazard Assessment manual, *"However the research on the effects of climate change in GeoHazards is at a very early stage and no quantitative predictions are available."*

> However the research on the effects of climate change on GeoHazards is at a very early stage and no quantitative predictions are available. They can be considered as a higher order of uncertainty compared with the direct assessment of current GeoHazards. Therefore no attempt is made to incorporate the effects of climate change in GeoHazard assessment in this Guide. For major projects where a full risk assessment is undertaken, including consequence-based risk, the potential effects of such climate-change induced changes to GeoHazard risk may be appropriate using, for example, the approaches described in PIARC (2013).
>
> Specific effects of climate change which will affect engineering structures, including sea level change, storm surge and flooding, are addressed in the Guide Volume 3 – Water Engineering Projects Design.

The sentence *"Specific effects of climate change which will affect engineering structures, including sea level change, storm surge and flooding, are addressed in the Guide Volume 3 – Water Engineering Projects Design."* shows that incorporation of climate change in the design is only available for flooding.

6.3 Use of the standards by LGUs

6.3.1 Design

The mentioned standards in the previous chapter act as a guide to Consultants, Contractors and LGUs in construction and design. The Local Government Unit of Nueva Ecija, in particular, also applies this in their projects. The Detailed Engineering Design is however always done by external Consultants. The procurement process for consultants in this respect, is prepared by LGU themselves, following the blue book and procurement manual.

6.3.2 Construction

For construction, on the other hand, standards are being followed as long as it is within RA 9184. Specifically, in relation to climate change, reference is made to the construction period that usually is the dry season. It is important to stress that especially compaction works (due to moisture contents) but also concreting only can take place during dry periods. LGUs have confirmed that indeed they need to stop performing these activities (by contractors) when it starts raining. They also report that they experience a decrease of the number of dry days per year in recent years when compared to former times. Appendix V presents an assessment on the expected changes of number of dry days due to climate change with the outcome that no reliable prediction can be made on the expected change of number of dry days towards the future.

6.3.3 Maintenance

For maintenance of infrastructures like bridges and roads, LGUs have their own process which is not particularly set by DPWH. There are assigned personnel who are in-charge of checking the condition of these infrastructures. The LGUs themselves, then, evaluate what proper actions should be done. This will be forwarded to their Governor who will approve their need for budget.

6.3.4 Managing disaster and climate risk

The standards listed in the previous chapter are not used for adapting to recurring floods. When the need arises, LGUs set ways how to improve their road due to flooding. They upgrade the elevation of the roads according to flood level in that particular area. This is not necessarily consulted to DPWH, based from the LGU. If elevating is not possible, accessories are made like slope-protection, wall-protection, concrete lining, repairing of carriageway and others. This process on identification and execution of additional measures however is not very clear and seems to be rather reactive as compared to pro-active based on modeling and forecasting activities.

It has become clear however that these recommendations are not uniformly used in practice. The LGUs rarely ask to consider this specific paragraph in their procurement of consultants and contractors. This leads to the situation that often the consultant decides whether or not climate change needs to be considered. On the other hand, many consultants make designs on the safe side and use a 20% increase of rainfall intensity due to climate change.

6.4 Conclusion and recommendations

6.4.1 General

It has become clear that in principle the DPWH standards and guidelines are quite well developed in relation to disaster risk management. Also, the effects of climate change are mentioned in these standards, and recommendations are provided on how to take climate change into account. The current standards in general work well with project designs of Consultants, Contractors and LGUs at present but there are some things that can be improved on.

6.4.2 Recommendations to improve inclusion of climate change in design standards

Climate change, as it can be noticed, is not discussed as widely in the standards. It is important, especially now, that there are standards set for this so a universal or consistent process can be followed by designers and LGUs. The way to consider climate change is not described in a lot of detail. This makes it more difficult for LGU to consider this important topic in the right way. Some recommendations for improvement are:

1. To explicitly describe and/or explain how the increase in rainfall intensity needs to be used in the design of new and evaluation of existing road assets. The following aspects are named in this respect:
    - To explain how the expected increase in rainfall intensity may be used in the design of road assets. One could redo the flood modeling with the higher expected rainfall intensity, but this is a fair amount of work that probably not always is possible within the scope of work. In that case, one could conservatively assume that the flow/discharge increases with the same amount (all additional rainfall is translated to run-off) (Bessembinder et al., 2018). This rule is a first order approach only, and should be applied with caution, as local conditions may require alternative changes to be considered. For instance, in larger catchments where time of concentration is long, soil conditions allow infiltration, and in larger catchments (larger than ~0.5 km^2), applying an analysis using empirical functions and/or modeling is worthwhile, to avoid an overly conservative design.

- To make clear how the required design return periods relate to the expected increase in climate change. It is now unclear whether for culvert design both the return period needs to be increased as well as the rainfall intensity.

2. Climate change is uncertain and this is currently not addressed in the standards. It is important that the engineers who apply the standards have a clear understanding of this uncertainty. In this respect the following is stated:
   - The increase of rainfall intensity may be lower or higher than the prescribed one. It is recommended to explain to the reader how the 10%, that currently is required to consider, has been derived and what the accompanying uncertainty is. Is the 10% an average of possible future scenarios or is this meant as a worst case? This is now unclear and leads to every engineer making own assumptions and decisions in this respect. It is noted that for 2050, based on a Japanese study for the Pampanga basin (Ushiyama et al., 2016), the change of intensity of rainfall may increase with virtually no change up to 20%. For 2100 the amount of change is ranging from virtually no change up to 50%.
   - To state for which time horizon the expected increase in rainfall intensity is valid. Is this for instance for 2050 or 2100 and to relate the expected lifetime of the asset to this increase. It is to be expected that the increase will be higher the further away in the future. For assets with a shorter lifetime expectancy it makes sense to use a shorter time horizon if compared with assets with a long lifetime expectancy.

3. Increase of rainfall intensity is only mentioned in relation to the hydraulic design. It should be noted that also the landslide hazard will intensify when the rainfall intensity increases. It is true that quantitative analyses are difficult to make, but we do not agree with the conclusion that climate change is not necessary to take into account. At least in a qualitative way this is possible and developments on quantitative assessment are going fast.

The LGU use the requirements of DPWH for the design of the provincial roads. These requirements are probably written while considering the national roads. During the work on the Integrated Water Resources Management and flood modeling, as reported in the adaptation strategies report, it has become clear that the provincial roads, in the contrary to national roads, are mainly vulnerable for flooding due to smaller creeks, tributaries and overland flow. The assets in this respect may be interpreted as ‘minor systems’, when referring to the DPWH standard Volume 3. The design return periods of these minor systems are much smaller than for the major systems, which may be correct for the national roads, but could lead to unacceptable risk for the provincial roads. It is recommended to investigate whether the design return periods should be changed for the provincial roads in Nueva Ecija, based on the specific situation in the Pampanga basin where the provincial roads are mainly exposed to floods from the smaller water systems.

6.4.3 Recommendations for LGU

It has become clear that maintenance actions of roads are based on experience. More specifically, roads will be elevated when the risk of flooding appears to be too high, based on experienced floods. While experience is an important input for asset management, it is advocated to undertake quantitative risk assessments, based on factual data of the road, its surroundings and modeling of floods and landslides. Reference is being made to the risk assessment report in this respect. By mapping exposure of the road and assessing damages and losses, it is possible to prioritize the roads for actions to reduce the risk. For this purpose, reference is being made to the adaptation strategy report in which various measures are described and analyzed.

Moreover, it is essential that LGU understand how to do things efficiently both for design and construction. Though elevating the road for observed flood depth can help eliminate flooding, it is important to address the main issue which is the drainage. Only through this the problem can be properly solved. For construction, on the other hand, LGU should make sure that roads adhere to standards through inspection since quality affects longevity and durability. Reference is made to the adaptation strategy report on how robust decisions can be made when choosing between various types of measures. It may make sense that elevating the road is not always the best solution.

It has been understood that the LGU have no clear idea on how design and construction in relation to the earthquake hazard should be undertaken. It is recommended to train the LGU on this subject.

It is unclear how road designs are being made with respect to the natural hazard of landslides. A highly detailed landslide susceptibility map is available from MGB. No reference has been found to this map, while this may provide good input for the planning purposes of disaster risk management and the design of assets in relation to landslides. It is recommended to train the LGU on this subject.

It is also best for Consultants, Contractors, and LGUs to not only know but also understand the background of the standards. It is important that consultants, contractors, and LGUs have the available standards at hand so they can refer to it for design and implementation. This promotes the use of the standards which can help should they have input for improvement for future revisions. Through this, LGU can also gradually build capacity to design for themselves. LGUs shall also check DPWH website every now and then for updates in the standards.

Finally, it has been understood that procurement by the LGU is using the national standards. These national standards include reference to climate change effects (and notice the specific recommendations in this respect) and when reference is made to the national standards it is in fact also requested to consider climate change. However, since climate change can be very significant, it is recommended to the LGU to specifically ask for considering climate change in the procurement of design and construction.

The number of dry days per year is an important factor since construction of roads relies on this for a big extent. It is unclear how the number of dry days per year may change due to climate change. It may decrease, stay the same or even increase. It is likely that the variability between years increases. It is therefore becoming more and more important to plan sufficiently ahead for the construction season. This means that we recommend the LGU to ensure that planning, design, procurement and contracting is finalized before the construction season (dry season) starts, ensuring a swift start of construction when the weather allows. It is recommended to monitor the development of the number of dry years in the coming decades in order to take other measures when necessary.

7 Summary Conclusions

This report has presented and discussed a proposed methodology for adaptive strategy building, IWRM considerations, and a strategic modelling approach to analyse potential flooding impacts for the provincial road network of Nueva Ecija. Implications of this methodology for existing roads design standards has also been presented.

Detailed conclusions and recommendations are proposed at the end of each chapter. The three main chapters, however, can be summarised and contextualised as follows. When undertaking strategic roads planning at the LGU level, we recommend following a structured, stepwise, iterative, quantitative analytical process like that recommended in the IWRM planning guidelines. Such a process would include the following steps:

1. It would commence with the risk assessment (refer previous report). This would identify hazard hotpots and prioritise road sections for upgrade.

2. For each road section or hotspot, select the appropriate archetype(s) and undertake an initial DMU analysis of potential measures using the semi-quantitative approach presented in Chapter 5, making sure to contextualise it to the realities of the road section/hotspot. This would identify the promising strategic measures and prioritise them into promising adaptation pathways.

3. Conduct a review of the relevant IWRM plan (Chapter 3) in order to ascertain any interactions between the plan and the prioritised road sections and hotspots.

4. Determine the fit-for-purpose, quantitative, strategic modelling approach (Chapter 4) to be applied to analyse current and future impacts of the prioritised measures from step 2 and any planned IWRM measures in step 3. Carry out these analyses to refine the initial measures prioritisation and adaptation pathways from Step 2 into preferred measures and pathways, being sure to account for the impacts of future uncertainties (e.g. climate change) in the analysis.

5. Consult with potential stakeholders who may be impacted by the preferred measures and pathways. Reassess, if necessary.

6. Repeat the Step 4 analysis with more detailed models as the preferred strategy becomes more definite. Commence action planning activities.

Figure 7.1 illustrates the above schematically. From this foundation, the provincial roads plan could then be finalised for the prioritized road sections. In implementing the above approach, we must highlight that:

- When undertaking DMU analyses, it is important to consider both the dynamics of decision-making through time (i.e. pathways) and to recognise the full plausible range of potential futures. For Nueva Ecija, the large uncertainty envelope means that its roads planning must be dominated by flexibility in order to effectively adapt to the conditions as they change. LGU roads planners need to be careful not to implement measures that prevent other actions in the future (i.e. create ‘lock-ins’).

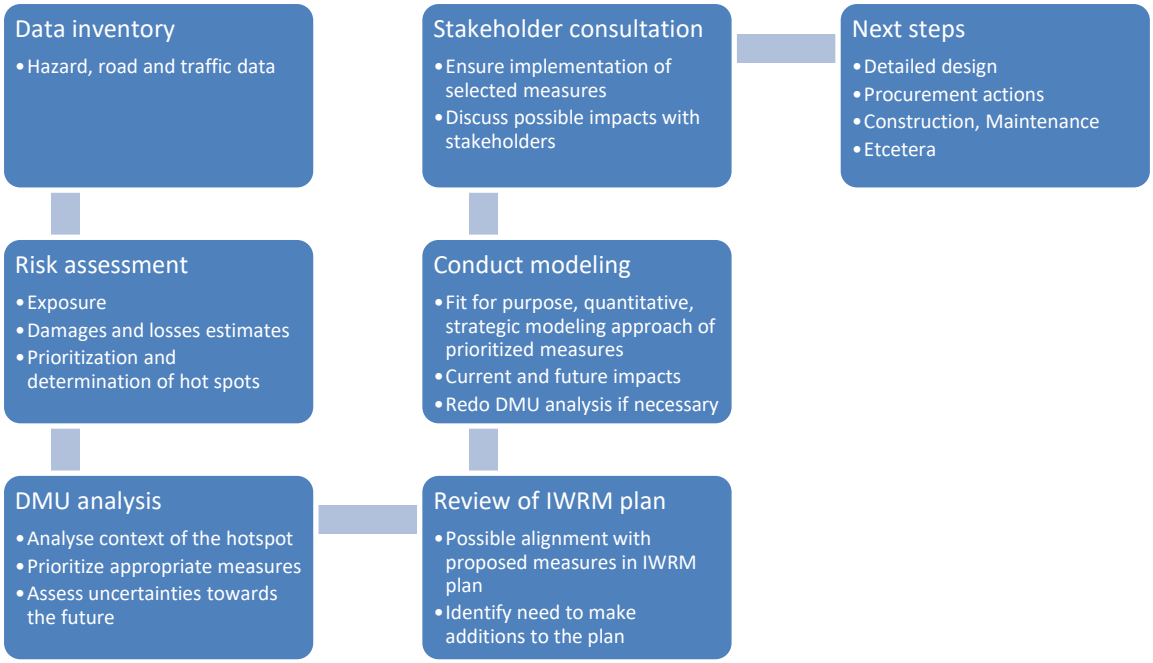


Figure 7.1: Schematic of the stepwise, iterative, quantitative analytical process outlined in this report

- IWRM plans will impact provincial roads planning and vice versa. LGU planners must therefore become more involved in river basin IWRM planning processes; not only to become better informed about any planned measures, but to also provide them with opportunities to inject their knowledge, perspectives and priorities into these processes and to deliver better integrated outcomes for the basin. Considering the integrated impacts of roads and hazard reduction measures will assist LGU planners implement measures which are more robust and resilient to these impacts both under present-day and uncertain future conditions.

- We cannot overstate the value of fit-for-purpose quantitative modelling when undertaking rapid strategic assessments. This means modelling that is performed at the appropriate scale and resolution for the hazard and the mitigation measures that need to be represented. For Nueva Ecija, the omission of smaller tributaries and creeks limited the effectiveness of our analysis for the two example systems. Input data (e.g. topographic data) must also be of an appropriate resolution to support meaningful analyses. These analyses then need to be followed up with more detailed studies at higher levels of detail in an iterative assessment and design process.

- With the availability of information and training of personnel, we believe the approaches and methodologies described in this report can be scaled and/or replicated in other provinces. Given the somewhat complex nature of the methodologies proposed in this report, we advise that LGUs planning to update their local infrastructure are selected by DILG to undertake these activities together with the support of local consultants. These reports may then be provided to the consultants for possible use and further learning by doing.

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Appendix I: Compliance Check of Existing IWRM Plan with National Framework

The existing IWRM plans prepared by JICA and updated by NEDA 3 were reviewed to ascertain compliance with the recently adopted National IWRM Planning Framework (section 4.2). These findings are presented in Table AI.1 and summarized below.

AI.1 Planning Framework

The preparation of the original JICA study predates the adoption of the National IWRM Planning Framework. As such, it applied an earlier framework as formulated by NWRB in 2006 (Figure AI.1). The NEDA 3 study applied the 'ridge-to-reef' integrated watershed ecosystem framework (Figure AI.2), which links conservation and utilization actions across sub-watersheds and coastal ecosystems. Hence, neither plan applied the National IWRM planning guidelines, such that there are several aspects to the plan which could be elaborated in line with the new guidelines.

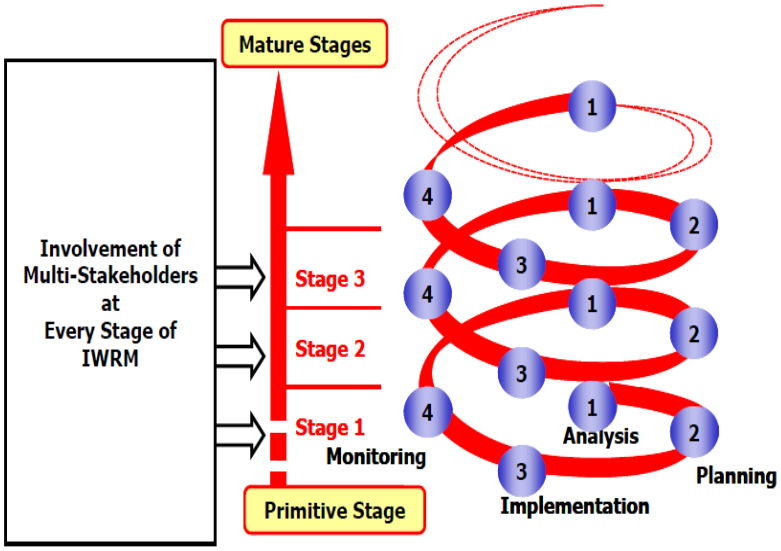


Figure AI.1 - NWRB IWRM Planning Framework applied in the JICA study

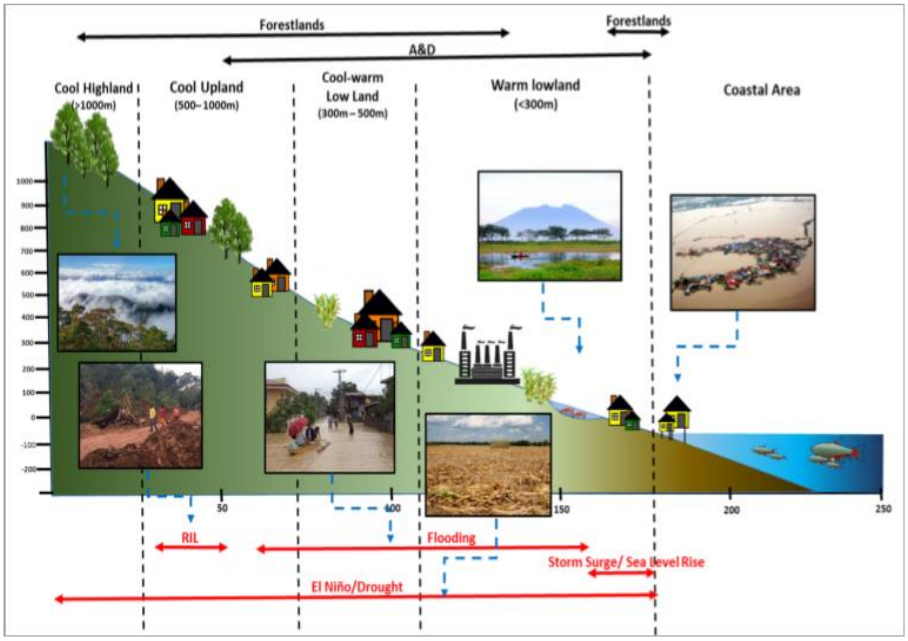


Figure AI.2 - Ridge-to-Reef Integrated Watershed Ecosystem Framework applied in the NEDA 3 update

AI.2 Inception Phase

a. Ascertaining Enabling Conditions

- Both studies included analyses of the institutional framework and enabling environmental policies in place; including the limited availability of management instruments.

b. Setting-up of Stakeholder Involvement Process

- Both studies identified relevant stakeholders (both those affected and those needed to implement the plan), organised the various stakeholders into various working groups and steering committees, and defined the extent of each stakeholder's participation.

c. Defining Analysis Conditions

- Both studies defined the necessary boundary conditions for the analysis, as well as the system components to be included. While the JICA study was relative short-term focussed with a planning horizon of approximately 15 years and excluded the impacts of climate change, the NEDA 3 study sought to rectify this by extending the outlook of the plan to 2030 and including a qualitative assessment of potential future climate impacts to 2050.

d. Defining Objectives and Criteria

- Both studies were formulated in harmony with the national development goals, national policy priorities with the following objectives:
    - JICA study objectives are: Enhancing livelihood; Improve quality of life; Decentralize development; Sustained ecosystem; and Empowered people
    - NEDA 3 objectives are: Improve water security; Conserve, protect, and rehabilitate watersheds; Sustain and manage ecosystems; Reduce vulnerability; reduce vulnerability and improve adaptive capacity to climate risks; and Capacitate institutions and empower stakeholders.

  However, in both plans these objectives remain relatively vague and general in nature, and specific, measurable and quantifiable performance criteria and indicators have not been identified nor specified within the plans, which does mean that assessing the performance of the plan will be challenging.

AI.3 Situation Analysis

a. Description of the Water Resources System

- The JICA study provided the description of the water resource system of PRB; description of all elements of WRS (natural resources, socio-economic, institutional system). These descriptions have been elaborated and updated in the NEDA 3 study, which also included an assessment of the potential impacts of climate change in both 2030 and 2050 (single scenario).

b. Structured Quantified Analysis Process

- Although a structured analysis process was followed, the approach adopted in both studies appears to be more qualified in nature, with the potential impacts of any measures not assessed through application of a computational framework.
- Base case analyses for both studies are the same and were conducted during the JICA study. They include quantified historical flood damages, including affected areas and population, and casualties.
- Scenario analyses included only a single outlook, encompassing the following drivers for the WRS: population, economic growth rates and GDP, and climate. For the latter, the JICA study considered historical climate only, while the NEDA 3 study assessed potential future conditions at 2030 and 2050 time horizons based on PAGASA data.
- Reference cases were developed via qualified analysis only for both studies.
- Qualified problem descriptions for the relevant sectors were therefore developed based on the outcomes of the base and reference cases analyses in both studies.
- Both structural and non-structural potential measures to address flood risks were identified during both studies.
    - In the JICA plan, government agencies and non-government entities provided currently implemented and/or proposed projects to target the identified problems/contribute to the specified objectives and sector goals. These were further supplemented by conceptual projects proposed during the planning study. A total of 10 flood risk management projects were identified.

  - The NEDA 3 study elaborated on this list and developed 12 strategies consisting of 40 projects under the thematic area of flood mitigation, hazard management and climate adaptation.

- Neither study specified in detail the computational framework that was applied during the assessment. The JICA study mentioned several computational tools – including GIS, rainfall-runoff, and water balance models; but ultimately a qualitative ranking and scoring matrix appears to have been used in the evaluation of measures/projects. The NEDA 3 study appears to have only utilised the existing information presented in the JICA study and GIS tools in the preparation of its update.

AI.4 Strategy Building

- In the JICA study, measures were prioritized based on MCA considering six categories (refer Table AI.1), before scheduling of project implementation was undertaken for the short, medium and long term. There does not appear to have been any impact assessment of measures/strategies undertaken in the NEDA 3 study.

- In neither study does it appear that a computational framework has been applied in the assessment of measures or strategies.

- In neither study do alternative strategies appear to have been compared and assessed, but rather all the proposed measures have been ultimately included in the plans.

- Neither study applied adaptive management principles in the development of the plans.

AI.5 Action Planning and Implementation

- In both studies, detailed elaborations of the formulated strategies were not presented. Nevertheless, a degree of action planning was undertaken, with prioritised investment plans developed for the “short” (<5 years), “medium” (5-10 years) and “long” (10-15 years) term for the relevant responsible agencies. In the JICA study, the necessary institutional framework was also elaborated, including all laws and regulations requiring amendment. Similarly, a preliminary environmental and social impacts assessment was carried out, and an environmental monitoring framework formulated. Further feasibility studies were also recommended for all projects. Far less information of this kind was present in the NEDA 3 update, however, it is assumed that the actions specified in the JICA study still apply.

- Despite the proposed environmental monitoring framework present in the JICA study, neither planning document specified a broader monitoring framework to assess the performance of the plan against its goals and objectives. However, the NEDA 3 study did recommend a River Basin Organisation be established to set up and implement a monitoring and evaluation framework for the plan.

Table AI.1: Compliance of existing IWRM plans with 2016 National IWRM Planning Framework

IWRM Activities	Activity tasks	JICA			NEDA-III		
		Y/N	Section	Details	Y/N	Section	Details
General							
Used the IWRM Framework		N	Vol.II - Chapter 1.2	- Developed prior to formulation of latest framework - Adopted the IWRM Framework formulated by NWRB in 2006	N	Vol.II - Chapter 1	- Applied 'ridge-to-reef' integrated watershed ecosystem framework, a holistic resource planning and management framework linking conservation and utilization actions across sub-watersheds and coastal ecosystems - Strategic, participatory approach - Takes into account the sustainability of resources and well-being of the stakeholders - Considers four major ecosystems: i) coastal, ii) urban, iii) upland, and iv) forest

IWRM Activities	Activity tasks	JICA			NEDA-III		
		Y/N	Section	Details	Y/N	Section	Details
Step I - Inception							
Ascertaining Enabling Conditions	- Availability of management instruments (assessment, information, allocation instruments) - Presence of enabling environment (policies, legislation) - Presence of institutional framework (central, local, river basin, public/private)	Y	Vol.II - Chapter 5	- National and local policies, laws and regulations in place - No specific institutional and legal arrangements in the study area for water-related sector planning and implementation, and IWRM. - Legal framework for policy, planning, approval, implementation of water-related projects and management similar to those applied nationwide (except those transferred to local government levels based on LGC-1991) - Power and attributes of local government, inter-government relationship, local legislation, organizational structure and staffing, local taxation and fiscal matters, local fiscal administration including budgeting, and share of local government units in the national wealth all enumerated in the LGC.	Y	Vol.II - Chapter 2.5	- Institutional framework and enabling environmental policies in place.

IWRM Activities	Activity tasks	JICA			NEDA-III		
		Y/N	Section	Details	Y/N	Section	Details
Setting-up of stakeholder involvement process	- Identification of relevant stakeholders (both those affected and those needed to implement the plan) - Extent of stakeholder participation	Y	Vol.II - Chapter 7.12 Vol.IV - Appendix - Minutes	- Various meetings conducted for Steering Committee, Stakeholders consultation group, Technical working group. - Initial two-day First Stakeholders' Consultation held on May 21-22, 2009 for upstream stakeholders (Tarlac and Nueva Ecija) and downstream stakeholders (Bulacan and Pampanga). - Subsequent SH meetings periodically conducted until end of project whereby the 'Draft Final Report' was discussed.	Y	Vol.II - Chapter 1 Figure 1-4	- Stakeholders involved in the planning process - PRB Planning Team (PPT) consisting of: i) Project Management Committee (PMC); ii) Technical Planning Unit (TPU); iii) Technical Support Group (TSG); and iv) Project Staff. - PMC highest policy and decision-making arm of PPT chaired by the Regional Director of NEDA 3 and co-chaired by the Executive Directors of RBCO and NWRB. Members included chairs of Advocacy and Monitoring TWGs of PRBC, along with RDC III Private sector Representatives (PSR) for Environment and Trade/Industry.
Defining Analysis Conditions	- Base year - Planning time horizon(s) (short, medium, long-term) - Discount rate to be applied in economic analysis - System boundaries, components, and level of detail to be included	Y	Vol.II - Chapter 8	- Coverage Area: Entire catchment of Pampanga River Basin which includes Nueva Ecija - Base year: 2009/2012 - Time horizon(s): 2015, 2020, 2025 (short, medium and long term)	Y	Vol.II - Chapter 4	- Coverage area: Entire catchment of Pampanga River Basin which includes Nueva Ecija - Base year: 2012/2015 - Time horizon(s): 2015-2030; BOT extends up to 2045

IWRM Activities	Activity tasks	JICA			NEDA-III		
		Y/N	Section	Details	Y/N	Section	Details
Defining Objectives and Criteria	- Harmonised with national development goals - References relevant national policy priorities - Contribution plan will make to development goals - General objectives translated into operational objectives - Specific measurable criteria defined for each objective, to be determined through monitoring	Y	Vol.II - Chapter 1.1 Vol.II - Chapter 8.3.3	- Objective 1: Enhanced Livelihoods, including building job opportunities in the agricultural sector; agricultural productivity with competitive production costs. - Objective 2: Improved Quality of Life, with a focus on contributions from (i) municipal water supply system (safe drinking water), and (ii) mitigation system against flood, sediment disasters and other water-related damages. - Objective 3: Decentralized Development, namely; (i) availability of adequate municipal water supply for the urban centres and adequate irrigation water supply; and (ii) minimization of damage by floods, sediment disasters and other water-related disasters. - Objective 4: Sustained Ecosystem, including reforestation of mangroves and other degraded ecosystems and inducement of sanitary facilities and efforts to improve the quality of surface water. - Objective 5: Empowered People, to be achieved via robust stakeholder involvement in planning processes - Objectives have been translated into goals for the relevant water-related sectors, but not quantifiable criteria and indicators	Y	Vol.II - Chap 4.2.2	- i) To improve water security; - ii) To conserve, protect, and rehabilitate watersheds; - iii) To sustain and manage wetland ecosystems; - iv) To reduce vulnerability and improve adaptive capacity to climate risks and other forms of hazard; and, - v) To capacitate institutions and empower stakeholders. - General objectives translated into specific sub-sector outcomes, to be achieved via Priority Investment Program (PIP), but not in terms of quantifiable criteria and indicators

IWRM Activities	Activity tasks	JICA			NEDA-III		
		Y/N	Section	Details	Y/N	Section	Details
Work Plan and decision-making	- Specification of activities and their timing during the planning process - Includes timing of interaction moments with decision makers and stakeholders	Y	Vol.II - Chapter 1.3 Vol.II - Chapter 7.12-7.13	- Study schedule included Figure 1.3.1 - Various stakeholders' meetings were scheduled from start to end of planning stage (Fig 7.13.1)	Y	Vol.II - Chapter 1.4	- Planning process flow provided in Figure 1-5 - Issues and development concerns gathered from stakeholders, agency specialists, and consultants through the conduct of focus group discussions (FGDs), workshops, and public consultations. - Decision-making via PMC
Step II - Situation Analysis							
Description of the Water Resources System	- Demonstrates uniqueness of the Water Resources System (WRS) - Description of all elements of WRS (natural resources , socio-economic, administrative and institutional systems) - Extensive description for the present situation (Base case) and future situation (Reference case) of the major problems and issues in terms of WRM faced by the national and regional authorities and stakeholder. - Formulation of potential measures based on the results of the description of the WRS, the problem analysis, and the scenario analysis.	Y	Vol.II - Chapter 2	- Present conditions of the Study Area	Y	Vol.II - Chapter 2	- River Basin profile (Geographic, Administrative, Political; Natural and geo-physical characteristics) - Material primarily taken from JICA study - Issues prioritized and summarized per thematic area - Vision and development goals from the existing master plan updated

IWRM Activities	Activity tasks	JICA			NEDA-III		
		Y/N	Section	Details	Y/N	Section	Details
(i) Natural Resources System	- Climate and (geo)physical conditions	y	Vol.II - Chapter 2 Vol.III - Sector A	- Comprehensive natural conditions: Topographic Conditions, Rivers, Meteorology, Hydrology	y	Vol.II - Chapter 2.2	- Natural and geophysical conditions (climate (including climate change), Topography, Water resources, Soils & geology, Land cover, Wetlands, Land degradation, Flora & fauna, Environmental conditions
(ii) Socio-Economic System	- Demographic, social and economic conditions of the surrounding economies	Y	Vol.II - Chapter 3 Vol.III - Sector B	- Comprehensive socio-economic conditions of the study area	y	Vol.II - Chapter 2.3	- Demographic conditions: population, urbanisation, economic characteristics; Infrastructure
(iii) Administrative and Institutional System	- Constitutional, legal and political system	Y	Vol.II - Chapter 5 Vol.III - Sector A	- Present Institutional Setup - Present framework of water resources management - Legal framework - Institutional setup	y	Vol.II - Chapter 2.5	- Existing constitutional, legal and political systems - Relevant national legislation and policies - Agencies responsible for water resources management
Structured Quantified Analysis Process	- Quantified information about the present problems (e.g. average flood damage) - Quantified impacts of the proposed measures (e.g. reduction in flood damage) - Quantified costs of these measures - Necessary structured analysis process and a computational framework	Y	Vol.II - Chapter 6 Vol.III - Sector A Report: Chapter A.7 Vol.III - Sector E Report: Chapter E.3	- Quantified indicators and costs of damages on recorded droughts and flooding, including affected areas, population, casualties - Quantified impacts of FRM measures do not appear to have been calculated - Schedule of on-going and proposed FRM projects (including costs) included in sector E Report	Y/N	Vol.II - Chapter 1 Figure 1-5	- Qualified analysis procedure only - Vision and development goals identified in the existing 2011 JICA master plan were refined and updated

IWRM Activities	Activity tasks	JICA			NEDA-III		
		Y/N	Section	Details	Y/N	Section	Details
(i) Base Case Analysis	- Analysis of the present situation - Study for infrastructure and water demands in the base case	Y		- Quantified indicators and costs of damages on recorded droughts and flooding, including affected areas, population, casualties	Y	Vol.II - Chapter 3	The report updates the JICA report; all base case analyses remain unchanged.
(ii) Scenario Analysis	- Study of developments outside the control of the WRS managers that might have impact the WRS (demand, supply, etc.);	Y	Vol.II - Chapter 8.2	- Projected population, economic growth rates and gross regional domestic product (GRDP) - Climate information based on historic data only (i.e. no Climate change effects included)	N	Vol.II - Chapter 2.2 Vol.II - Chapter 2.3	- Projected population, economic growth and GRDP for 2030 - Future climate impacts considered for 2020 and 2050 based on existing PAGASA data
(iii) Reference Case	- Analysis of the performance of the WRS in the future if no additional measures are added	Y		- Qualified analysis only	N	Vol.II - Chapter 2 Vol.II - Chapter 3	- Qualified analysis only
(iv) Problem Description	- Problem description carried out based on the base and reference case analyses in combination with the problems and issues perceived by the decision makers and stakeholders	Y		- Qualified analysis only, for each of: (i) water resources development, allocation and distribution for irrigation, municipal water and other various water demands; (ii) flood and sediment disaster management; (iii) watershed management; and (iv) other water-related environmental management. -Some problems and issues not limited to a single sector, but extend across several sectors causing inter-sector conflicts.	Y	Vol.II - Chapter 3	- Qualified analysis only, for each of (i) Water Resources Management (ii) Watershed Management and Development (ii) Wetland Management (iv) Flood mitigation, Hazard management, and Climate adaptation (v) Institutional arrangements

IWRM Activities	Activity tasks	JICA			NEDA-III		
		Y/N	Section	Details	Y/N	Section	Details
(v) Potential Measures	- Inventory of measures based on the present and future problems identified	Y	Vol.II - Table 9.4.1	- Various government agencies and non-government entities provided currently implemented and/or proposed projects targeting identified problems or contributing to specified visions, objectives and sector goals - Conceptual projects, to address any gaps were then further proposed as components of the IWRM Plan. - A total of ten (10) FRM projects were identified (3 completed, 5 on-going and 2 more under the pre-investment stage) - Projects include both structural and non-structural works. Non-structural projects include the completed Pinatubo Hazard Urgent Mitigation Project (PHUMP) Phase III Part II, PHUMP Phase IV; Pampanga Delta Development Project (PDDP), Phase II and Phase III; and maintenance and rehabilitation works for the existing flood and sediment prevention and management structures	Y	Vol.II - Chapter 4.6 River Basin Management Strategy & Comprehensive Report: Section D	- Achievable strategies to address development challenges identified and formed basis to prioritise interventions or PPAs. - Past, on-going, and committed PPAs in PRB included in the assessment and evaluated -A total of 12 strategies were developed for flood mitigation, hazard management and climate adaptation, comprising 40 projects - Both structural and non-structural projects
(vi) Supporting Computational Framework (Data and Modelling Tools)	- Computational framework used in the problem analysis (could be developed in excel or other available standard software)	Y	Vol.II - Chapter 7-7.8 Vol.II - Annex-T 7.8.1 Vol.III-Sector A	- Detailed computational framework not specified; rainfall-runoff calculated using Thornthwaite water balance model - Qualitative ranking and scoring matrix were used in the evaluation of measures/ projects - GIS was used - Qualitative assessment informed by DEM, rainfall-runoff simulation model, water balance (MODSIM) simulations for existing conditions only	Y	Vol.II - Chapter 1 Figure 1-5	- Qualitative Ranking of measures/strategies only - Used data from JICA study - GIS instruments used throughout planning process

IWRM Activities	Activity tasks	JICA			NEDA-III		
		Y/N	Section	Details	Y/N	Section	Details
Decision Making in Step II	- Formal agreement between stakeholders on the urgent problems to be solved	Y	Vol.II - Chapter 7.12	Steering committee meeting informed by prior stakeholder consultation meetings	Y	Vol.II - Chapter 1 Figure 1-5	- Decisions taken by PMC following strategy formulation activities in stakeholder Technical Working Groups
Step III - Strategy Building							
Strategy Building Process	- Development of coherent combinations of potential measures to satisfy objectives defined in the situation analysis	Y	Vol.II - Table 9.4.1	- On-going (4), proposed (2) and conceptual (4) FRM projects from relevant agencies were collated or developed for inclusion in the plan. All projects were selected. Conceptual projects all require further feasibility study. - Alternative strategies do not appear to have been formulated or compared.	Y	Vol.II - Chapter 4.6	- 12 Strategies prepared to reduce vulnerability and improve adaptive capacity to climatic risks and other hazards. Disaster risk reduction and climate change adaptation efforts intended to dramatically reduce the impacts and damages caused by geologic and hydro-meteorological hazards to production areas, settlements, protected areas, and physical assets in PRB. - Alternative strategies not compared, but all those prepared were to be implemented to address key issues and challenges
Alternative strategies	- Strategies considered from Promising Measures - Strategies proposed by the stakeholders are evaluated in terms of their impacts.		Vol.II - Sector E - Table E. 3.3.5	- 9 alternatives (3 options x 3 return periods) for conceptual flood mitigation project (FL-C-01) specific to the Pampanga Delta (not NE) were compared, but no firm recommendation made			
Impact Assessment	- Promising alternative strategies are evaluated using the computational tools developed - Impacts are expressed in terms of criteria defined to measure how far the objectives as stated in Step I are being achieved	Y	Vol.II - Chapter 7.8 Vol.II - Annex-T 11.2.5	Actions were prioritised according to MCA, with the evaluation made for six (6) categories: (i) Viability of the Project; (ii) Enhanced Livelihood; (iii) Improved Quality of Life; (iv) Decentralized Development; (v) Sustained Ecosystem; and (vi) Empowered People	N		- No impact assessment of measures/strategies undertaken in this update

IWRM Activities	Activity tasks	JICA			NEDA-III		
		Y/N	Section	Details	Y/N	Section	Details
Comparison Strategies	- Evaluation carried out to rank the strategies and/ or determine the preferred strategy - Evaluation method used			Prioritisation informed scheduling of projects in the short, medium and long term, but all actions included in the plan.	N		- No comparison undertaken in this update
Allocation Planning	- Decisions on which user(s) will get priority in certain instances when shortages will occur - Computational framework developed in the situation analysis can be used to decide on the preferred allocation	Y	Vol.II - Chapter 9.7 Vol.II - Chapter 6.7	- Water resources allocation identified as an issue in the basin; however, no allocation planning undertaken as part of the IWRM plan - 4 conceptual projects included in the plan to: (i) improve groundwater monitoring (ii) commence study to develop new water resources and decrease demands in Angat-Umiray system (Metro Manila) (iii) improve surface water monitoring (iv) develop relevant agency capacity in water allocation distribution	N		- None undertaken in this update
Adaptive management	- Adaptive management approach incorporating future uncertainties in boundary conditions in the designs and make them part of a dynamic strategy	N		- No adaptive planning approach utilised in the preparation of the IWRM plan	N		- No adaptive management approach proposed in this update
Preferred strategy	- Preferred strategy by decision makers and stakeholders based on evaluation (e.g. via score cards)	Y	Vol.II - Chapter 7	- All identified projects were included in the plan. Impact assessment prioritisation via MCA informed scheduling of projects in the short, medium and long term, but all actions included in the plan.	Y	Vol.II - Chapter 4.6 Table 4-6	- All identified projects/strategies were included in the plan

IWRM Activities	Activity tasks	JICA			NEDA-III		
		Y/N	Section	Details	Y/N	Section	Details
Decision making on Strategy Building	- Interaction with the stakeholders and decision makers on strategy building	Y	Vol.II - Chapter 7.12 Vol.IV - Appendix-Minutes	Steering committee meeting informed by prior stakeholder consultation meeting	Y	Vol.II - Chapter 1 Figure 1-5	- Decisions taken by PMC following strategy formulation activities in stakeholder Technical Working Groups
Step IV & V - Action Planning and Implementation							
Action Planning	- Concrete actions performed once the preferred strategy has been selected	Y/N	Vol.II - Chapter 11 Vol.II - Chapter 12 Vol.II - Chapter 13	- Elaboration of specific strategies not present. - Investment plan for each focus topic prepared, including projected investment needs in the short-, mid- and long-term for the responsible agencies. - Institutional framework developed, including laws/regulations to be amended, organisational capacity development identified for the implementation of the IWRM plan as a whole. - Preliminary environmental and social impacts assessment undertaken for the plan - Formulation of monitoring framework	Y/N	Vol.II - Chapter 4.6	- Elaboration of specific strategies not present - Priority Investment Program formulated (typically measures all to be implemented in the short-term <5 years)
Investment Planning	- Financing schemes, dependent on type and size of measure. - Investment plan showing recurrent costs, payment	Y	Vol.II - Chapter 11 Vol.II - Table 11.3.7 Vol.II - Table 11.3.8	- Investment needs for all on-going and proposed projects specified for responsible agencies (70% from national budget, via DPWH) - Short-, mid- and long-term investment needs specified	Y	Vol.II - Chapter 4.6	Project profiles were prepared indicating project: - location, - sub/sub-sector, - executing agency and - other details (funding source, implementation schedule, total cost, objectives, description)

IWRM Activities	Activity tasks	JICA			NEDA-III		
		Y/N	Section	Details	Y/N	Section	Details
Feasibility Study and EIA	- Feasibility studies to be undertaken, i.e. more detailed studies of the projects (measures) proposed in the RBP	N	Vol.II - Chapter 7-7.2.4 Vol.II - Chapter 13.3	- Feasibility study recommended for all projects, to be undertaken before commencement of physical project works - Screening of all projects for their possible negative environmental impacts - Environmentally Critical Projects (ECPs) provisionally assumed taking conceptual alternative approaches into account - Preliminary qualitative assessment for ECPs only	N		- No information presented in this update
Institutional Framework for Implementation	- Institutional framework to be applied to both Steps IV (Action Planning) and V (Implementation). - Assignment of projects to relevant agencies - Governance procedures and relationships - Updates to relevant legislation/regulations - Specification of new institutions (if required) - Capacity development requirements	Y	Vol.II - Chapter 12 Vol.IV - Sector L	- Institutional framework developed, including laws/regulations to be amended, organisational capacity development identified for the implementation of the IWRM plan as a whole -There are proposed countermeasures to empower existing and new institutions and /or organizations including legal, organizational and financial aspects	Y	Vol.II - Chapter 4.8	- Proposed countermeasures to empower existing and new institutions and /or organizations including legal, organizational and financial aspects
Promotion	- Project is promoted to selected stakeholders.	Y	Vol.II - Chapter 7.12	- Not specified in the plan beyond stakeholder consultation meetings undertaken during the planning process. - Planning reports made available to the relevant agencies.	Y		- Not specified in the plan beyond stakeholder meetings undertaken during the planning process. - Planning reports made available to the relevant agencies.

IWRM Activities	Activity tasks	JICA			NEDA-III		
		Y/N	Section	Details	Y/N	Section	Details
Implementation	- Implementation Plan consisting of: · Institutional framework · Implementation plan (who, what, how, etc., incl. financing) · Operational planning · Monitoring framework · Financial – economic consequences · Risks and risk management · Communication, public awareness and gender issues	Y/N	Vol.II - Chapter 11 Vol.II - Chapter 12	- NWRB recommendation to organize river basin organization - Phased implementation schedule for grouped projects were programmed in order of the priority order of projects - Prioritisation may be re-examined and modified when the development scenarios proposed are not accepted by stakeholders - No risk management plan - No communication, public awareness or gender analysis	Y	Vol.II - Chapter 4.6	- Priority Investment Program formulated only, with indicative costs for all measures
			Vol.II - Chapter 11	- Proposed implementation plan consisting of phasing of projects, project costs (initial and recurrent), and responsible agencies	N	Vol.II - Chapter 4.6	- Project Implementation schedule varies from 2012 to 2025
Monitoring			Vol.II - Chapter 13.4	- Recommended environmental impacts monitoring framework for construction phase for 5 environmental parameter categories: soil erosion, air quality, water quality, waste, noise and vibration - Recommended environmental impacts monitoring framework for operation phase for 3 environmental parameter categories: biodiversity, water quality and bottom sediment - No monitoring of other decision criteria and performance indicators specified	N	Vol.II - Chapter 4.8	- No monitoring framework specified, however, monitoring is being undertaken by the Pampanga River Basin Committee (PRBC). - No monitoring of other decision criteria and performance indicators specified

IWRM Activities	Activity tasks	JICA			NEDA-III		
		Y/N	Section	Details	Y/N	Section	Details
Evaluation	- Evaluation framework to evaluate project performance	N		- No specification of evaluation framework for the performance of the plan/projects	N	Vol.II - Chapter 4.8	- No specification of evaluation framework for the performance of the plan/projects - Recommendation for establishment of an M&E system to be implemented by a proposed River Basin Organisation

Appendix II: IWRM Measures Listed in IWRM Planning Documents

Table AII.1 lists all flood mitigation, hazard management and climate adaptation identified in the JICA and NEDA 3 planning documents. Measures of relevance to Nueva Ecija are highlighted in orange. The structural measures (darker shade of orange) are those which the project team has assessed to likely impact the road network in Nueva Ecija. In general, most of the structural measures identified in the JICA study are in the downstream areas of the PRB, with only two projects targeting flood control maintenance works for the Rio Chico branch. In the NEDA 3 update, additional structural measures have been identified of relevance to Nueva Ecija, including:

- Rehabilitation and strengthening of ring levees (e.g. in Arayat-Cabiao)
- Dredging and widening of critical river sections, construction of river training works, dikes and flood levees (e.g. for Rio Chico)
- River training works and slope stabilization of other rivers (e.g. Coronell, Talavera)
- Construction of segments of the North Luzon East Expressway and other highways
- Road widening and embankment heightening, provision of drainage systems for existing expressways and other roads

Table AII.1: Measures for flood mitigation, hazard management and climate adaptation listed in both JICA and NEDA 3 studies

Source	Measure Name	Description	Imple-mentation Schedule	Status	Implementing Agency	Province	Location	Type	System Focus		
									Phys.	SocEc.	Inst.
JICA	FL-G-01: Pinatubo Hazard Urgent Project (PHUMP) Phase III Part I	Flood mitigation by new structural measures to address insufficient structural capacity for flood mitigation	2011-2015	Completed	DPWH	Pampanga	San Fernando City, Mexico, Santo Tomas, Bacolor, Guagua, San Sasmuan, Floridablanca, Porac, Santa Rita and Lubao	Structural	Y	N	N
JICA	FL-G-02: Pinatubo Hazard Urgent Project (PHUMP) Phase III Part II	Flood mitigation by new non-structural measures to address increment of flood potential	2005-2015	Completed	DPWH	Pampanga	San Fernando City, Mexico, Santo Tomas, Bacolor, Guagua, San Sasmuan, Floridablanca, Porac, Santa Rita and Lubao	Non-Structural	N	Y	Y

Source	Measure Name	Description	Imple-mentation Schedule	Status	Implementing Agency	Province	Location	Type	System Focus		
									Phys.	SocEc.	Inst.
JICA	FL-G-03: Maintenance and Rehabilitation Works for River Dike and Slope	River channel maintenance and rehabilitation (dike slope protection, dike rehabilitation, and channel excavation & dredging) of Pampanga Main River Channel, Rio Chico River and Pasac river system as a regular program	2008-2014/ 2011-2015	On-going	DPWH	Pampanga, Nueva Ecija	Pampanga, Nueva Ecija	Structural	Y	Y	N
JICA	FL-G-04: Flood Forecasting and Warning System Capacity Building Project upon Dam Release in the Philippines for Pantabangan and Angat	Capacity building on flood forecasting and warning for the appropriate dam reservoir operation in Pampanga river basin as well as Agno and Cagayan River basin	2009-2025	On-going	PAGASA	NE, Bulacan	Pantabangan, Angat	Non-Structural	Y	Y	N
JICA	FL-P-01: Flood Control Measures in Pinatubo Devastated Area-Focus on Pasac delta	Flood mitigation by new structural measures to address insufficient structural capacity for flood mitigation	2009-2025	On-going (DE)	DPWH	Pampanga	Pasac	Structural	Y	N	N
JICA	FL-P-02: Bacolor Comprehensive Master Plan	Flood mitigation by new structural measures to address insufficient structural capacity for flood mitigation	2009-2015	Completed	LGU & DPWH	Pampanga	Bacolor	Structural	Y	Y	Y

Source	Measure Name	Description	Imple-mentation Schedule	Status	Implementing Agency	Province	Location	Type	System Focus		
									Phys.	SocEc.	Inst.
JICA	FL-C-01: Flood Mitigation for Pampanga Delta	Flood mitigation	2011-2020	Pre-investment (consultancy under procurement stage	DPWH	Pampanga	Pampanga Delta	Structural	Y	N	N
JICA	FL-C-02: Community Based Flood Early Warning System for Provinces of Pampanga, Tarlac and N. Ecija	Flood Early Warning System	2015	On-going (part of the regular program)	LGU	Pampanga, Tarlac, Nueva Ecija	Pampanga, Tarlac, Nueva Ecija	Non-structural	Y	N	N
JICA	FL-C-03: Maintenance, Rehabilitation and Improvement for Drainage and Flood Control Facilities under Jurisdiction of LGUs	River channel maintenance and rehabilitation (dike, slope protection, dike rehabilitation, and channel excavation and dredging) of Pampanga Main River Channel, Rio Chico River and Pasac River System as regular maintenance	2008-2025	On-going	LGU's	Pampanga, Tarlac, Nueva Ecija	Pampanga, Tarlac, Nueva Ecija	Structural	Y	N	N
JICA	FL-C-04: Integration of Salient Points of IWRM for Pampanga River Basin into School Curricula	Flood mitigation	2011-2025	On-going	DE-Region III	Bulacan, Pampanga, Tarlac, Nueva Ecija	Pampanga River Basin	Non-structural	N	Y	Y

Source	Measure Name	Description	Imple-mentation Schedule	Status	Implementing Agency	Province	Location	Type	System Focus		
									Phys.	SocEc.	Inst.
NEDA 3	Flood Mitigation for Pampanga Delta (PDDP-FC Phase II)	Continuation of the PDDP - FC Phase I. It has the following components: a. river training works for Labangan floodway b. establishment of Calumpit-Plaridel low water channel training works and setback levee development c. establishment of Calumpit-Masantol low water channel training works and setback levee development d. intown resettlement of project affected communities	2018-2022	Not started	DPWH	Pampanga, Bulacan	Macabebe, Apalit, San Simon, Calumpit, Hagonoy	Structural	Y	Y	N
NEDA 3	South Candaba Swamp Flood Control Project (PDDP-FC Phase III)	Establishment of flood control structures, establishment of a temporary floodwater retarding basin, and river training works in South Candaba Swamp.	2018 - 2021	Not started	DPWH	Pampanga	Candaba, Pampanga	Structural	Y	Y	N
NEDA 3	North Candaba Swamp Flood Control Project	Establishment of flood control structures, establishment of a temporary floodwater retarding basin, and river training works in North Candaba Swamp.	2018-2021	Not started	DPWH	Pampanga	Candaba, Pampanga	Structural	Y	Y	N
NEDA 3	Strengthening of Arayat-Cabiao Ring Levee	Rehabilitation and strengthening of ring levee in the municipalities of Arayat, Pampanga and Cabiao, Nueva Ecija.	2018 – 2020		DPWH	Pampanga, Nueva Ecija	Arayat, Pampanga and Cabiao, Nueva Ecija	Structural	Y	Y	N

Source	Measure Name	Description	Imple-mentation Schedule	Status	Implementing Agency	Province	Location	Type	System Focus		
									Phys.	SocEc.	Inst.
NEDA 3	Strengthening of Masantol-Macabebe-Arayat Setback Levee	Establishment of flood control structures and river training works with the following components: a. establishment of Masantol-Macabebe-Arayat low water channel training works and setback levee development b. road dike development c. local bridge construction d. onsite resettlement of project affected communities	2018 - 2020		DPWH	Pampanga	Masantol, Macabebe, and Arayat, Pampanga Sector	Structural	Y	Y	N
NEDA 3	Abacan Corridor Integrated Urban Renewal and Urban Flood Risk Reduction Project	Establishment of flood control structures and river training works with the following components: a. establishment of low water and high-water river training works b. road dike development c. establishment of riverine recreational & mixed-use parks d. in-city resettlement of project affected communities			DPWH	Pampanga	Pampanga	Structural	Y	Y	N

Source	Measure Name	Description	Imple-mentation Schedule	Status	Implementing Agency	Province	Location	Type	System Focus		
									Phys.	SocEc.	Inst.
NEDA 3	Rehabilitation Program for Pampanga Delta Development Project (PDDP) Phase I	Establishment of flood control structures and river training works with the following components: a. establishment of low water and high-water river training works b. road dike with settlement development c. on-site resettlement of project affected communities	2018 - 2021		DPWH	Pampanga	Pampanga	Structural	Y	Y	N
NEDA 3	Rio Chico River Flood Control Project	i) Dredging and widening of critical portions of the river network, ii) construction of river training works and slope stabilization structures, iii) construction of dikes and flood levees.	2018 - 2022		DPWH Unified Project Management Office-Flood Control Management Cluster (UPMO-FCMC/MPE)	Nueva Ecija	Rio Chico, NE	Structural	Y	Y	N
NEDA 3	Tarlac River Overall Improvement Works	i) Dredging and widening of critical portions of the river network, ii) construction of river training works and slope stabilization structures, and iii) establishment of dikes and flood levees.	2018-2022		DPWH	Tarlac	Tarlac	Structural	Y	Y	N
NEDA 3	Dinalupihan-Hermosa Flood Control Project	Channelling Works and diking with slope protection works of about 2,683 km.	2016-2018	Not started	DPWH	Batan	Bataan	Structural	Y	Y	N

Source	Measure Name	Description	Imple-mentation Schedule	Status	Implementing Agency	Province	Location	Type	System Focus		
									Phys.	SocEc.	Inst.
NEDA 3	Coronell River Integrated Flood Control Project (The project involves river training works, slope stabilization and construction of roads and bridges)	River training works, slope stabilization and construction of roads and bridges	2018 – 2020	Not started	DPWH	Nueva Ecija	Nueva Ecija	Structural	Y	Y	N
NEDA 3	Strengthening Flood Forecasting and Warning System in Pampanga River Basins Project	Upgrading existing flood forecasting and warning system (FFWS) Pampanga river basin to include the following components: i) Expansion of coverage to include the entire Central Luzon Region, ii) Capacity building of partner agencies and local government units, iii) Installation of automated weather stations, iv) Upgrading of FFWS equipment and facilities, and v) Hiring of additional staff	2018 – 2020		DOST-PAGASA	Bulacan, Pampanga, Nueva Ecija, Tarlac	Bulacan, Pampanga, Nueva Ecija, Tarlac	Non-structural	N	Y	N

Source	Measure Name	Description	Imple-mentation Schedule	Status	Implementing Agency	Province	Location	Type	System Focus		
									Phys.	SocEc.	Inst.
NEDA 3	Almacen River Improvement	i) dredging and widening of critical portions of the river network, ii) construction of river training works, slope stabilization structures, and dikes.	2015-2021		DPWH Unified Project Management Office-Flood Control Management Cluster (UPMO-FCMC/MPE)	Bataan	Bataan	Structural	Y	Y	N
NEDA 3	Flood Control Works in Porac-Gumain, San Fernando River, Lubao, Sasmuan, Guagua and City of San Fernando	Slope Protection works, widening of existing evacuation road with slope protection of about 11.643 km.	2016-2017		DPWH Unified Project Management Office-Flood Control Management Cluster (UPMO-FCMC/MPE)	Pampanga	Pampanga	Structural	Y	Y	N
NEDA 3	Flood Control Works-Sacobia-Bamban-Abacan River Training Works	Diking, sheet piling with slope protection works of about 2.979km.			DPWH	Pampanga and Tarlac	Pampanga and Tarlac	Structural	Y	Y	N

Source	Measure Name	Description	Imple-mentation Schedule	Status	Implementing Agency	Province	Location	Type	System Focus		
									Phys.	SocEc.	Inst.
NEDA 3	Integrated DRR and CCA Measures in Low Lying Areas of Pampanga Bay Project	The rivers of interest in the project include four rivers: Third River, Eastern Branch, Caduang Tete River and Sapang Maragul River. The scope of the project includes the following: - Clearing and grubbing 873,600 sqm - Channel Excavation/Embankment 509,127 cubic meter - Dredging 1,886,313 cubic meter - Ground sill is lumpsum - Diversion from left bank is 1 km - Embankment from right bank is 5 km	2014-2019		DPWH	Pampanga	Pampanga	Structural	Y	Y	N
NEDA 3	Community Based Early Warning System for Pampanga River Basin	Establishment of an interprovincial network of community-based early warning system in the entire river basin.		On-going	Provinces and LGUs	Bulacan, Pampanga, Tarlac, and Nueva Ecija	Bulacan, Pampanga, Tarlac, and Nueva Ecija	Non-structural	N	Y	N
NEDA 3	Cabiao-San Isidro-Gapan-San Antonio Flood Control Project	Establishment of flood control structures and river training works with the following components: a. establishment of San Antonio Swamp ring dike b. establishment of Cabiao-San Isidro-Gapan low water channel training works and setback levee development	2018 – 2021	Not started	DPWH	Nueva Ecija	Nueva Ecija	Structural	Y	Y	N

Source	Measure Name	Description	Imple-mentation Schedule	Status	Implementing Agency	Province	Location	Type	System Focus		
									Phys.	SocEc.	Inst.
NEDA 3	Talavera River Flood Control Project	i) Dredging and widening of critical portions of the river network, ii) construction of river training works, slope stabilization structures, and dikes.	2018 – 2021	Not started	DPWH	Nueva Ecija	Nueva Ecija	Structural	Y	Y	N
NEDA 3	Rehabilitation and widening of connecting roads leading to and from tollway exits, entries, and interchanges in NLEx, SCTEx, and TPLEx Project	Widening, provision of drainage systems, traffic lights and signals, geometric improvement works, and right of way clean-up.	2009 – 2020	On-going	DPWH	Bulacan, Pampanga, Nueva Ecija, and Tarlac	Bulacan, Pampanga, Nueva Ecija, and Tarlac	Structural	Y	Y	N
NEDA 3	Cagayan Valley Road Widening and Rehabilitation Project	Widening and embankment heightening, provision of drainage systems, traffic lights and signals, geometric improvement works, and right of way clean-up	2019 – 2023	Not started	DPWH	Bulacan, Pampanga, and Nueva Ecija	Bulacan, Pampanga, and Nueva Ecija	Structural	Y	Y	N
NEDA 3	MacArthur Highway Redevelopment Project	Improvement/ rehabilitation/ upgrading of the highway including bridges from Bulacan to Tarlac	2005-Continuing		DPWH	Bulacan, Pampanga and Tarlac	Bulacan, Pampanga and Tarlac	Structural	Y	Y	N
NEDA 3	DPWH-DOT Tourism Road Infrastructure Project (TRIP)	Improvement/Widening/Reconstruction of roads, canals, bridges of the identified tourism infrastructure	2012 - 2016		DPWH	Regionwide	Regionwide	Structural	Y	Y	N

Source	Measure Name	Description	Imple-mentation Schedule	Status	Implementing Agency	Province	Location	Type	System Focus		
									Phys.	SocEc.	Inst.
NEDA 3	DPWH-DTI Roads Leveraging Linkages for Industry and Trade (ROLL-IT) Project	Industry-developing infrastructure projects in priority economic and manufacturing zones in the Philippines.	2016 - 2020		DPWH	Regionwide/ Nationwide	Regionwide /Nationwide	Structural	Y	Y	N
NEDA 3	Arterial Road Bypass Project Phase III	Full development of the existing 2-lane Plaridel bypass road into 4-lanes road bypass from NLEx in Balagtas Bulacan to Cagayan Valley Road in San Rafael, Bulacan. It has the following components: construction of an additional two-lane road, construction of bridges, establishment of animal crossings.	2018 – 2022		DPWH	Bulacan	Bulacan	Structural	Y	Y	N
NEDA 3	San Jose Del Monte - San Rafael - Candaba Inter-urban Road Project	Widening, provision of drainage systems, traffic lights and signals, geometric improvement works, and right of way clean-up.	2019 – 2025	Not started	DPWH	Bulacan and Pampanga	Bulacan and Pampanga	Structural	Y	Y	N
NEDA 3	Gapan-San Fernando-Olongapo Road Improvement Project	Road expansion from 2 lanes to 4 lanes. The project involves widening, provision of drainage systems, traffic lights and signals, geometric improvement works, and right of way clean-up	2018 – 2022	Not started	DPWH	Pampanga and Nueva Ecija	Pampanga and Nueva Ecija	Structural	Y	Y	N
NEDA 3	Angeles-Dinalupihan Road Rehabilitation Project	Widening, provision of drainage systems, traffic lights and signals, geometric improvement works, and right of way clean-up.	2018 - 2022	Not started	DPWH	Pampanga and Bataan	Pampanga and Bataan	Structural	Y	Y	N

Source	Measure Name	Description	Imple-mentation Schedule	Status	Implementing Agency	Province	Location	Type	System Focus		
									Phys.	SocEc.	Inst.
NEDA 3	Central Luzon Link Expressway (CLLEx) Project	To improve transportation between Metro Manila and Central Luzon by expanding Subic-Clark-Manila-Batangas Corridor northward through the construction of an expressway connecting Tarlac and Cabanatuan, thereby contributing to the promotion of industrial space and economic development in the northern part of Luzon.	2013 - 2020	Not started	DPWH-Roads Management Cluster1Bilateral-Unified Project Management Office (DPWH-RMC1-UPMO)	Tarlac and Nueva Ecija	Tarlac and Nueva Ecija	Structural	Y	Y	N
NEDA 3	North Luzon East Expressway (NLEE)	Construction of new 91.10 km., 4-lane expressway which consists of 4 segments: Segment 1: Bigte-San Miguel-Jct. Biak na Bato Road - 30.91 kms. Segment 2: San Miguel-Jct. Biak na Bato Road-Gapan City-Jct. Fort Magsaysay Road - 30.56 kms. Segment 3: Gapan City-Jct. Fort Magsaysay Road-Cabanatuan City-Jct. Palayan City Road - 17.64 kms. Segment 4: Cabanatuan City-Jct. Palayan City Road-Central Luzon Link Expressway (CLLEX Ph 2) - 11.99 kms.	2021 – 2027	Not started	DPWH	Bulacan and Nueva Ecija	Bulacan and Nueva Ecija	Structural	Y	Y	N
NEDA 3	Sto. Tomas-Dinalupihan-North Luzon expressway (NLEx) Spur Road	A new interchange in Sto. Tomas, traversing Minalin, Sasmuan, Lubao and merge with SCTEx in Dinalupihan.	2018 – 2022	Not started	DPWH	Pampanga and Bataan	Pampanga and Bataan	Structural	Y	Y	N

Source	Measure Name	Description	Imple-mentation Schedule	Status	Implementing Agency	Province	Location	Type	System Focus		
									Phys.	SocEc.	Inst.
NEDA 3	NLEx-SCTEx Connector Road in Angeles City	Construction of a new road link connecting the Subic-Clark-Tarlac Expressway (SCTEx) to the North Luzon Expressway (NLEx) passing through the Abacan Riverbank located in Angeles City.	2018 - 2020	Not started	DPWH	Angeles City	Angeles City	Structural	Y	Y	N
NEDA 3	Clark International Airport Development Project	Construction of 82,200 sqm. new passenger terminal building (PTB) to accommodate 3-8 million passengers per annum (MPPA), to be implemented in two phases. Alos, construction of: (i) landside facilities such as main access road, passenger car park, taxi buffer and bus station, (2) airside facilities such as apron, taxiway, and shoulder surface to support the operations of the PTB, and (3) facilities integrating the existing PTB with the New PTB.	2016 - 2020		Department of Transportation (DOTr) and Clark International Airport Corporation (CIAC)	Pampanga	Pampanga	Structural	Y	Y	N
NEDA 3	New Clark City Development Project	Development of a 9,450-hectare smart, green and disaster-resilient city	2019 - 2028	Not started	Bases Conversion Development Authority (BCDA)	Pampanga and Tarlac	Pampanga and Tarlac	Structural	Y	Y	N

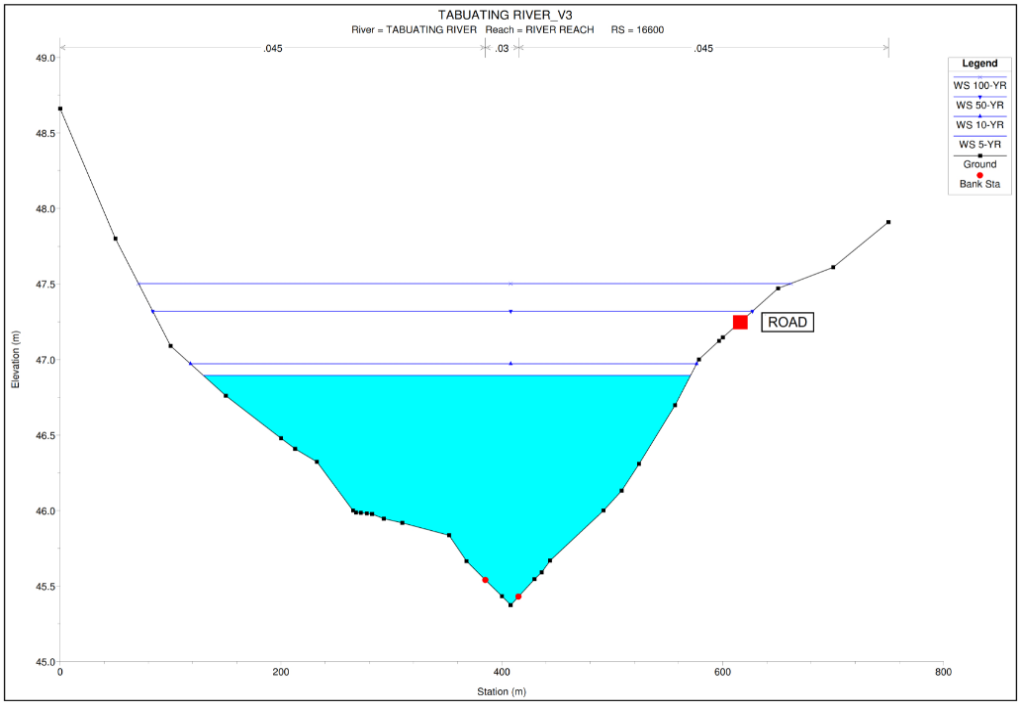
Source	Measure Name	Description	Imple-mentation Schedule	Status	Implementing Agency	Province	Location	Type	System Focus		
									Phys.	SocEc.	Inst.
NEDA 3	Integrated Command Center Project for Major Urban Centers in PRB	Establishment of high definition CCTV command centres with data analytics technology for traffic management, peace and order monitoring, and disaster risk management. It has the following components: a) Metro Clark b) Malolos City c) Tarlac City d) Cabanatuan City e) Gapan City f) San Jose City	2019 – 2022	Not started	LGU	Urban Areas in PRB	Urban Areas in PRB	Non-structural	Y	Y	N
NEDA 3	Water-sensitive urban development initiatives project	Implementation of water-sensitive urban development initiatives with the following key components: i) Household rainwater harvesting facilities; ii) Porous and permeable pavements; iii)Rainwater percolation intakes; iv) Local creeks and water channel restoration activities; v) Waterway clean-up activities; and, vi) Inclusion of water-sensitive urban development policies in the CLUPs and ZOs of LGUs.	-	Not started	DPWH	Urban Areas in PR	Urban Areas in PRB	Structural /Non-structural	Y	Y	N
NEDA 3	Solar Farms in Bamban and Concepcion Area	Establishment of a 300 MW solar farm in marginal agricultural lands	2019 - 2021	Not started	DPWH	Bamban and Concepcion, Tarlac	Bamban and Concepcion, Tarlac	Structural	Y	Y	N

Source	Measure Name	Description	Imple-mentation Schedule	Status	Implementing Agency	Province	Location	Type	System Focus		
									Phys.	SocEc.	Inst.
NEDA 3	Power Transmission (Bataan to Mexico)	Construction of Mexico-Clark Transmission/Bataan-Mexico transmission line.	2019 – 2023	Not started	National Grid Corp. of the Philippines (NGCP)	Bataan and Mexico	Bataan and Mexico	Structural	Y	Y	N
NEDA 3	Manila – Clark Railway Project	The 106 – km railway project will link Tutuban in Manila with Clark Freeport Zone (CFZ) in Pampanga passing through several towns in Bulacan	2018 - 2021	Not started	DOTr	Bulacan and Pampanga	Bulacan and Pampanga	Structural	Y	Y	N
NEDA 3	Manila Bay Bridge Project	Construction of a 20 kilometre (km) bridge from Mariveles, Bataan passing through Corregidor Island and going to Naic, Cavite.	2018 - 2024	Not started	DPWH	Bataan	Bataan	Structural	Y	Y	N

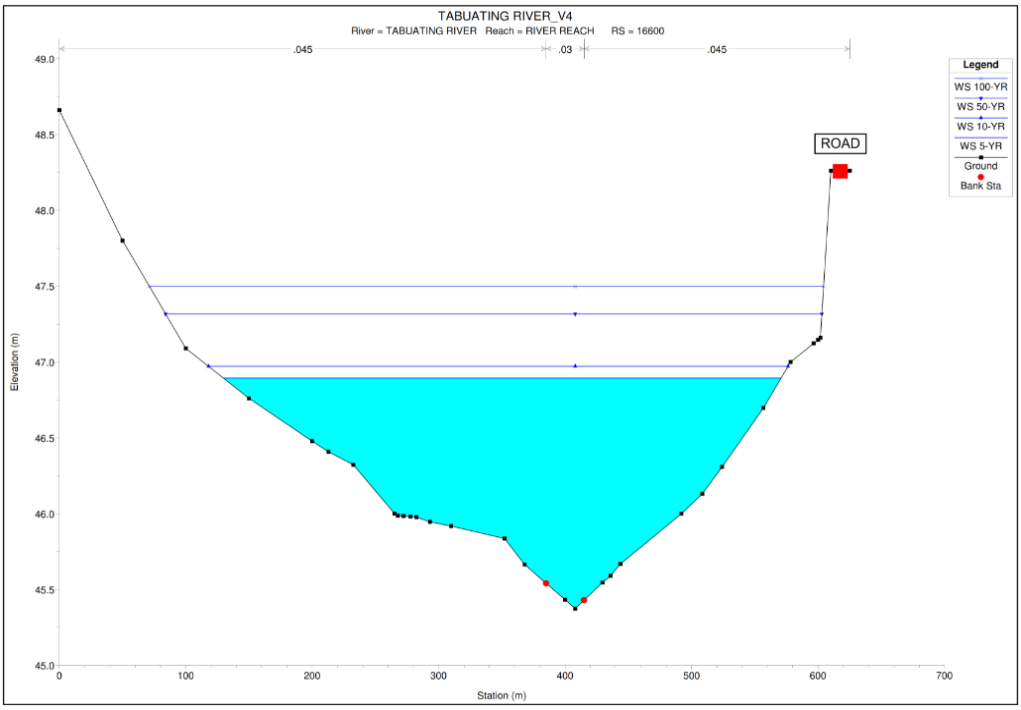
Appendix III: Tabualing River HEC-RAS Modelling Results

AIII.1 - TABUALING HEC-RAS OUTPUTS FOR LOCATION 1- Sta. 16+600

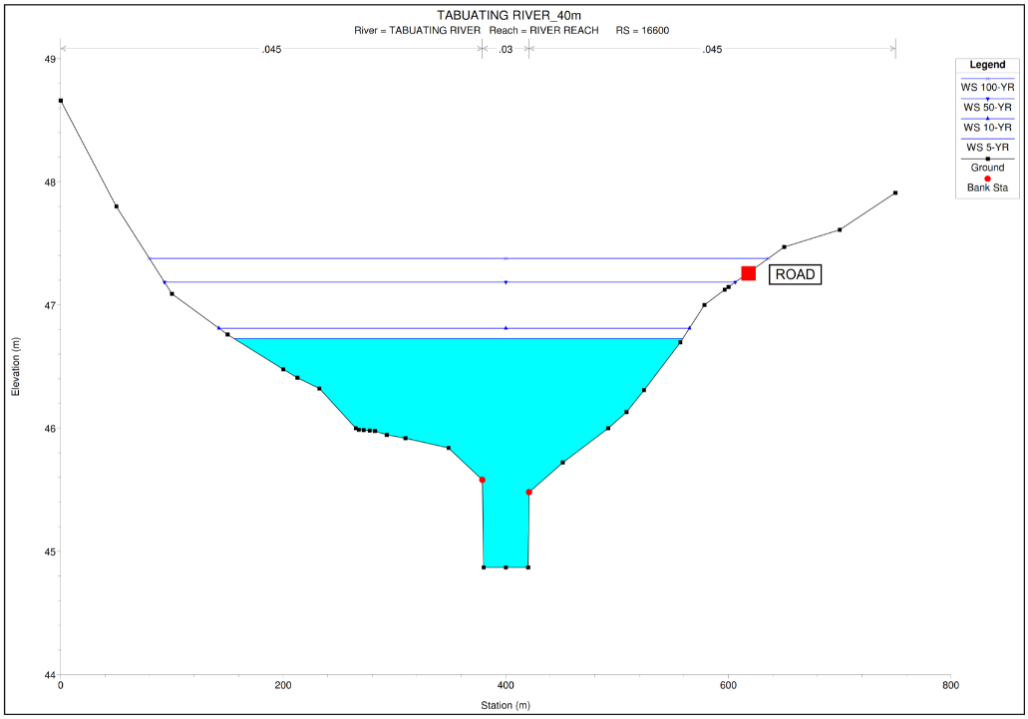
No Measures (Without Climate Change)



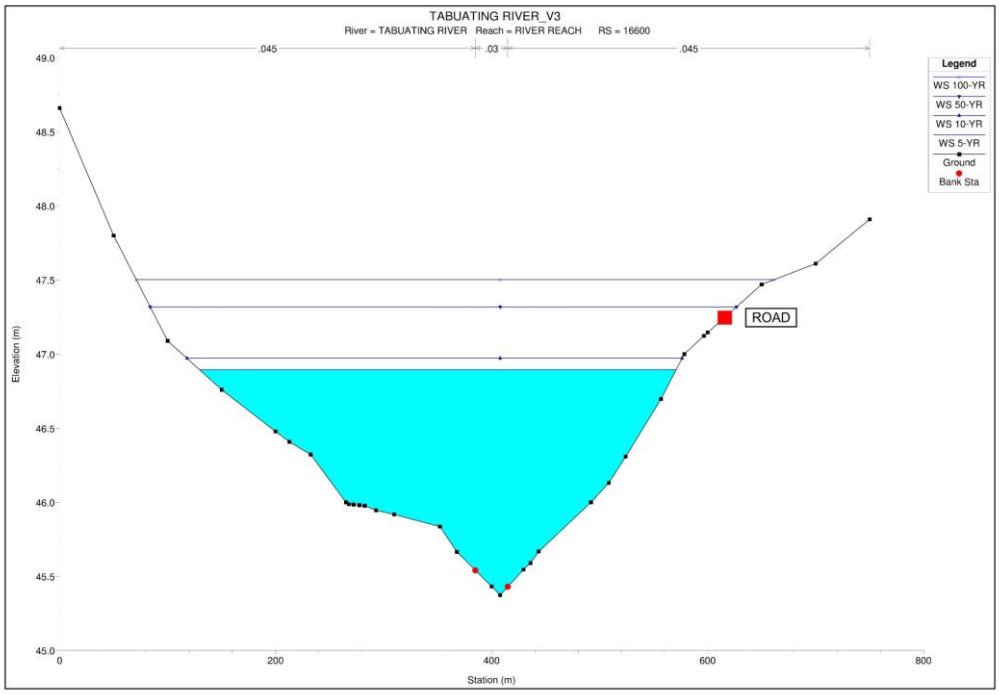
Measure 1- Elevated Road (Without Climate Change)



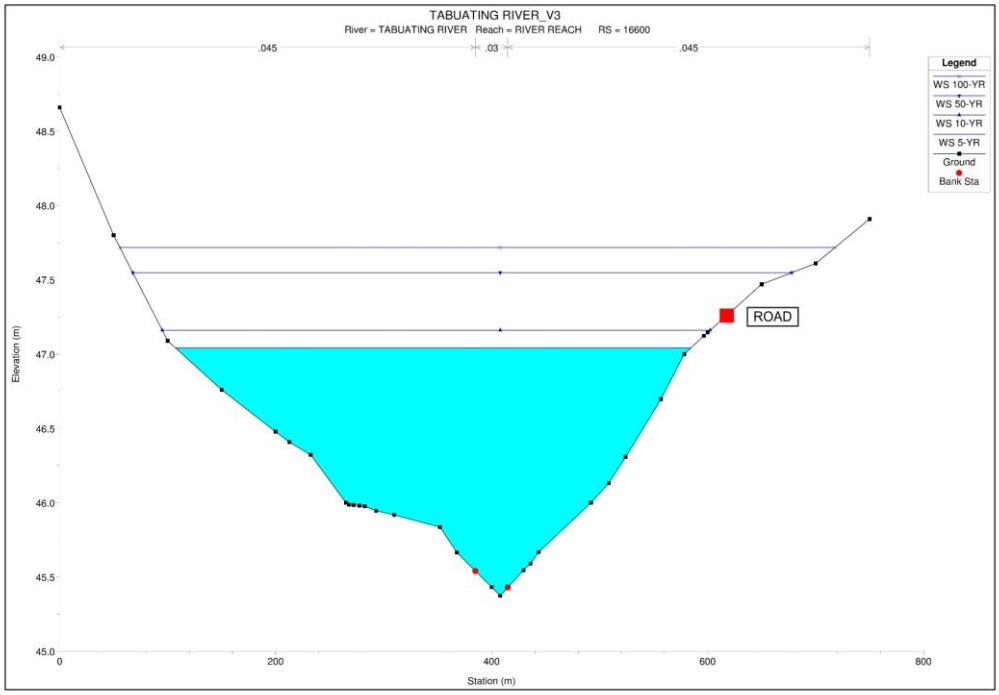
Measure 2- With Dredging (Without Climate Change)



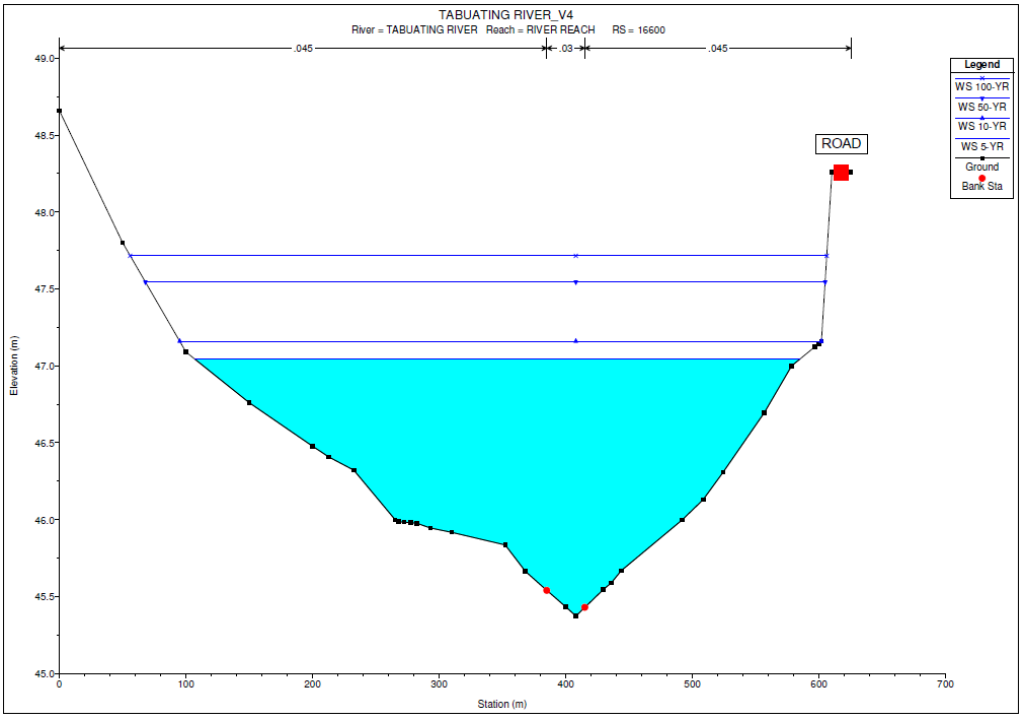
Measure 3- With Retention/ Detention (Without Climate Change)



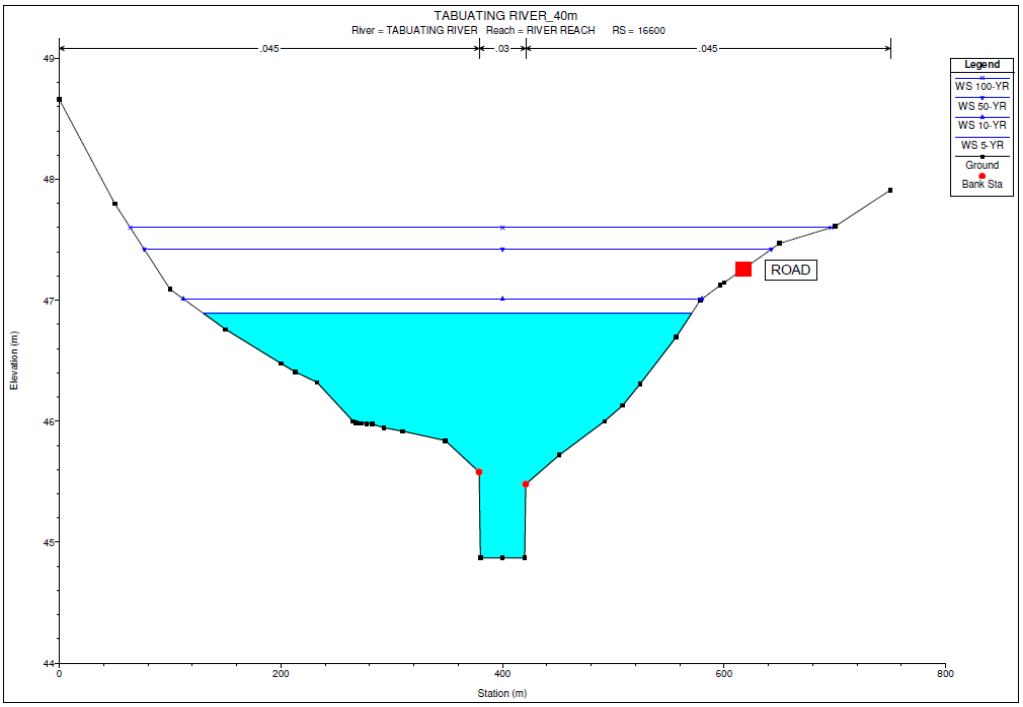
No Measure- (High Climate Change to 2050)



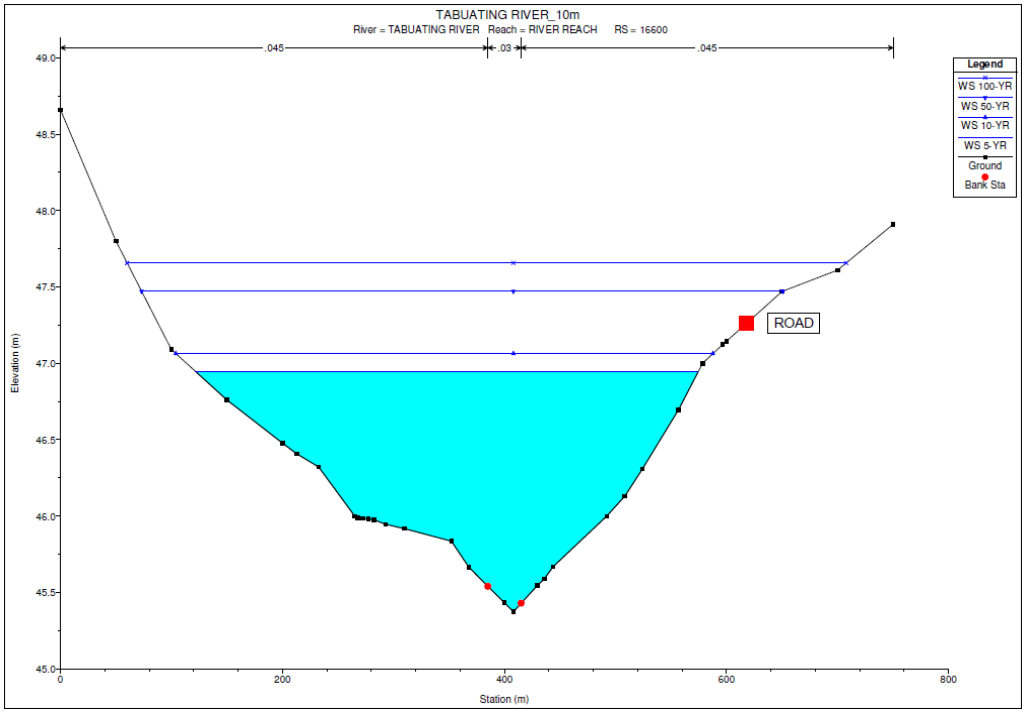
Measure 1- Elevated Road (High Climate Change to 2050)



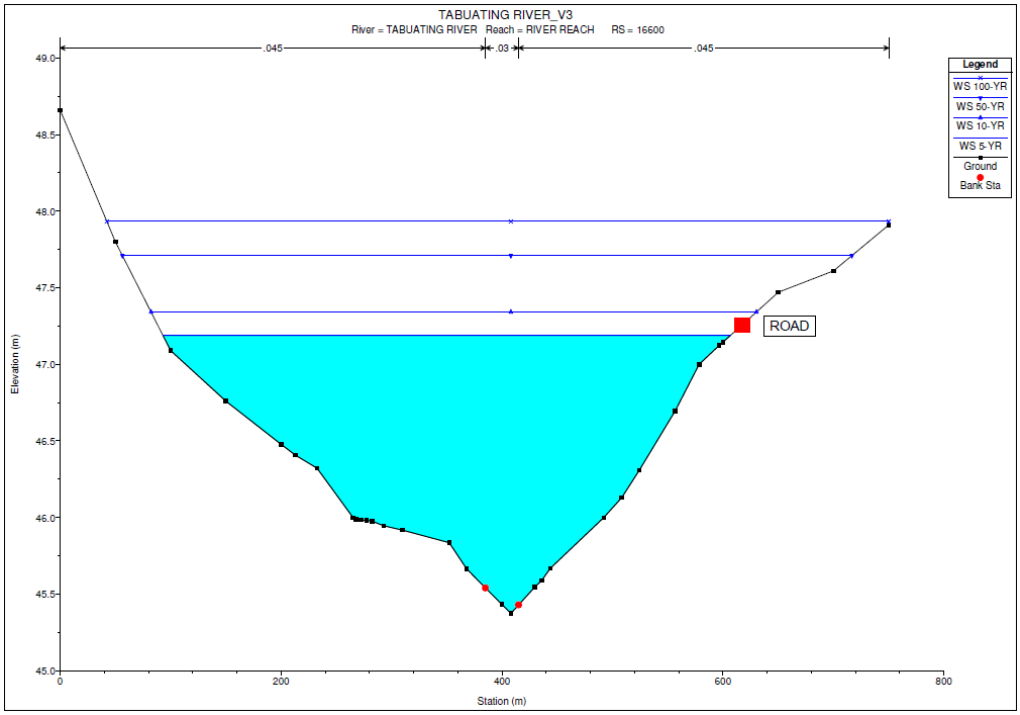
Measure 2- With Dredging (High Climate Change to 2050)



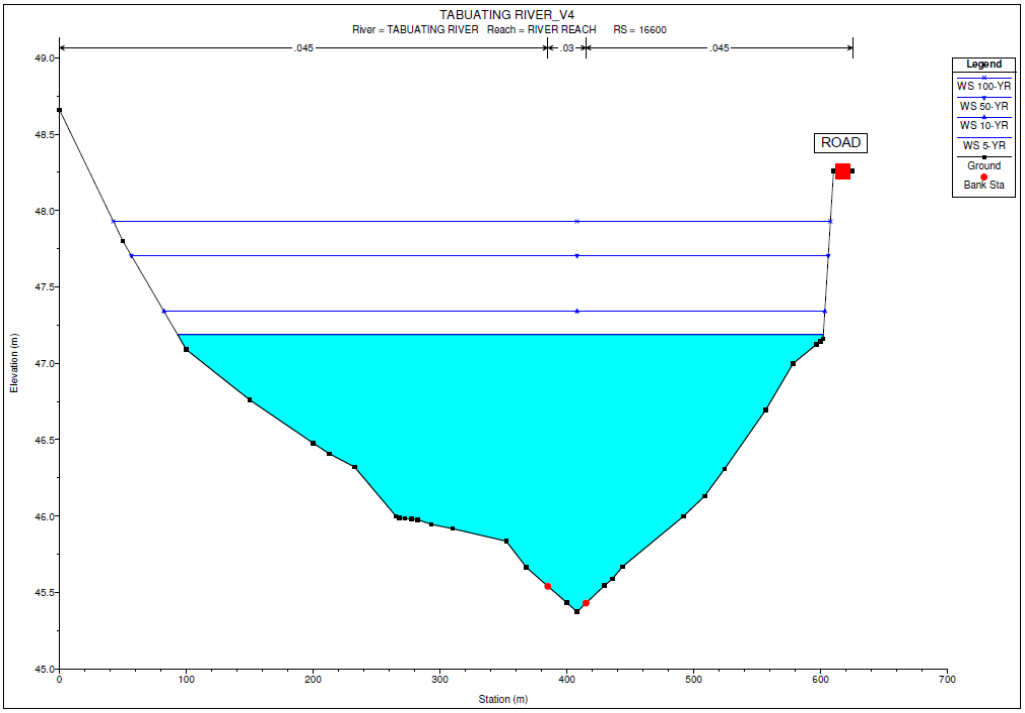
Measure 3- With Retention/ Detention (High Climate Change to 2050)



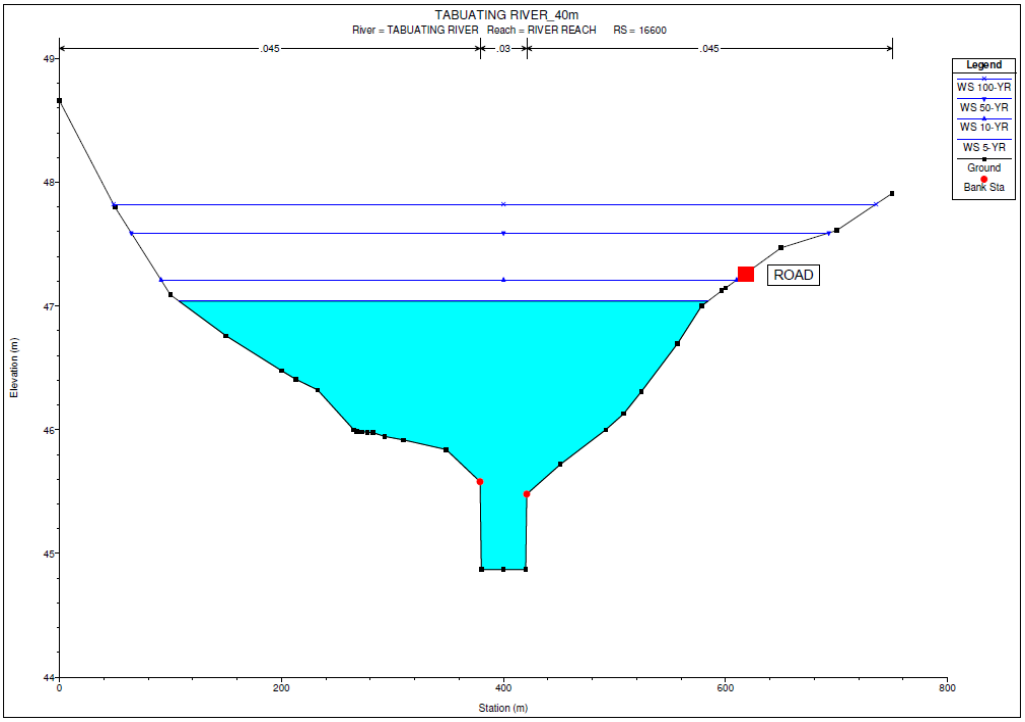
No Measure- (High Climate Change to 2100)



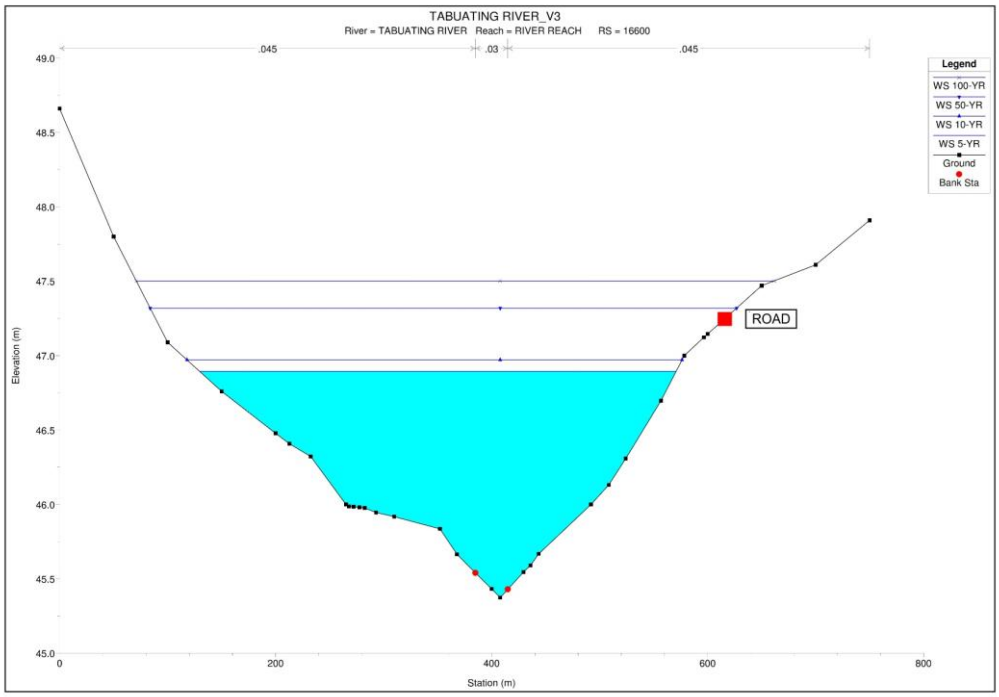
Measure 1- Elevated Road (High Climate Change to 2100)



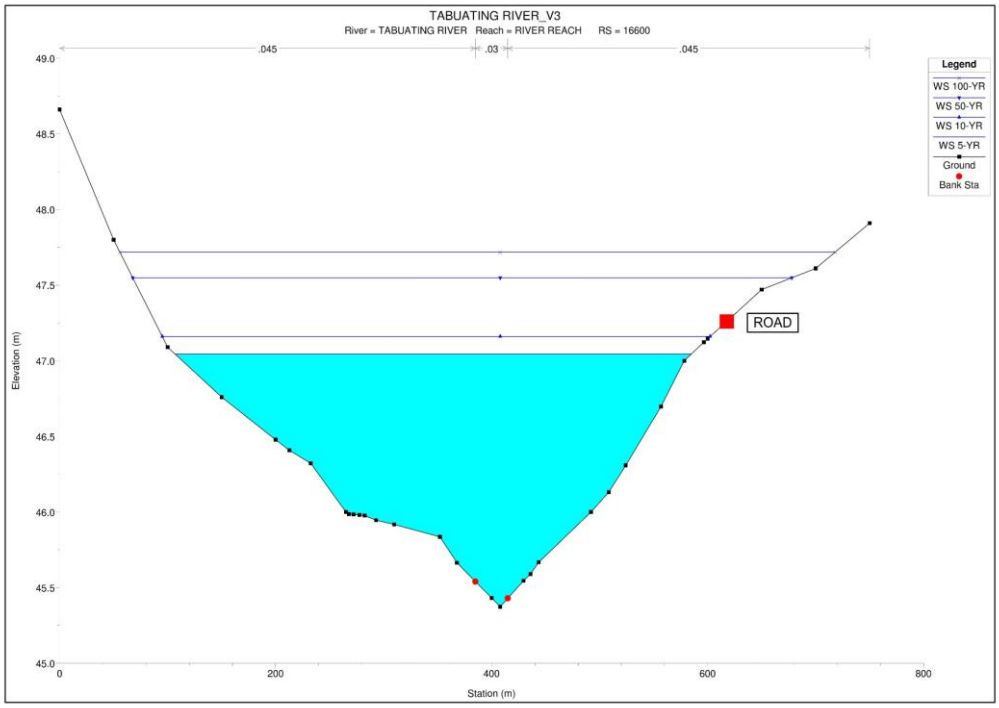
Measure 2- With Dredging (High Climate Change to 2100)



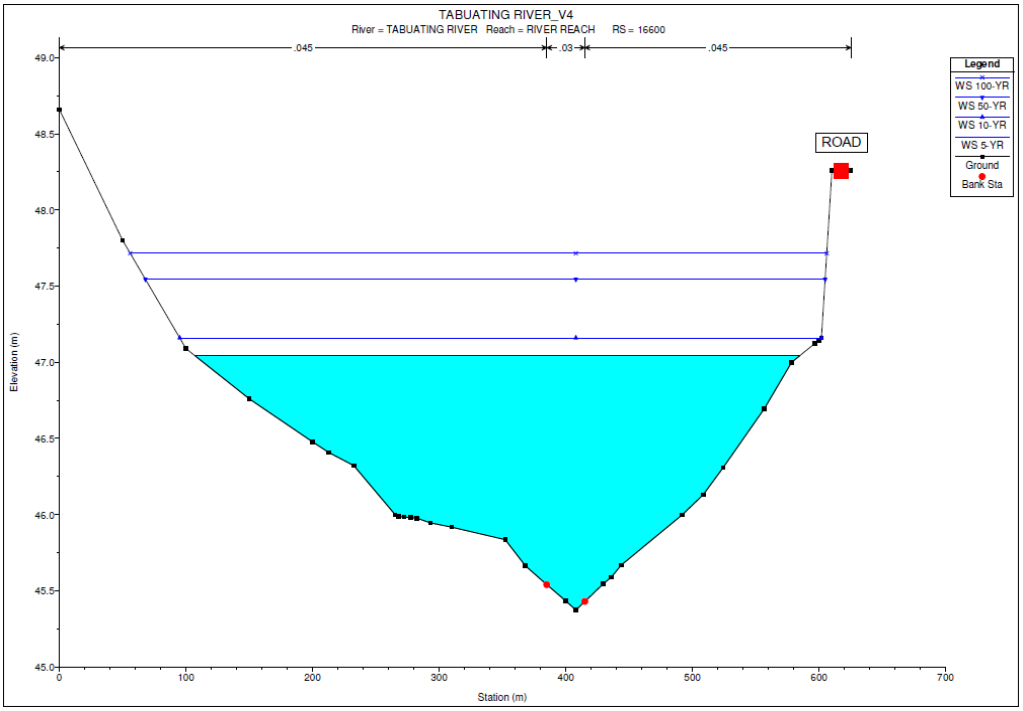
Measure 3- With Retention/ Detention (High Climate Change to 2100)



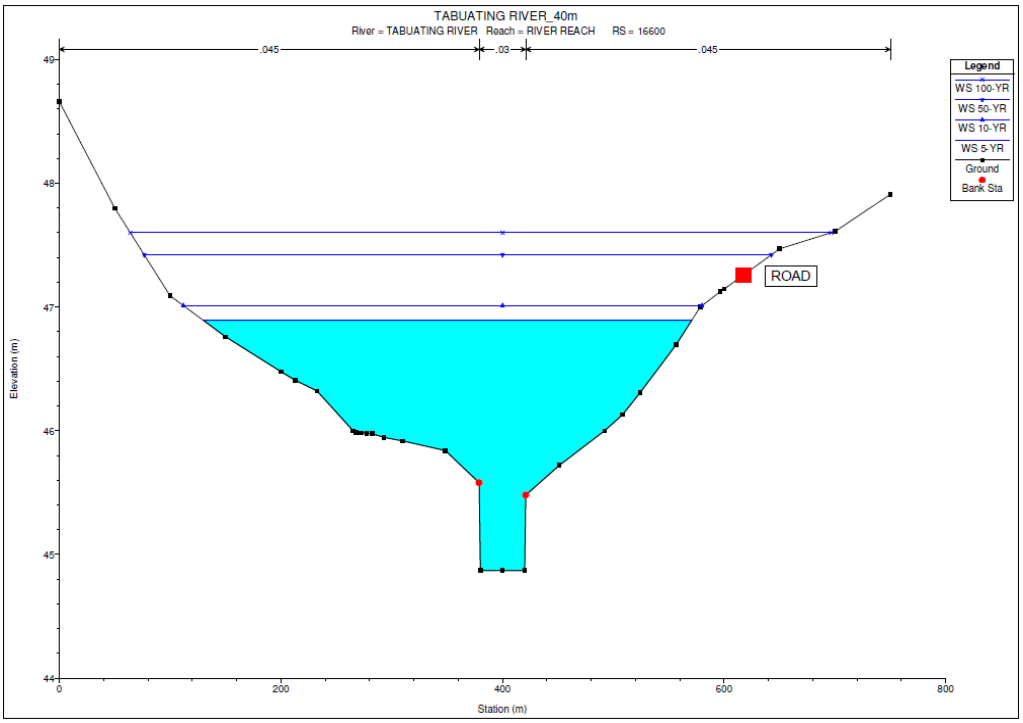
No Measure- (High Climate Change to 2050)



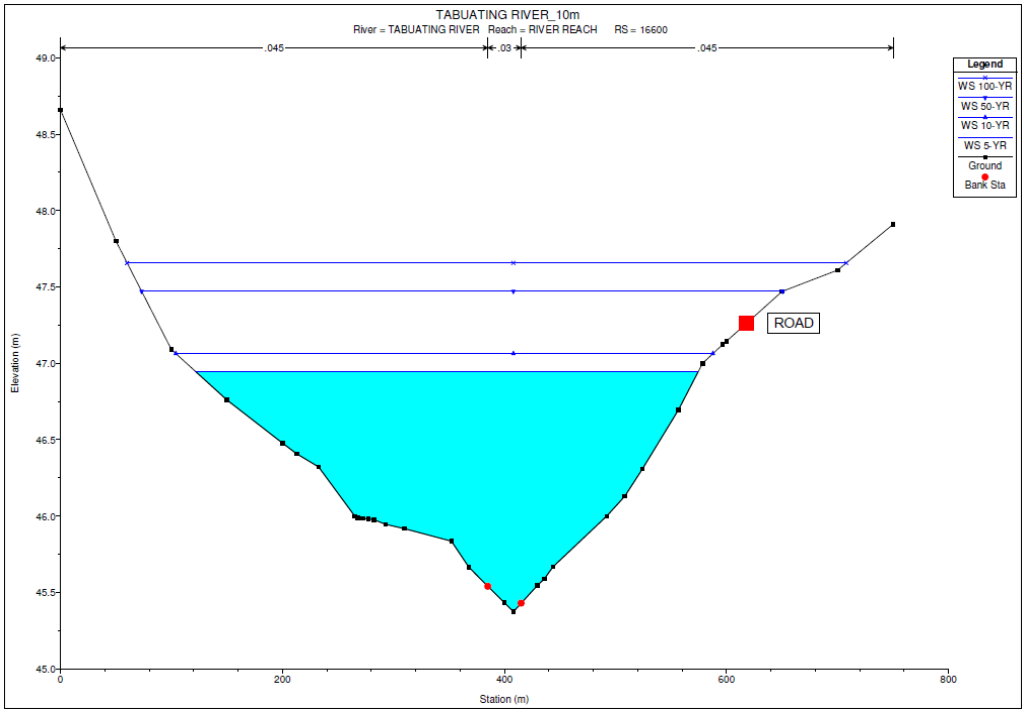
Measure 1- Elevated Road (High Climate Change to 2050)



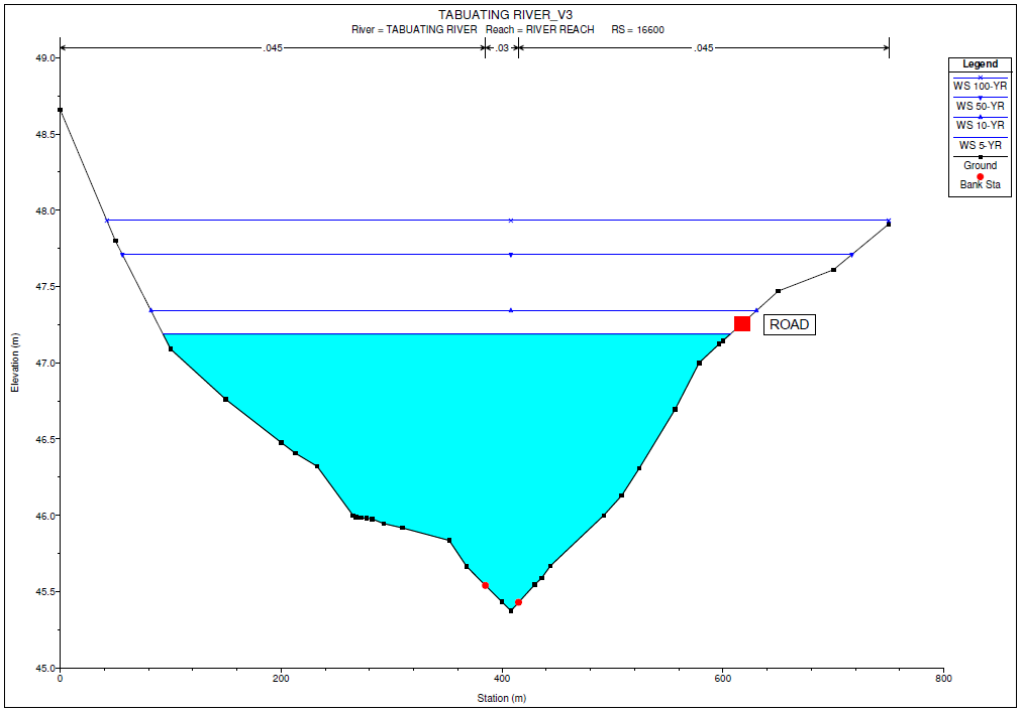
Measure 2- With Dredging (High Climate Change to 2050)



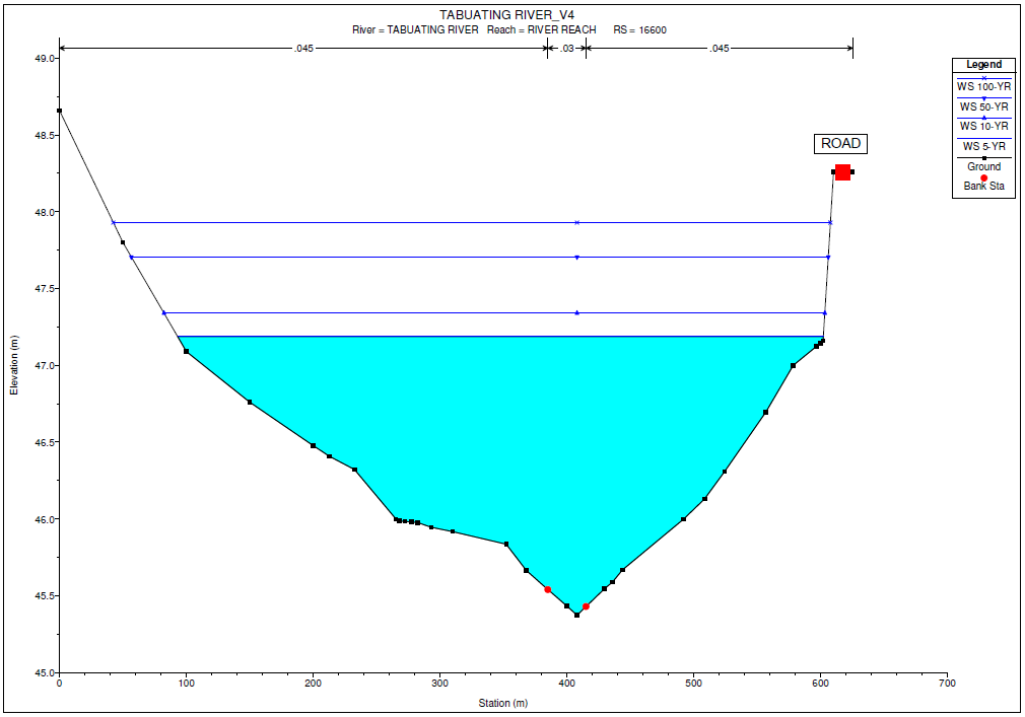
Measure 3- With Retention/ Detention (High Climate Change to 2050)



No Measure- (High Climate Change to 2100)



Measure 1- Elevated Road (High Climate Change to 2100)



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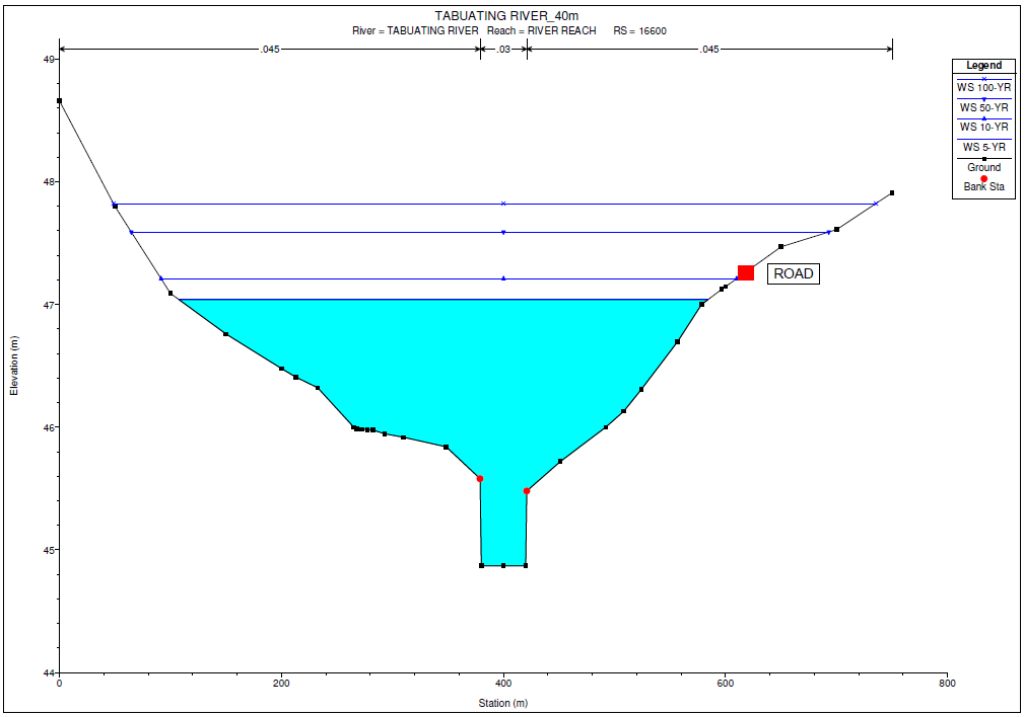
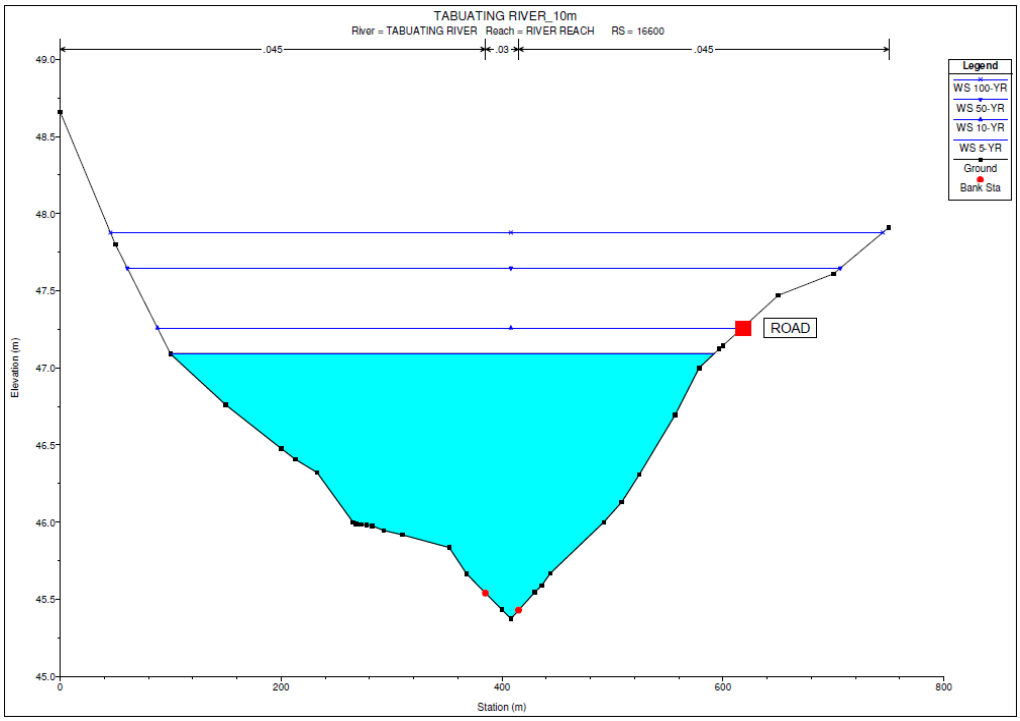


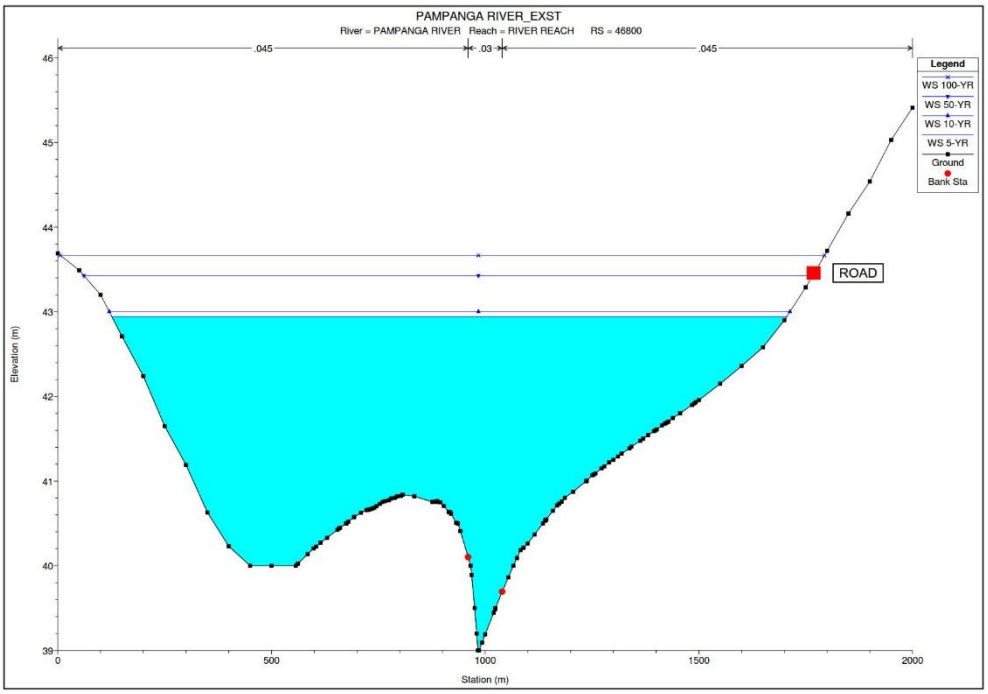
Measure 3- With Retention/ Detention (High Climate Change to 2100)



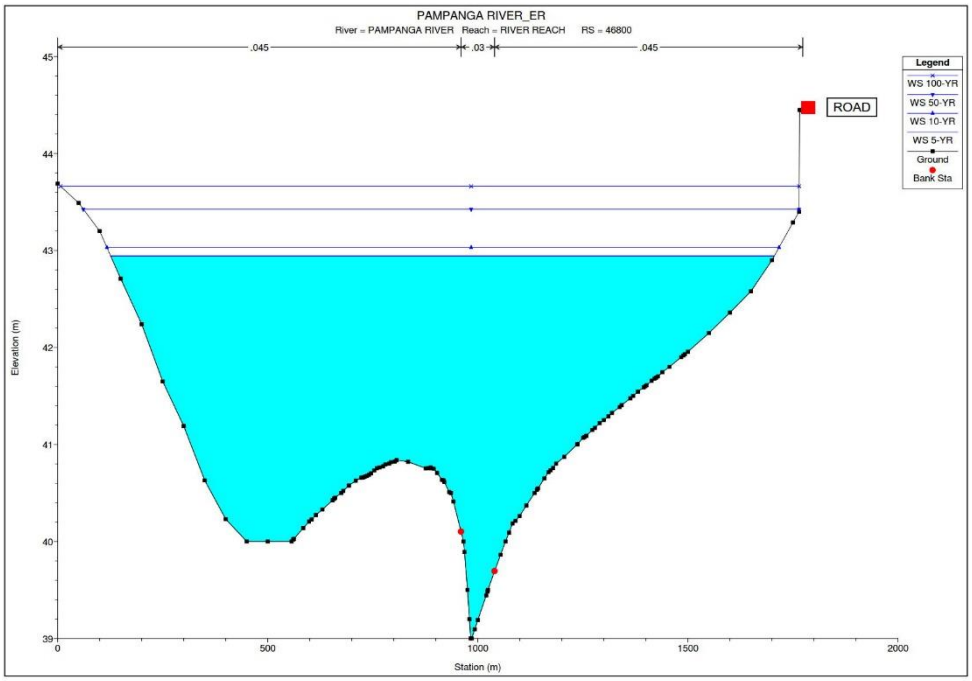
Appendix IV: Pampanga River HEC-RAS Modelling Results

AIV.1 - PAMPANGA HEC-RAS OUTPUTS FOR LOCATION 2-Sta. 46+800

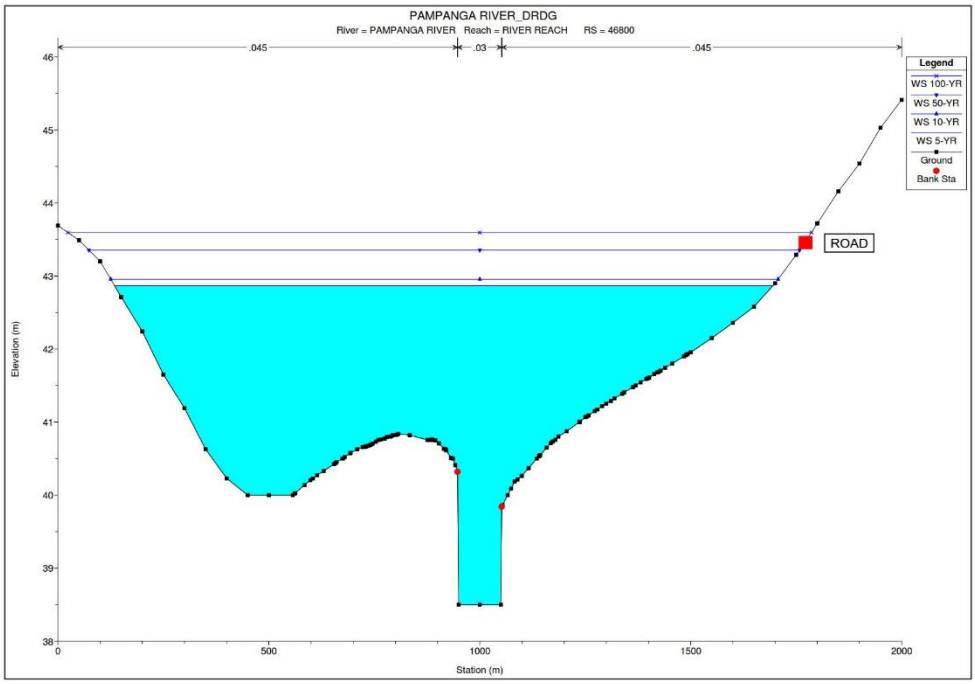
No Measure (Without Climate Change)



Measure 1- Elevated Road (Without Climate Change)



Measure 2- With Dredging (Without Climate Change)



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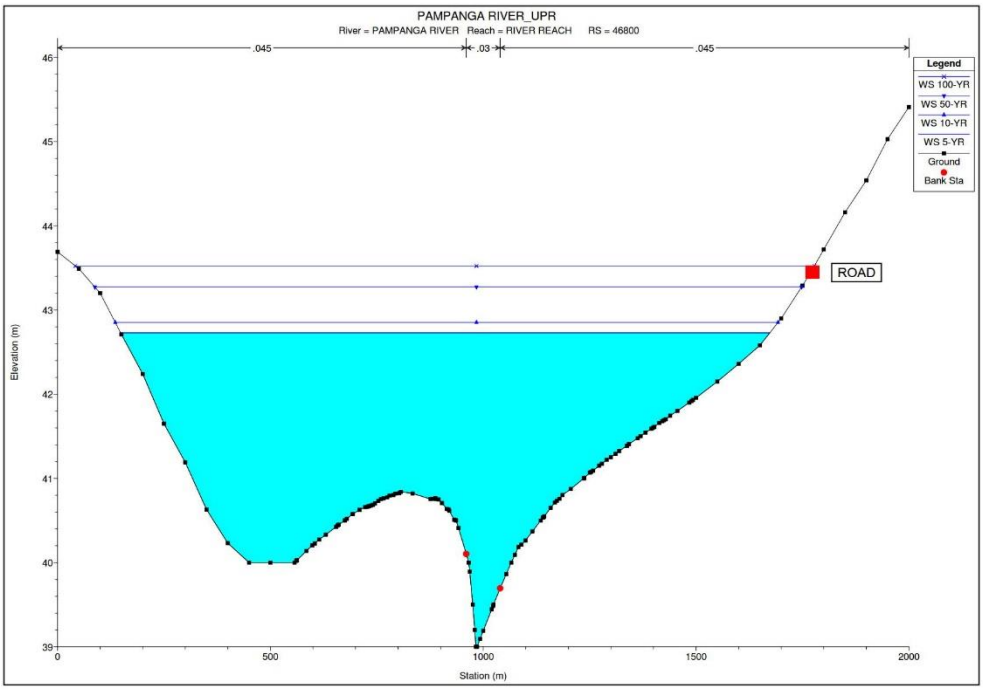
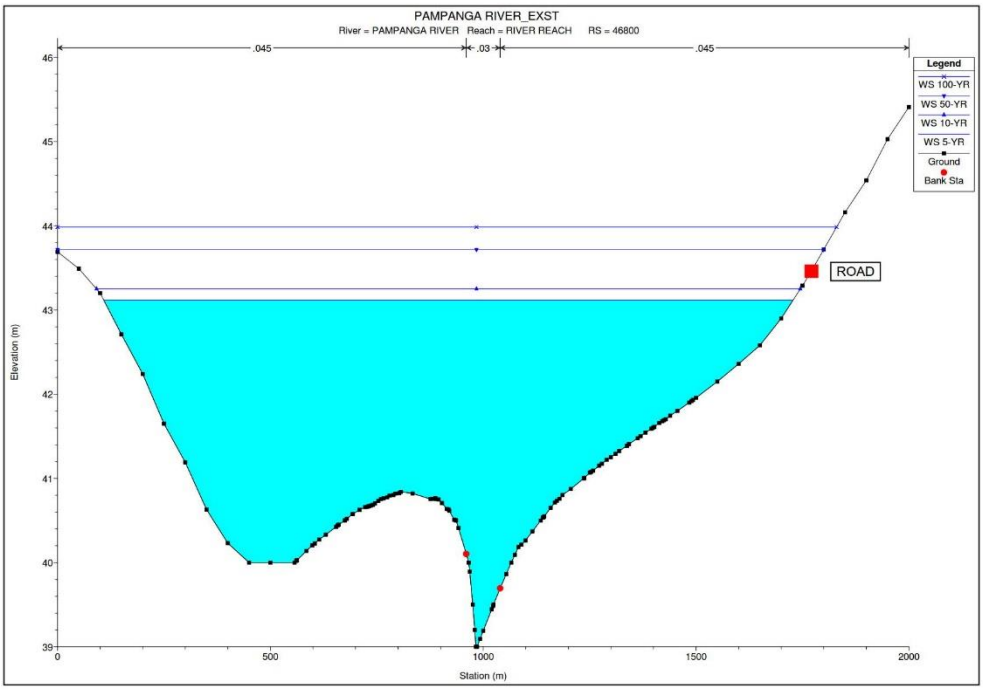
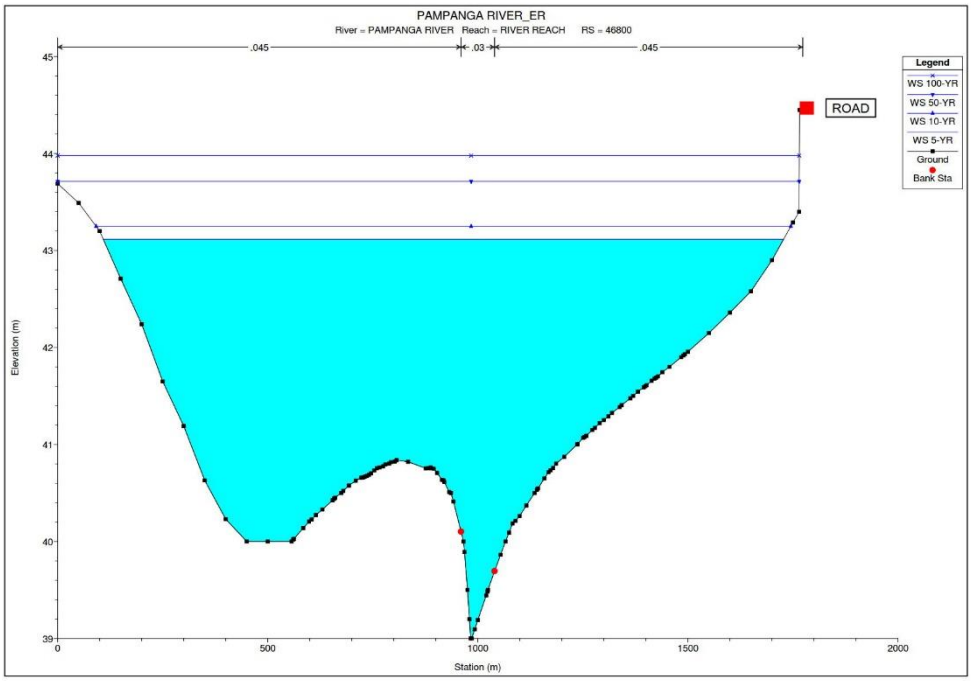


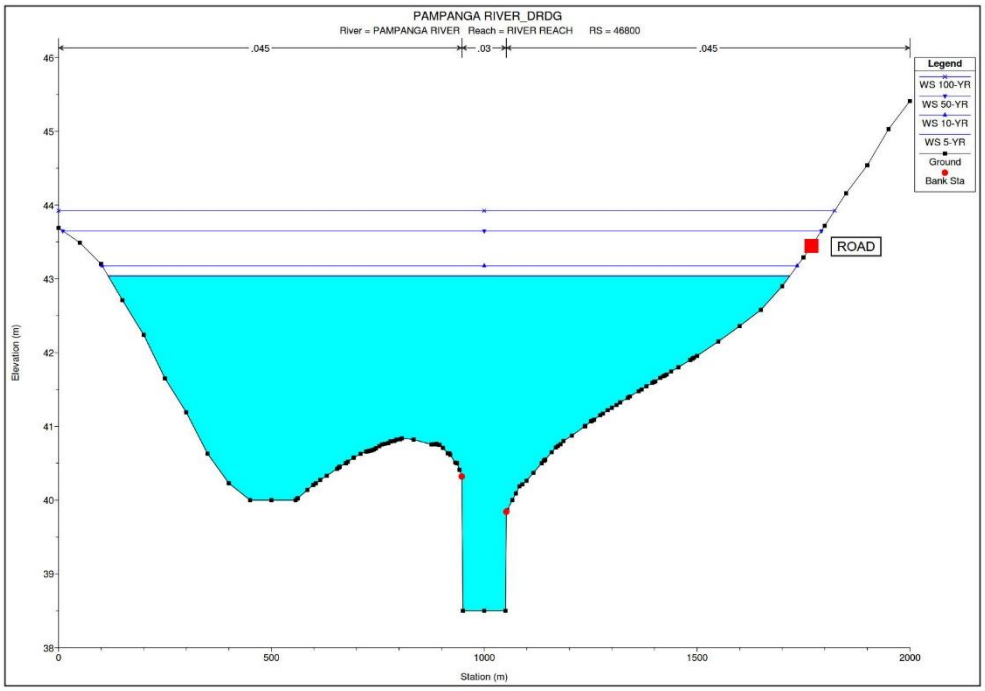
No Measure- (High Climate Change to 2050)



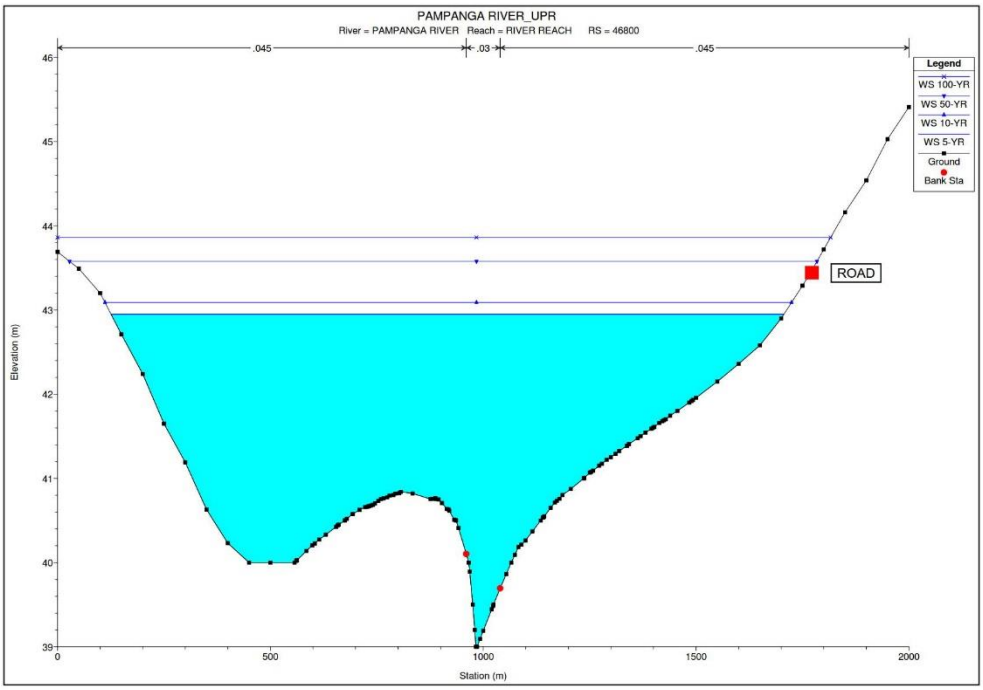
Measure 1- Elevated Road (High Climate Change to 2050)



Measure 2- With Dredging (High Climate Change to 2050)



Measure 3- With Retention/ Detention (High Climate Change to 2050)



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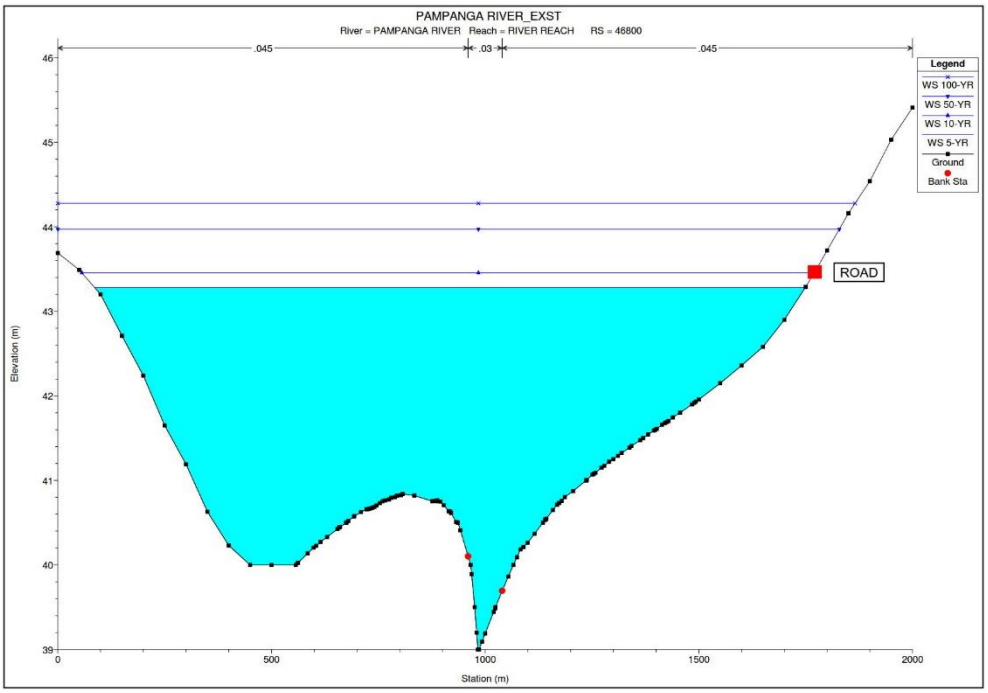
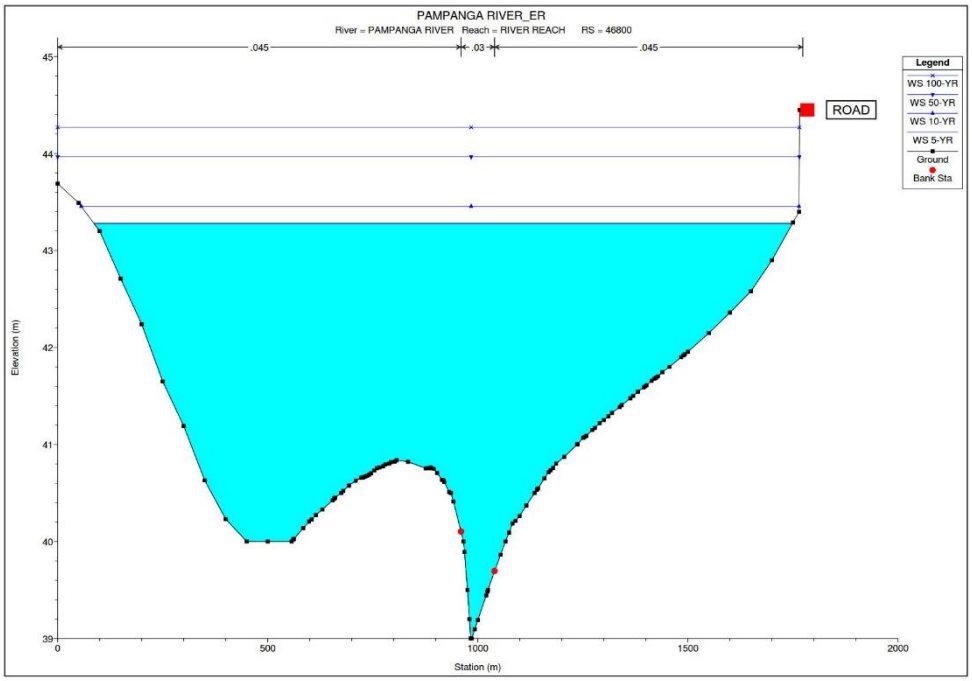
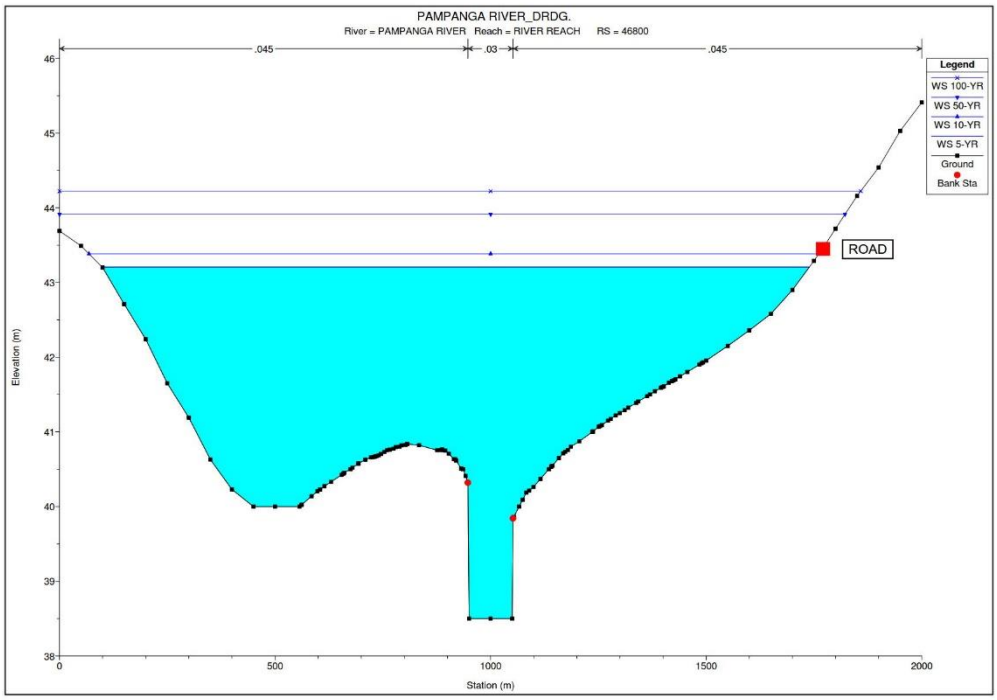


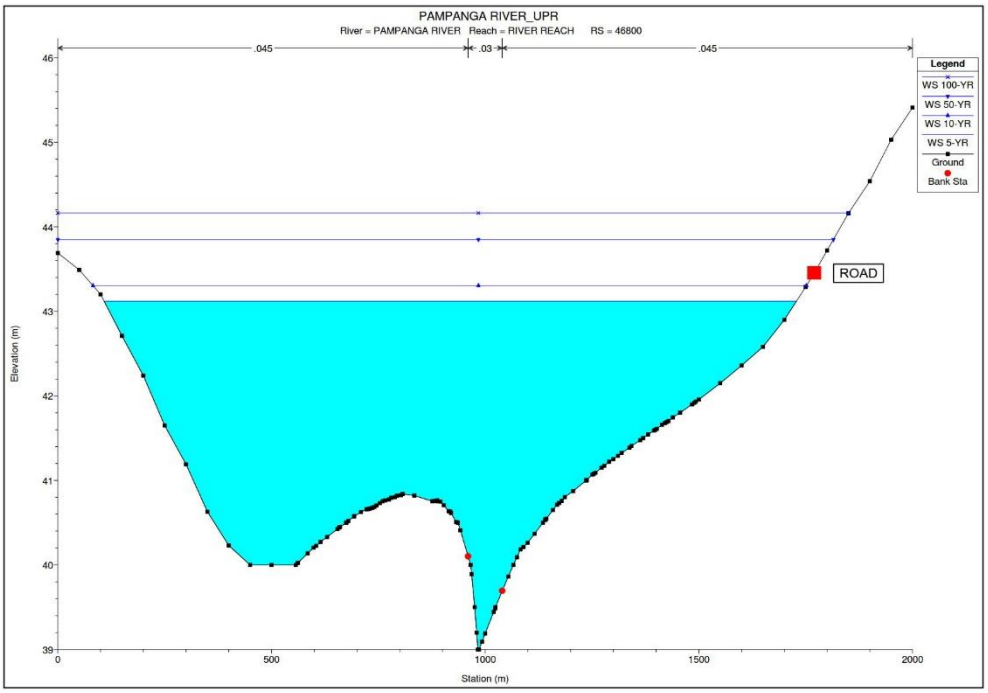
Measure 1- Elevated Road (High Climate Change to 2100)



Measure 2- With Dredging (High Climate Change to 2100)

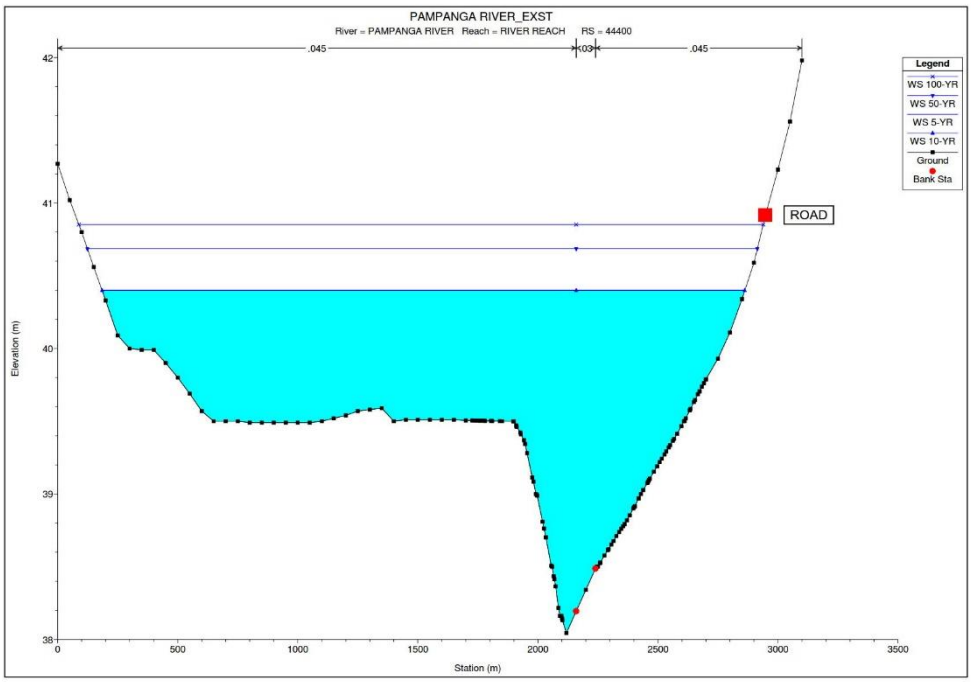


Measure 3- With Retention/ Detention (High Climate Change to 2100)

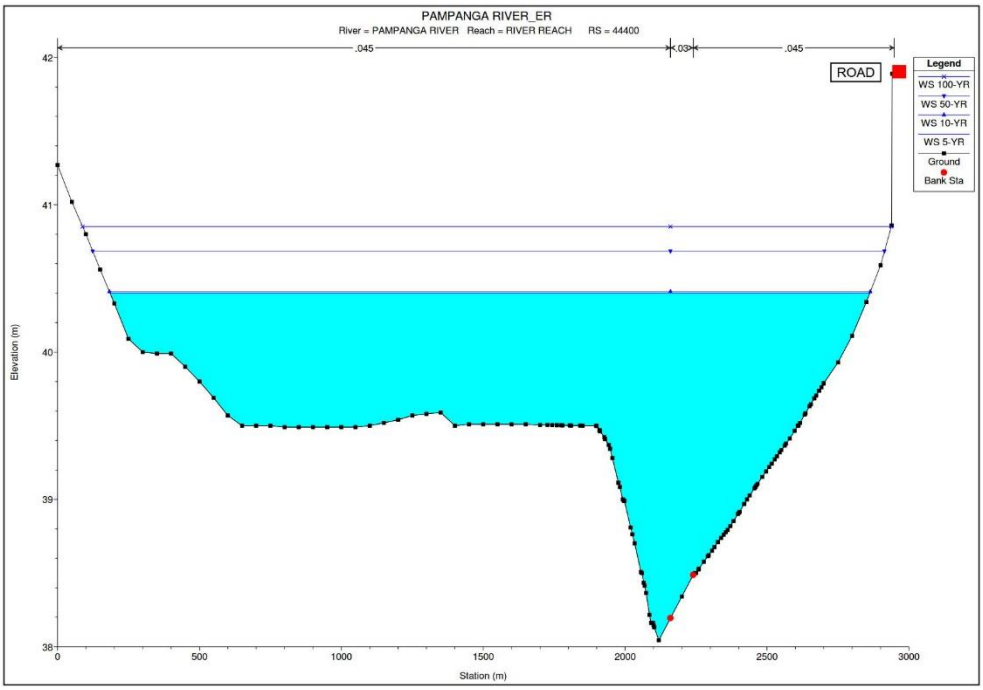


AIV.2 - PAMPANGA HEC-RAS OUTPUTS FOR LOCATION 2-Sta. 44+400

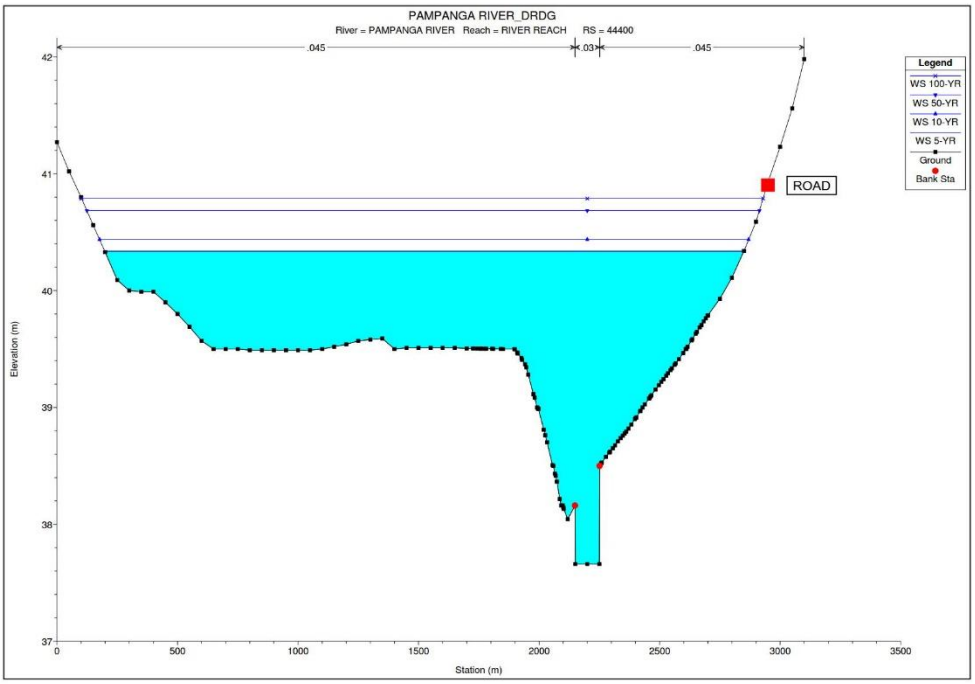
No Measure (Without Climate Change)



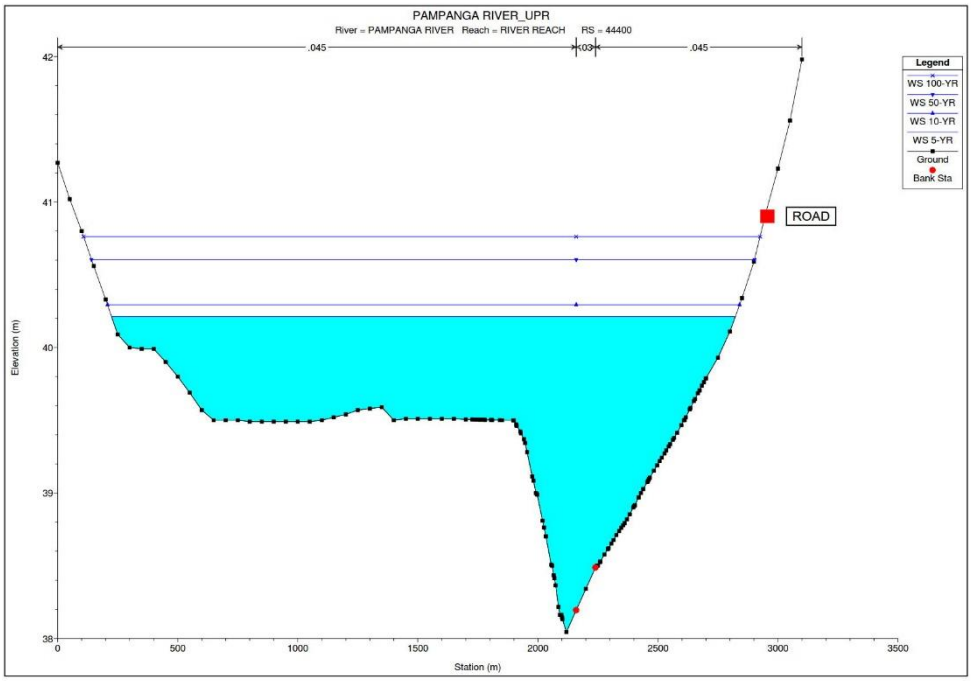
Measure 1- Elevated Road (Without Climate Change)



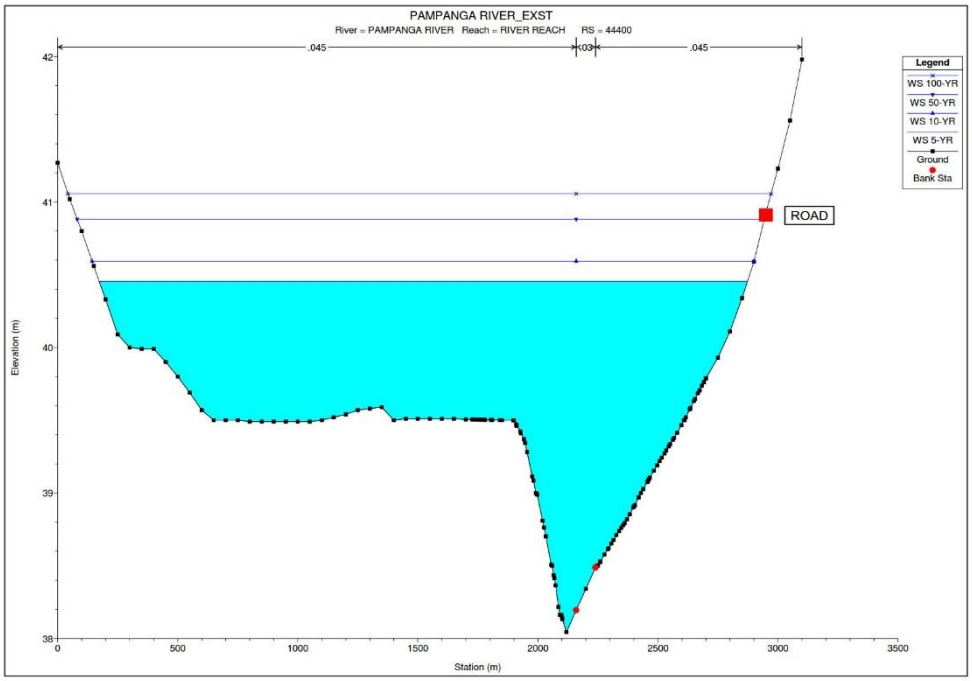
Measure 2- With Dredging (Without Climate Change)



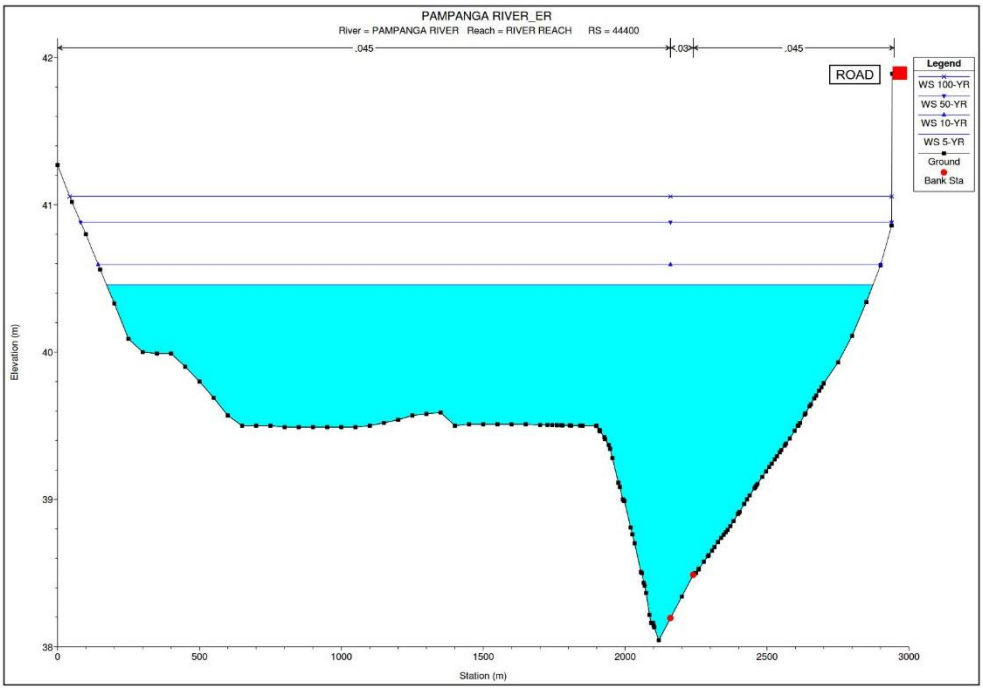
Measure 3- With Retention/ Detention (Without Climate Change)



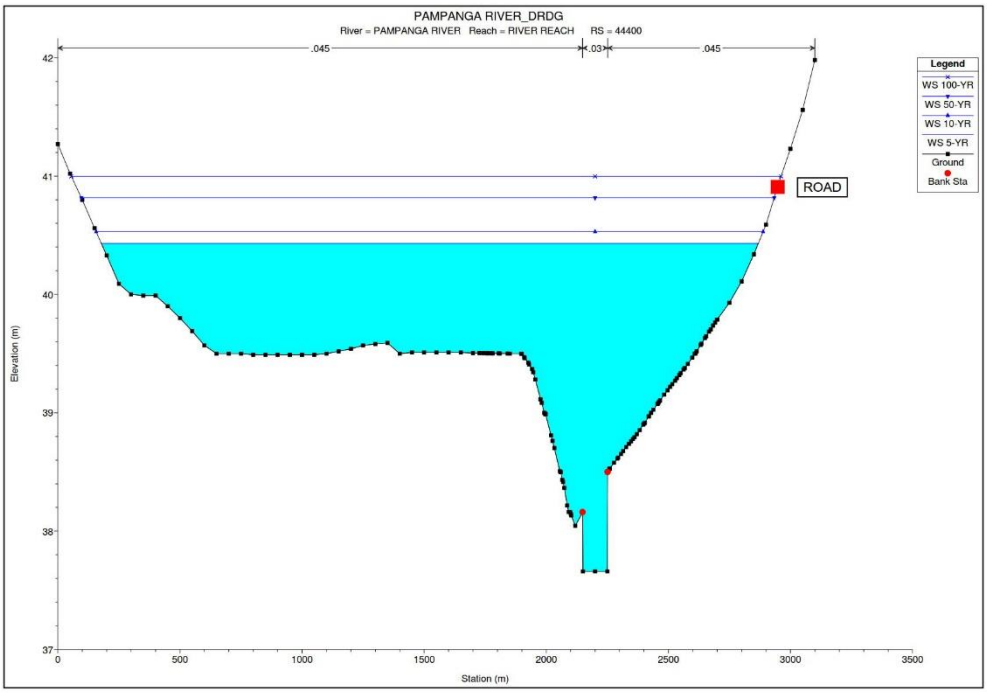
No Measure- (High Climate Change to 2050)



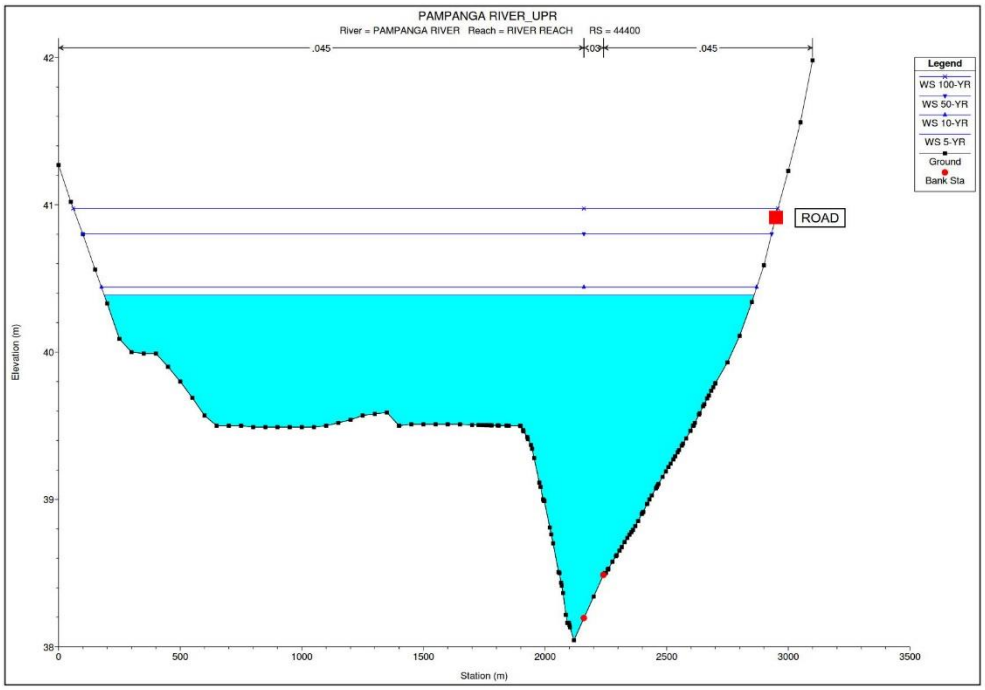
Measure 1- Elevated Road (High Climate Change to 2050)



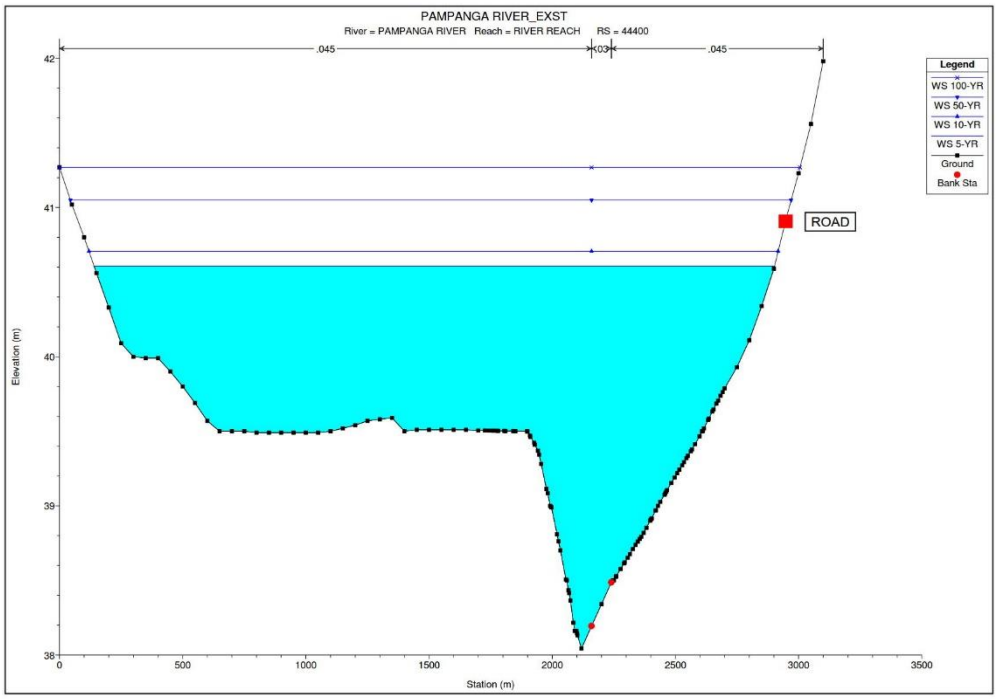
Measure 2- With Dredging (High Climate Change to 2050)



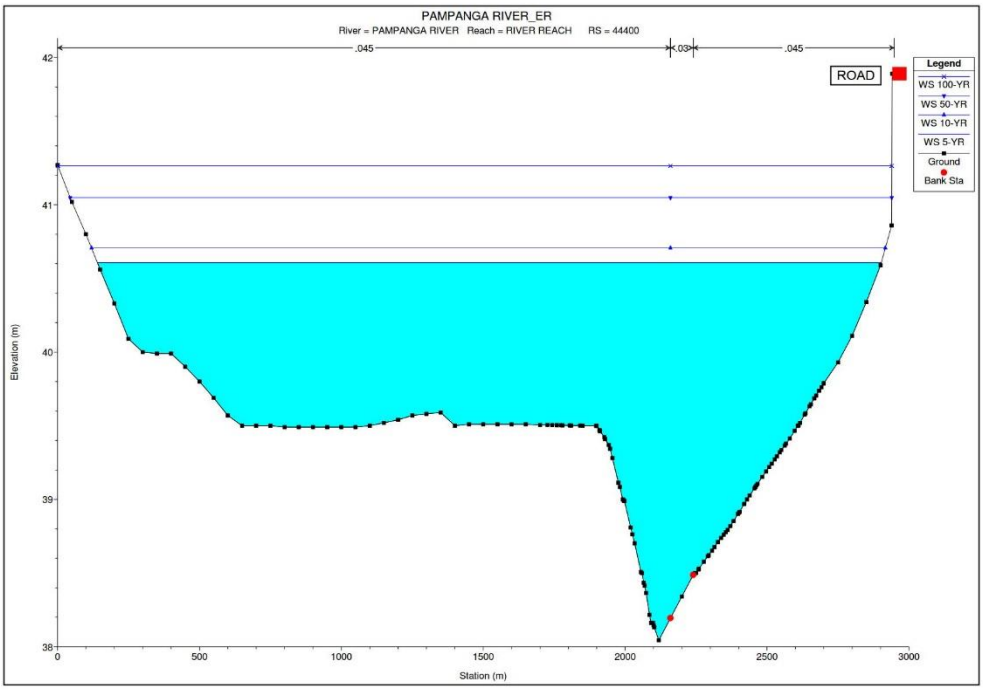
Measure 3- With Retention/ Detention (High Climate Change to 2050)



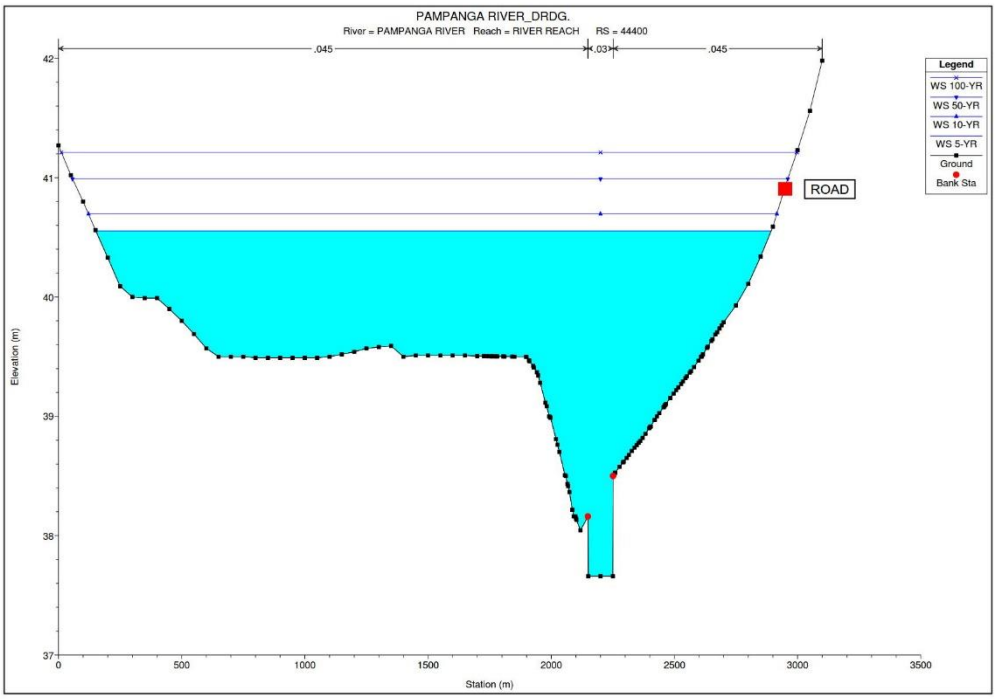
No Measure- (High Climate Change to 2100)



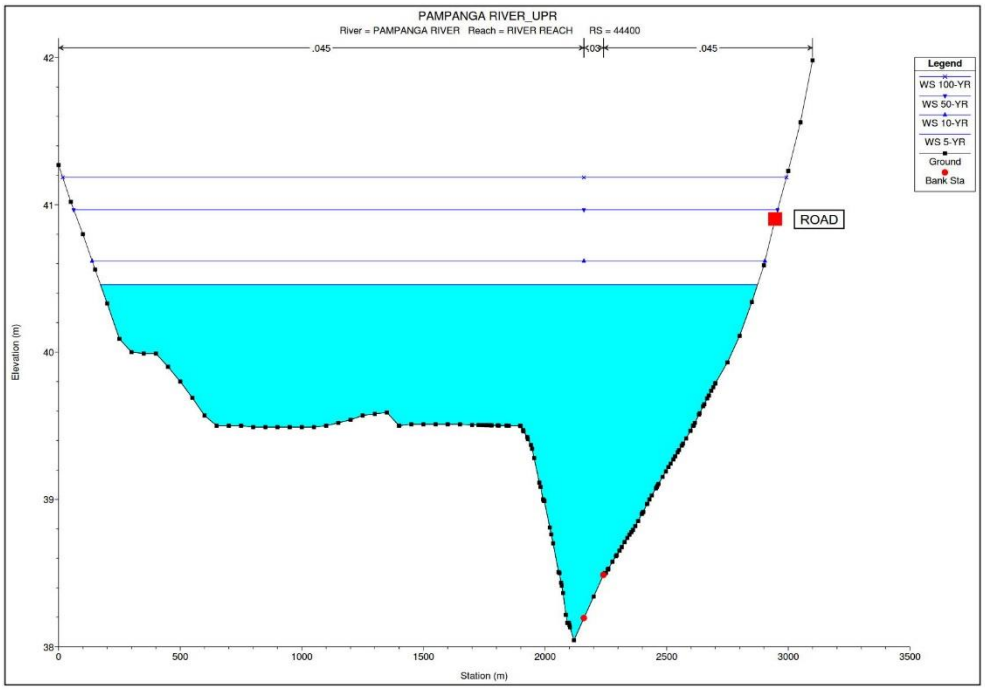
Measure 1- Elevated Road (High Climate Change to 2100)



Measure 2- With Dredging (High Climate Change to 2100)

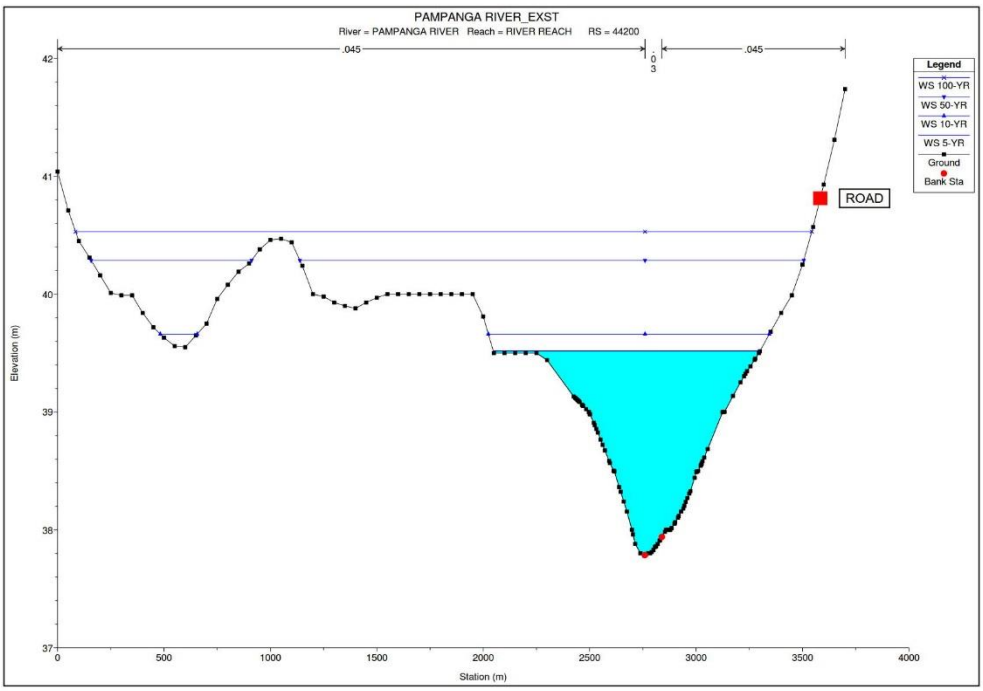


Measure 3- With Retention/ Detention (High Climate Change to 2100)

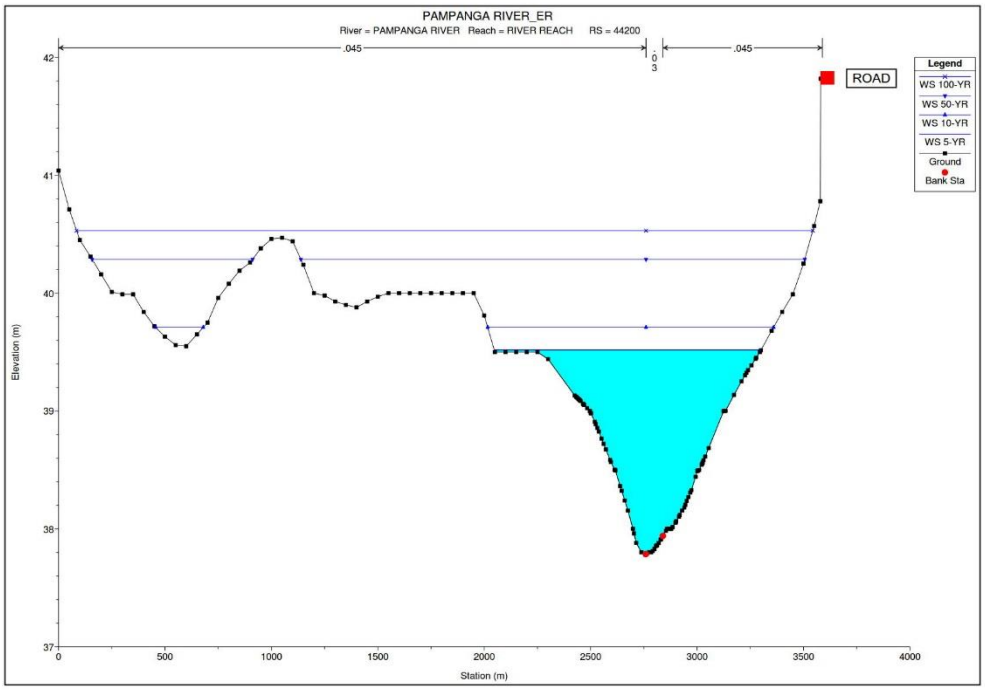


AIV.3 - PAMPANGA HEC-RAS OUTPUTS FOR LOCATION 2-Sta. 44+200

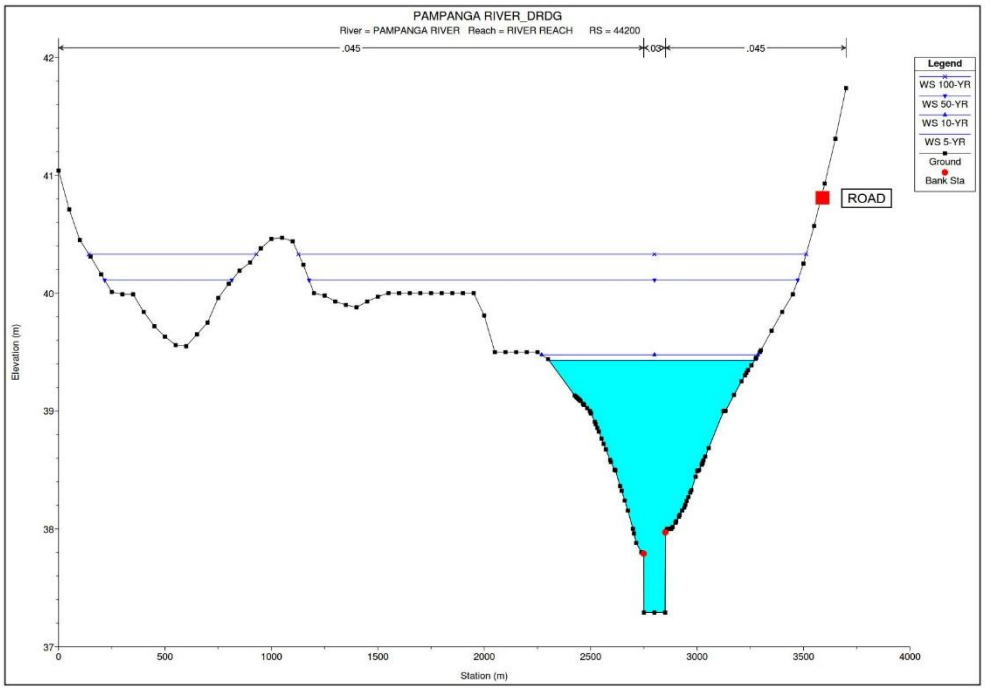
No Measure (Without Climate Change)



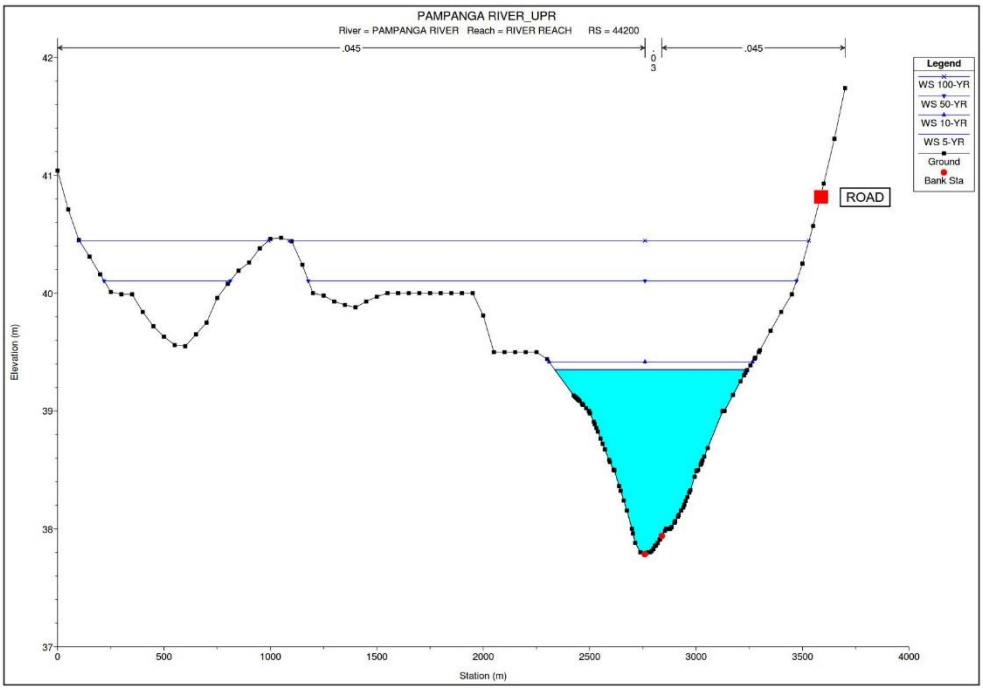
Measure 1- Elevated Road (Without Climate Change)



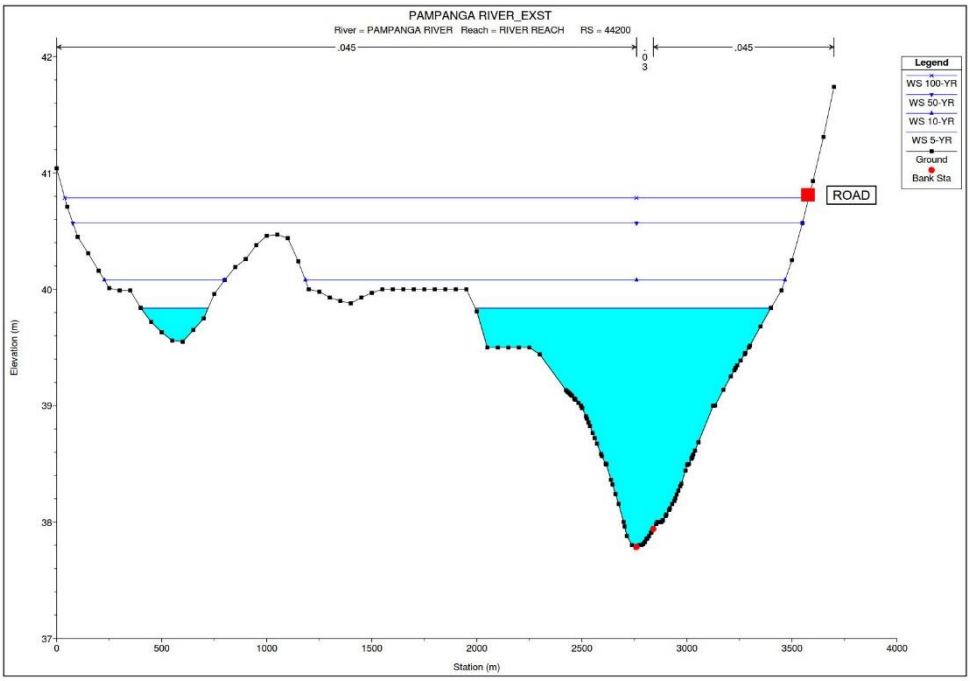
Measure 2- With Dredging (Without Climate Change)



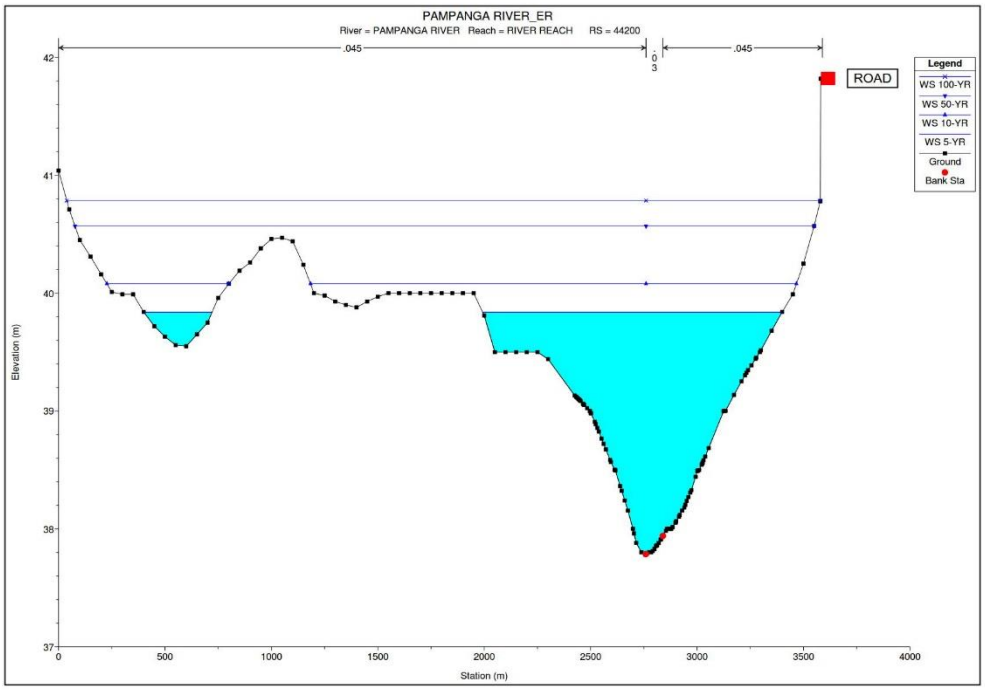
Measure 3- With Retention/ Detention (Without Climate Change)



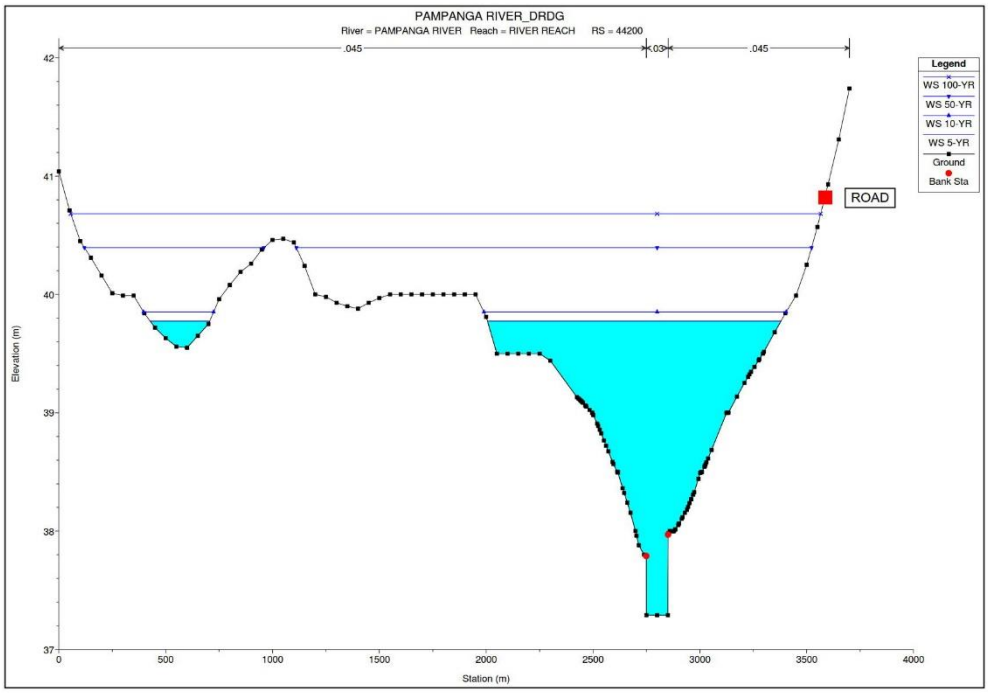
No Measure- (High Climate Change to 2050)



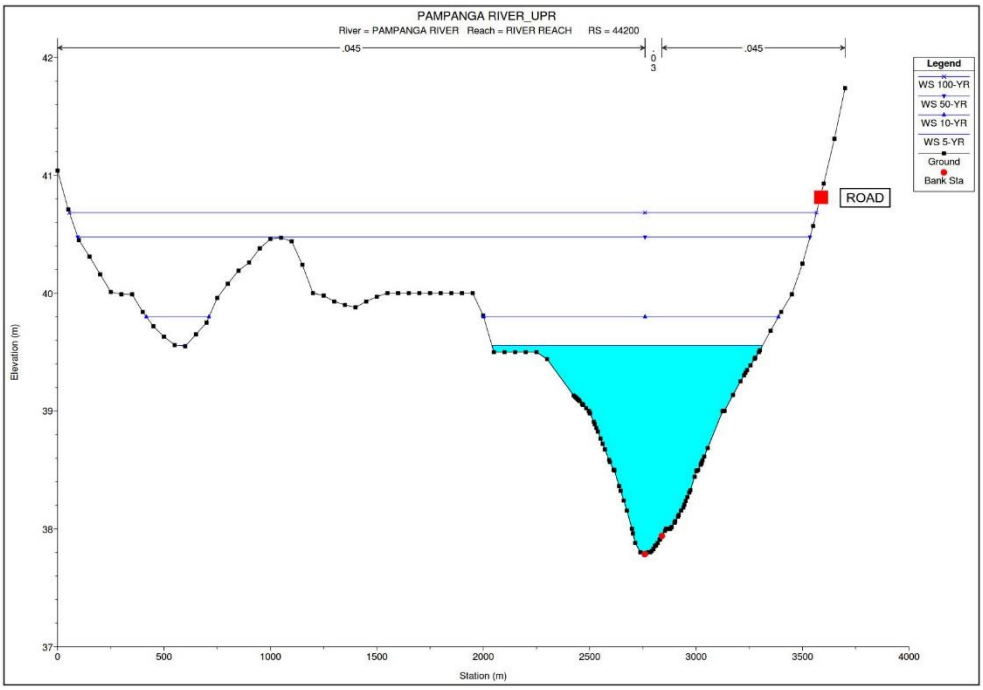
Measure 1- Elevated Road (High Climate Change to 2050)



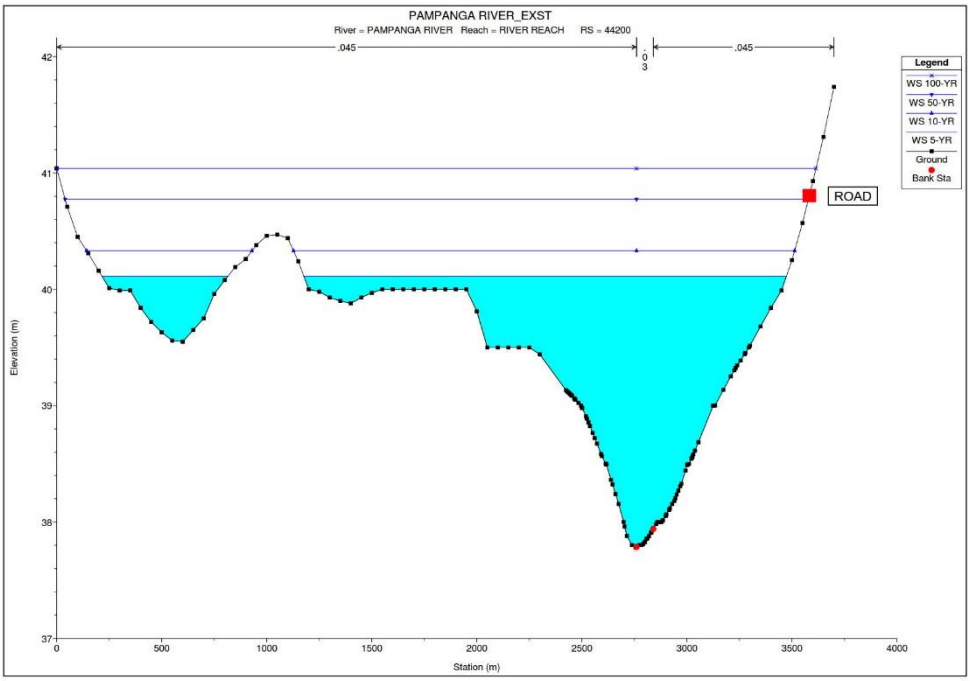
Measure 2- With Dredging (High Climate Change to 2050)



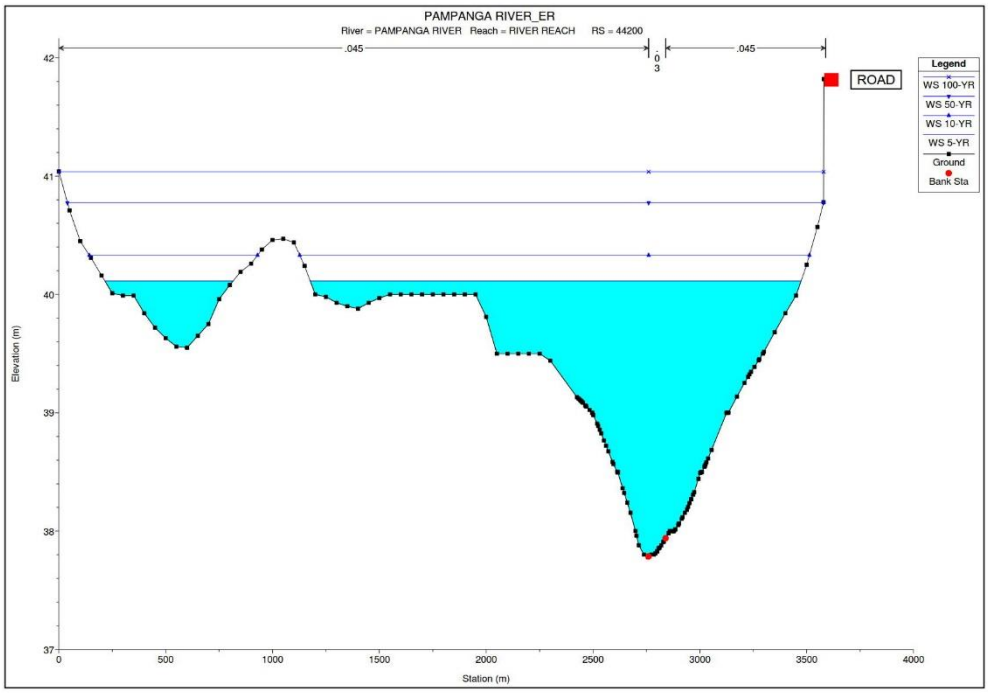
Measure 3- With Retention/ Detention (High Climate Change to 2050)



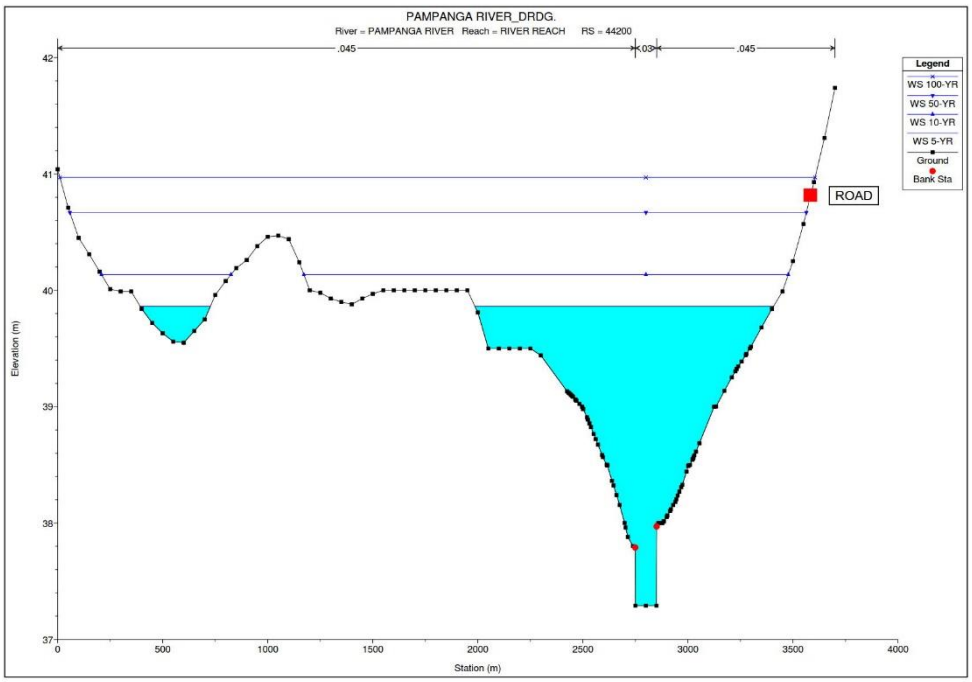
No Measure- (High Climate Change to 2100)



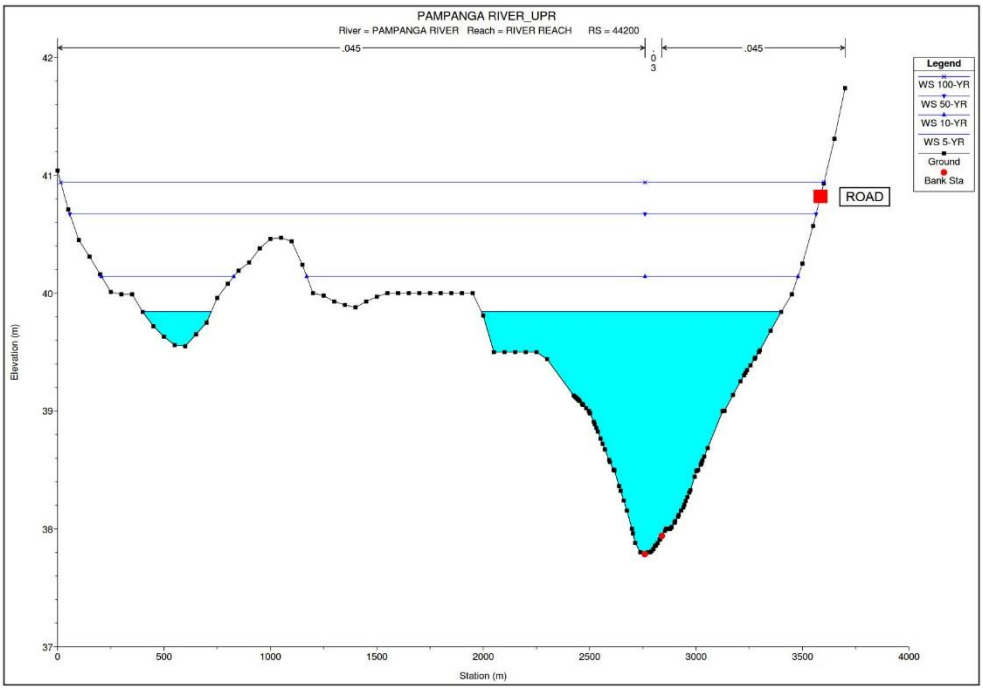
Measure 1- Elevated Road (High Climate Change to 2100)



Measure 2- With Dredging (High Climate Change to 2100)

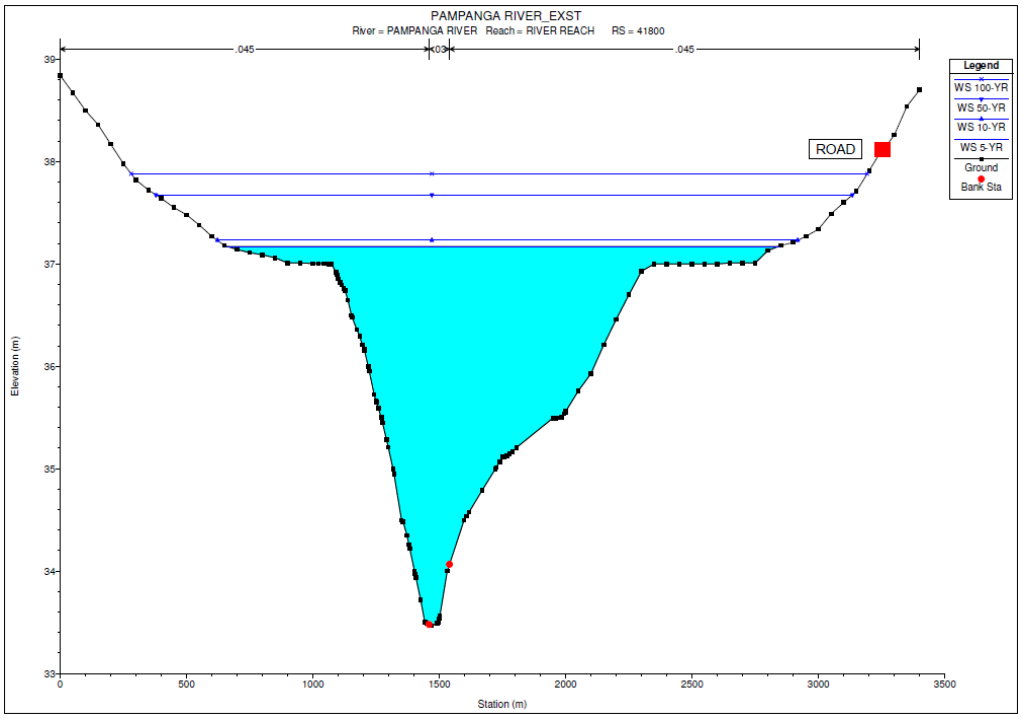


Measure 3- With Retention/ Detention (High Climate Change to 2100)

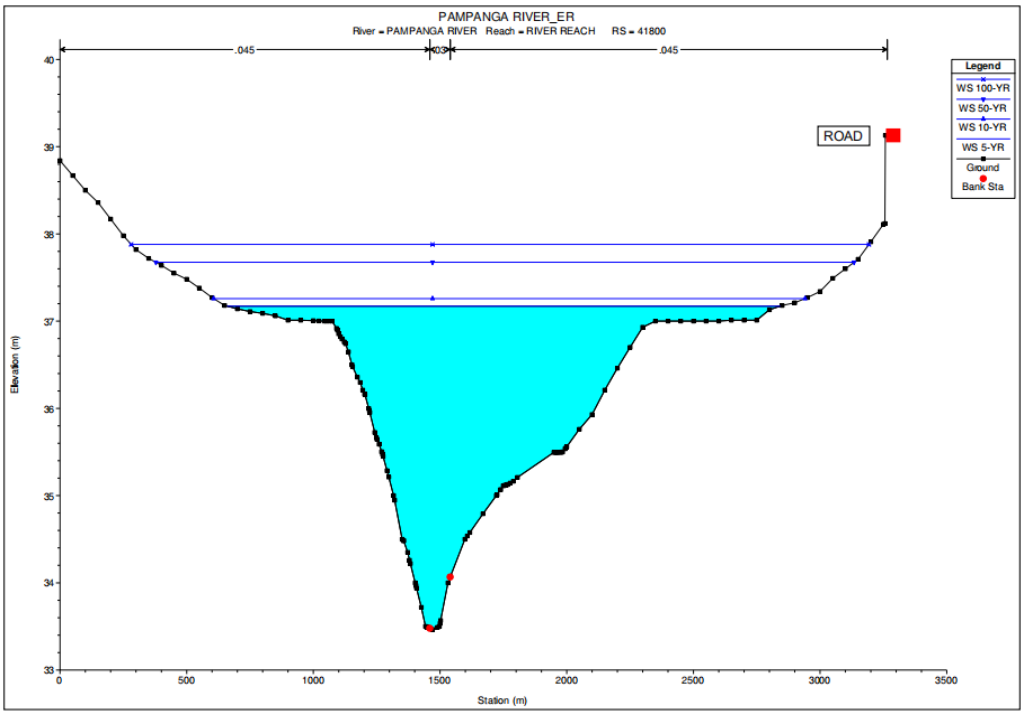


AIV.4 - PAMPANGA HEC-RAS OUTPUTS FOR LOCATION 2-Sta. 41+800

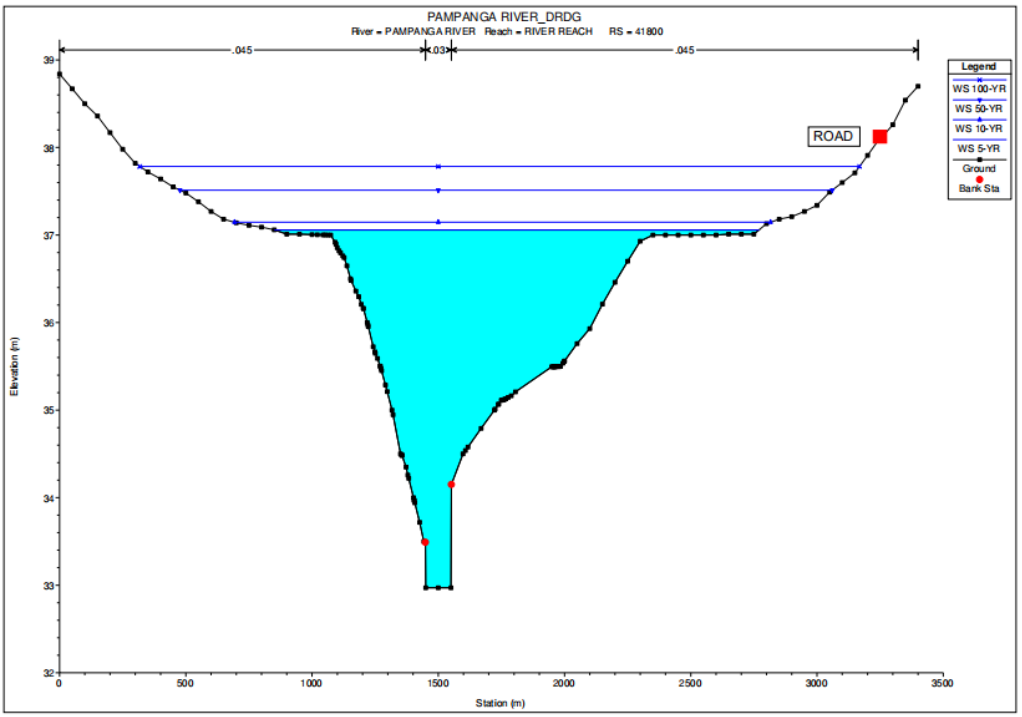
No Measure (Without Climate Change)



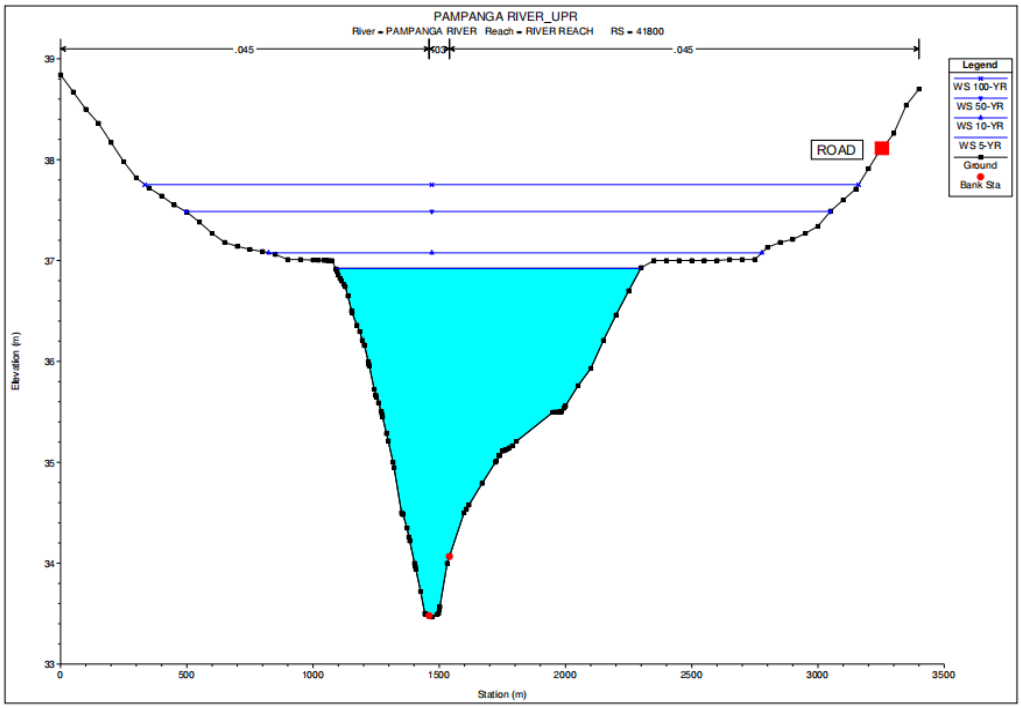
Measure 1- Elevated Road (Without Climate Change)



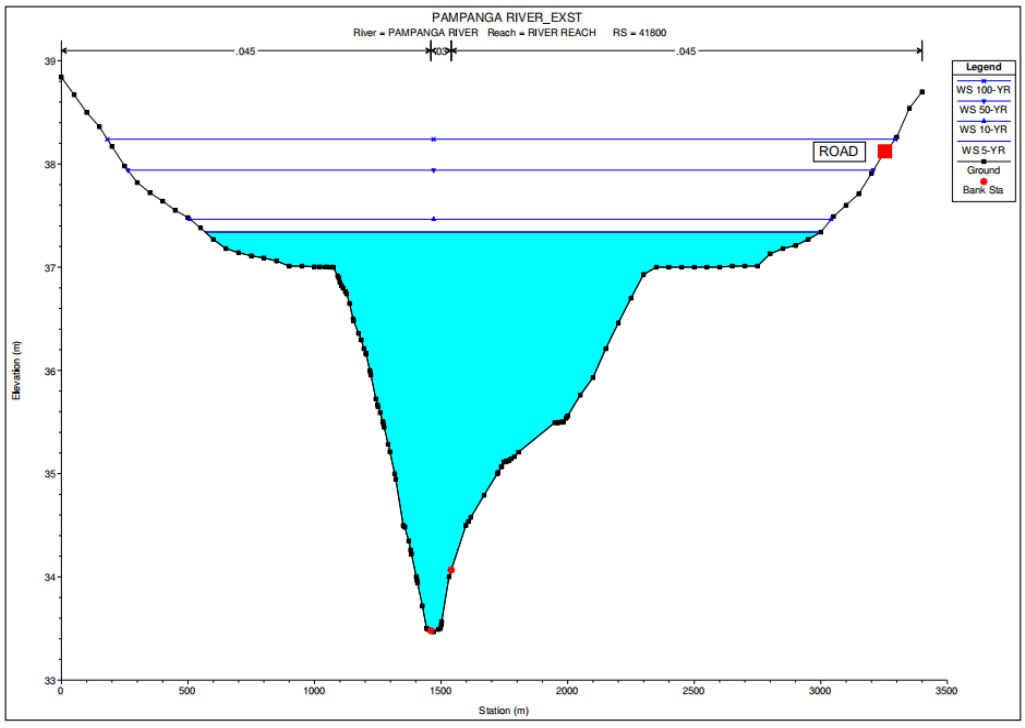
Measure 2- With Dredging (Without Climate Change)



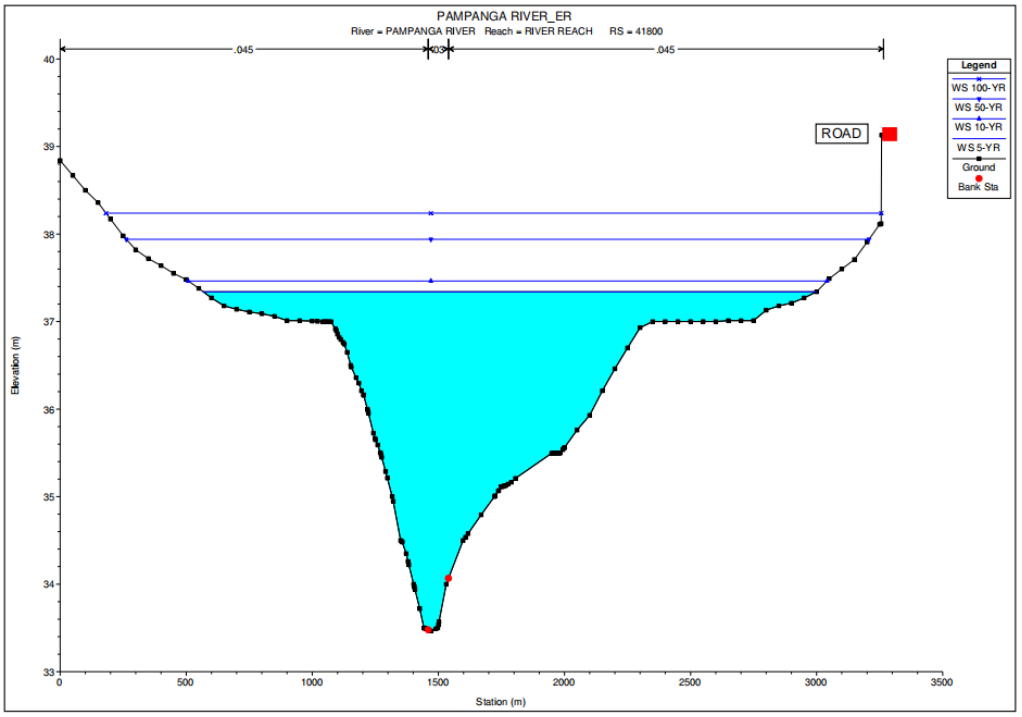
Measure 3- With Retention/ Detention (Without Climate Change)



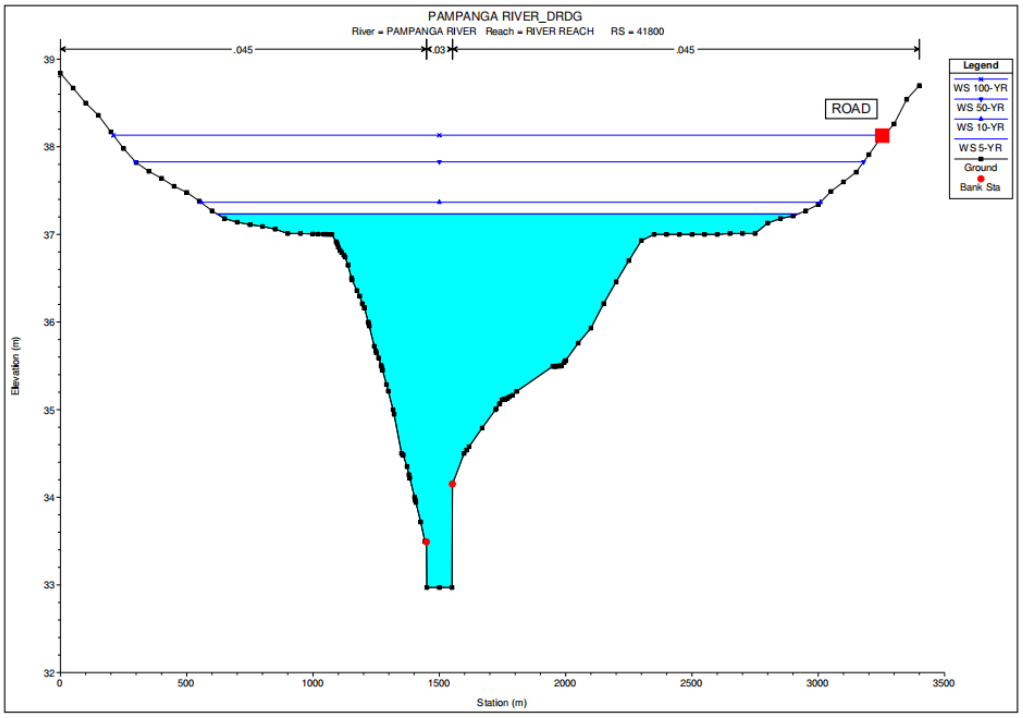
No Measure- (High Climate Change to 2050)



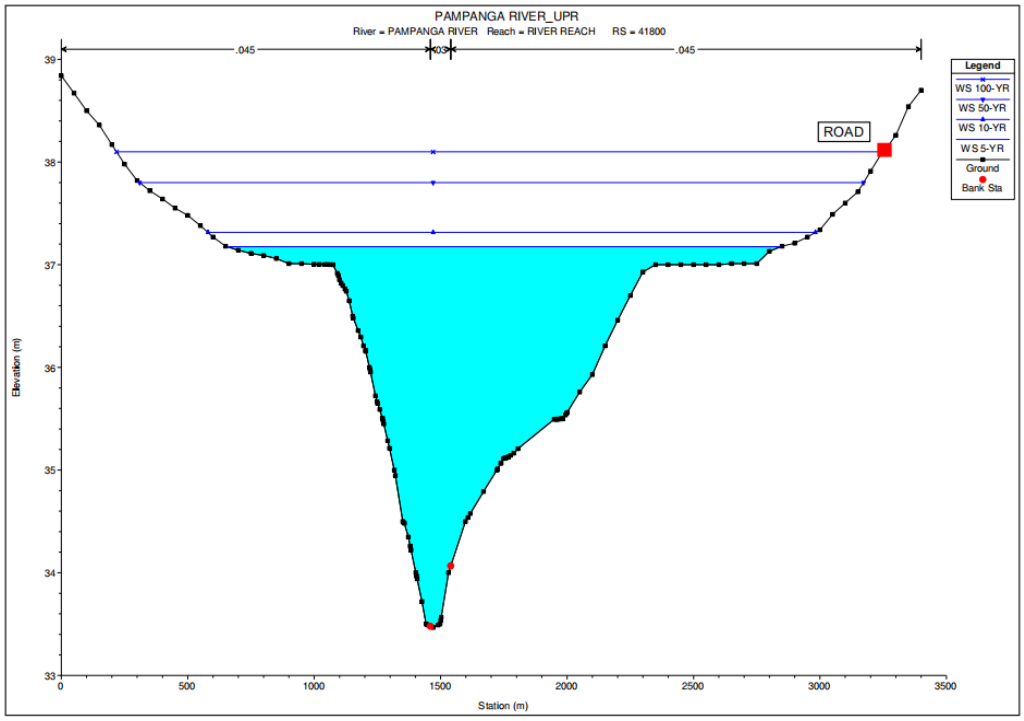
Measure 1- Elevated Road (High Climate Change to 2050)



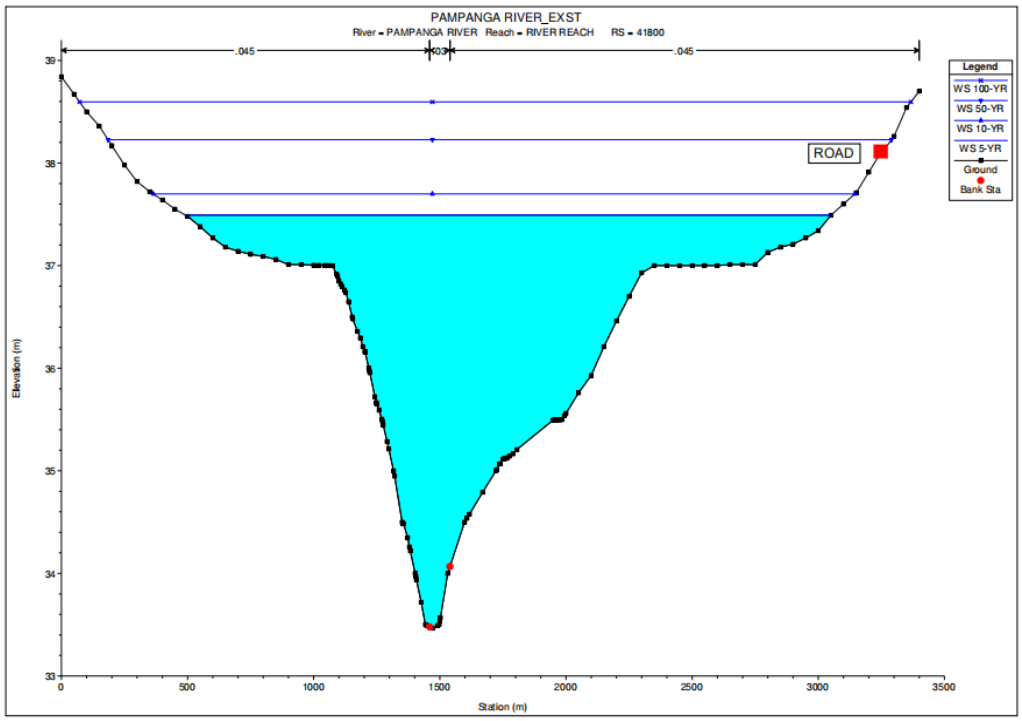
Measure 2- With Dredging (High Climate Change to 2050)



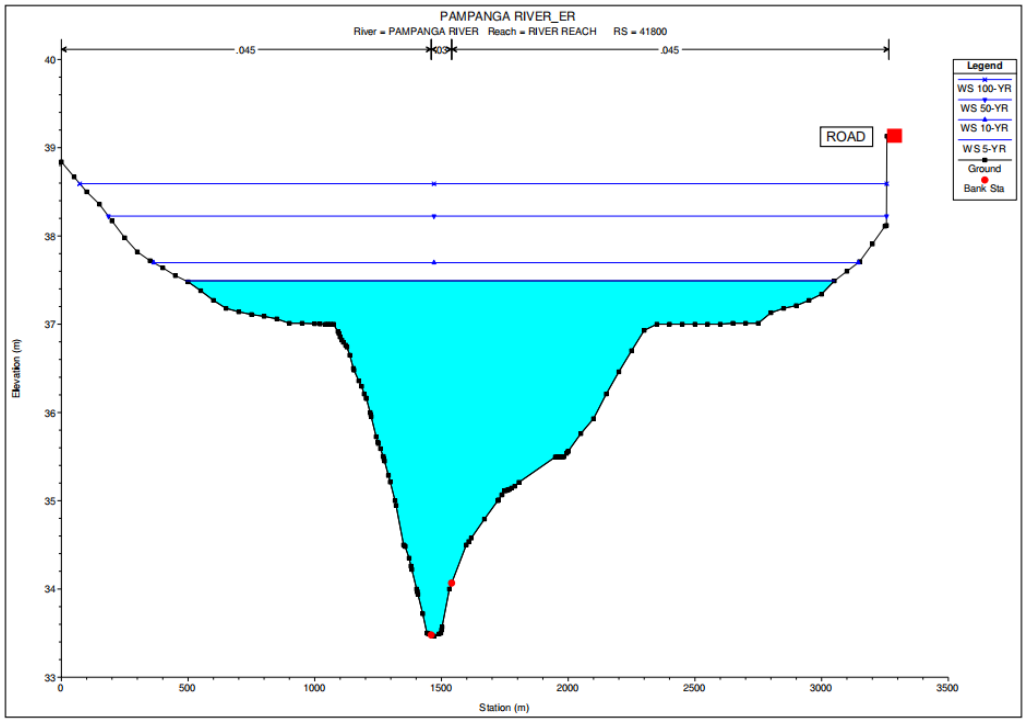
Measure 3- With Retention/ Detention (High Climate Change to 2050)



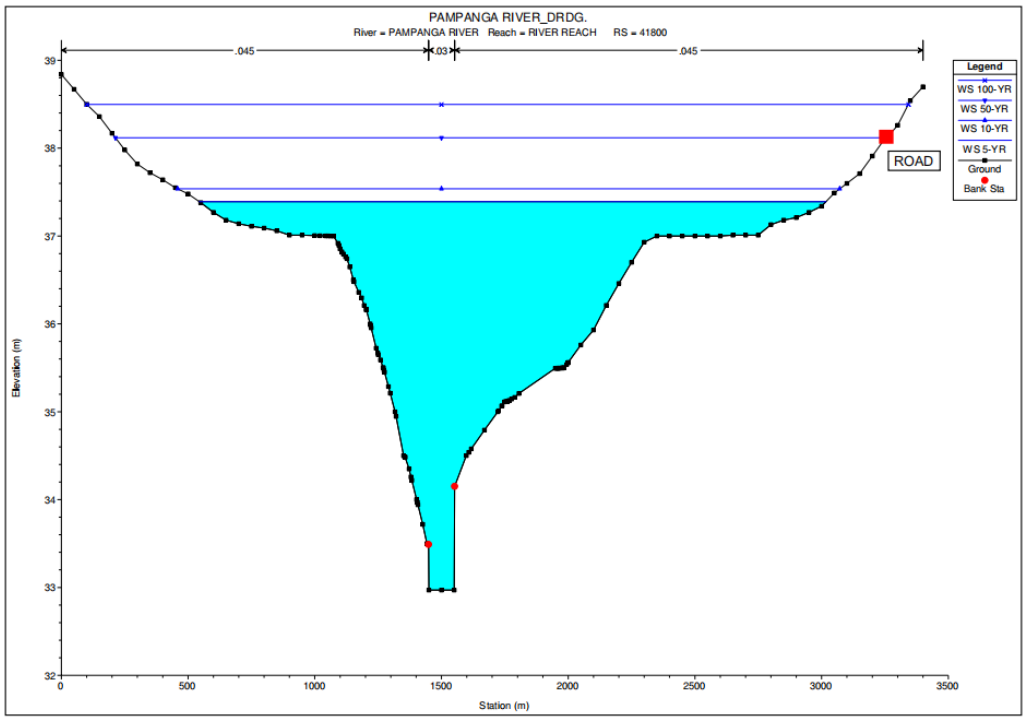
No Measure- (High Climate Change to 2100)



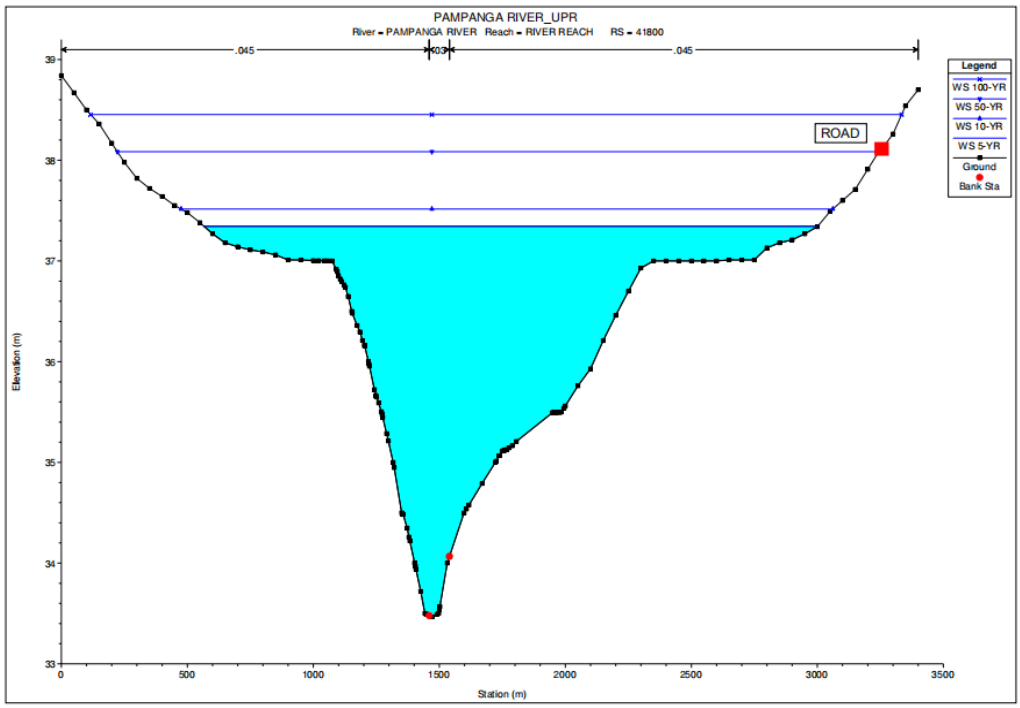
Measure 1- Elevated Road (High Climate Change to 2100)



Measure 2- With Dredging (High Climate Change to 2100)

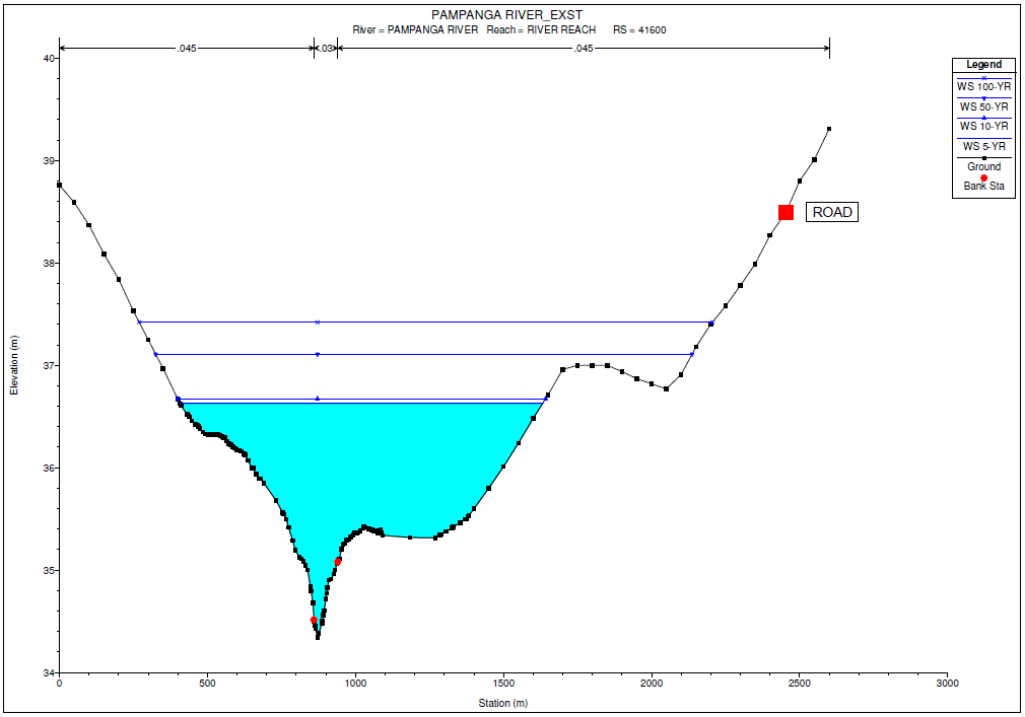


Measure 3- With Retention/ Detention (High Climate Change to 2100)

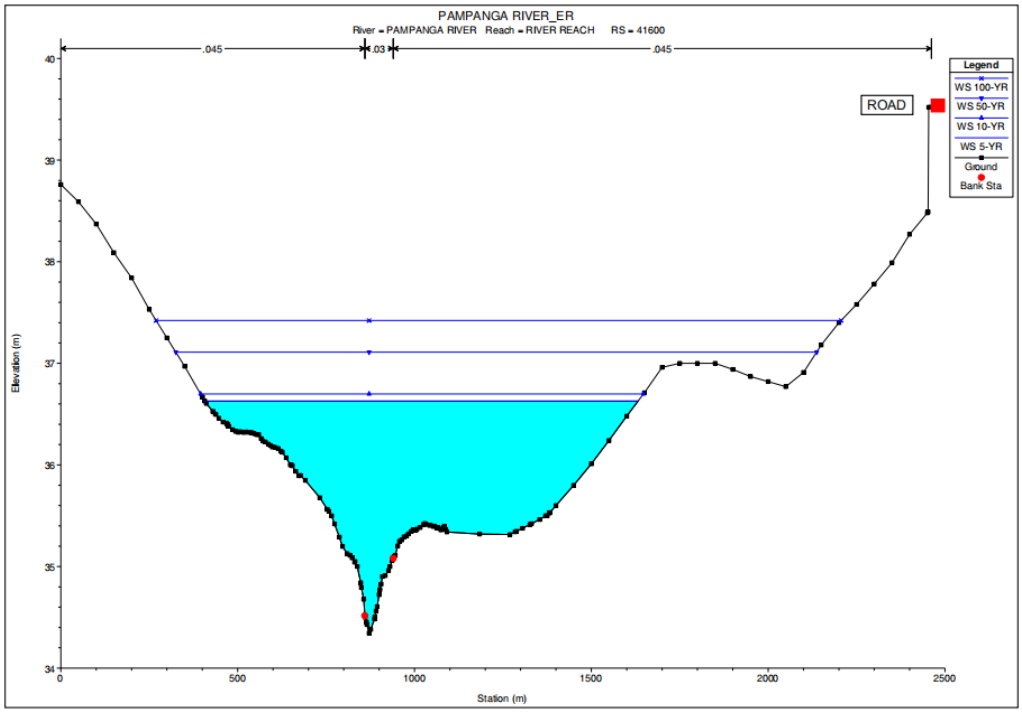


AIV.5 - PAMPANGA HEC-RAS OUTPUTS FOR LOCATION 2-Sta. 41+600

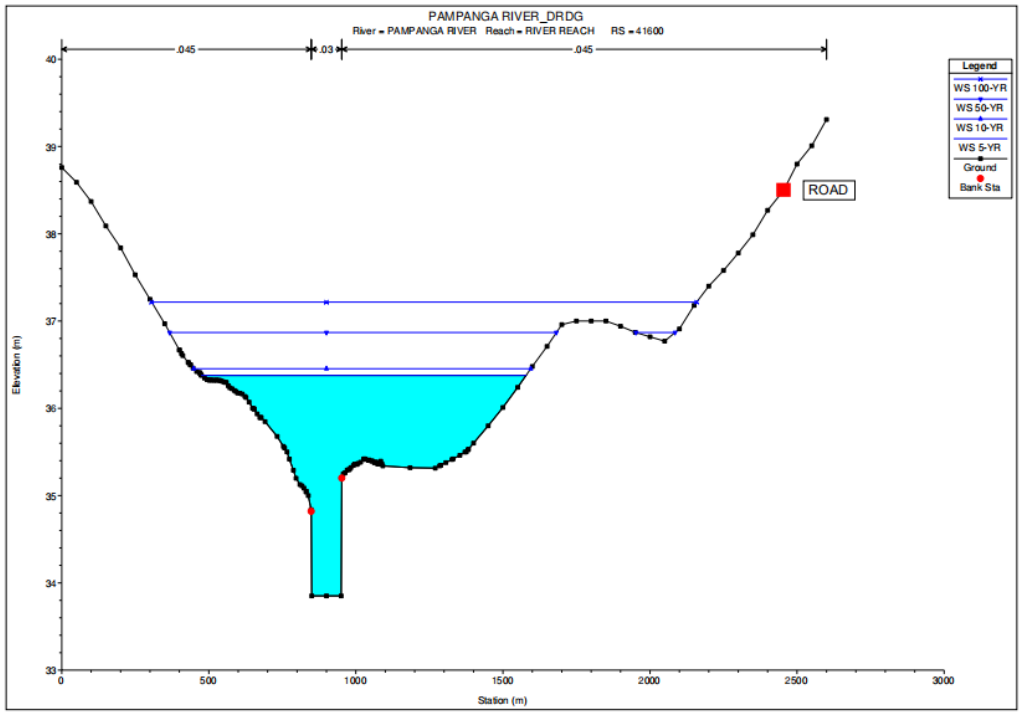
No Measure (Without Climate Change)



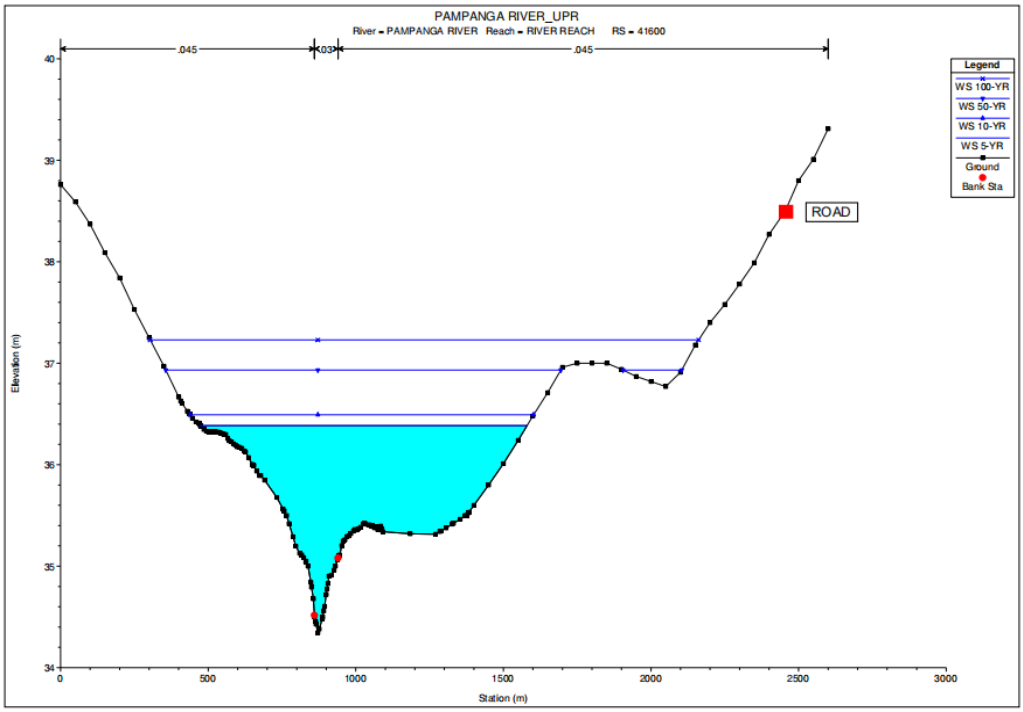
Measure 1- Elevated Road (Without Climate Change)



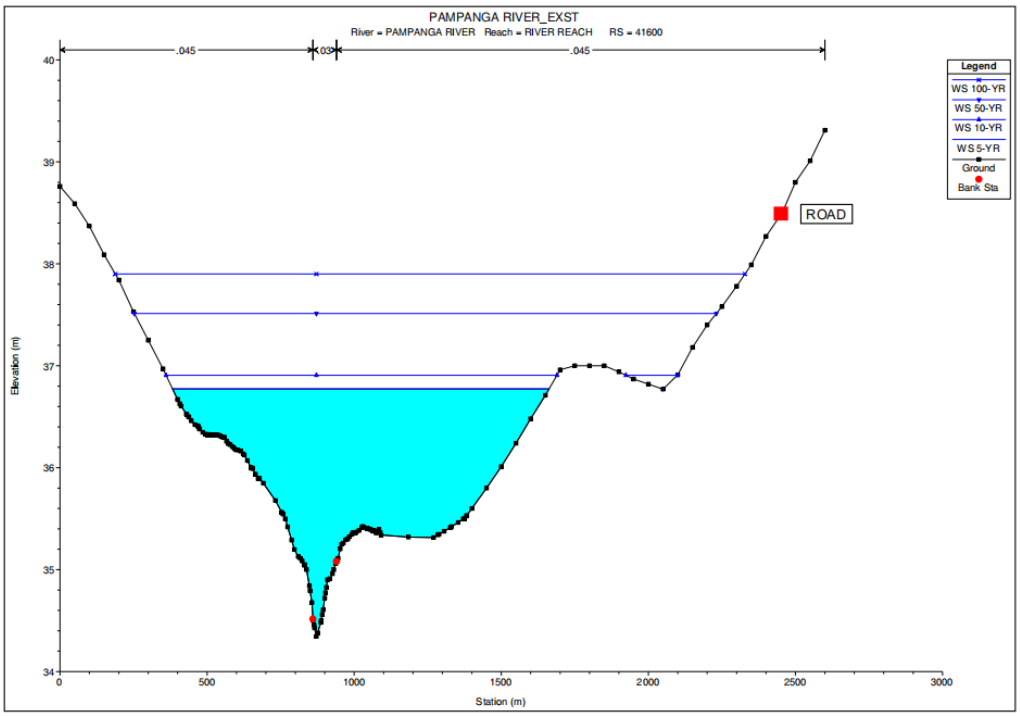
Measure 2- With Dredging (Without Climate Change)



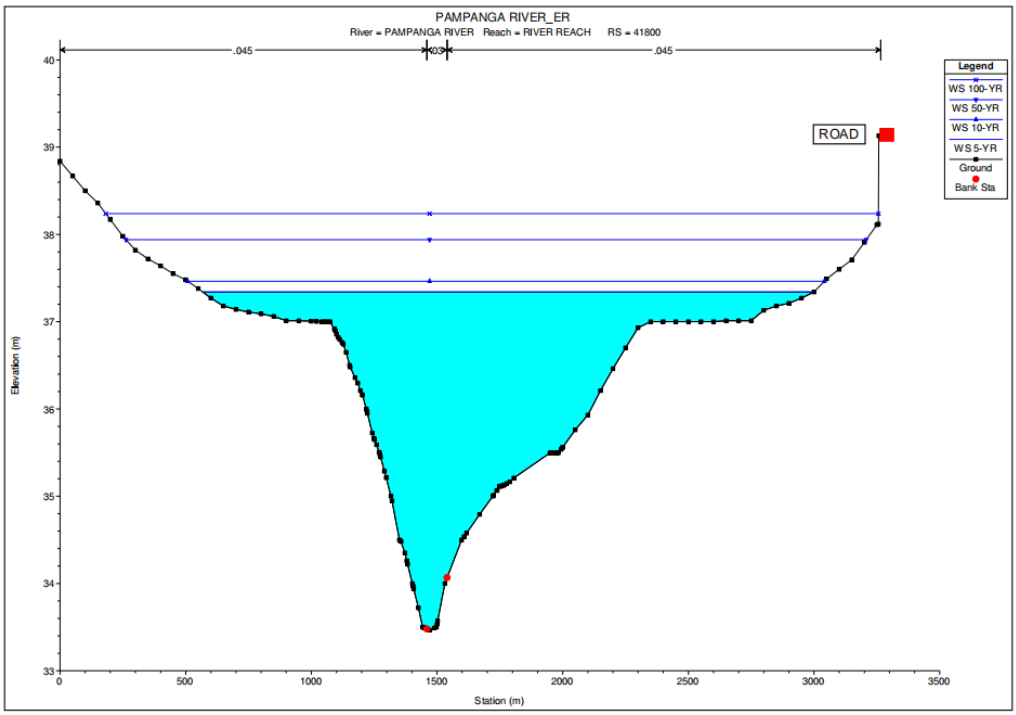
Measure 3- With Retention/ Detention (Without Climate Change)



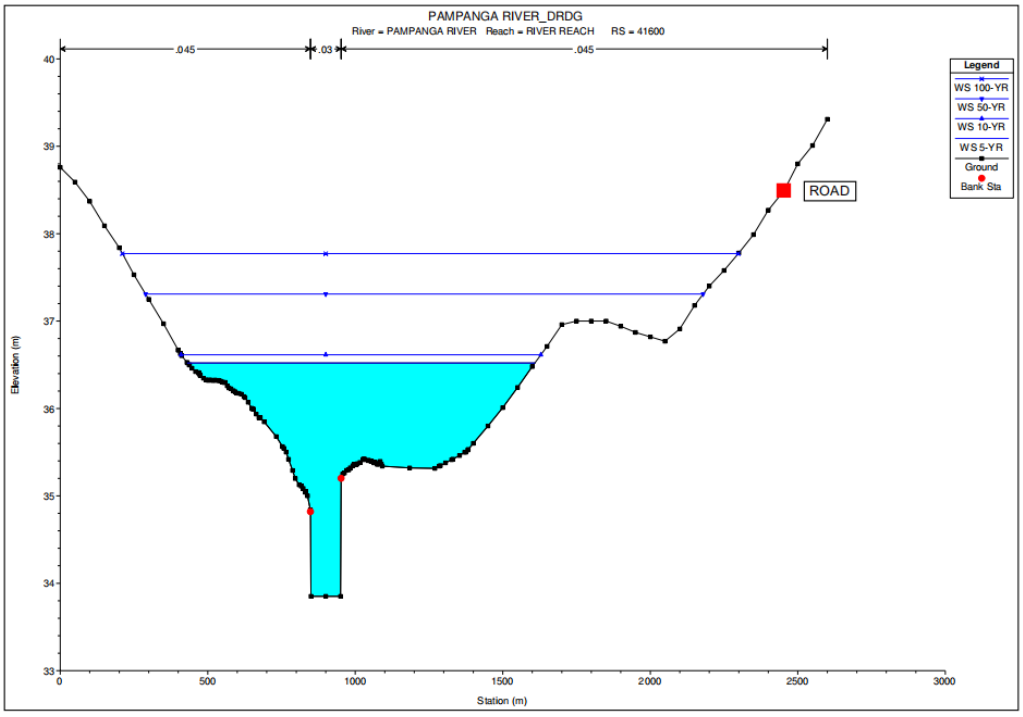
No Measure- (High Climate Change to 2050)



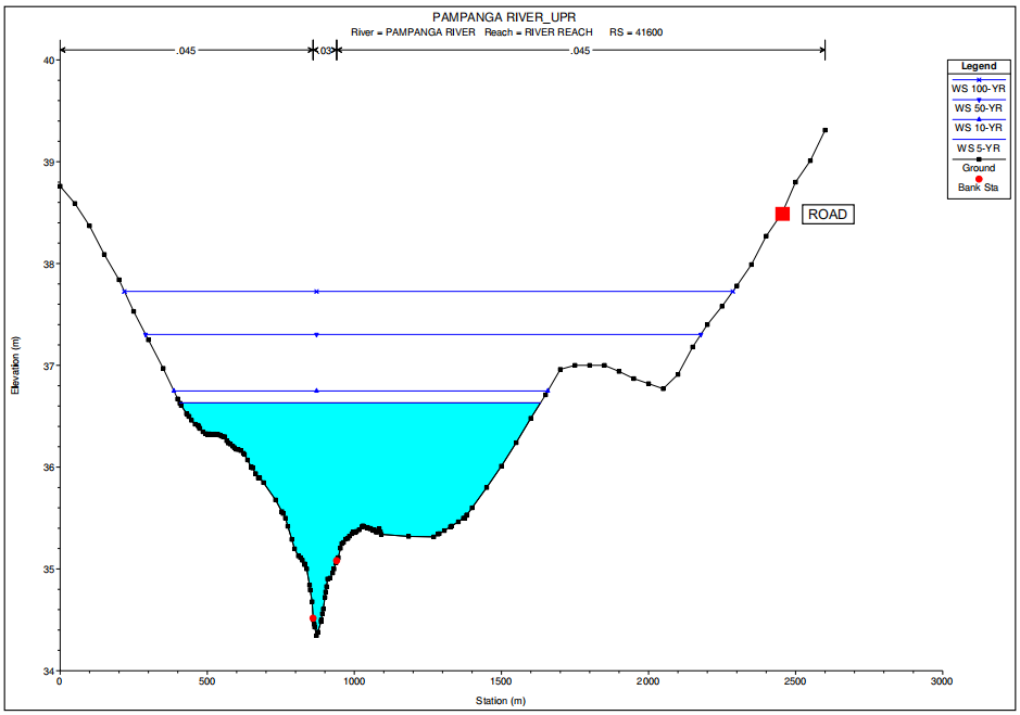
Measure 1- Elevated Road (High Climate Change to 2050)



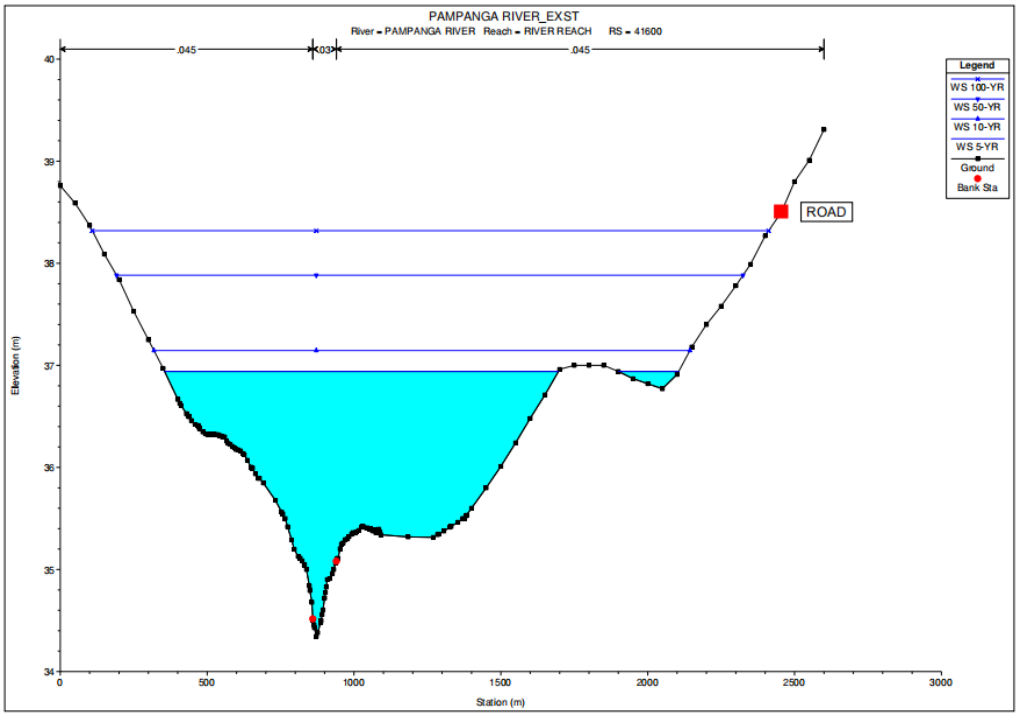
Measure 2- With Dredging (High Climate Change to 2050)



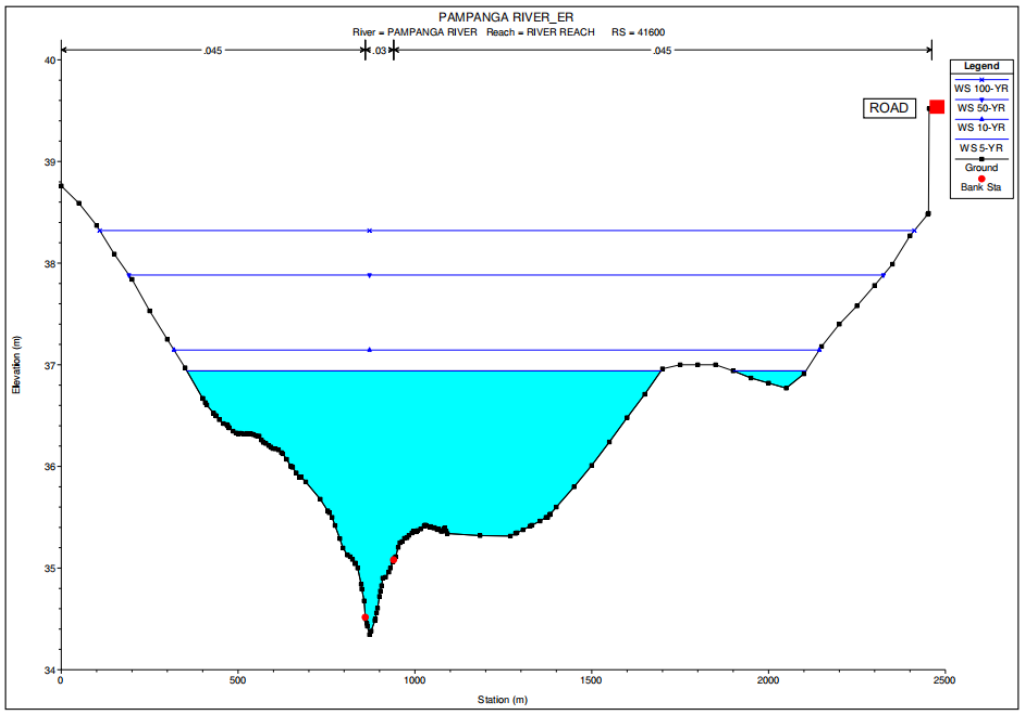
Measure 3- With Retention/ Detention (High Climate Change to 2050)



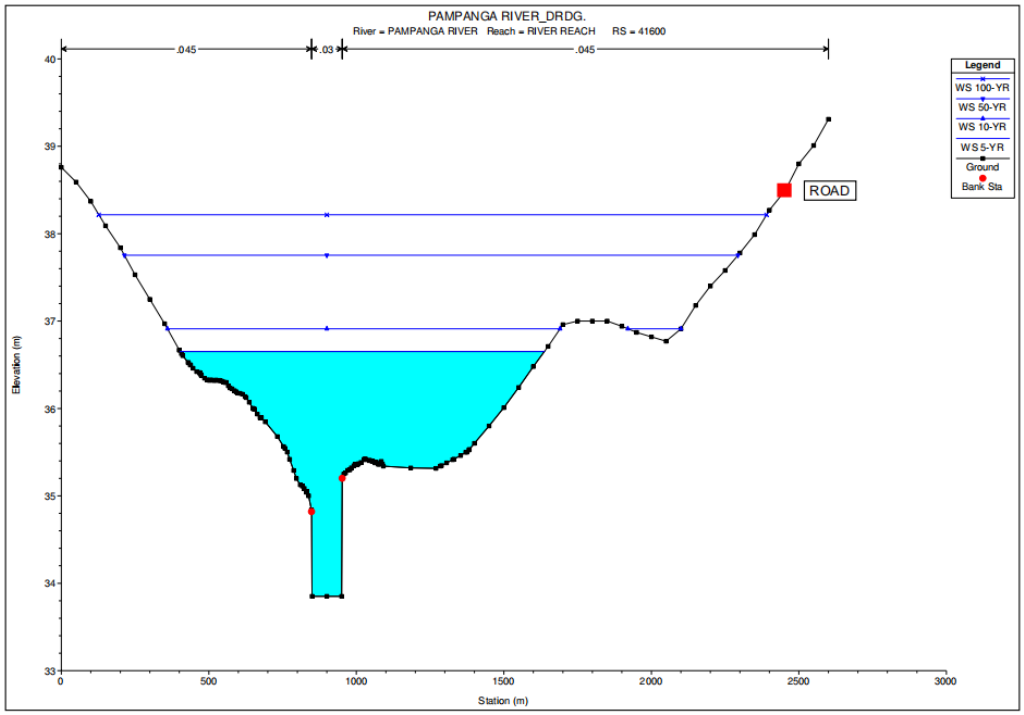
No Measure- (High Climate Change to 2100)



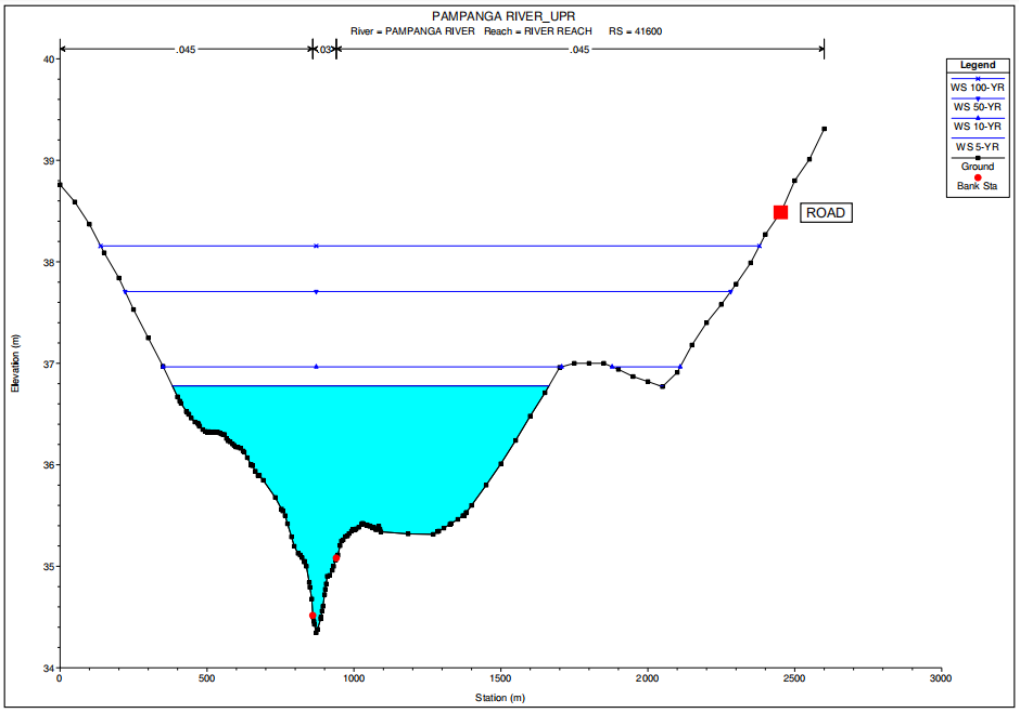
Measure 1- Elevated Road (High Climate Change to 2100)



Measure 2- With Dredging (High Climate Change to 2100)

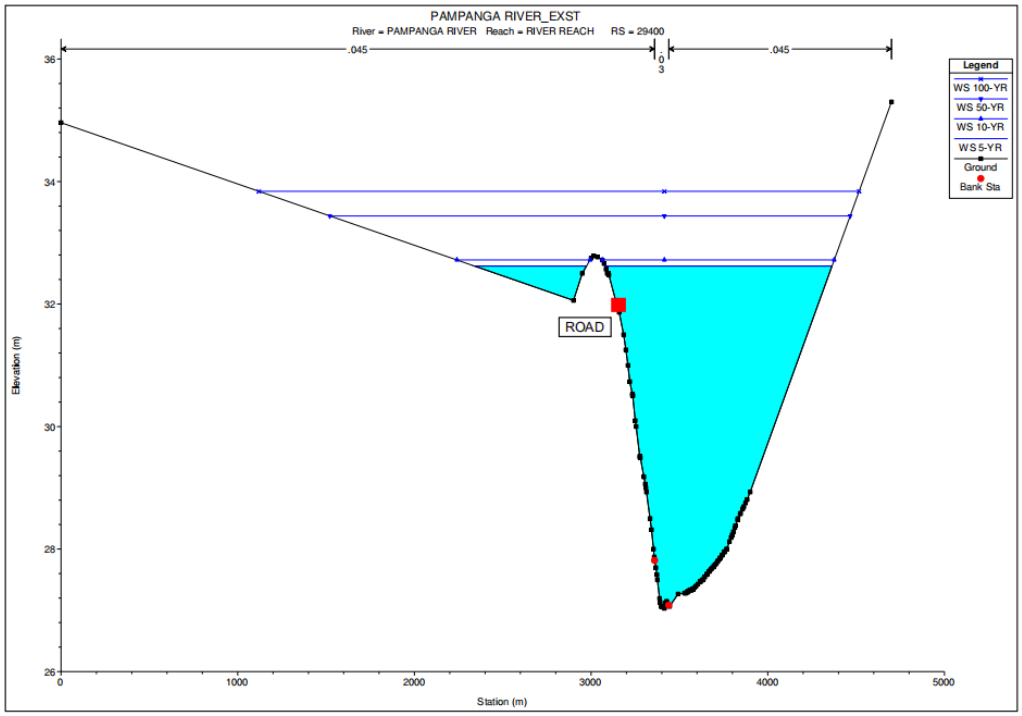


Measure 3- With Retention/ Detention (High Climate Change to 2100)

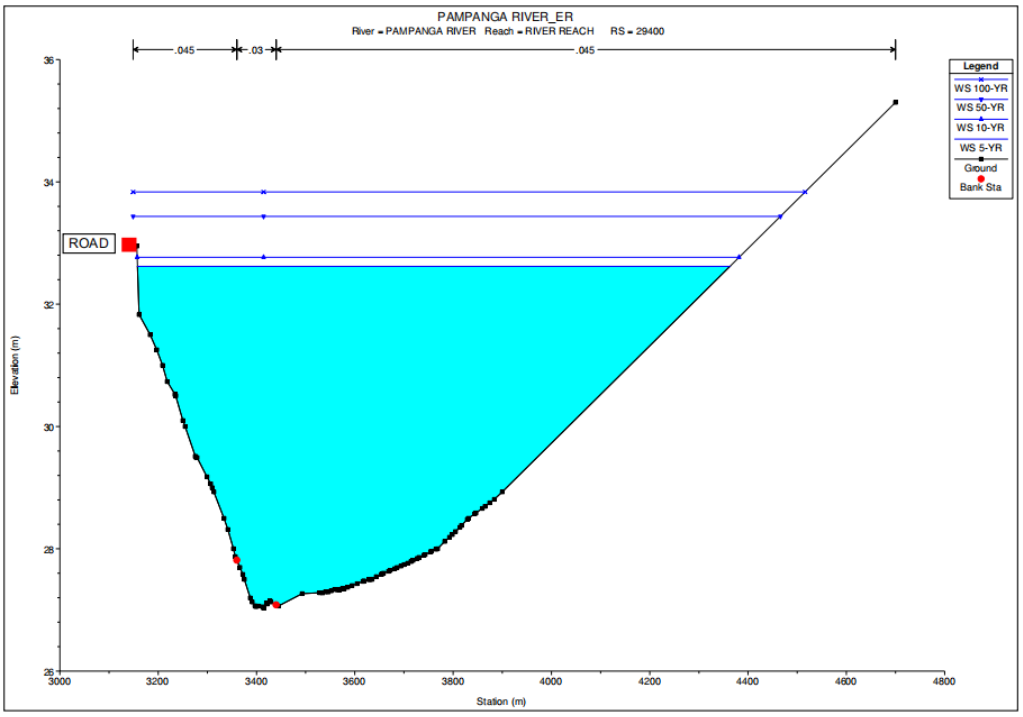


AIV.6 - PAMPANGA HEC-RAS OUTPUTS FOR LOCATION 3-Sta. 29+400

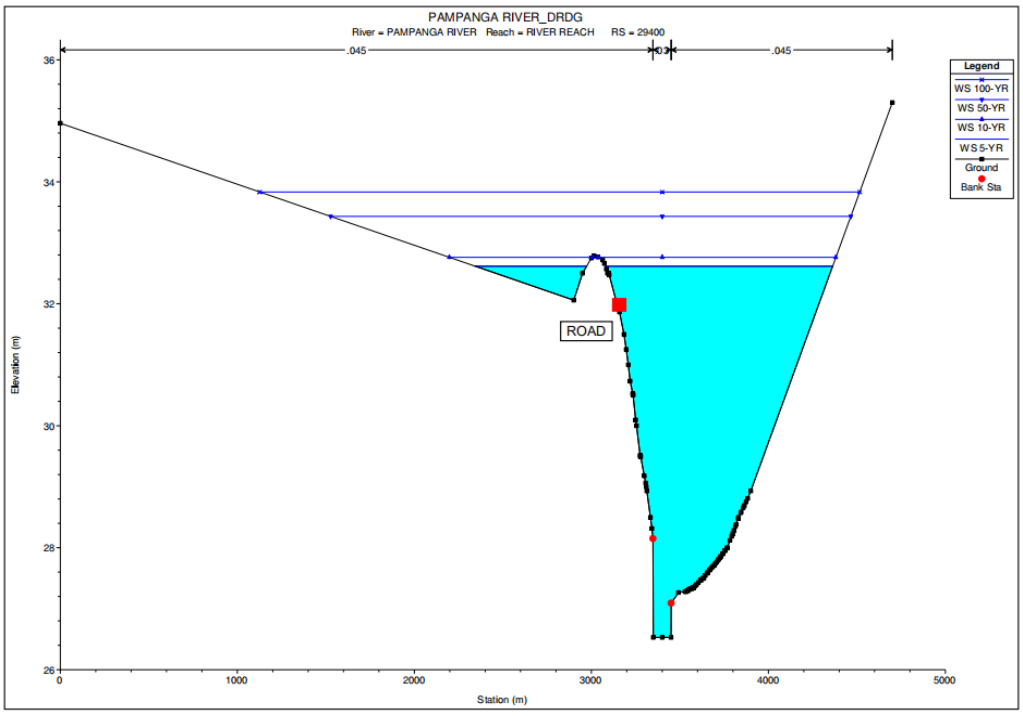
No Measure (Without Climate Change)



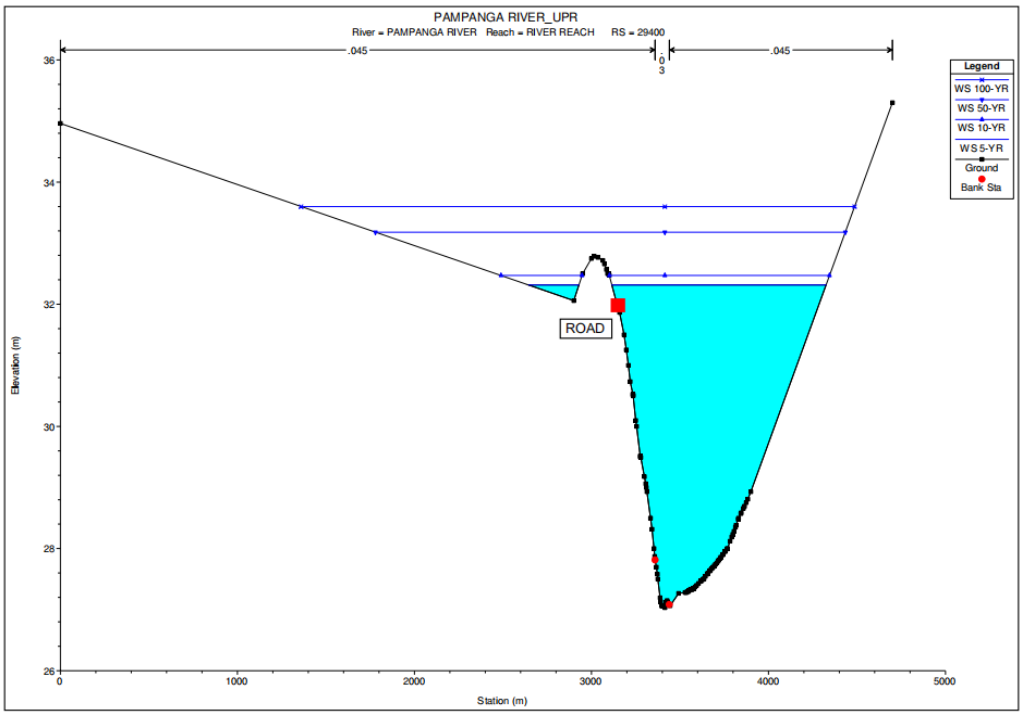
Measure 1- Elevated Road (Without Climate Change)



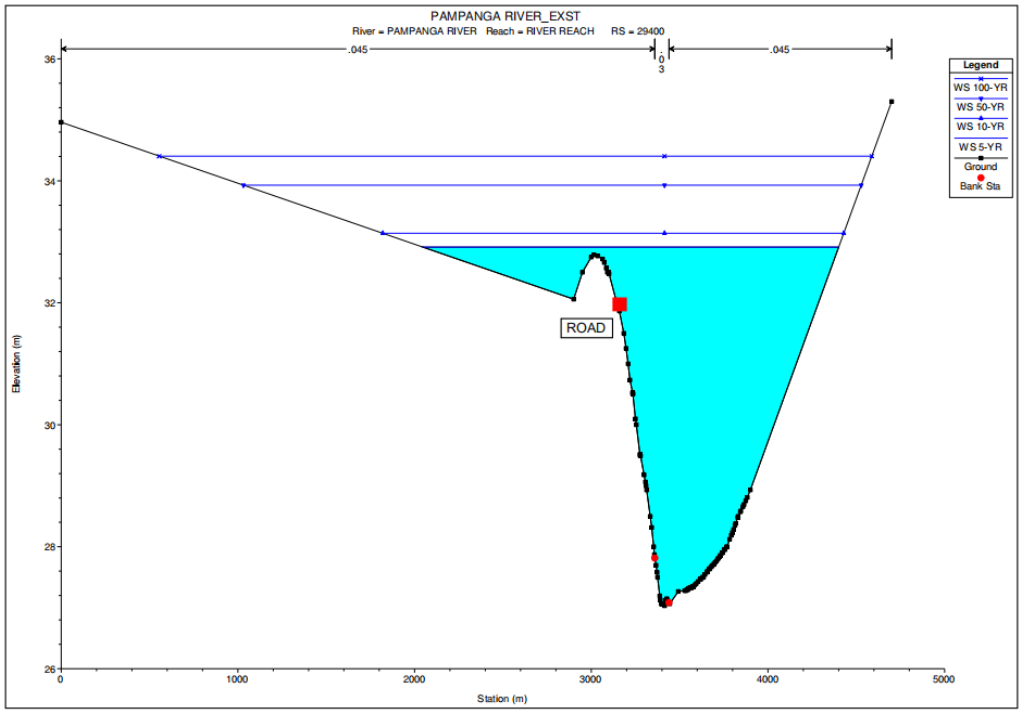
Measure 2- With Dredging (Without Climate Change)



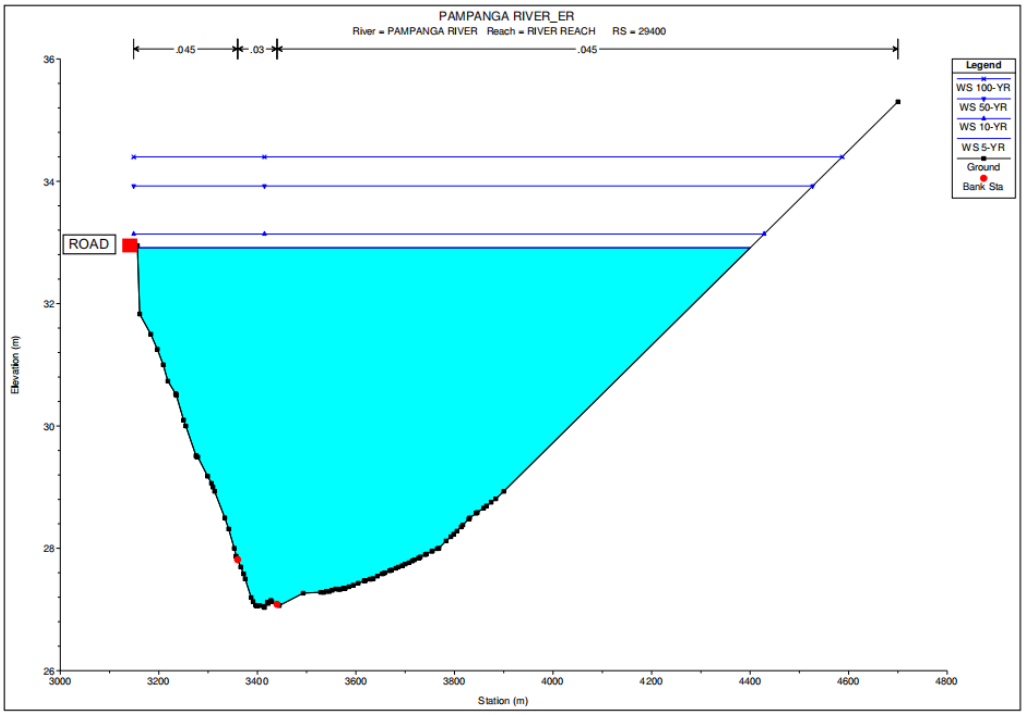
Measure 3- With Retention/ Detention (Without Climate Change)



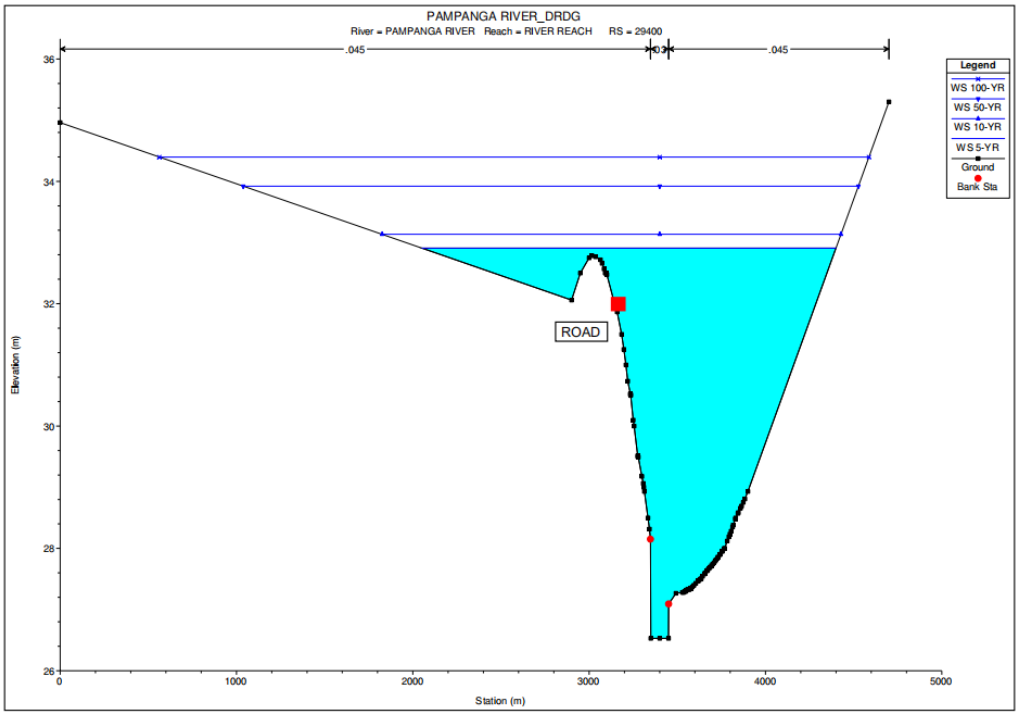
No Measure- (High Climate Change to 2050)



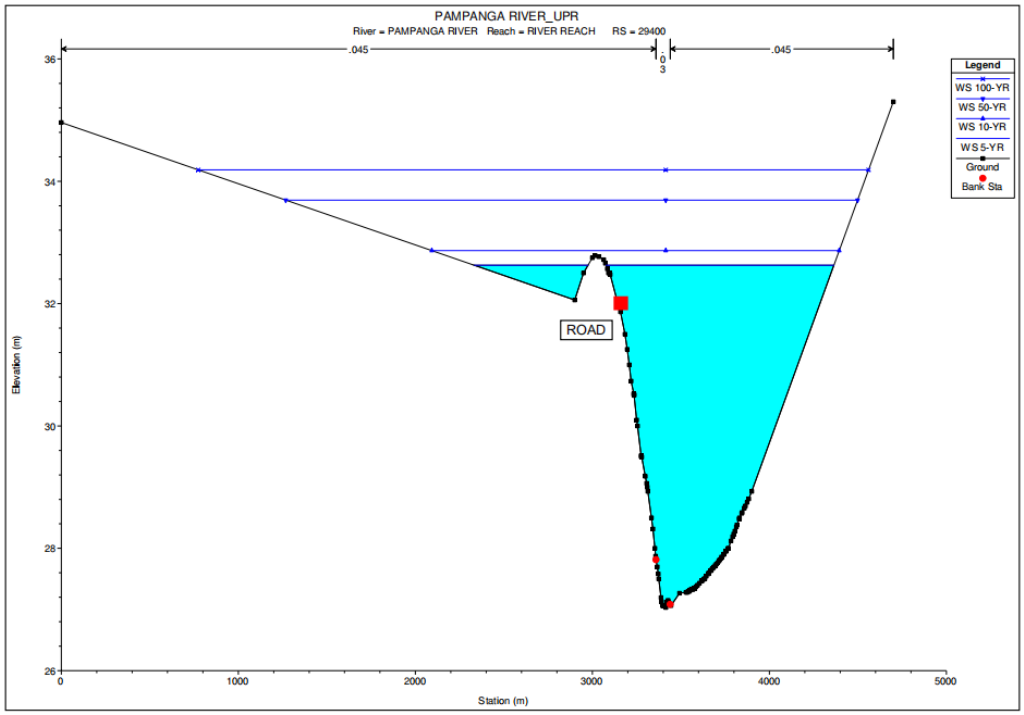
Measure 1- Elevated Road (High Climate Change to 2050)



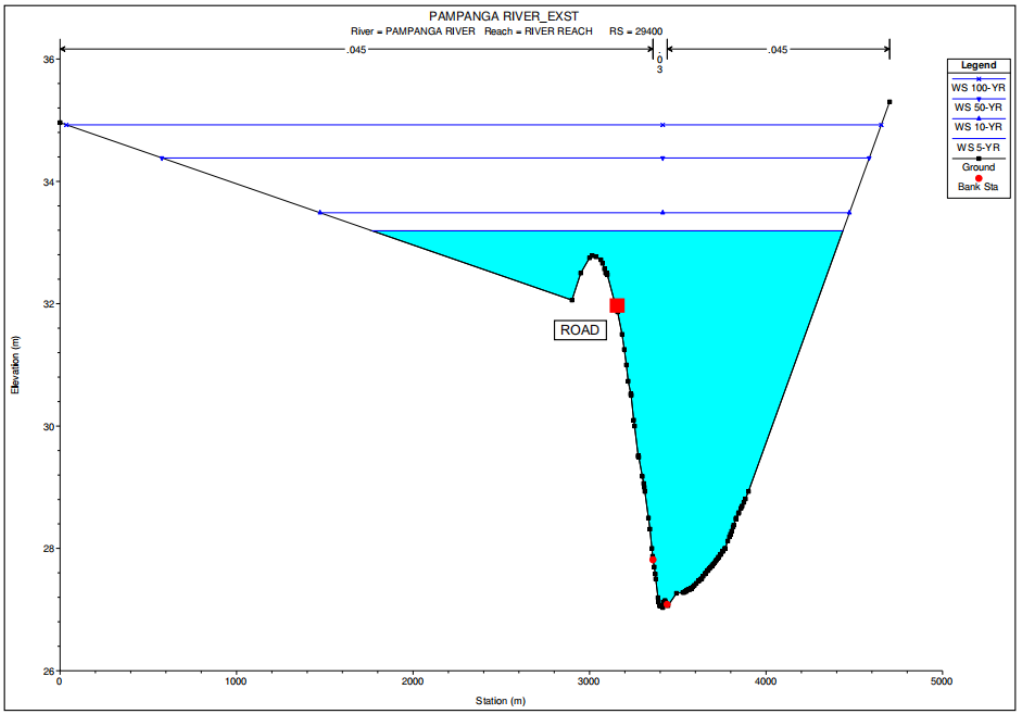
Measure 2- With Dredging (High Climate Change to 2050)



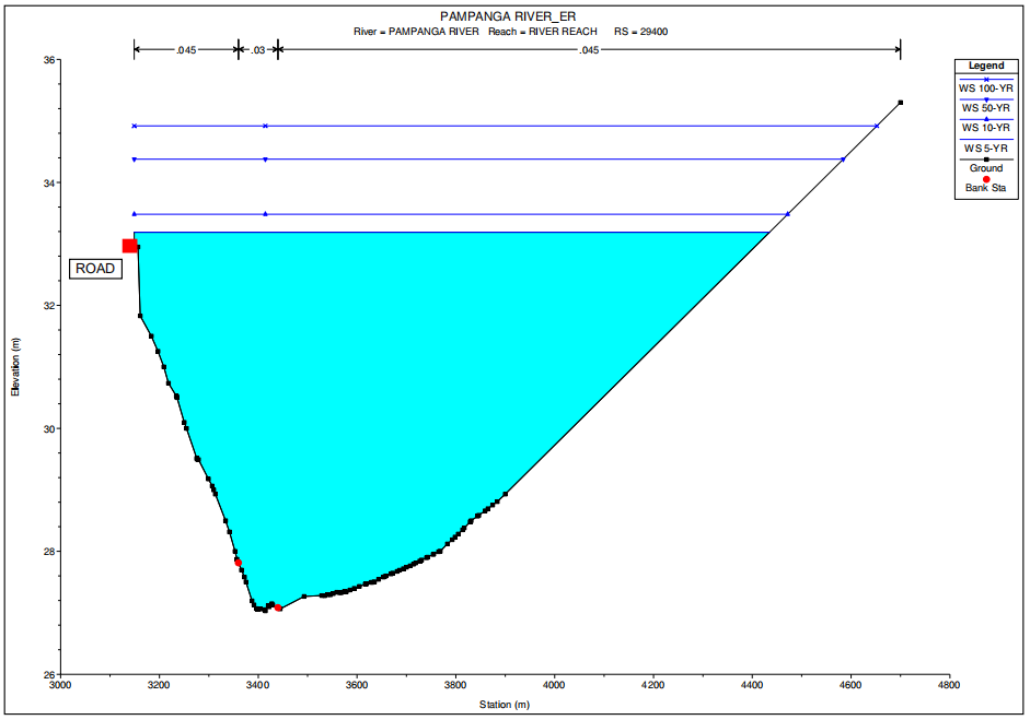
Measure 3- With Retention/ Detention (High Climate Change to 2050)



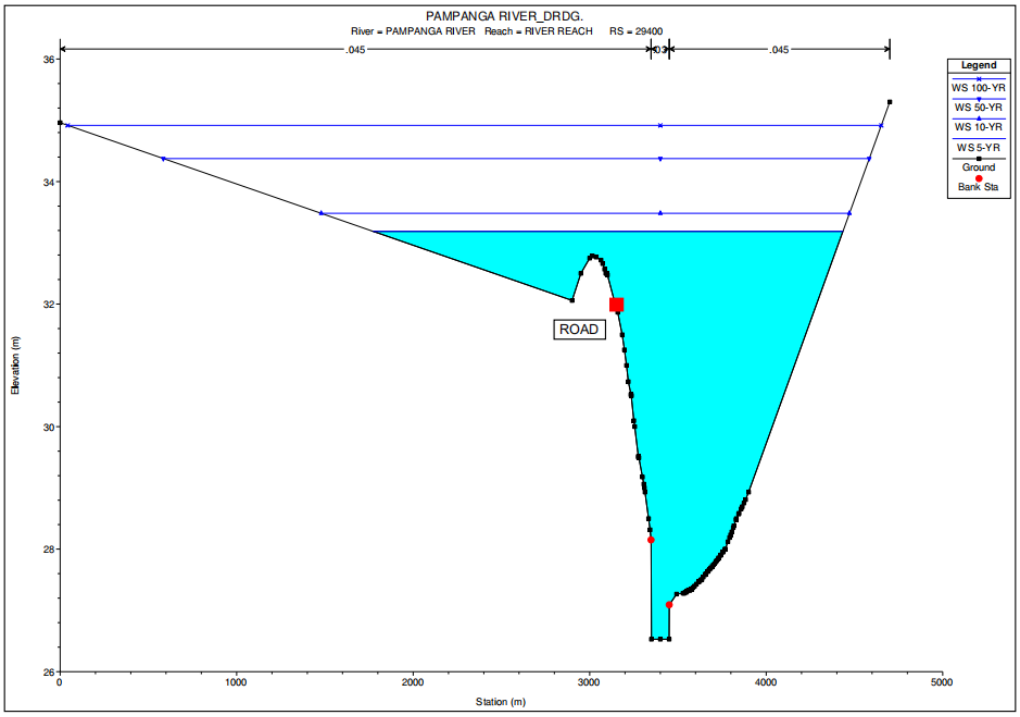
No Measure- (High Climate Change to 2100)



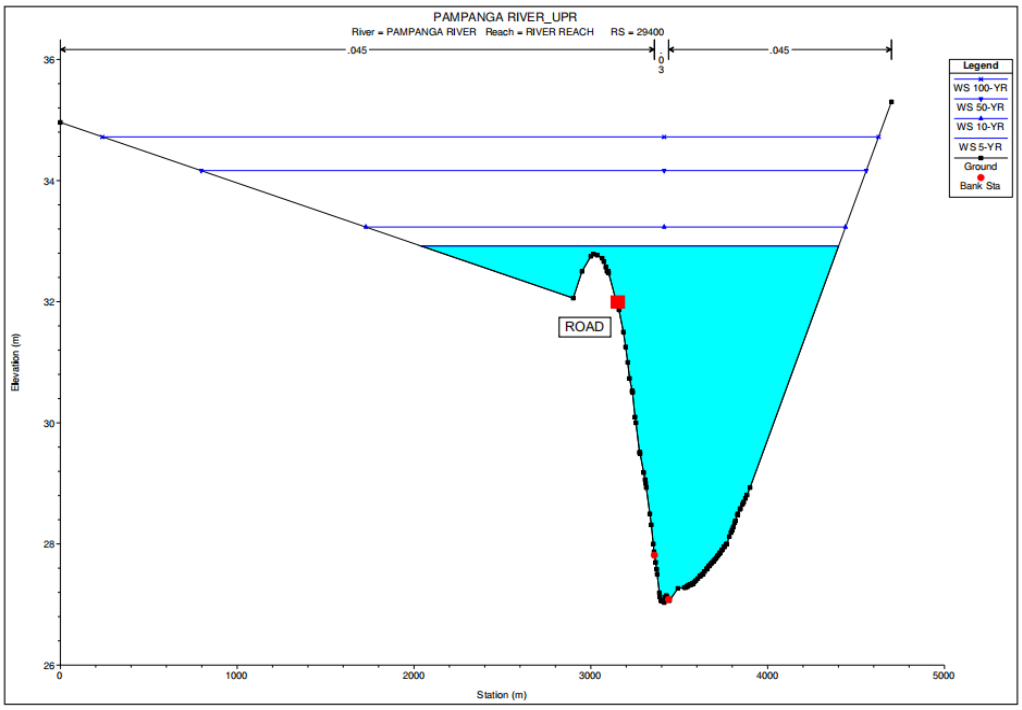
Measure 1- Elevated Road (High Climate Change to 2100)



Measure 2- With Dredging (High Climate Change to 2100)

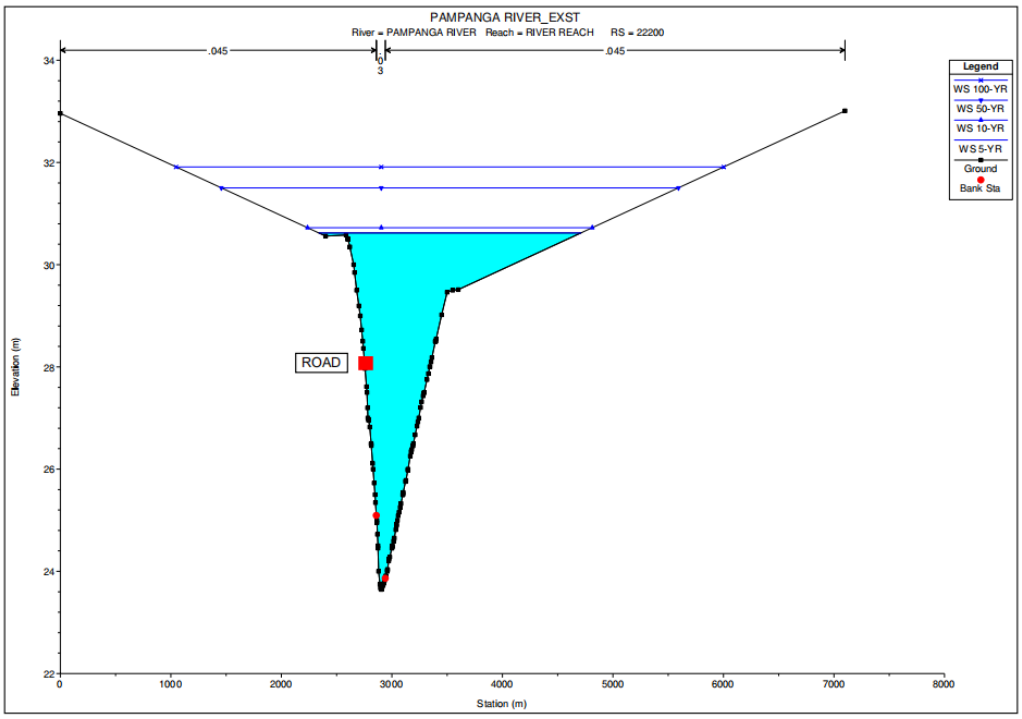


Measure 3- With Retention/ Detention (High Climate Change to 2100)

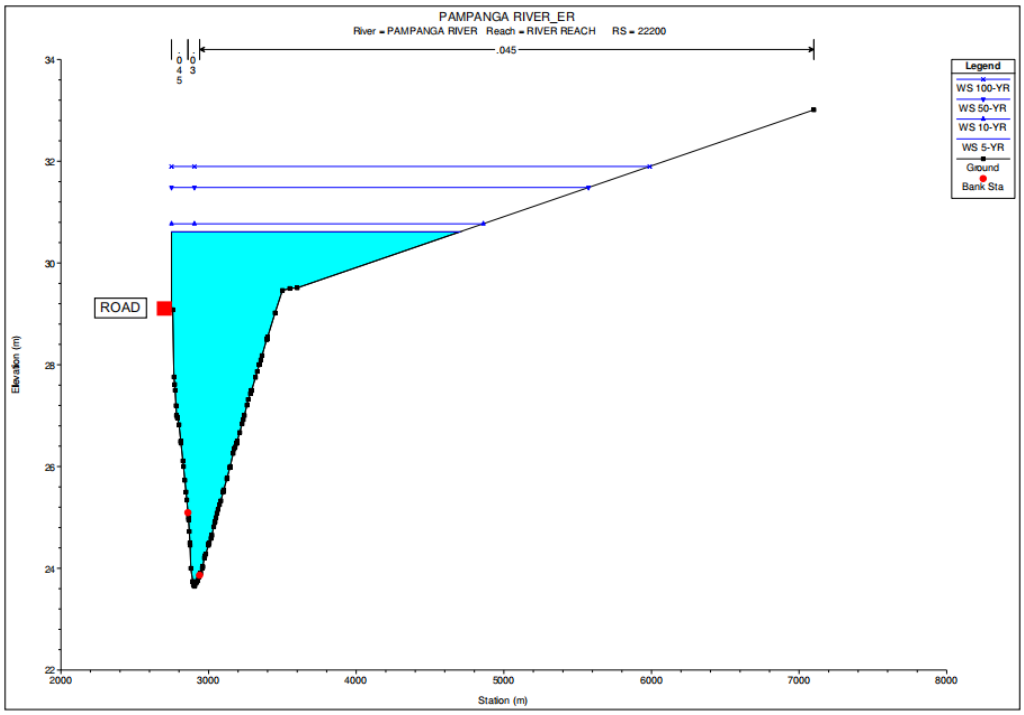


AIV.7 - PAMPANGA HEC-RAS OUTPUTS FOR LOCATION 3-Sta. 22+200

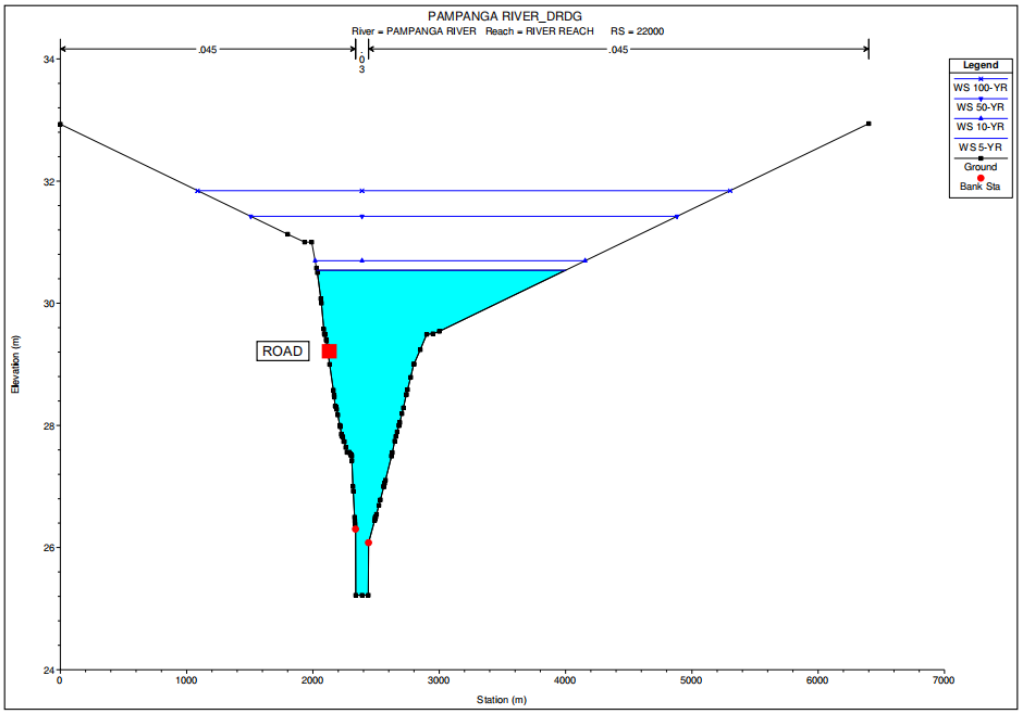
No Measure (Without Climate Change)



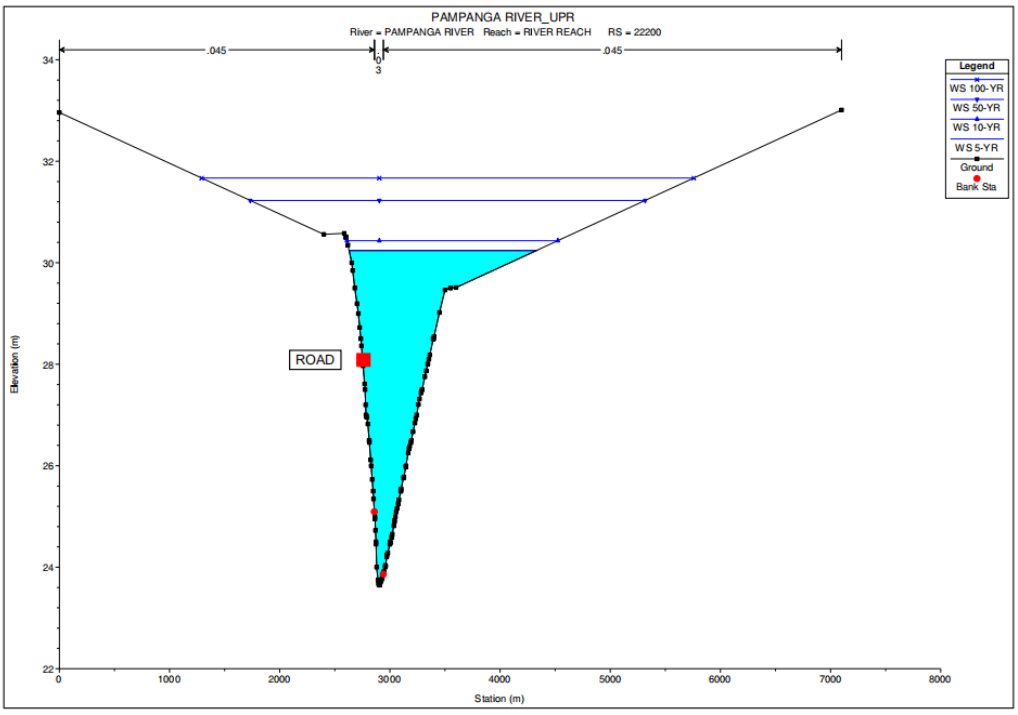
Measure 1- Elevated Road (Without Climate Change)



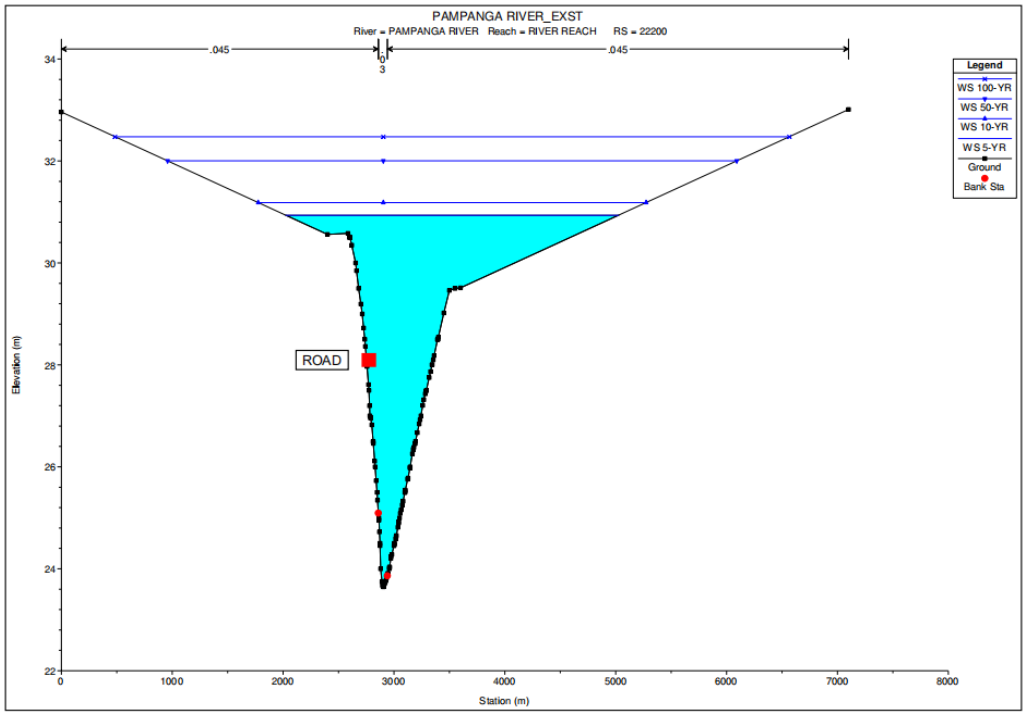
Measure 2- With Dredging (Without Climate Change)



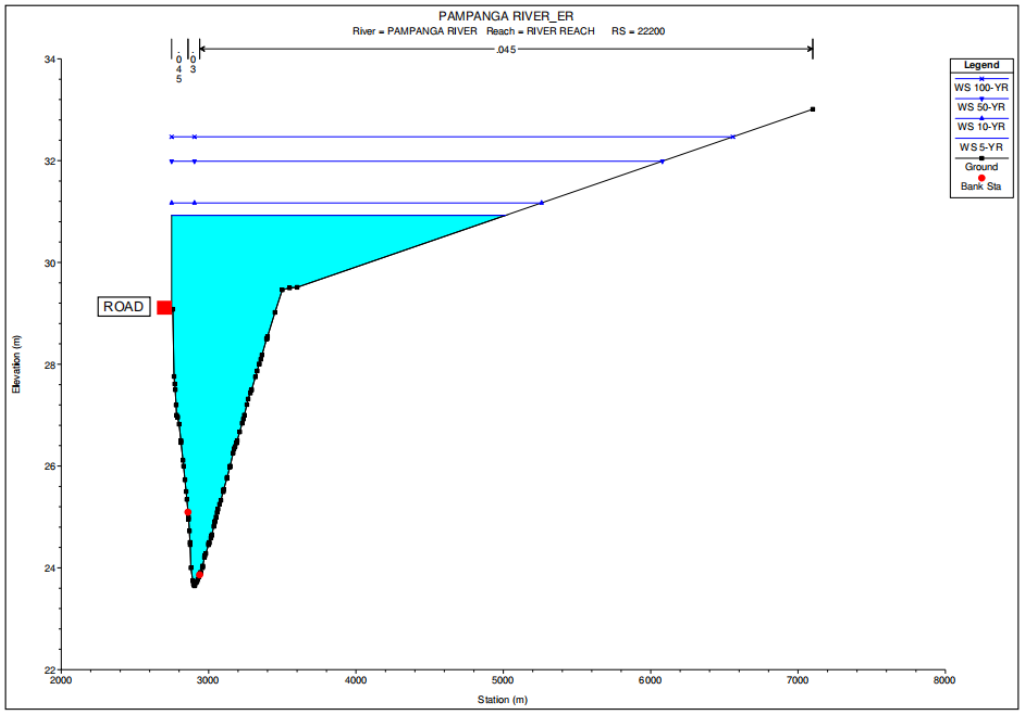
Measure 3- With Retention/ Detention (Without Climate Change)



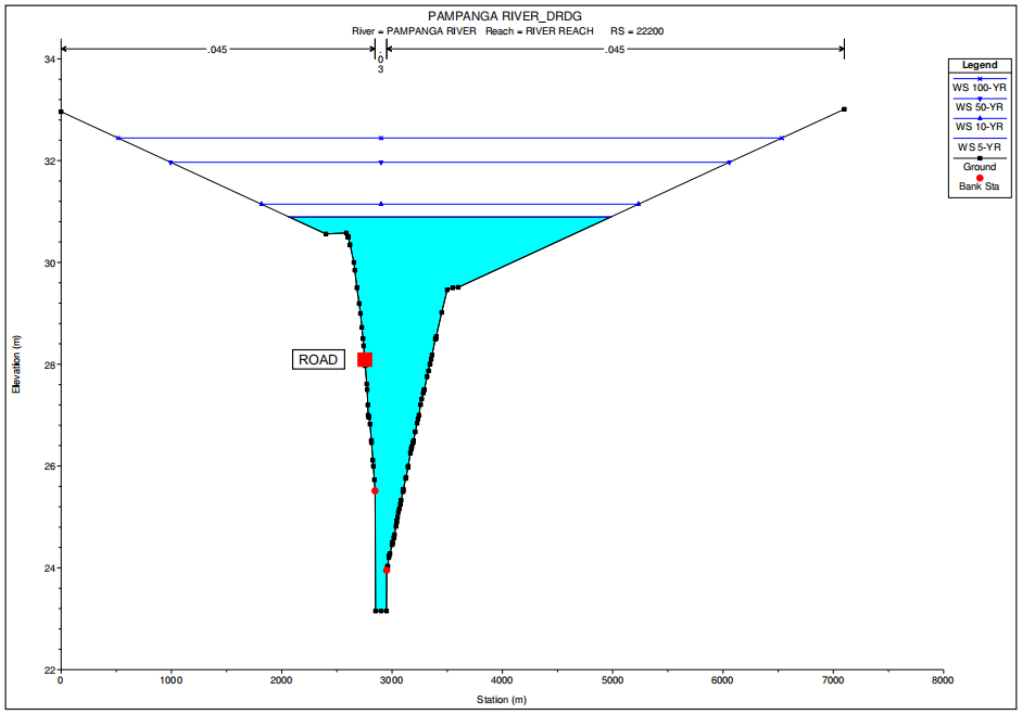
No Measure- (High Climate Change to 2050)



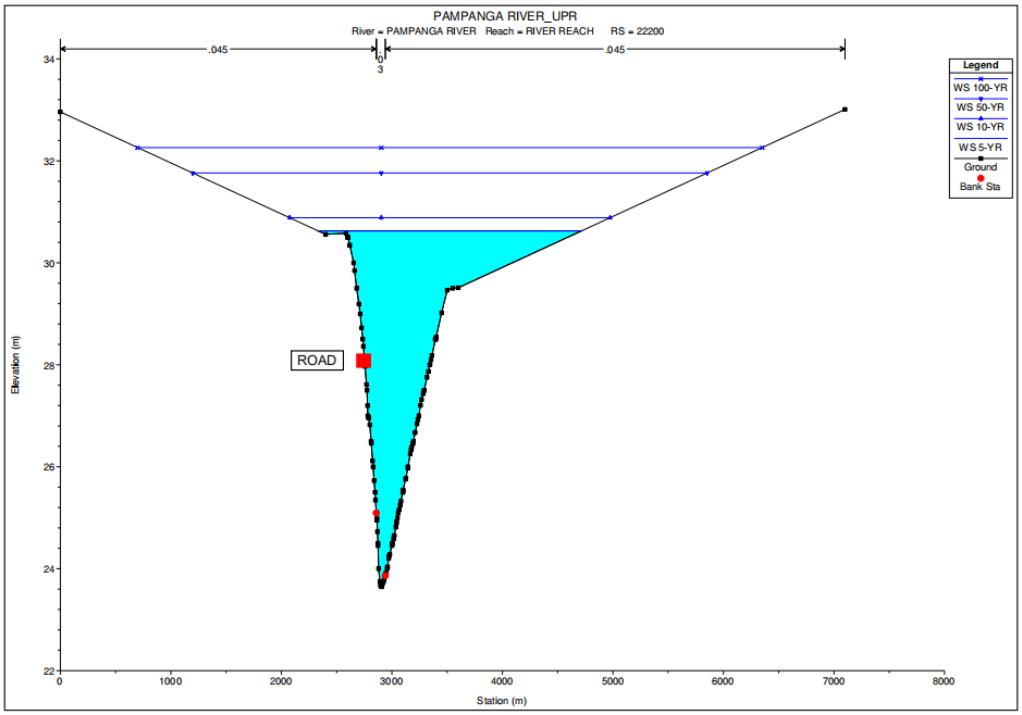
Measure 1- Elevated Road (High Climate Change to 2050)



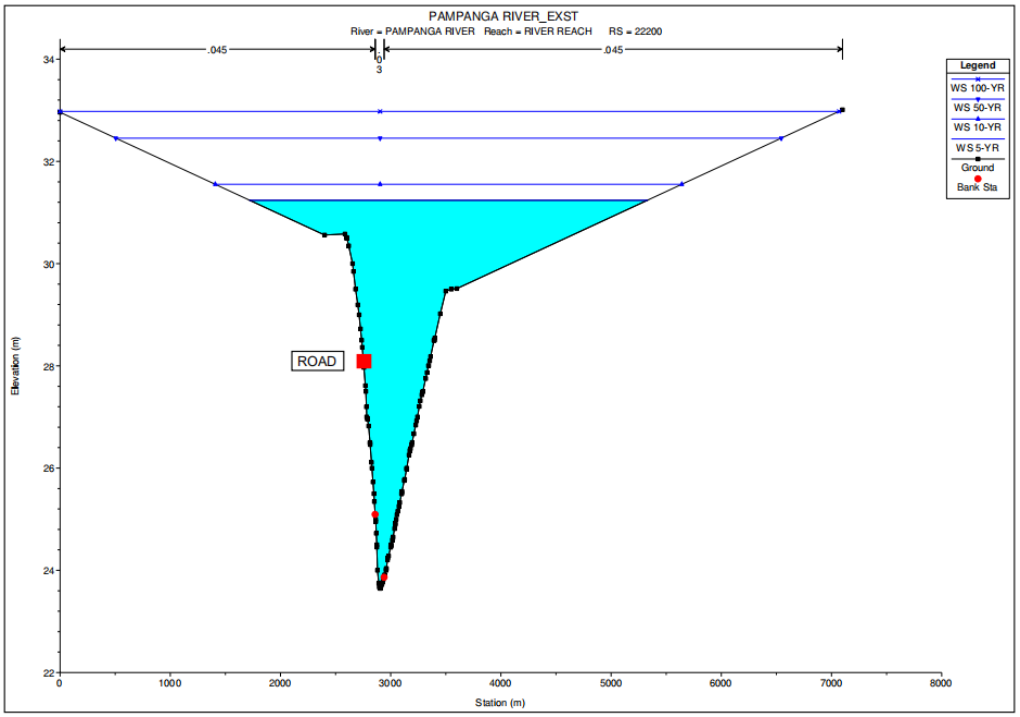
Measure 2- With Dredging (High Climate Change to 2050)



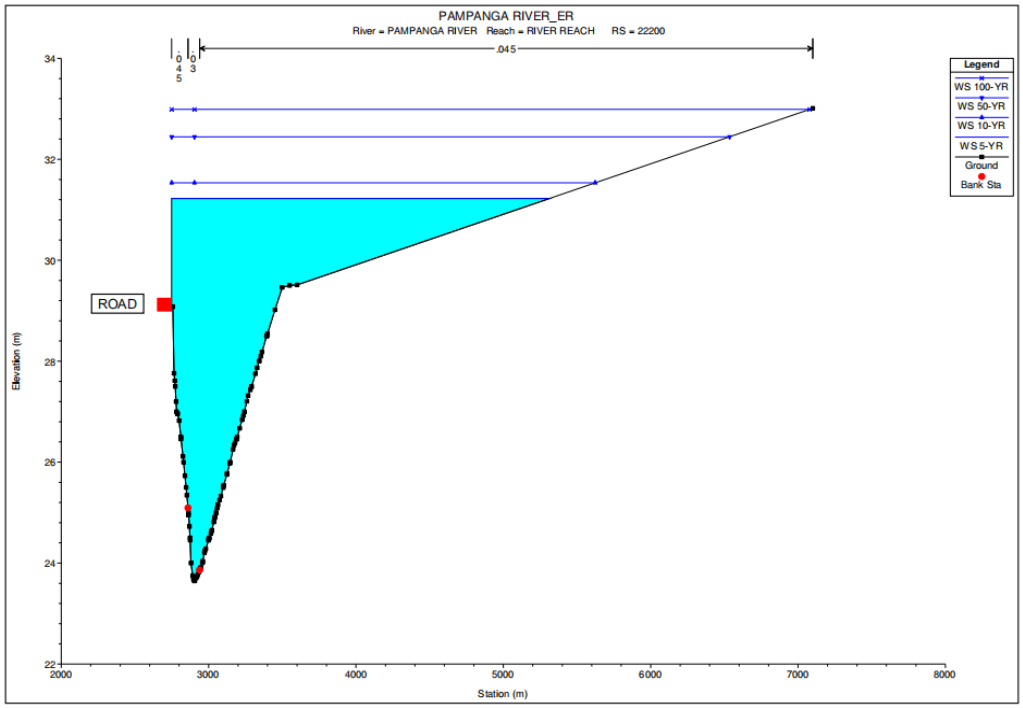
Measure 3- With Retention/ Detention (High Climate Change to 2050)



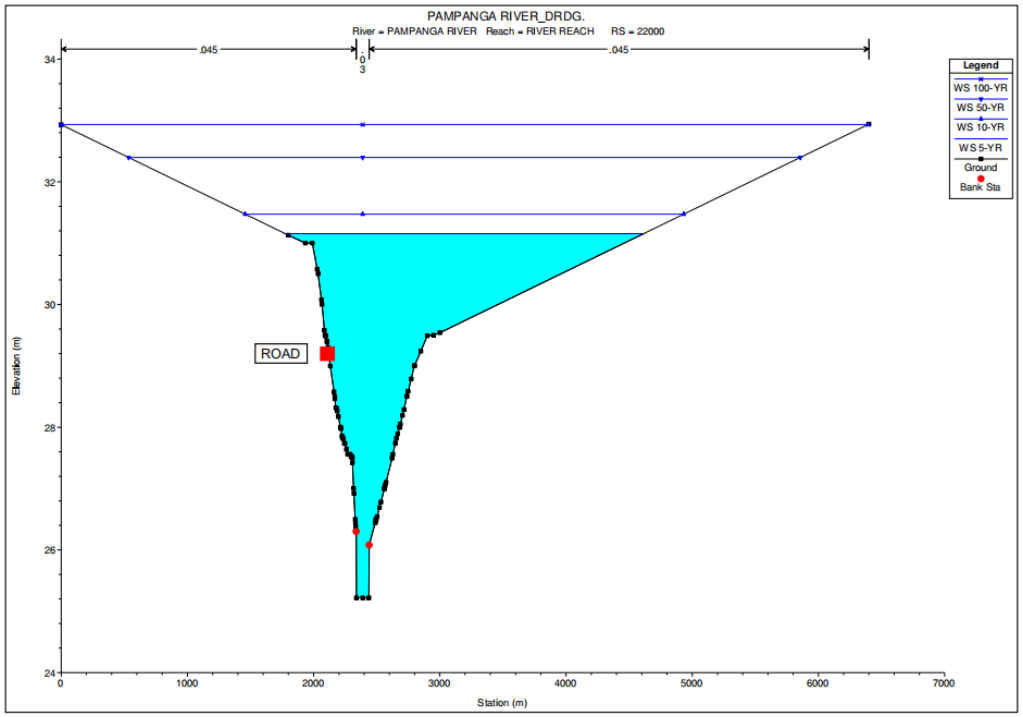
No Measure- (High Climate Change to 2100)



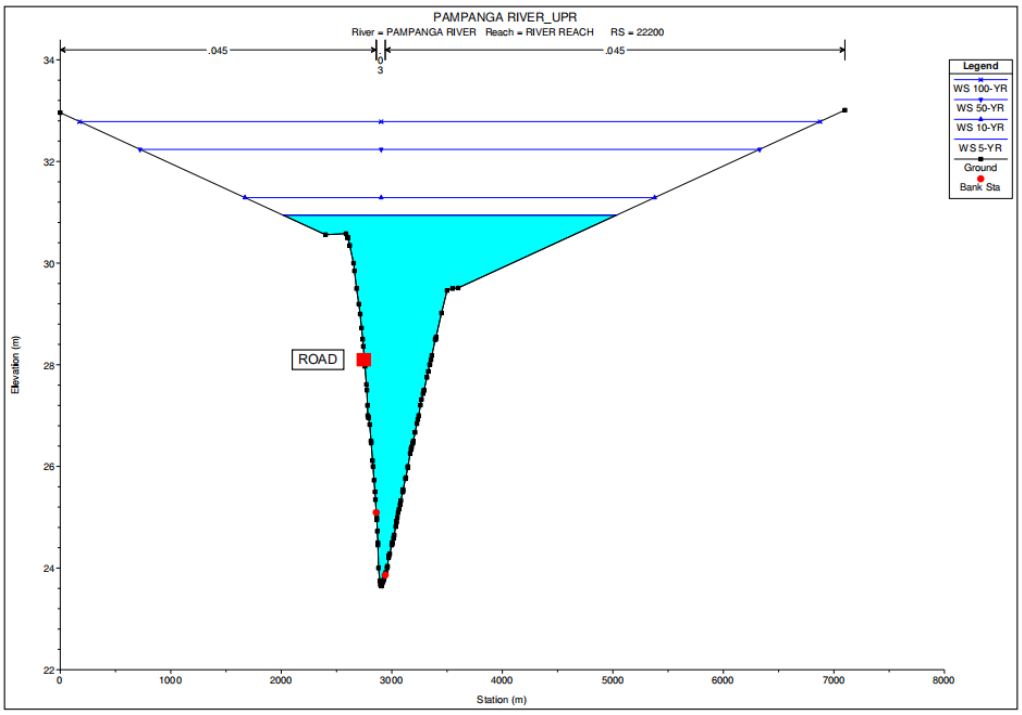
Measure 1- Elevated Road (High Climate Change to 2100)



Measure 2- With Dredging (High Climate Change to 2100)

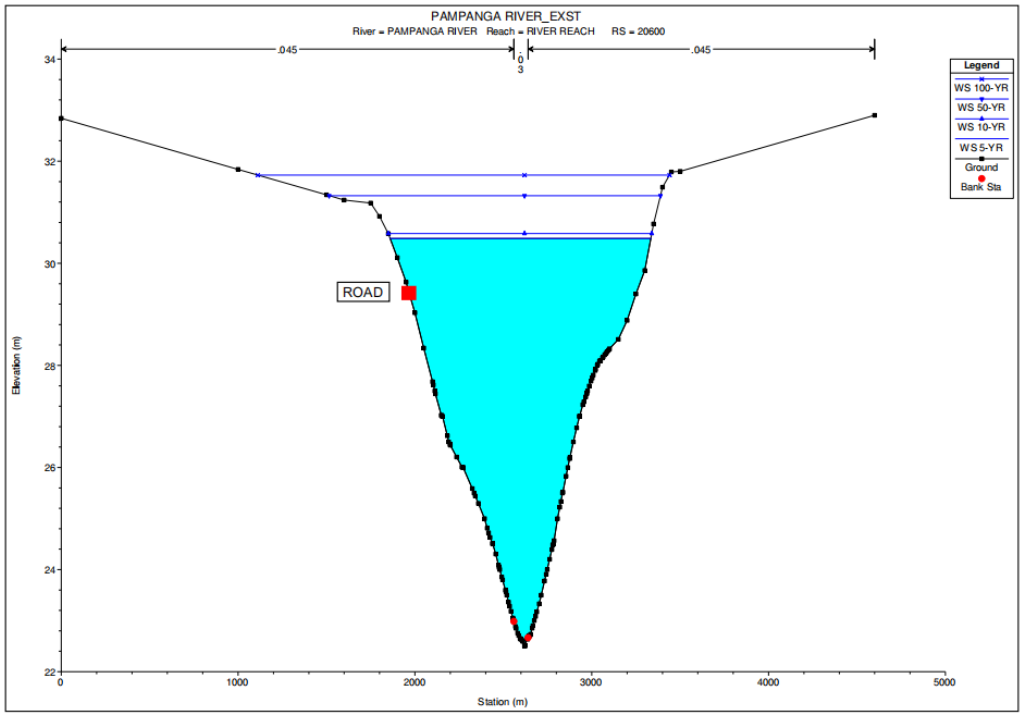


Measure 3- With Retention/ Detention (High Climate Change to 2100)

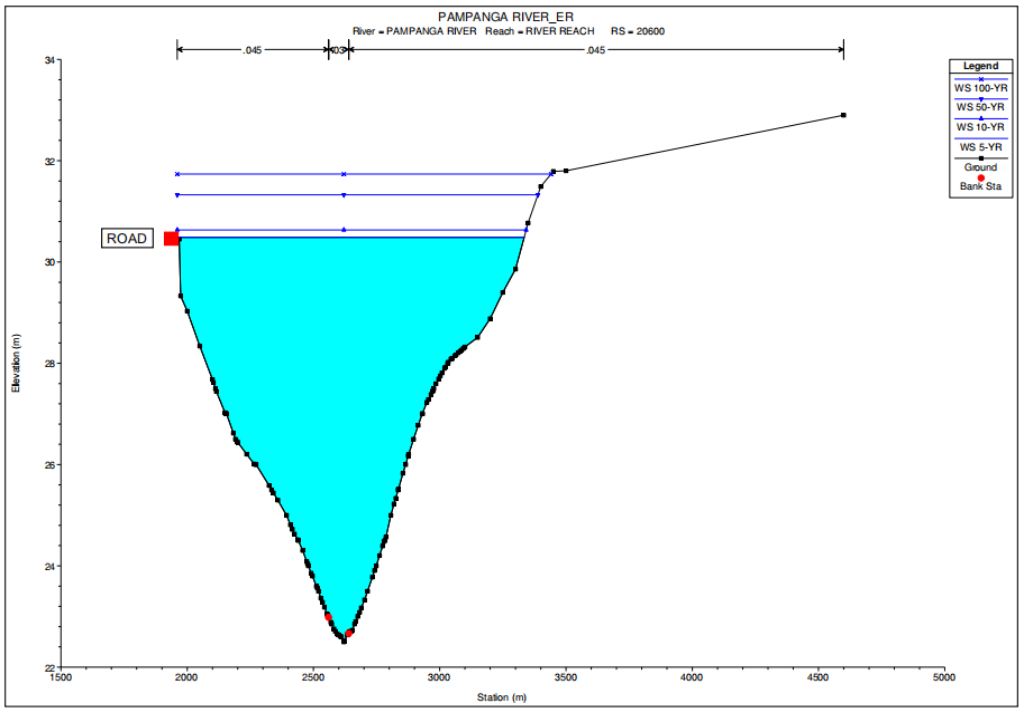


AIV.8 - PAMPANGA HEC-RAS OUTPUTS FOR LOCATION 3-Sta. 20+600

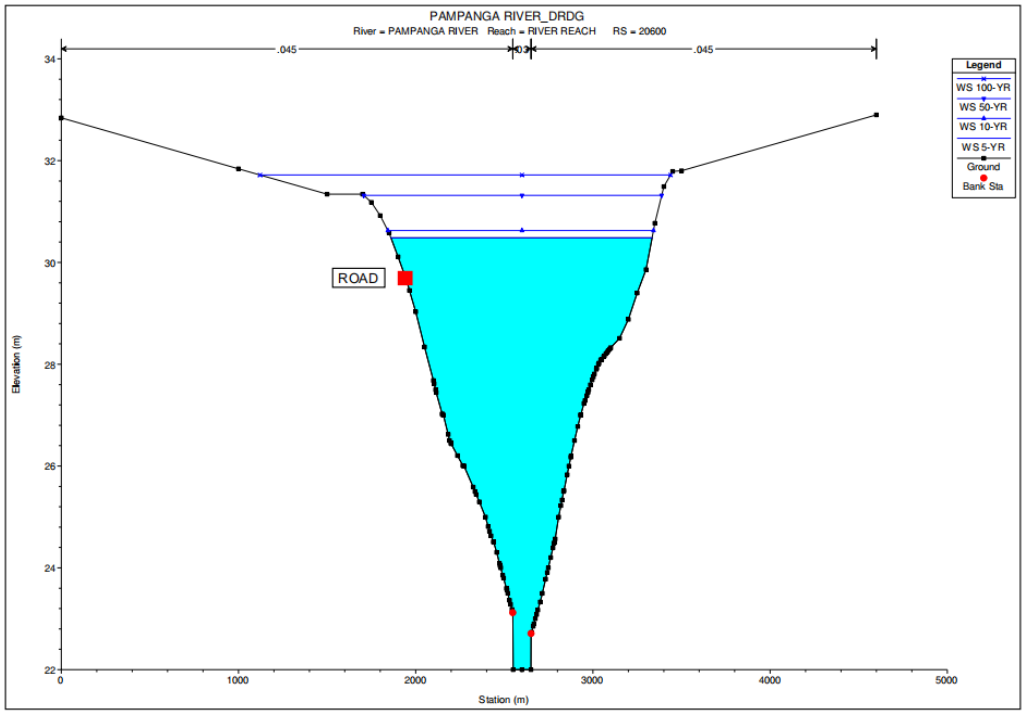
No Measure (Without Climate Change)



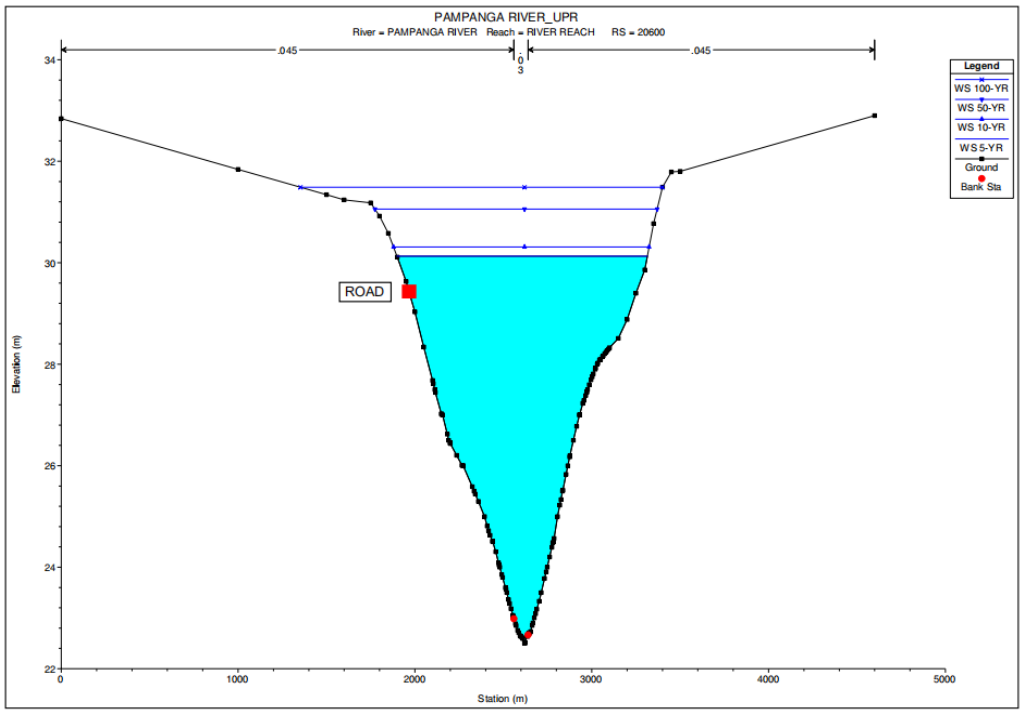
Measure 1- Elevated Road (Without Climate Change)



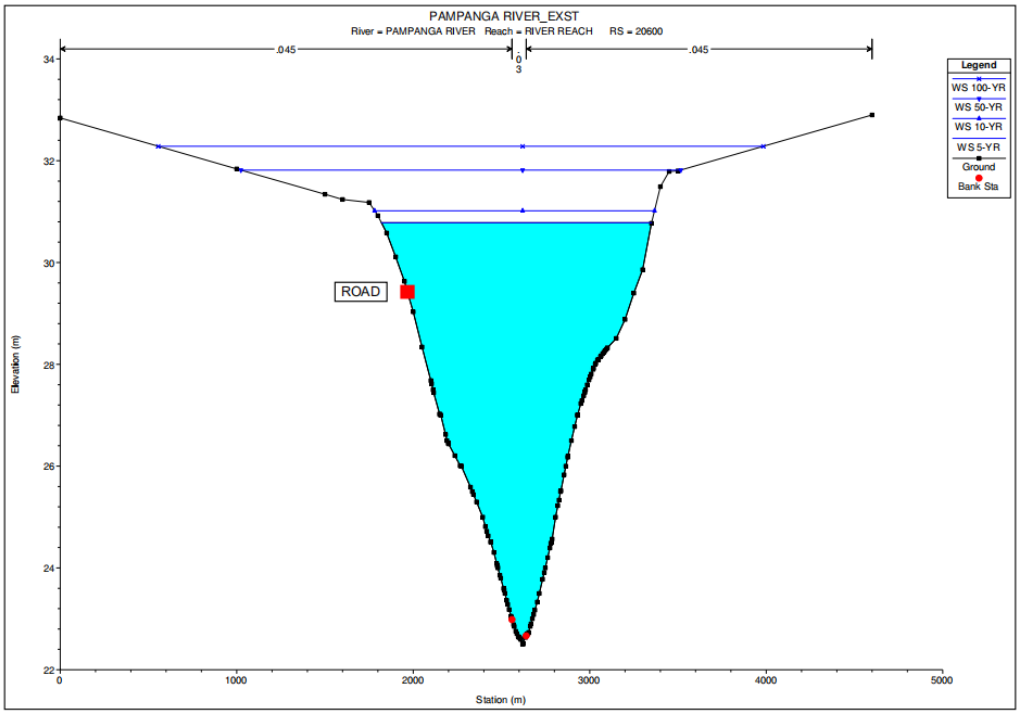
Measure 2- With Dredging (Without Climate Change)



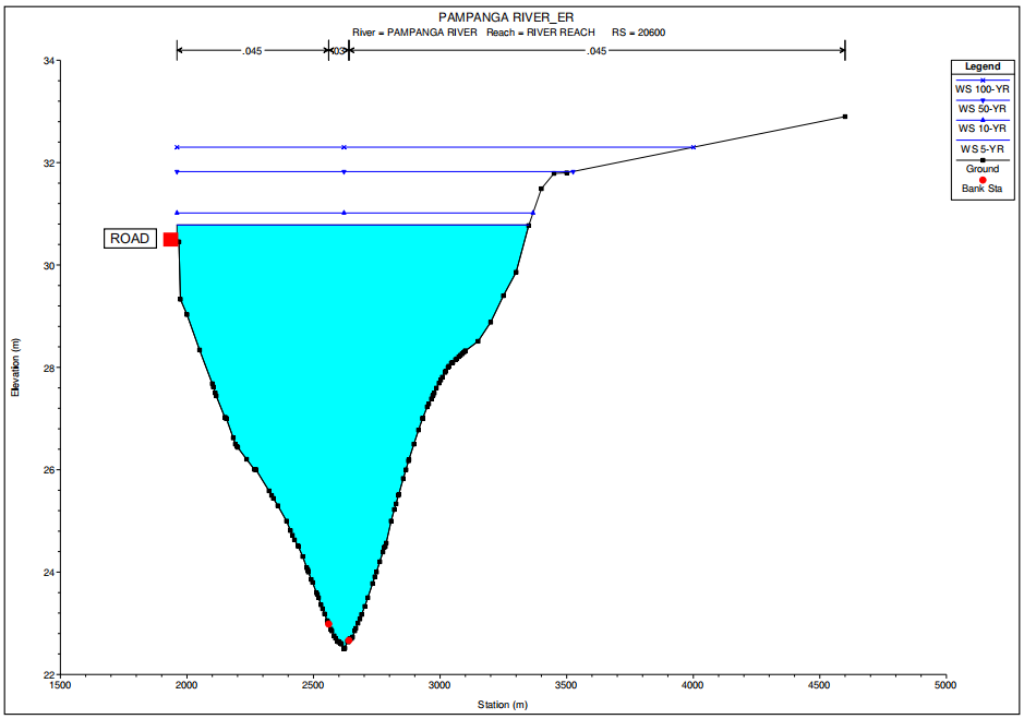
Measure 3- With Retention/ Detention (Without Climate Change)



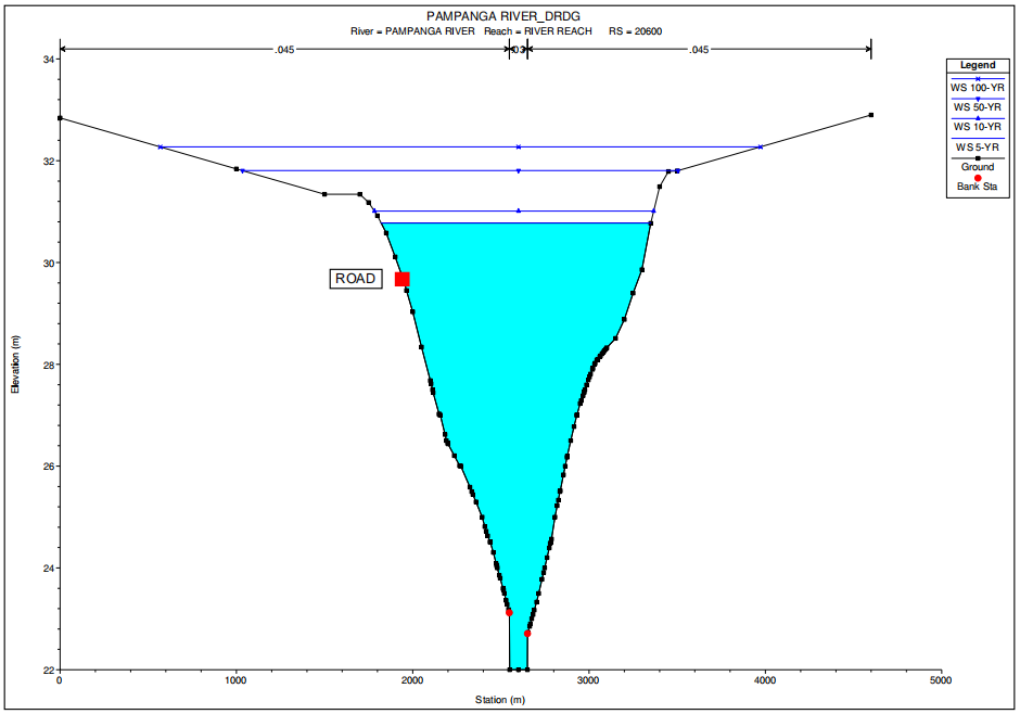
No Measure- (High Climate Change to 2050)



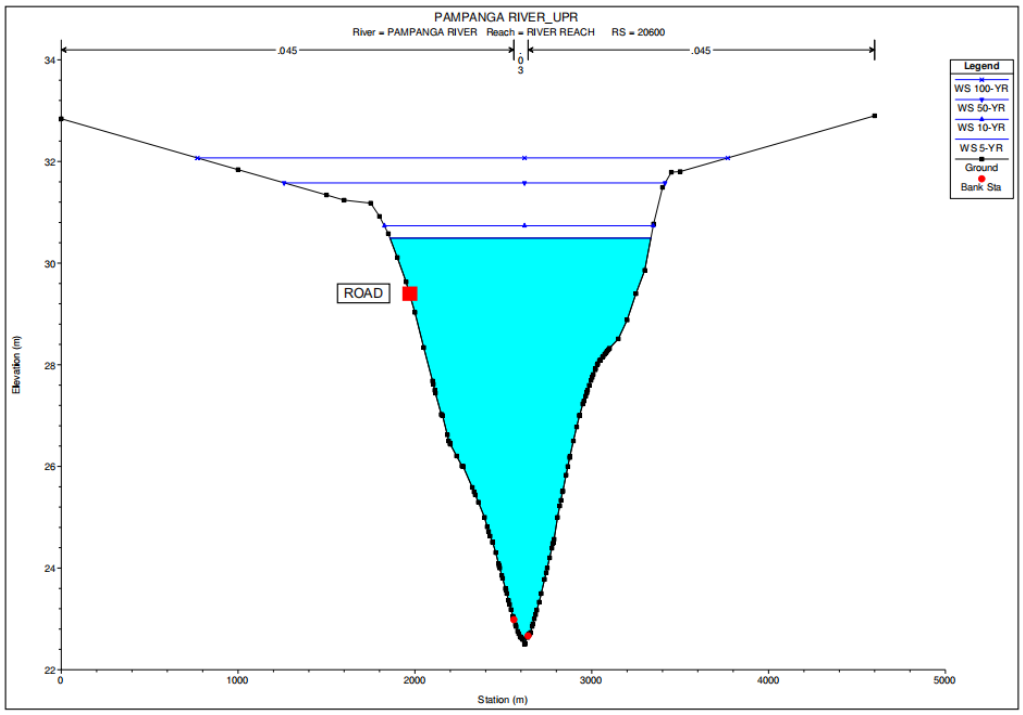
Measure 1- Elevated Road (High Climate Change to 2050)



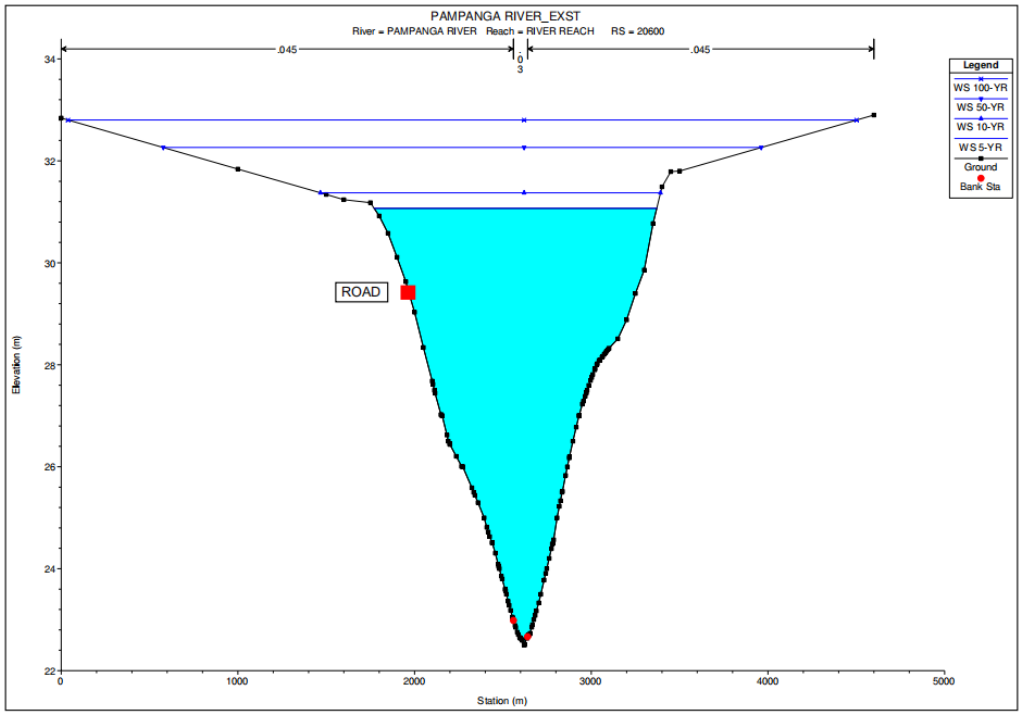
Measure 2- With Dredging (High Climate Change to 2050)



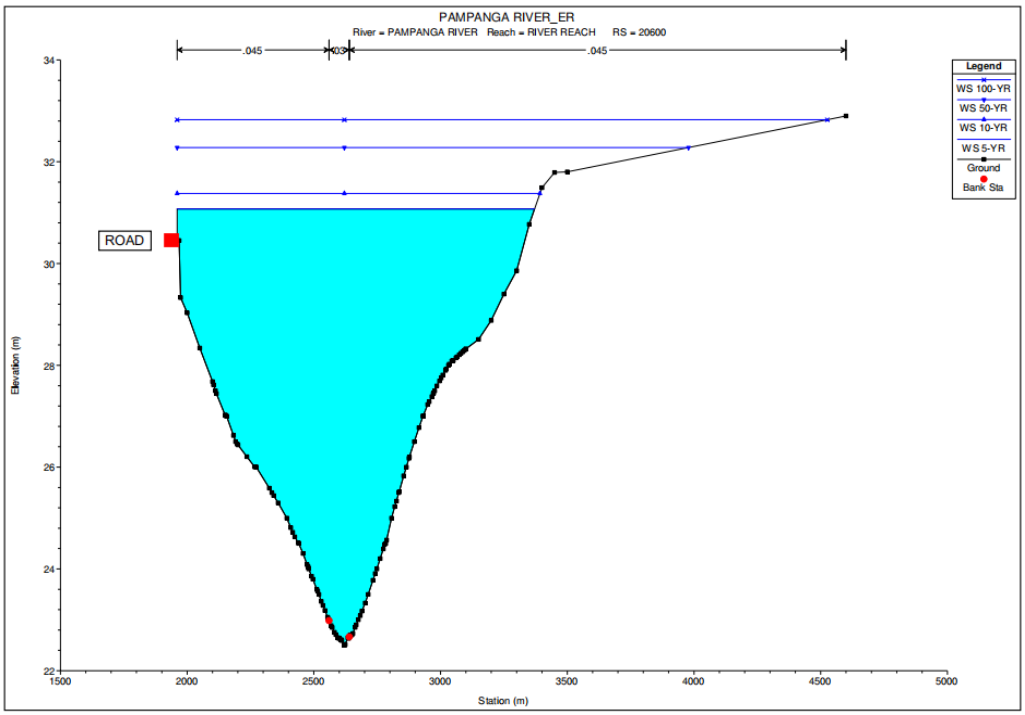
Measure 3- With Retention/ Detention (High Climate Change to 2050)



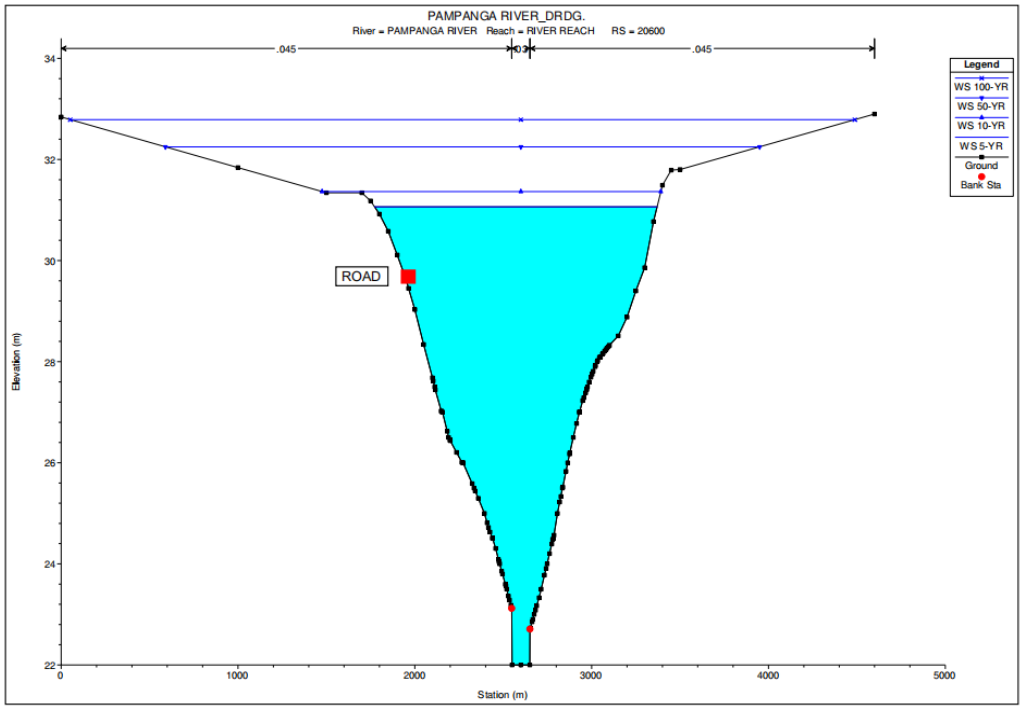
No Measure- (High Climate Change to 2100)



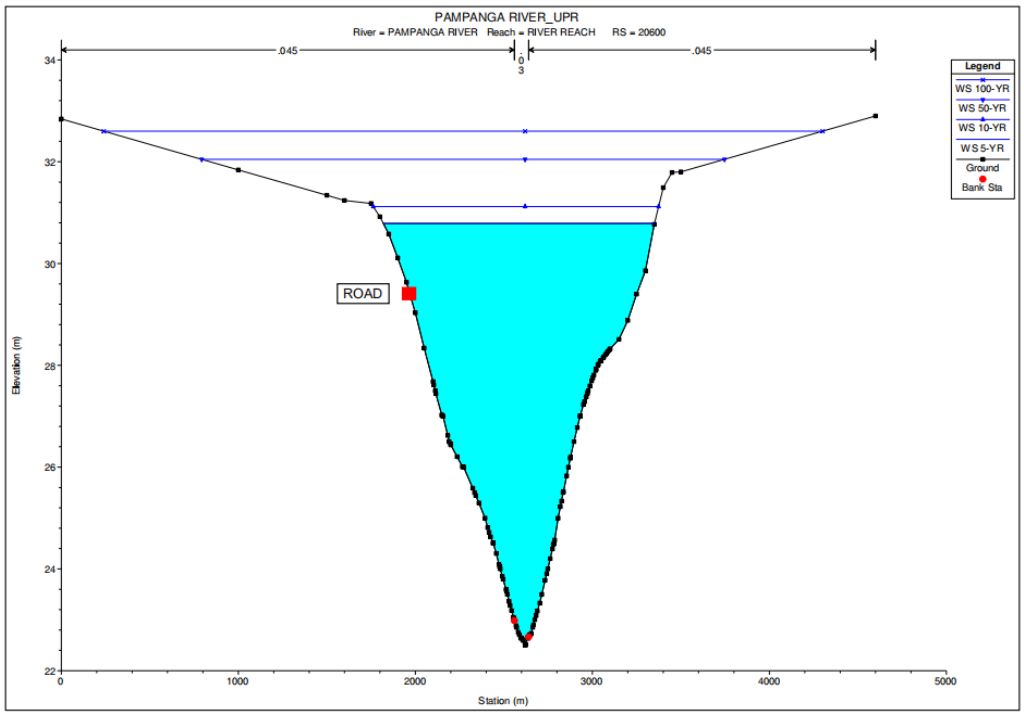
Measure 1- Elevated Road (High Climate Change to 2100)



Measure 2- With Dredging (High Climate Change to 2100)

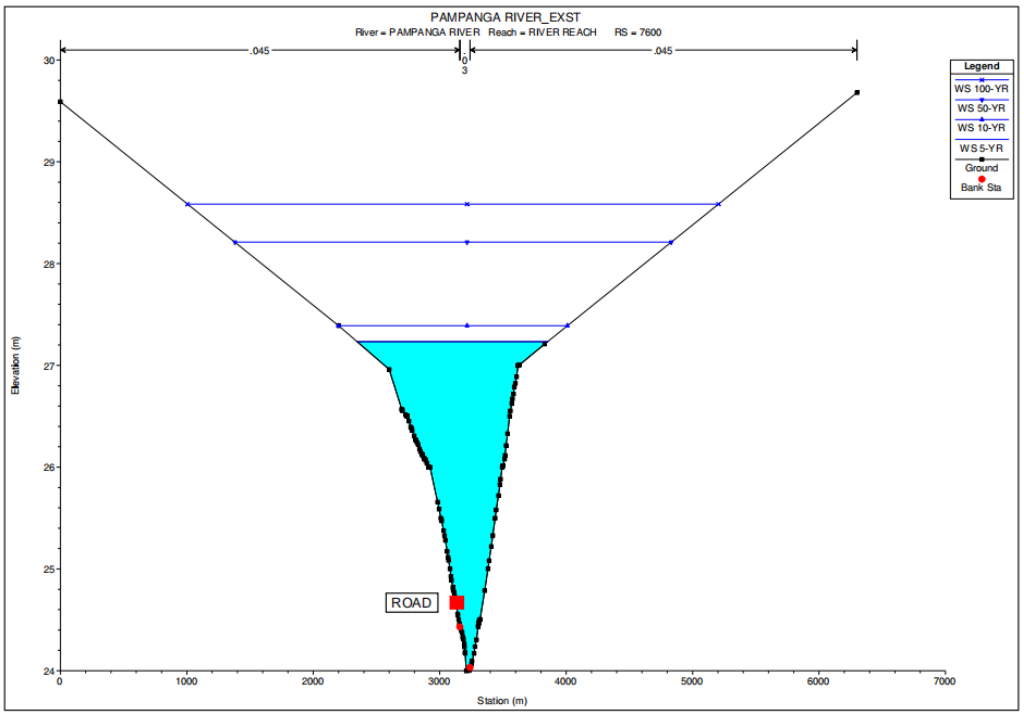


Measure 3- With Retention/ Detention (High Climate Change to 2100)

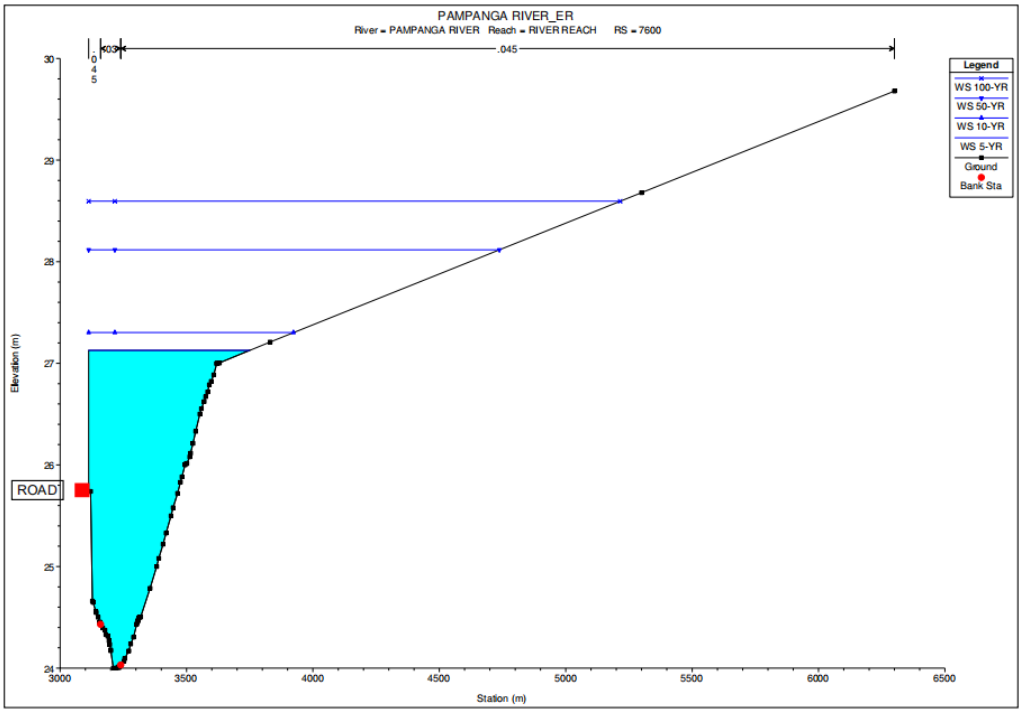


AIV.9 - PAMPANGA HEC-RAS OUTPUTS FOR LOCATION 4-Sta. 7+600

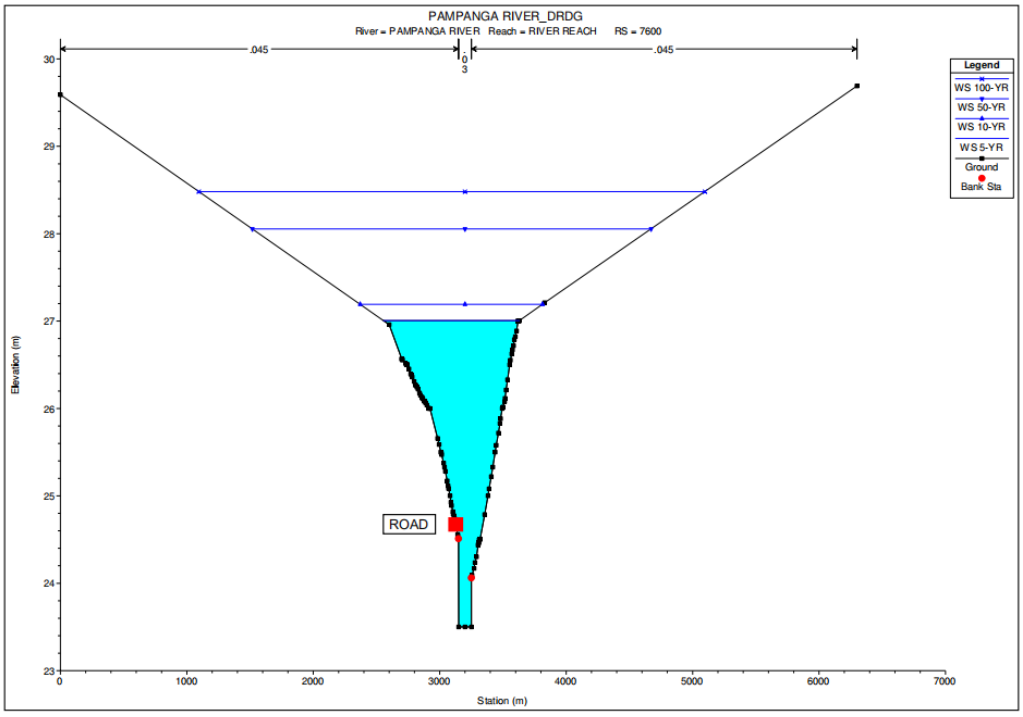
No Measure (Without Climate Change)



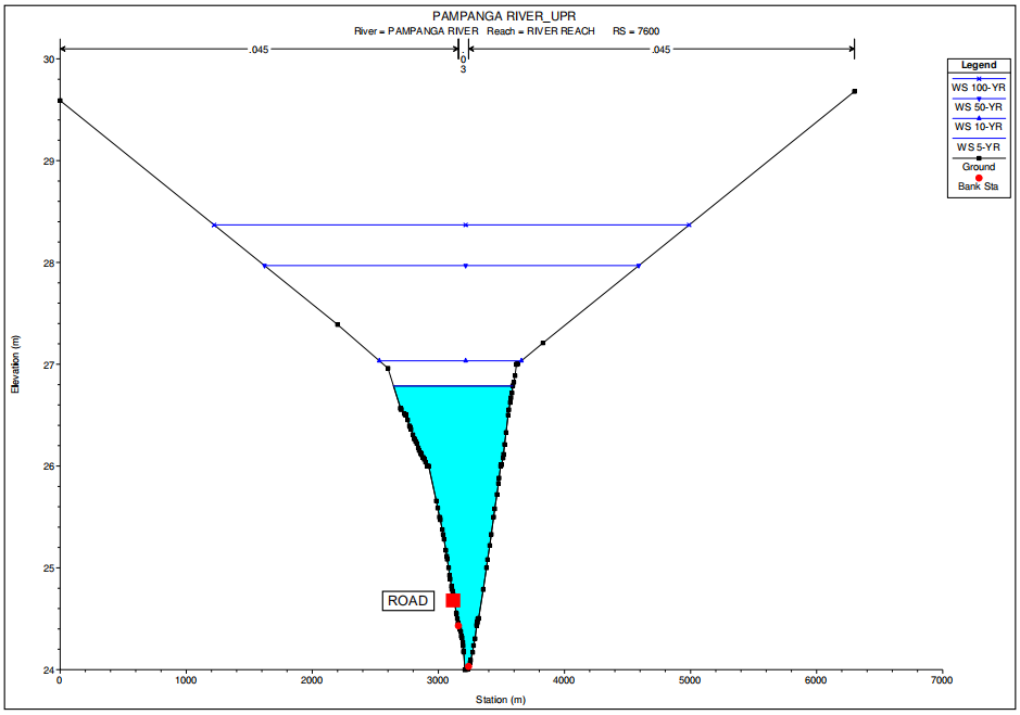
Measure 1- Elevated Road (Without Climate Change)



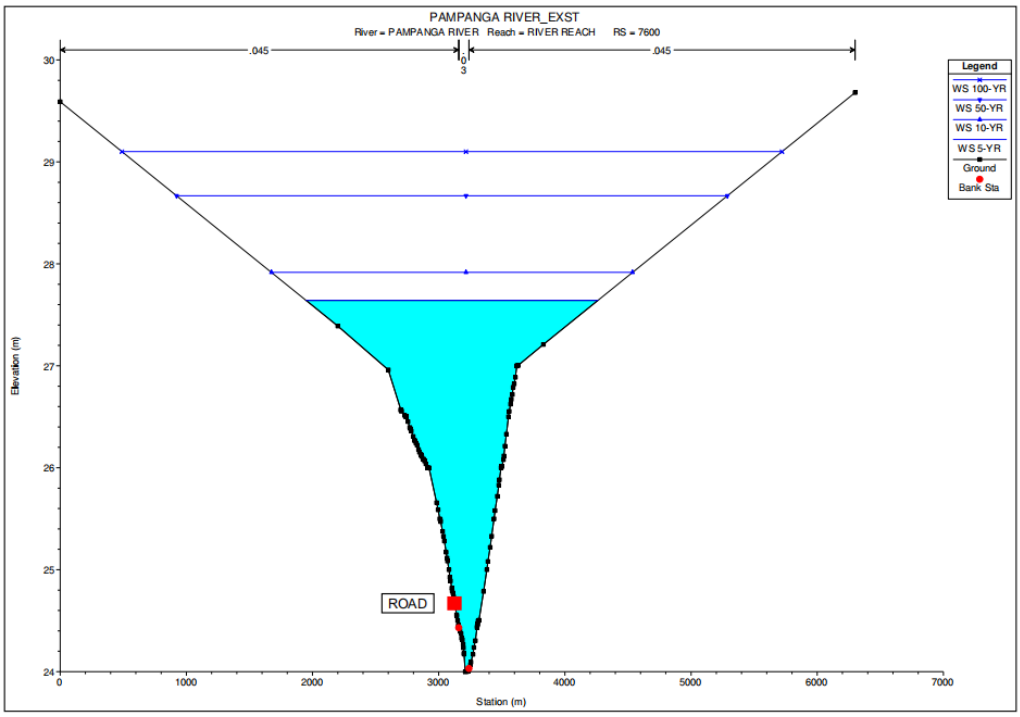
Measure 2- With Dredging (Without Climate Change)



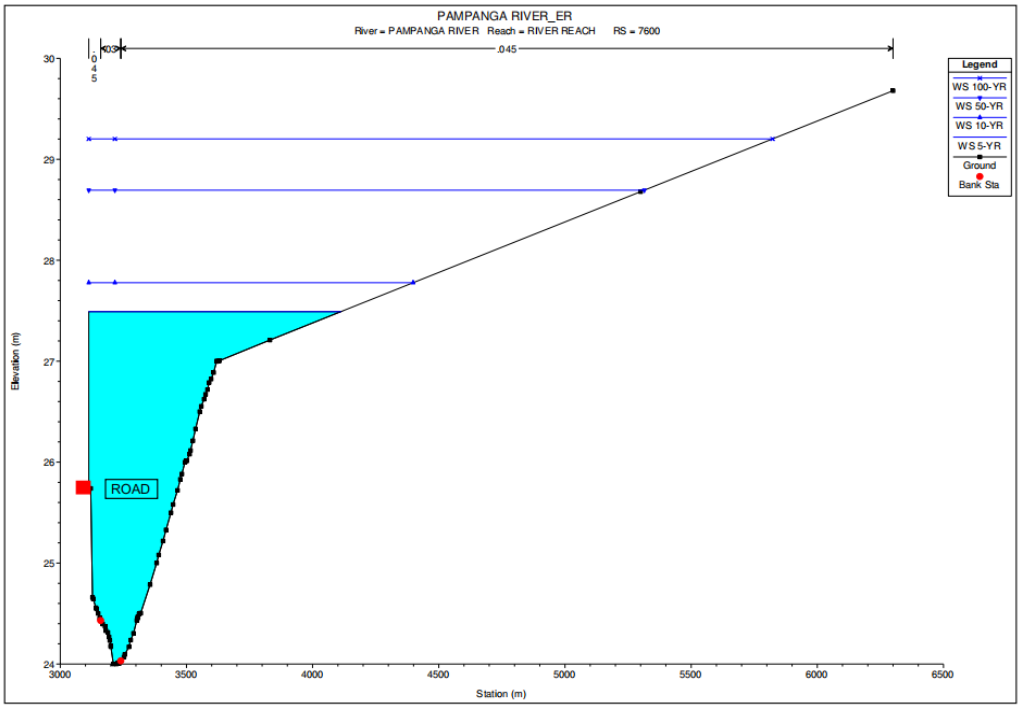
Measure 3- With Retention/ Detention (Without Climate Change)



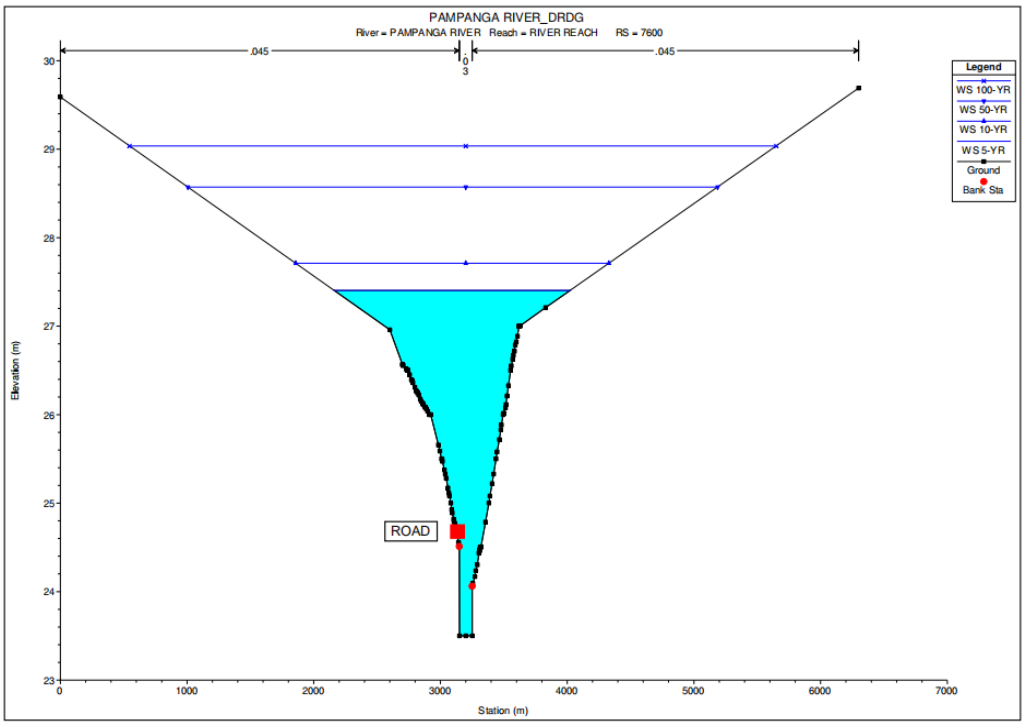
No Measure- (High Climate Change to 2050)



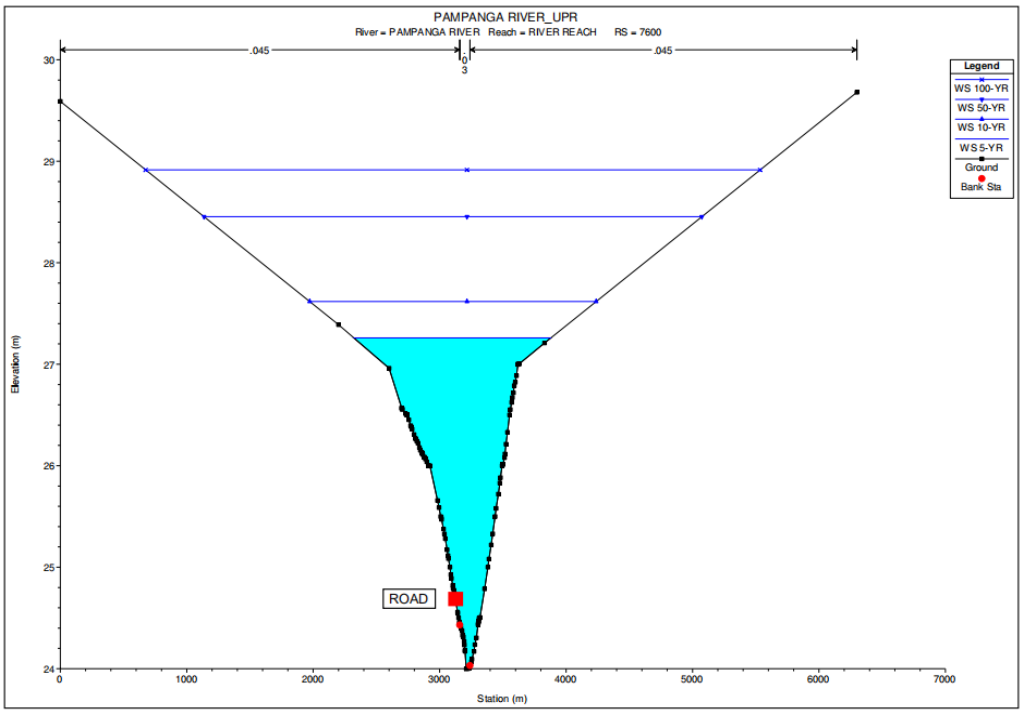
Measure 1- Elevated Road (High Climate Change to 2050)



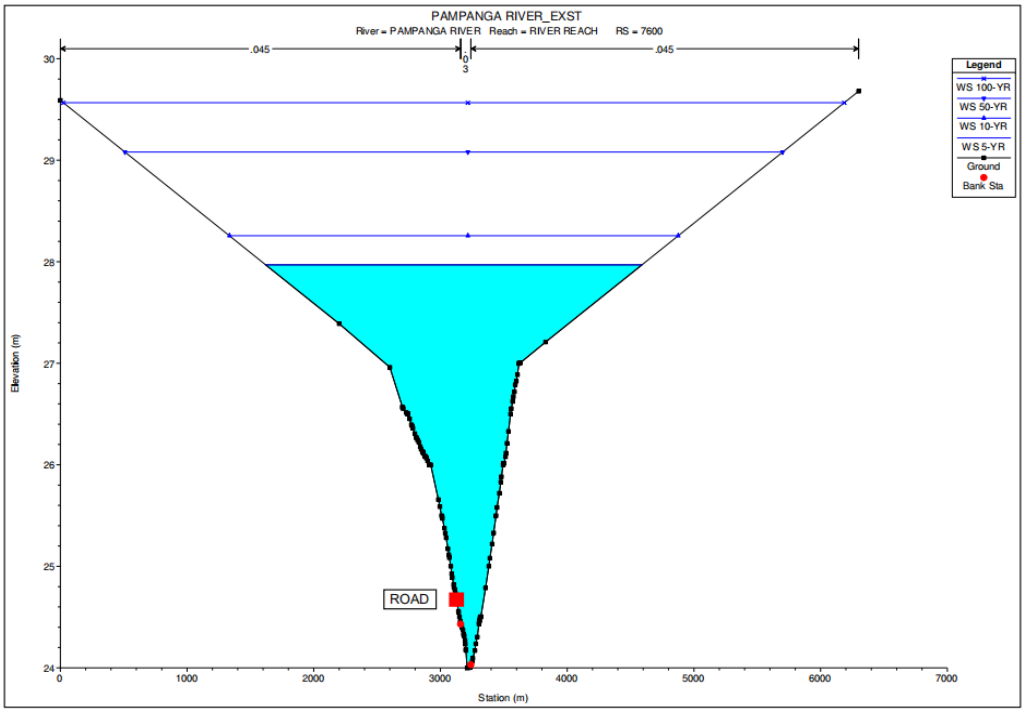
Measure 2- With Dredging (High Climate Change to 2050)



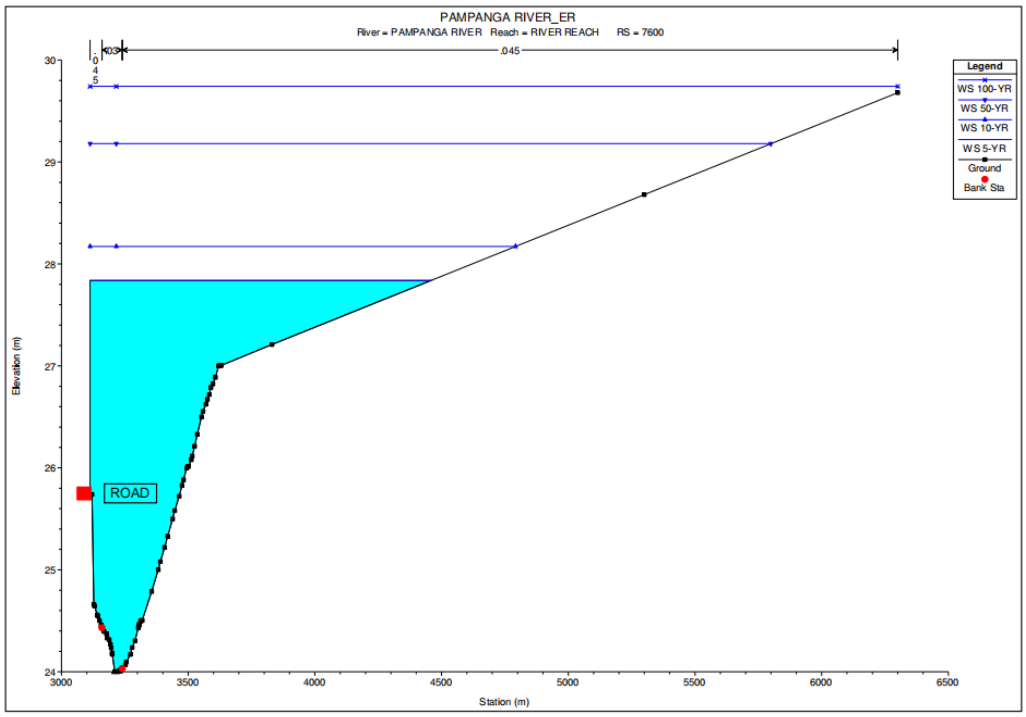
Measure 3- With Retention/ Detention (High Climate Change to 2050)



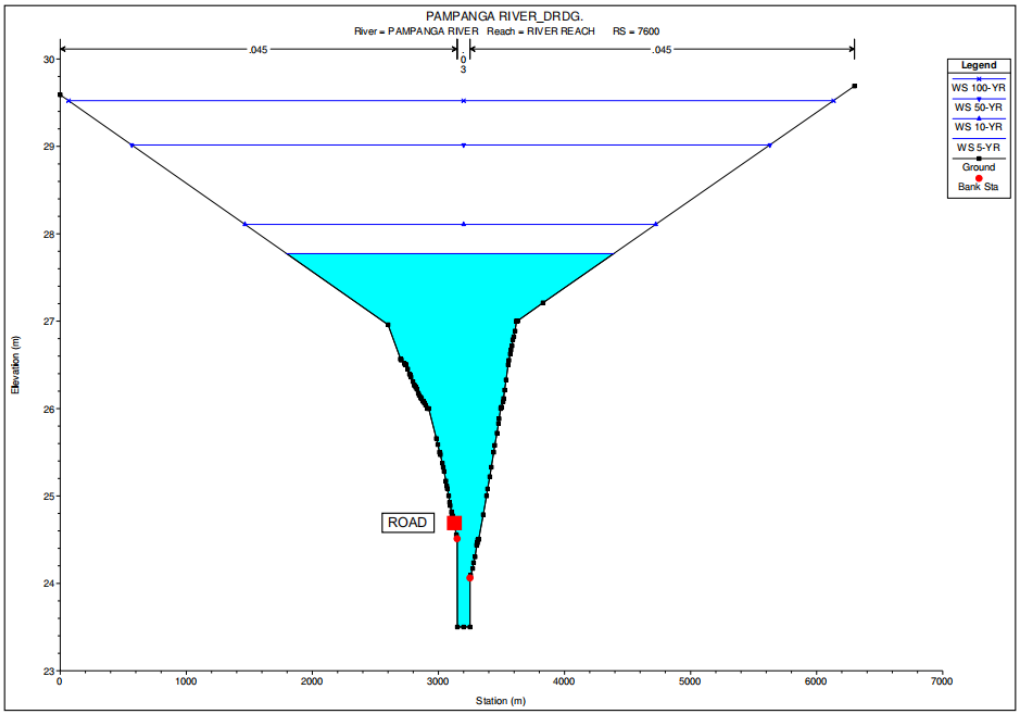
No Measure- (High Climate Change to 2100)



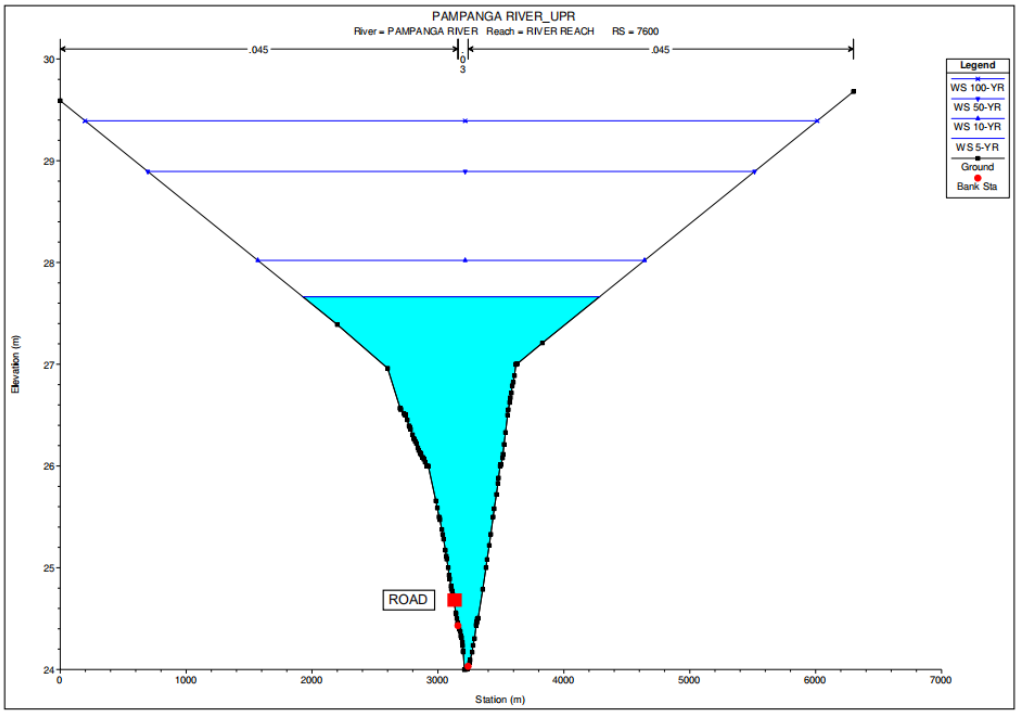
Measure 1- Elevated Road (High Climate Change to 2100)



Measure 2- With Dredging (High Climate Change to 2100)

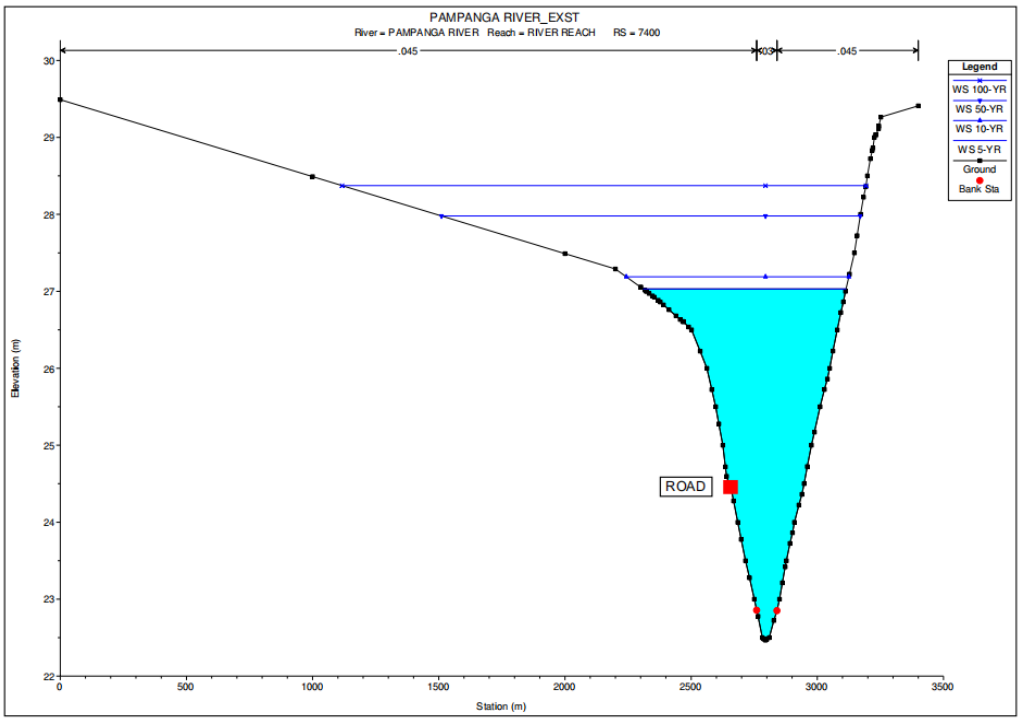


Measure 3- With Retention/ Detention (High Climate Change to 2100)

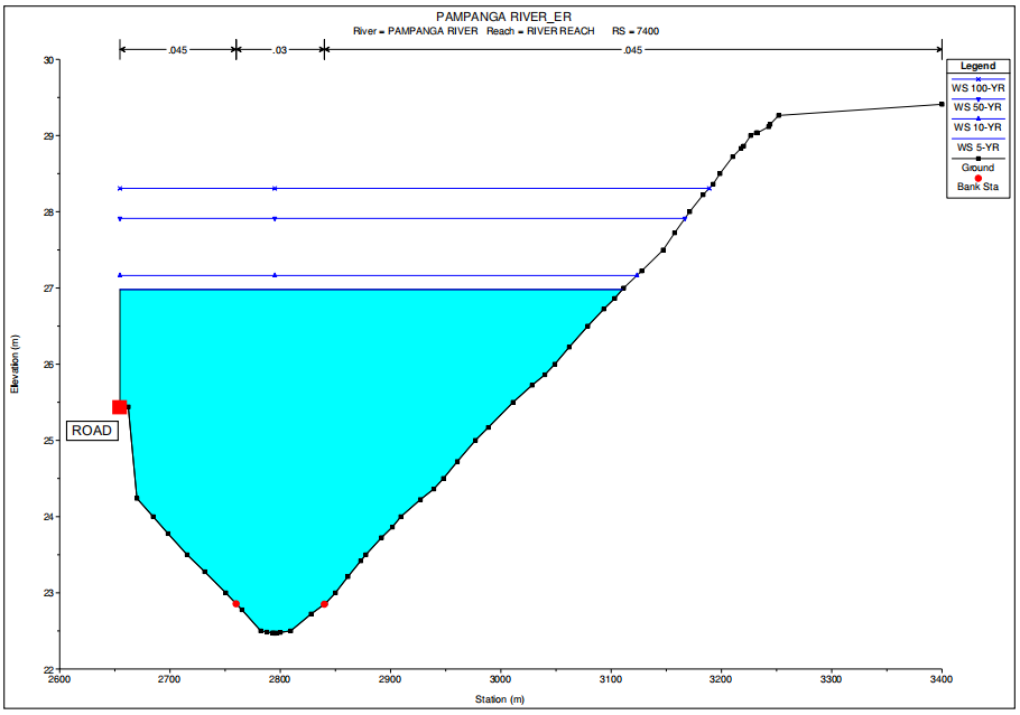


AIV.10 - PAMPANGA HEC-RAS OUTPUTS FOR LOCATION 4-Sta. 7+400

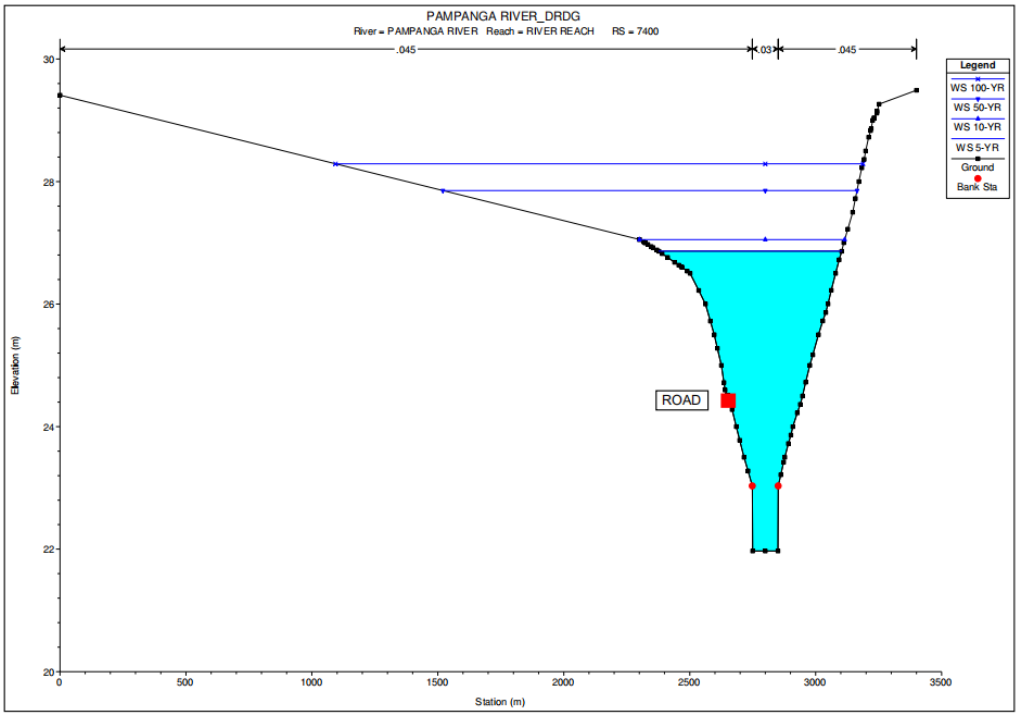
No Measure (Without Climate Change)



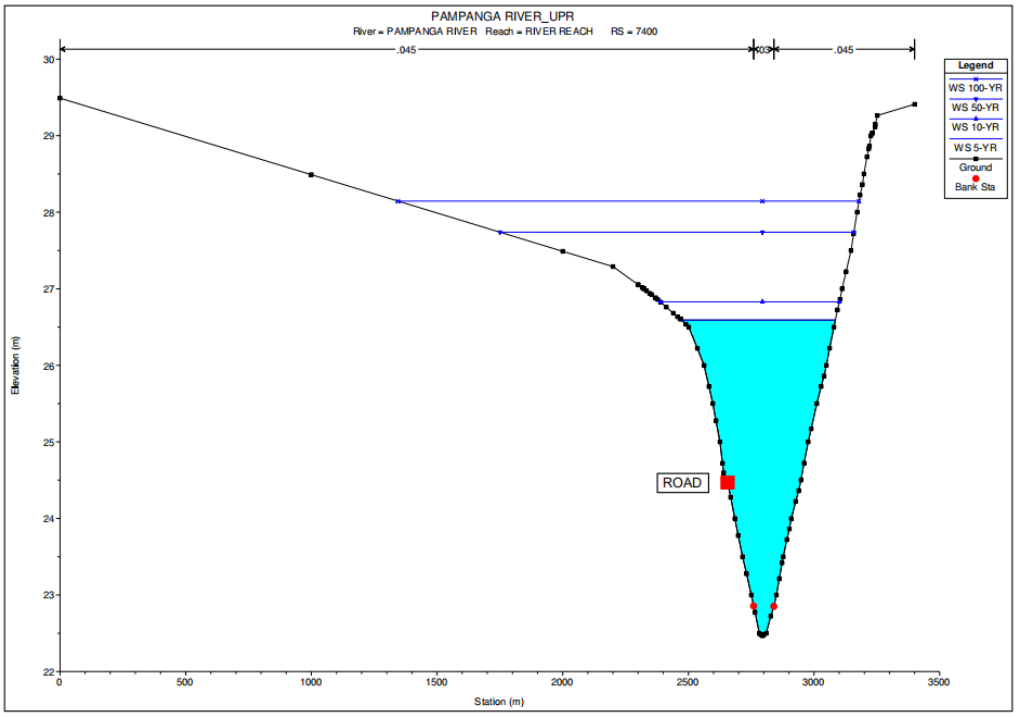
Measure 1- Elevated Road (Without Climate Change)



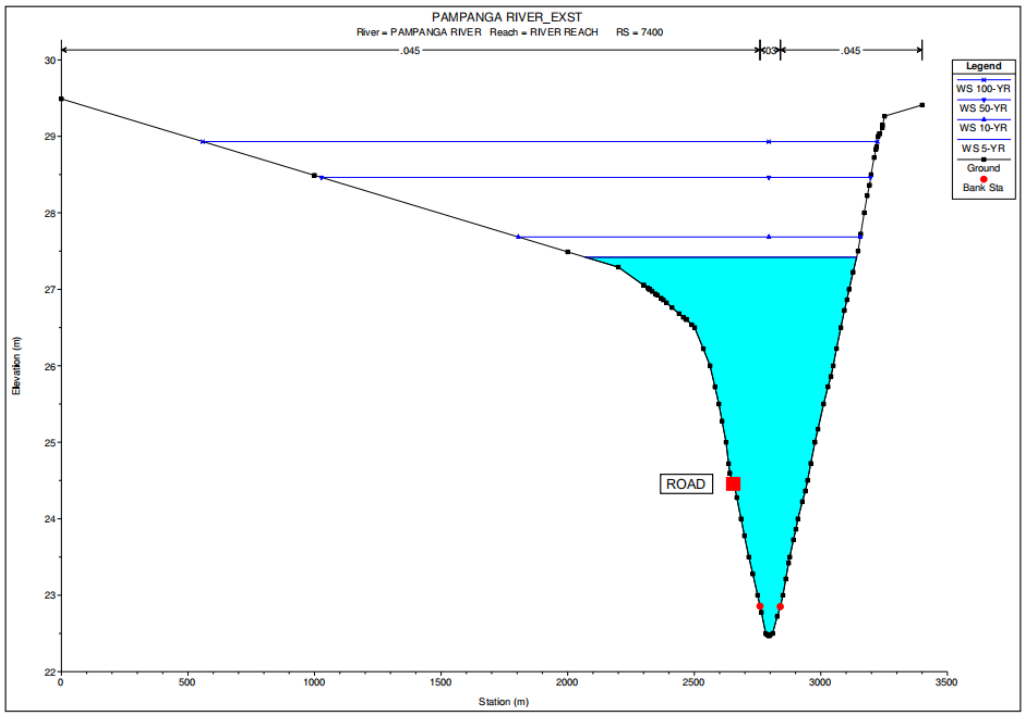
Measure 2- With Dredging (Without Climate Change)



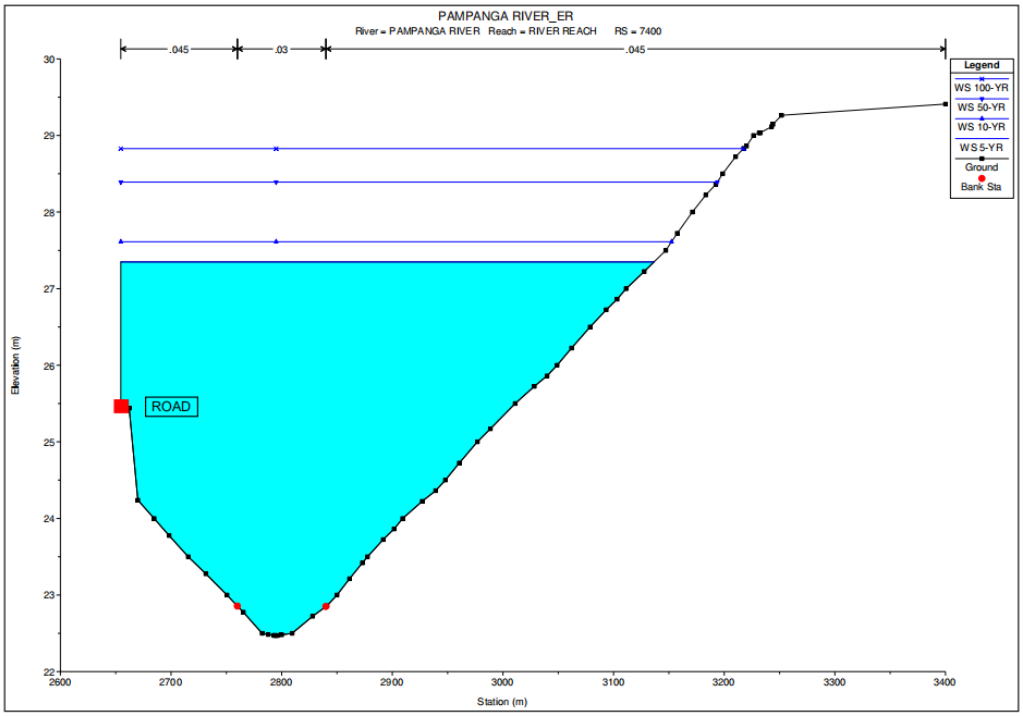
Measure 3- With Retention/ Detention (Without Climate Change)



No Measure- (High Climate Change to 2050)



Measure 1- Elevated Road (High Climate Change to 2050)



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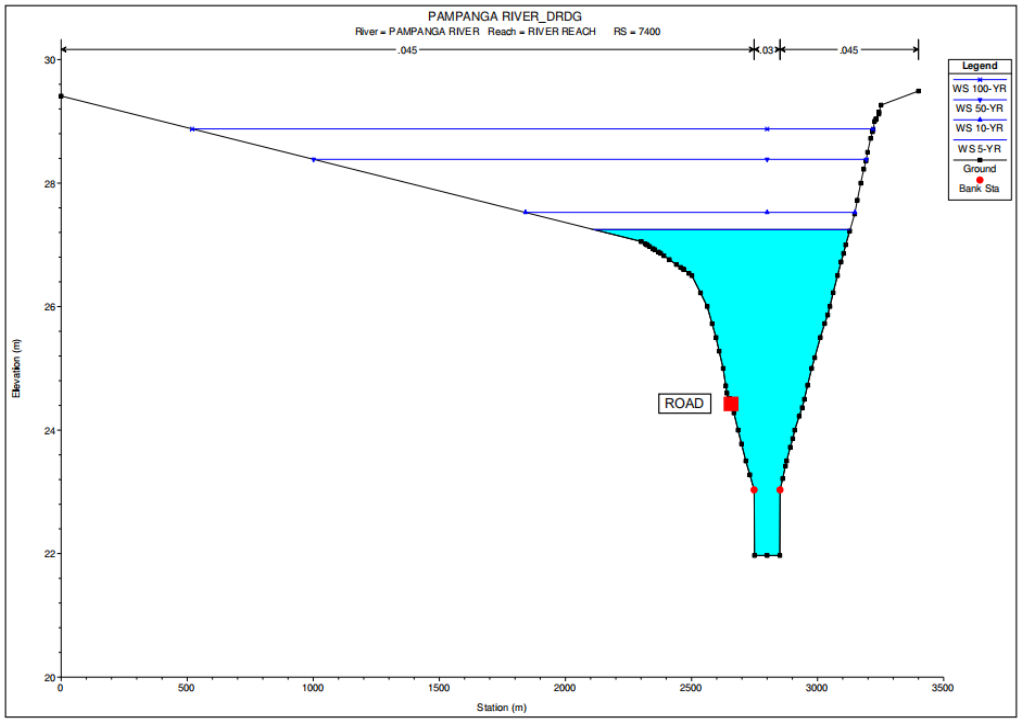
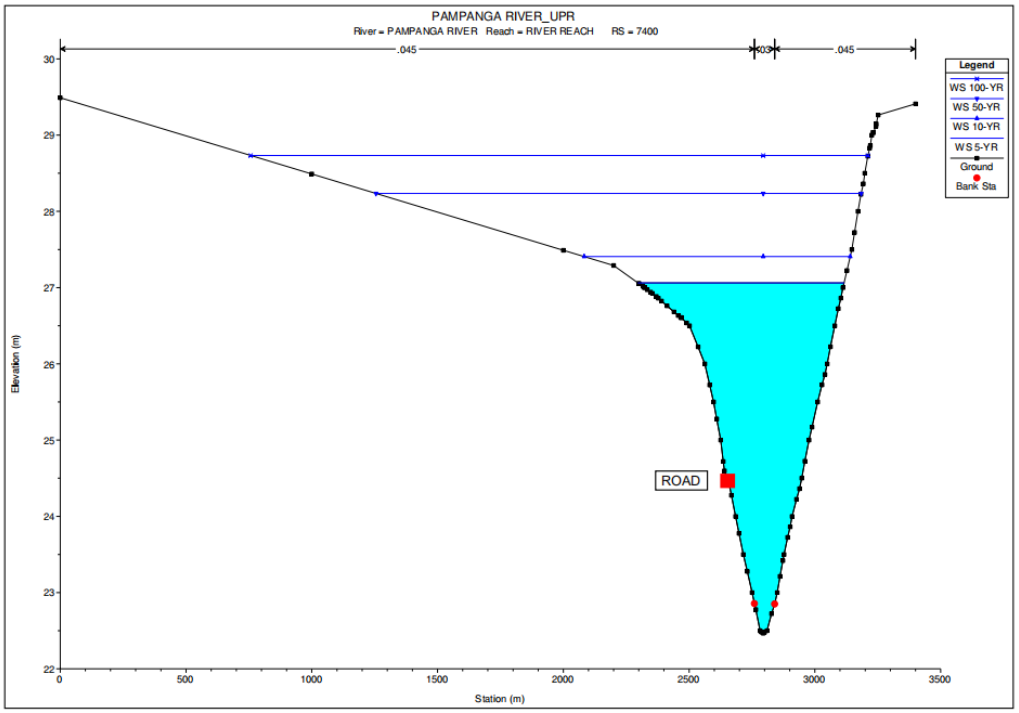
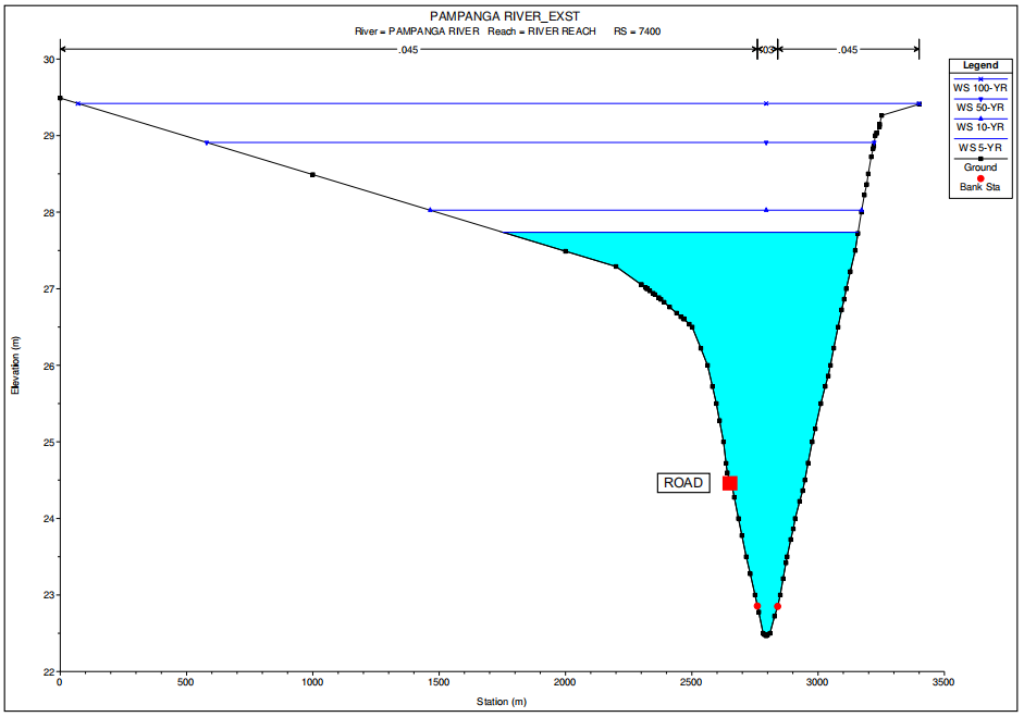


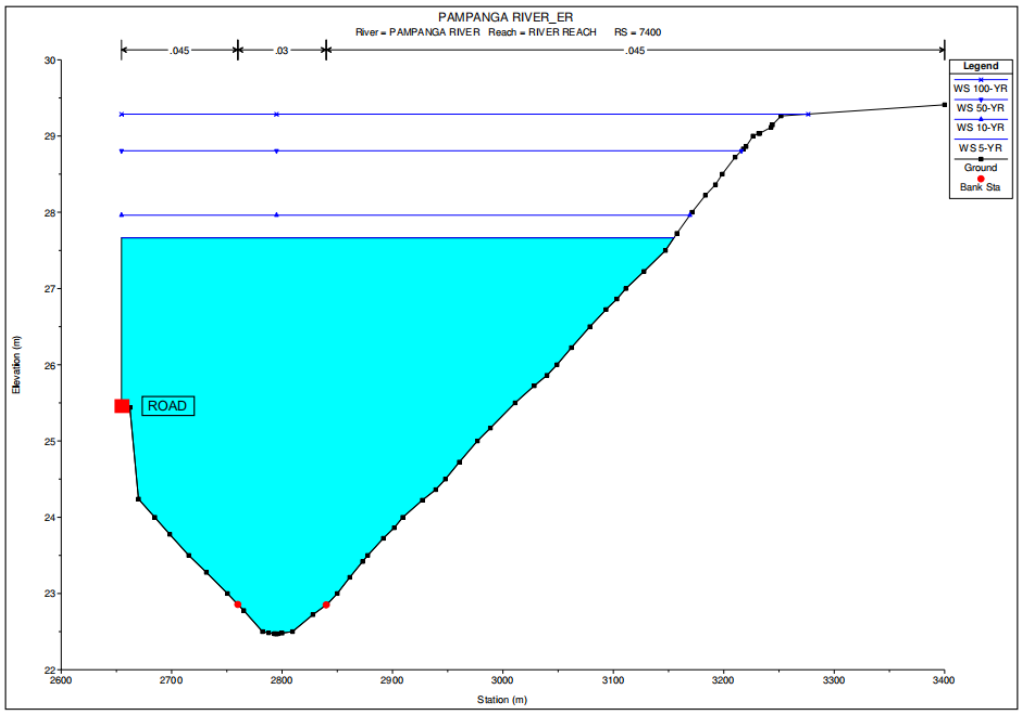
Measure 3- With Retention/ Detention (High Climate Change to 2050)



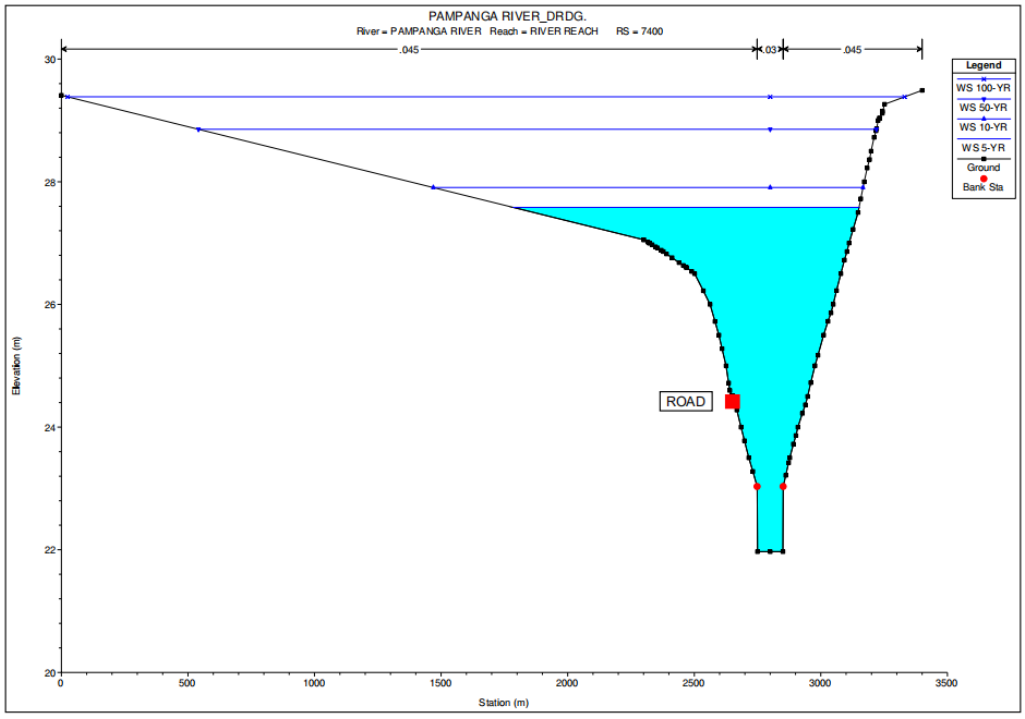
No Measure- (High Climate Change to 2100)



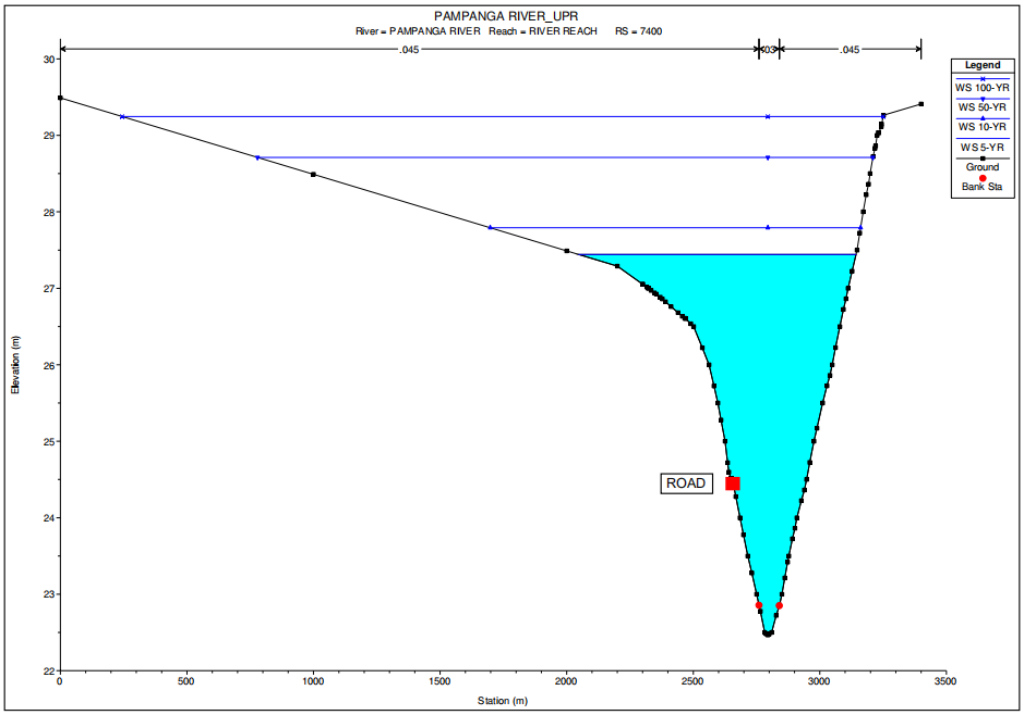
Measure 1- Elevated Road (High Climate Change to 2100)



Measure 2- With Dredging (High Climate Change to 2100)



Measure 3- With Retention/ Detention (High Climate Change to 2100)



Appendix V: Expected changes in number of dry days per year due to climate change

Climate change may lead to a change of the number of dry days. A small literature study has been conducted to check how much change is to be expected in this regard.

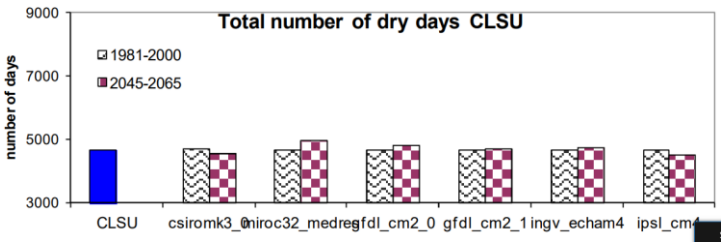
- The report 'Climate Change in the Philippines' (PAGASA, 2011) provides information on the observed number of dry days in Nueva Ecija (Cabanatuan).
  - The observations are made for the period of 1971-2000 and learns that on average a year consists of 270 dry days. Also, climate modelling has been performed for the medium-range emission scenario A1B. This shows a predicted amount of number of dry days per year of 204 and 207 days for 2020 and 2050 respectively. This clearly shows a lower amount of days if compared with the observations. However, one may not directly compare predictions with observations due to possible biases in the model. It would have been better when the model was also used to calculate the number of dry days in the reference period.
  - Having mentioned the possible bias when comparing models and observations one can look at the expected change. Looking at the predicted change with the model from 2020 to 2050, there is hardly any change predicted. This may indicate that indeed a bias is present between observations and model and that the expected amount of change could be small and in the order of 3 days increase of number of dry days.

Table c: Frequency of extreme events in 2020 and 2050 under medium-range emission scenario in provinces in Region 3

Provinces	Stations	No. of Days w/ Tmax >35 °C			No. of Dry Days			No. of Days w/ Rainfall >200mm		
		OBS (1971-2000)	2020	2050	OBS	2020	2050	OBS	2020	2050
AURORA	Baler	397	819	2008	1295	6176	6161	12	43	43
NUEVA ECIJA	Cabanatuan	1293	3271	4796	8113	6117	6202	9	13	17
PAMPANGA	Clark	355	1855	3108	889	5701	5754	8	12	12
ZAMBALES	Iba	259	573	1573	8034	6500	6325	4	12	13

Note:
- For Tarlac, use values of Clark.
- For Bulacan, use values of Science Garden (page 35).

- The paper 'Bias correction method for climate change impact assessments in the Philippines' (Nyunt et al., 2013) provides information on the number of dry days for the Pampanga basin. The following conclusions may be drawn:
  - The average amount of dry days per year is currently around 225 days (difficult to clearly read figure 8, but around 4500 days in a period of 20 years)
  - Six General Circulation Models are used to calculate the number of dry days both for the past (1981-2000) as well as the future climate (2045-2065). These calculate a similar amount of dry days for the current climate as observed.
  - Four out of six models predict an increase in the number of dry days with about 3-4 days per year
  - Two out of six models predict a decrease in the number of dry days with approximately the same amount
  - The predictions are made using the A1B scenario of the previous IPCC report. When compared with the current RCP scenarios it may be said that for the year of 2050 this is comparable with the RPC8.5 scenario.
  - To summarize, the change of the number of dry days is expected to be small and may lead to both an increase and decrease in the number of dry days



Final conclusion is that it is unclear whether the number of dry days will increase or decrease. This is due to the uncertainty of climate change. This is important information when taking decisions, since the future may enfold differently.