Climate Change Vulnerability Assessment and Adaptation Strategy

Project No. 47235-001
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Islamic Republic of Pakistan: Proposed Trimmu and Panjnad Barrages Improvement Project

Contents

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SUMMARY AND CONCLUSIONS

1. The study describes the Indus basin and Chenab river and requirements for rehabilitation and upgrading the existing Trimmu and Panjnad barrages securing reliable water supply to about 1.7 million ha. It assessed the climate impacts, projections of temperature and precipitation over the catchment areas, and their probable impacts to the river flows at the project sites. It conducted the hydrological assessment using longtime flow data. The approach includes (i) checking the original capacity of the existing barrages with climate change projections; (ii) checking the requirement to upgrade the barrages for flood risk management (FRM); and (iii) selecting final discharging capacity that meets the requirement of climate change, FRM, and upstream structure for more reliable and cost-effective designs.

2. The analysis of an annual maximum river flows for the last 80 years identified a decreasing trend at both the project sites. However, climate projections, by using global circulation models (GCM) and downscaling through regional climate models (RCM), indicated that temperature and precipitation in the catchment area will increase. The precipitation may increase in a range of 2% to 7%. However, a part of the increased precipitation may translate into the river flows. The rainfall projections vary between 2% (low), 4.5% (medium), and 7% for high case scenarios. A high variability in projections and uncertainties in the results has been noted. Medium projection scenario through a linear translation of rainfall into runoff results maximum increase of flow by 4.5%

3. The design flow of both the barrages was also estimated considering FRM through optimization, capacity of upstream structures, and safety of the proposed upgraded barrages. The FRM scenario combined with upstream structures requires increasing the design flow of Trimmu barrage by 35% and Panjnad barrage by 24%. As this estimate results in higher flows than the climate change and was adapted for these barrages. The main conclusions are as follows:

- Rainfall projections through downscaling of three GCMs for the project do not show significant increase in rainfall during 2011 and 2050. However, it indicates an increase during a period from 2051 to 2098. However, the country level existing studies show significant increase in temperature and precipitation.
- Longtime flow data shows a decreasing trend in annual maximum flows, contradicting the results of climate change projections.
- Uncertainties in climate data, models the results of the climate projections, necessitates for adapting a conservative approach for design of barrages.
- The approach followed for the design—that optimizes design for flood risk management, probable damages, performance, climate change, and structural safety is appropriate.
- The proposed design of the barrages is sound and provide adequate safeguard against climate change.

I. INTRODUCTION

1. Trimmu and Panjnad Barrages Improvement Project (TPBIP) aims to rehabilitate and upgrade the 80 years old Trimmu barrage and 90 years old Panjnad barrage on river Chenab in Pakistan. The two barrages provide irrigation water to 1.74 million ha and primarily benefit to about 4.0 million people in seven districts in Punjab.[1] The barrages face safety and operational risks due to aging and expanded activities of economic development in the command areas, which can cause high damage cost, if the barrages fail. The proposed rehabilitation and upgrading of these barrages will improve their hydraulic performance and reduce risks of their failure. Trimmu barrage is located at downstream of confluence of Jhelum and Chenab rivers (Figure 1). Panjnad barrage is located at downstream of Trimmu barrage at the tail end of the Chenab River.

2. The study followed a standard methodology: (a) hydrological analysis; (b) project risk rating by using AWARE model; (c) climate change impacts assessment and adaptation strategy; and (d) possible implications to the design flood. The study used results of global circulation models (GCM), regional downscaled modelling results, and checking the climate change impacts on hydrological frequency analysis and floods. The study used temperature and precipitation—the most probable impact parameters. The study compared the original design floods of the barrages without and with incorporating projected climate change impacts. Because of their locations and similarities, the study assumed similar impacts on both the barrages. The study benefitted from the existing hydrological and hydrodynamic modelling.

3. This report presents (i) a brief overview of the Indus basin (Chenab river is a part); (ii) hydrological assessment of the project; (iii) climate change risk rating; (iv) probable impacts of climate change projections on the existing structures; and (v) adaptation strategy and associated costs. Although command area and agriculture is out of scope of this project, an overview of probable climate change impacts on agriculture and government strategy to address the issue is also presented. This report is a Supplementary Appendix of the project's RRP.

II. OVERVIEW OF INDUS BASIN AND CHENAB RIVER

4. The Indus basin comprises the Indus river and seven contributing rivers. The Indus river and five of its tributaries are transboundary.[2] The Indus basin has 1,140,000 square kilometers (km^2) area. It is about 2,800 kilometers (km) long, with 2,682 km in Pakistan. Its alluvial plain area is about 207,200 km^2, while its deltaic area is about 20,000 km^2. The Indus basin climate is semi-arid to arid, with average temperatures ranging between 2º and 49º Celsius. Mean annual rainfall varies between 90 millimeters (mm) in the downstream to 500 mm in the middle and more than 1,000 mm in the upper catchments. Mean evaporation ranges between 1,650 mm and 2,040 mm from middle to downstream, respectively. Rivers base flows are dominated by the snowmelt, when monsoonal rains mainly cause the floods. The monsoon rains fall from June to September. The annual water runoff is about 200 cubic kilometers (km^3), and sediment discharge is approximately 200 billion kilograms yearly.[3]

5. The Indus basin in Pakistan has three reservoirs—Mangla, Tarbela and Chashma, 19 barrages, 12 inter-river link canals, about 56,000 km of canals, and 110,000 km of water courses. The inter-river link canals transfer water from the Indus and Jhelum rivers to the

[1] Districts Jhang, Multan, Vehari, Muzaffargarh, Lodhran, Bahawalpur and Rahimyar Khan in Punjab.
[2] The Indus Water Treaty (1960) between India and Pakistan governs water rights over transboundary rivers.
[3] A. Ali, 2013. *Indus Basin Floods: Mechanisms, Impacts and Management.* Asian Development Bank Manila, Philippines.

Chenab, Ravi, and Sutlej rivers. The Upper Chenab Canal and Marala-Ravi Link Canal transfer flows from the Chenab River to the Ravi River to feed areas previously irrigated by Ravi and Sutlej rivers. Overall, the Indus basin irrigates about 14 million hectares (ha) of land in Pakistan. Tarbela, Mangla, and Chashma reservoirs regulate flows at downstream. Indus water treaty between India and Pakistan allows India to use water from Beas, Ravi, and Sutlej rivers and Pakistan to use water from Chenab, Jhelum, and Indus rivers.

6. Chenab River drains 114,125 km^2 at upstream of Trimmu barrage. It has Jhelum river as main right bank tributary and Ravi and Sutlej rivers as left bank tributaries. Most of the upper catchment areas of the Chenab river and its tributaries are located in India. On river Chenab, Marala barrage is the first hydraulic structure in Pakistan followed by Khanki, Qadirabad, Trimmu and Panjnad barrages. Five bridges also exist upstream of Trimmu barrage. India has constructed Salal dam at 77 km upstream of Marala barrage and Baglihar dam further 80 km upstream is under construction. Jhelum river is 800 km long and drains 62,770 km^2 area at its confluence with Chenab river at upstream of Trimmu barrage. The major structures on Jhelum river includes Mangla dam, Rasul barrage and four bridges. These major hydraulic structures affect the river flows to the extent of their design capacity. Mangla dam regulates the flow of Jhelum river and is assumed as a boundary between catchment and channel flow contribution. Standard operating practices (SOP) of Mangla reservoir allows maximum reservoir outflows as 14,159 m^3s^{-1}. Ravi and Sutlej rivers join Chenab river at downstream of Trimmu, but upstream of Panjnad barrage.

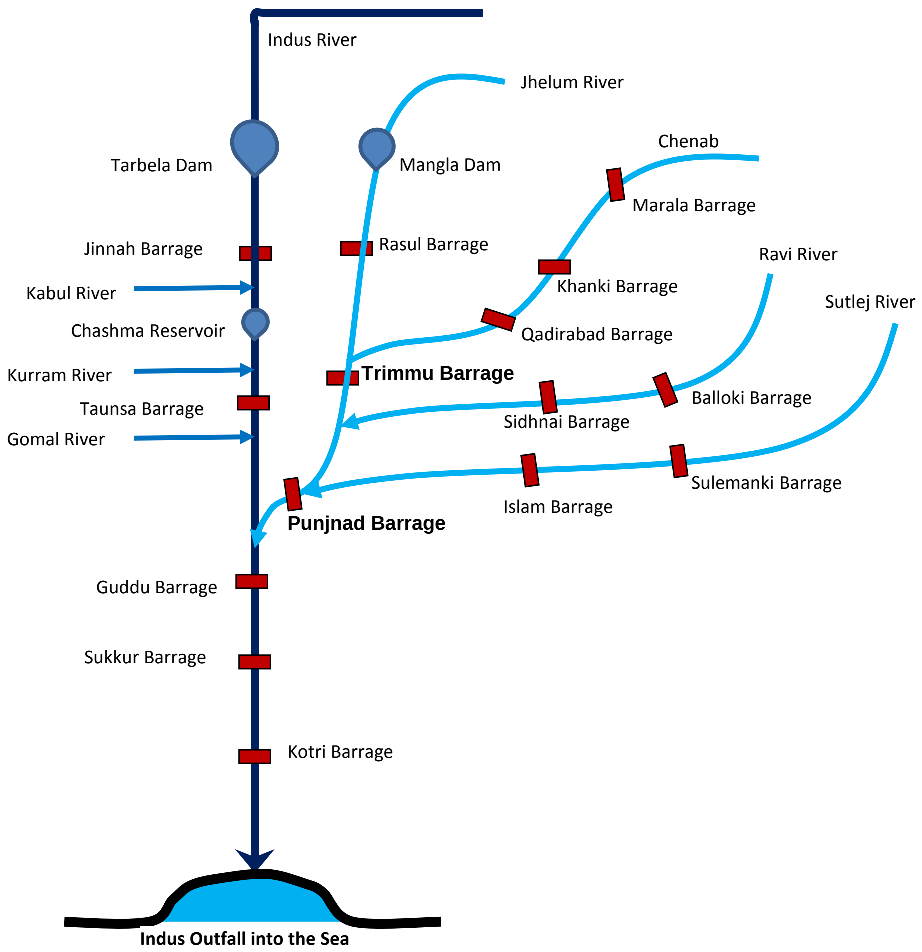
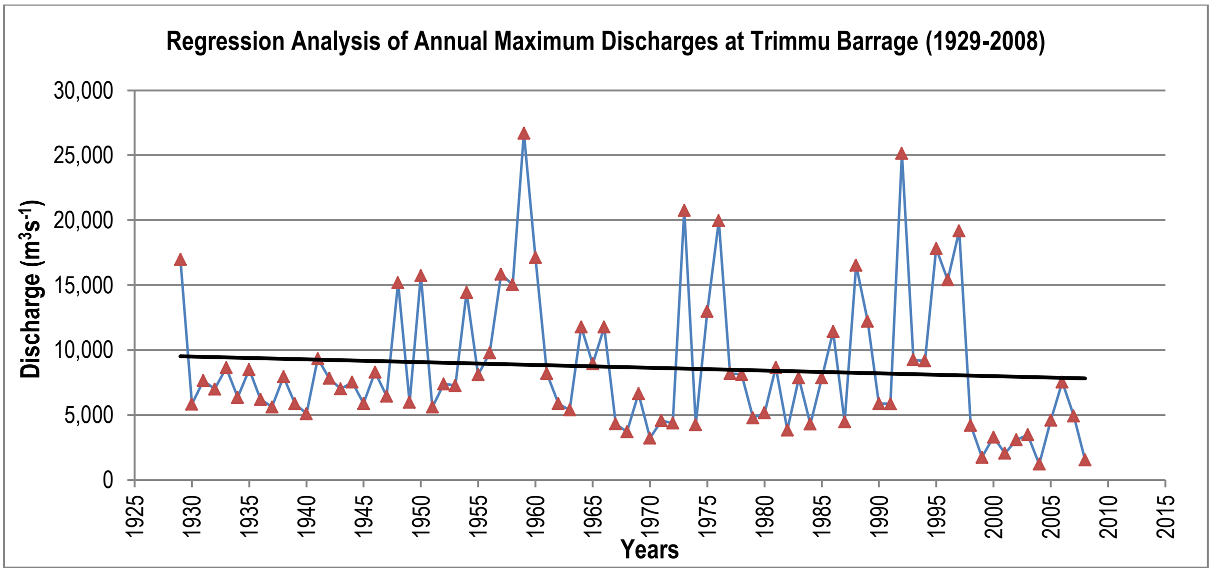


Figure 1. Indus River System and Major Hydraulic Structures

III. HYDROLOGICAL ASSESSMENT

7. The hydrological assessment at Trimmu and Panjnad barrages was conducted using historical annual maximum discharges data of around 80 years and using hydrological and hydrodynamic modelling. Major floods on Chenab and Jhelum rivers occurred in 1929, 1948, 1959, 1973, 1992 and 2005. Flood wave travel time from Marala to Trimmu barrage is 4 days and Trimmu to Panjnad barrage is about another 4 days. Travel time from Mangla dam to Trimmu barrage is 3 days.

8. Regression analysis of annual maximum flows at Trimmu and Panjnad barrages for a data of about 80 years indicates decreasing trends over the period, which means that on an average the annual maximum flow decreased (Figure 2). Analyzing non-stationary (6 subsets) also shows decreasing trend for 3 subsets and increasing trend for another 3 subsets. Overall, the annual maximum flows do not show increasing trend between 1929 and 2010. These trends are in accordance with GRDC (2004), who based on analysis of worldwide 195 long time series of annual maximum flows, also concluded no growth of flood flows (27 increased; 31 decreased and 137 with no change).[4]



[4] Global Runoff Data Centre (GRDC). 2004. Detection of Change in world-wide hydrological time series of maximum annual flow. Report 32.

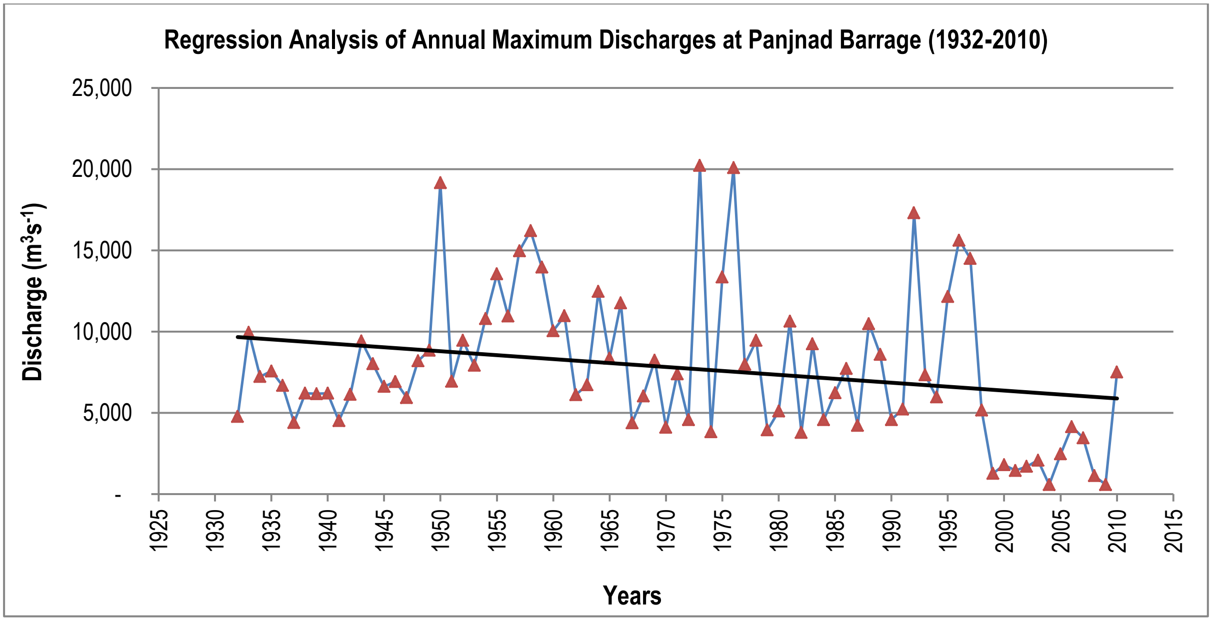


Figure 2. Annual Maximum Discharges at Trimmu and Panjnad Barrages

9. The original design flood of Trimmu barrage in 1939 was 18,265 m^3s^{-1}. The Panjnad barrage was originally designed for a discharge of 19,822 m^3s^{-1} in 1929. Flood frequency analysis of annual peak discharges of 79 years for Trimmu barrage and 88 years for Panjnad barrage was carried out using Gumbel probability distribution function (Table 1). Hydrodynamic modelling was used to route the flow through Mangla dam, rivers, and other main structures.[5]

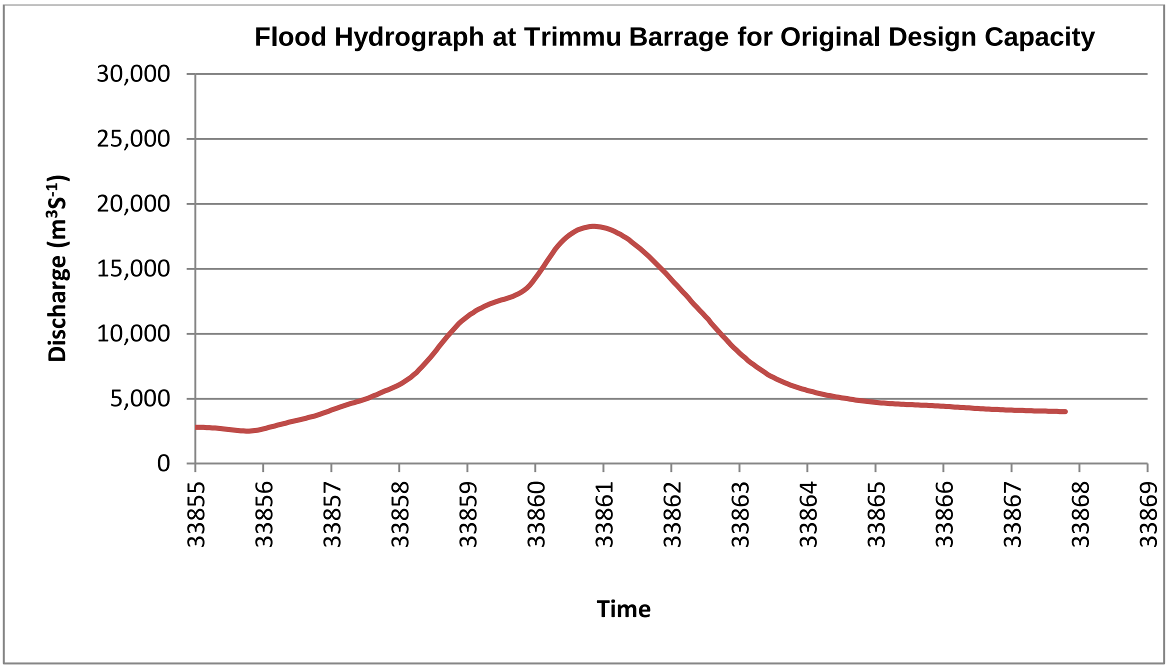
Table 1. Flood Frequency Analysis of River Flow at Trimmu and Panjnad Barrages

Return Period	Discharge (m^3s^{-1})	
	Trimmu barrage complete series (1929-2008)	Panjnad barrage complete series* (1922-2010)
100	24,641	22,941
75	23,443	21825
50	21,752	20,379
25	18,841	17,797
10	14,918	14091
5	11,813	11,565
2.33	8,000	8,184

*values interpolated for 75 and 10 years floods.

10. A hydrodynamic analysis for Trimmu and Panjnad barrages was conducted considering SOP Mangla, contribution of catchment at downstream of Mangla and impacts of upstream barrages and channels routing on peak flows at Trimmu and Panjnad barrages. Flow hydrographs for original design capacity for both the barrages (Trimmu barrage = 18,265 m^3s^{-1}; Panjnad barrage = 19,822 m^3s^{-1}) were developed and are in Figure 3. A complete description is provided in the feasibility studies of the two barrages.

[5] HEC-RAS and Flood Early Warning System (FEWS) Models were used in an integrated manner.



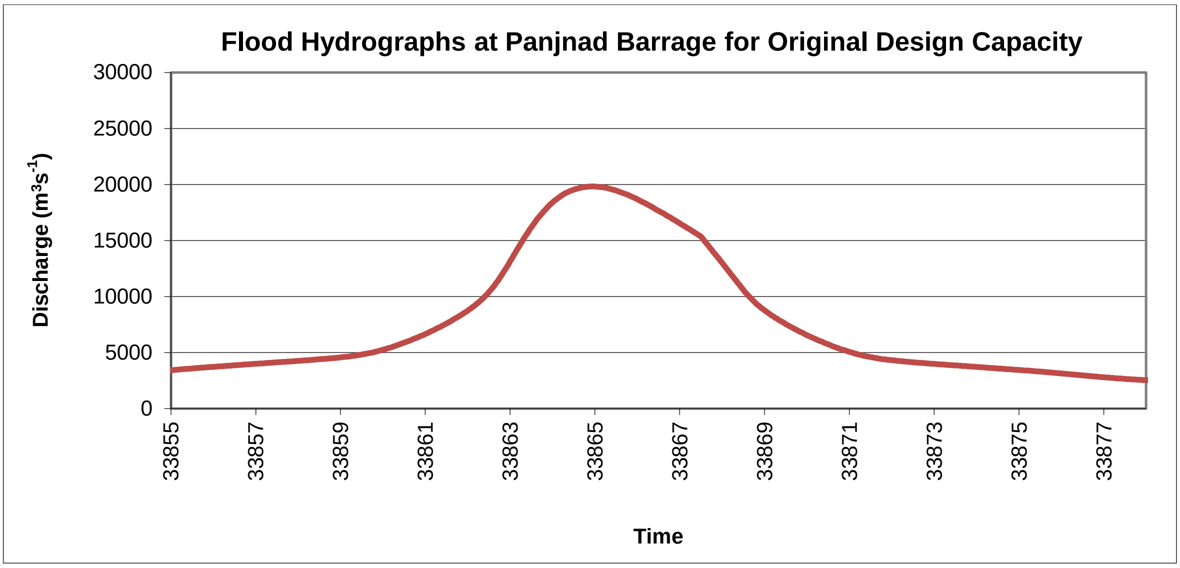


Figure 3. Computed Flood Hydrographs at Trimmu and Panjnad Barrages

IV. CLIMATE CHANGE PROJECTIONS AND PROBABLE RISKS

Project Risk Rating

11. The project's climate screening was conducted using AWARE Model (the Model). The Model uses geographic data set together with climatic parameters and project changes in the future, where available. The AWARE data set operates at a resolution of 0.5 x 0.5 decimal degrees (approximately 50 km x 50 km at the equator). It uses Global climate model output, from the World Climate Research Program's (WCRP's) Coupled Model Inter-comparison Project phase 3 (CMIP3) multi-model dataset (Meehl et al., 2007), downscaled to a 0.5 degree grid.

12. The overall model risk rating is "Medium" (see result in Figure 4) including "Low" for temperature and onshore storms, "Medium" for precipitation and "High" for flood. The risk rating summary for main climatic parameters is described below. A detailed results and related commentary is provided in Appendix A.

13. **Temperature**. The Model shows low risk to temperature rise. A barrage is a mass concrete structure and is designed for extreme conditions. Further, average temperature rise by about 2˚C will not cause problem as these structures have already sustained against high temperature of 45˚C without problem for about one century.

14. **Precipitation**. The Model assesses precipitation increase as medium risk. A small increase in local rainfall will not negatively affect the barrages structure. The increase in rainfall in the catchment may generate higher runoff volume, but due to effect of upstream structures and channel routing, likely negative impacts will significantly reduce. This aspect is further elaborated under floods.

15. **Floods**. The Model rates high risk due to floods. The upstream structures due to their routing and regulatory effects will significantly reduce the flood peaks. Further, a flood peak higher than the capacity of upstream structure cannot be passed on to the proposed barrages. As the Model does not have simulation capacity of these situations, therefore, its high rating can be of alerting nature but not an actual threat.

16. **Water availability**. The Model rates low water availability as high risks. This prediction contradicts with the prediction of glacial melt due to temperature rise and increase in Indus flows for the next 30 years (project's design life) and reduction thereafter. However, in reality, low water availability does not have any effect on the barrages diversion capacity. The low water availability, if any, may impact command area, which is out of the scope of this project. Further, reduced water availability for irrigation due to government policy change or climate change impact, has already been included as a risk in the project's design and monitoring framework.

17. The Model uses locations and global climate parameters. The Model neither claims nor it is capable of handling the complex ground-truth, processes and mechanisms of flow generation and transmission. The Model's results are mainly based on the accuracy of answers to its inbuilt questions which requires related experience and professional judgment. Therefore, its results are of qualitative nature and can be used only to sensitize the planners, but these may not be used for real decision-making. The Model's inherited weaknesses also restrict its applications and therefore, it should be used cautiously.

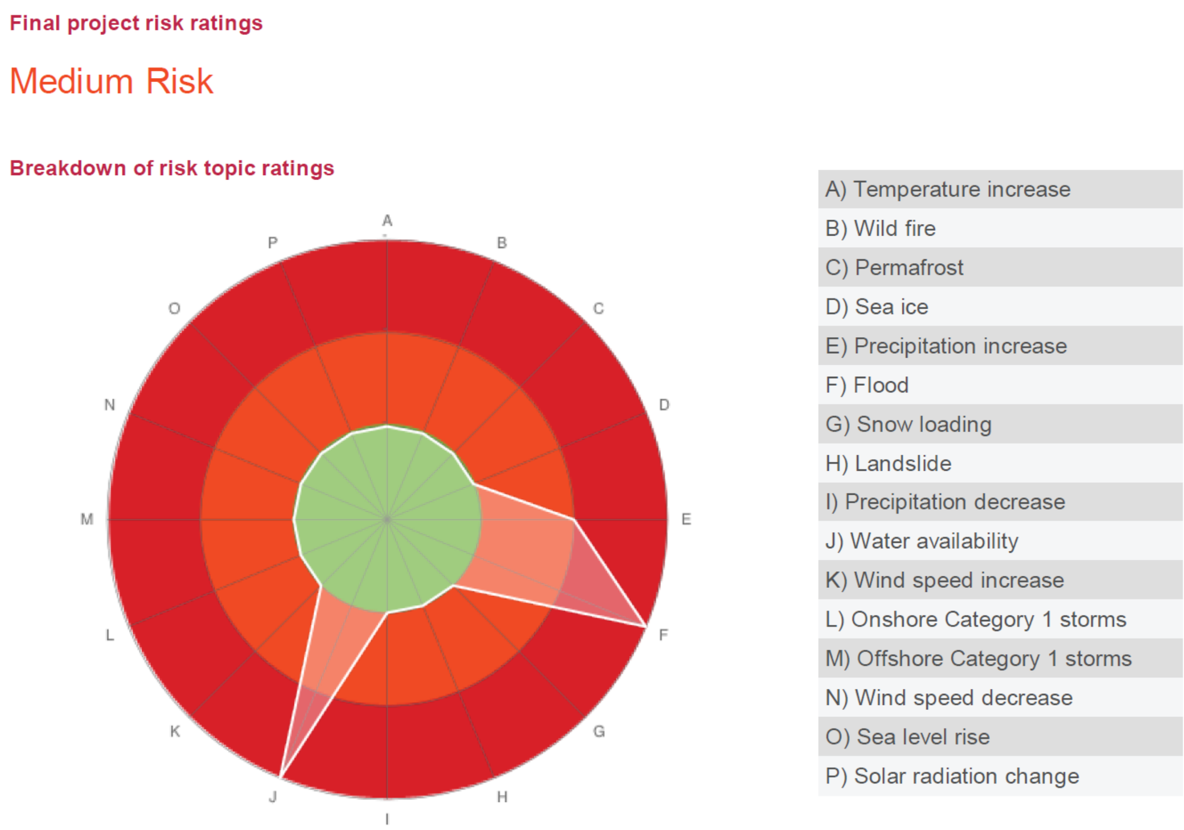


Figure 4. Project Risk Rating Based on Aware Model

Climate Change Projections

18. Climate change is projected to impact Indus basin due to (i) increased temperature; (ii) increased river base flows due to glaciers melt in first 30 years starting from 2011 and decrease thereafter; and (iii) change in rainfall pattern, which are discussed hereunder.

A. Temperature Rise

19. During the last century, the average annual temperature over Pakistan increased by 0.6 °C, which is in agreement with the global trend, with the temperature increase over northern Pakistan being higher than over southern Pakistan (0.8 °C versus 0.5 °C). Studies based on the ensemble outputs of several GCMs project that the average temperature over Pakistan will increase in the range 1.3°C to 1.5 °C by 2020, 2.5 °C to 2.8 °C by 2050 and 3.9°C to 4.4 °C by 2080, corresponding to an increase in average global surface temperature by 2.8°C to 3.4 °C by the end of the 21st century.

20. The country's Global Change Impact Studies Centre (GCISC) developed temperature scenarios by downscaling 17 GCMs at 30-year time-steps for the 21st century. For A2 scenario, the projected temperature increases in the 2080s in northern and southern Pakistan are 4.67°C and 4.22°C, compared to 3.4°C average global temperature increase for the 2090–2099 periods relative to 1980–1999. For A1B scenario, the corresponding values are 4.12°C, 3.73°C, and 2.8°C, respectively. The current annual average temperatures for northern and southern Pakistan are about 19°C and 24°C. Overall, the temperature rise in Pakistan's areas of the Indus basin is projected to be 4.81^{o}C for the A2 scenario and 4.29^{o}C for A1B. Based on the above discussion, an average temperature rise of 2.5 °C to 2.8 °C is expected during the project design life time of 30 years.

21. **Probable Implications of the Temperature Rise.** The projected temperature can increase (i) glacier melt contribution to the river flows; (ii) catchment's evaporation, rainfall abstractions, and reduced runoff per unit area; and (iii) evapotranspiration demand of the crops. Although, the changes in river flow due to the two contrasting phenomena—increased snowmelt and reduced rainfall-runoff, is difficult to quantify due to the uncertainties induced by topographical variations and land use changes over a large catchment area, net impact of increased baseflow for some period in the future is frequently reported. The increase in evapotranspiration demand in the command area can increase the crop water requirement. As command area is out of scope of this project, therefore, vulnerability assessment and associated measures under this project have not been further investigated. Nevertheless, reported climate change impacts on agriculture and associated Government of Punjab's strategy to deal with these impacts has been discussed at the end of this report.

22. The increased baseflow, if any, will help maintain the river channel and will have overall positive impact. The barrages are not sensitive to the increased baseflow due to their capacities to deal with floods. The temperature rise will not affect the proposed barrages project as neither structures nor materials are vulnerable to the temperature rise. The barrages are designed considering several safety factors including earthquake, fires and high hydrodynamic pressures. These barrages have already demonstrated withstanding against extreme historical temperatures such as 45^{o}C in the past. Therefore, a few degree Celsius rise over an average temperature (29°C) will have no adverse impact on the barrages. The proposed project has no risk to temperature rise.

B. Glacier Melt and Glacial Lake Outburst Flood

23. Several studies involving field based observations, satellite imagery, and repeated photography have shown that a majority of Himalayan glaciers are retreating. A notable exception is the Karakorum region where some glaciers have shown advancement (Hewitt, 2005). Hewitt (2011) recently outlined important climatic conditions that make Karakoram glaciers different from the rest of the Himalayas. Kotlyakov and Lebedeva (1998) showed that glacier-covered areas in the Hindu Kush, Hindu Raj, and Naga Parbat massifs will expand, while the glaciers in the Himalayas, especially in their eastern part, will shrink. IPCC indicates that glaciers melt in Himalayan will increase river flows during the next thirty years followed by reduce flows for another 50 years. As indicated above, increase in average flows during the next 30 years (almost project design life) will not impact the barrages negatively as these structures are designed for extreme events.

24. About 35 destructive glacial lake outburst flood (GLOF) events were recorded in the last 200 years to 2003 (Hewitt 1982; Hewitt 1998; Mool et al. 2003) in the Indus basin.[6] A GLOF from the Shyok area in August 1929 in the Indus river system extended 1,300 km downstream to Attock and had a discharge greater than 15,000 m^3s^{-1}. In a case study of the Astor catchment in the northern part of the Indus basin, the same authors identified several potentially dangerous glacial lakes. In total, 126 glacial lakes were identified in this basin, among them 9 as potentially dangerous. The catchment areas of Jhelum and Chenab rivers are less prone to GLOF phenomena as compared with the Indus river. Probable GLOF threat in the upper catchments and their impacts will be substantially subsided and will not be transferred at the project site due to upstream existing structures. Further, the proposed project aims to increase the flood capacity much greater than the worst observed GLOF and combined together with provision of breach section on these barrages; the proposed project will be able to better address the GLOF situation, if any.

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[6] Islamic Republic of Pakistan: Glacial Melt and Downstream Impacts on Indus Dependent Water Resources and Energy. ADB RETA 6420-PAK, 2010.

C. Rainfall Variability

25. Although the precipitation projections by various GCMs vary a great deal, the analysis conducted by GCISC using the ensemble outputs of 13 GCMs for the A2 scenario and 17 GCMs for the A1B scenario indicates (GCISC 2009b) that precipitation is likely to increase in summer and decrease in winter in both northern and southern Pakistan, with no significant change in annual precipitation in either part. Pakistan Meteorological Department (2009) based IPCC 2007 scenarios of emission, estimated an increase of rainfall +4.6 mm per decade for A2 scenario, +2.9 mm/decade for A1B scenario, and (-)1.3 mm per decade for B1 scenario for northern areas. On an average, summer monsoonal rains in the upper Indus basin contribute 20% to 30% of the total annual precipitation and no significant change has been observed. However, at lower elevations winter and summer precipitation occurs at about 60:40 ratio and a little increase in monsoon share has been noticed.[7]

26. Rasul et al. (2010)[8] studied climate change scenarios for the entire Indus basin and at smaller time steps. The study under A1B scenario shows little change in the future precipitation regime (2001–2050) as compared to the baseline (1951–2000). However, the already humid regions in the north are projected to become wetter, whereas drier regions in the south will get even drier. Islam et al. (2009) shows 5.58% increase in annual, 5.2% increase in summer and 20.05% increase in winter rainfall for Jhelum river basin (Table 2).

Table 2. Projected Precipitation Changes (%), 2017-2100 (Source: Islam et al. 2009)

Region	Annual (%)	Summer (%)	Winter (%)
Upper Indus Basin	19.62	14.83	-4.33
Jhelum River Basin	5.58	5.20	20.05
Kabul River Basin	4.26	2.54	16.20

27. Rasul et al. (2010) indicted an increase of rainfall by 2.48 mm per decay for A2 (2.5% increase on average annual value) and 1.91 mm per decay for A1B, and decrease of 0.78 mm per day for B1 climate change scenario for a period from 2011 to 2099 for Indus basin. Global Climate Change Impact Center (GCCIC) (2013) and Rasul et al (2010) projected precipitation from 2011 to 2099 using A2, A1B and B1 scenarios (Table 3). The projections show 4.8 mm per decade for A2 scenario (4% increase on average annual value), 2.7 mm per decade for A1B, and (-)1.5 mm per decade for B1 scenario. With an average annual rainfall of 625 mm over the catchment, the percentage increase was 2% by 2050 and 4% by 2099 following Rasul et al. (2010) projections. It was estimated at 4% by 2050 and 7% by 2099 following GCCIC projections. Given the high variations in projections (from 2% to 7%), the low (2%), medium (4.5%) and worst case scenario of 7% increase in the rainfall was used for this study to develop flood hydrograph with climate change scenario.

7 ADB, IUCN and ICIMOD. July 2010. Glacial Melt and Downstream Impacts on Indus Basin-Dependent Water Resources and Energy. RETA 6420-PAK Promoting Climate Change Impact and Adaptation in Asia and The Pacific.

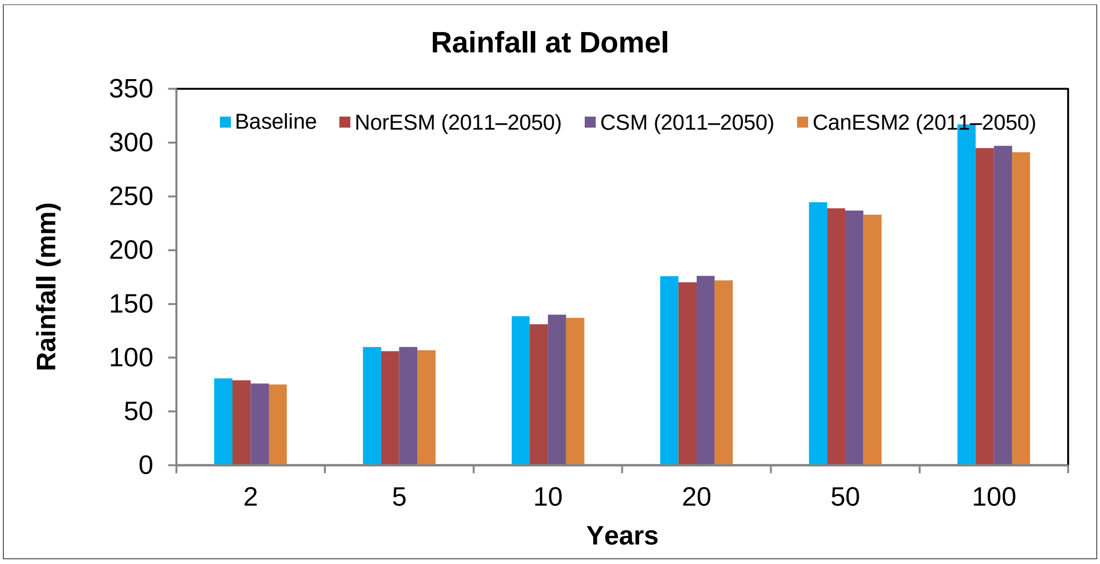
8 Rasul et al. 2010. Characteristics of Upper Indus Basin Precipitation Regime. In press.

Table 3. Linear Trends Across Climatic Zones, 2011-2099

Region	Precipitation (mm/per 10 year)		
	A2	A1B	B1
Upper Indus	4.8	2.7	-1.5
Northern Punjab, Upper Khyber Pakhtunkhwa	8.1	6.10	-0.10
Central and Southern Punjab and Lower Khyber Pakhtunkhwa	-3.1	-1.97	-0.5
High Balochistan	2.14	1.33	-0.18
Southeastern Sindh	7.3	5.2	-0.01
Sindh, Lower Balochistan	-2.87	-1.13	-0.09

28. Under the proposed project, rainfall data of the two stations i.e. Domel and Garhi Dopatta, in the catchment of Jhelum river at upstream of Mangla dam was analyzed for return periods varying from 2 year to 100 year. The daily time series rainfall data of three GCM's: NorESM, CanESM2, and CSM from 1980 to 2098 were used. The impact on extreme rainfall was analyzed for the three GCMs for the baseline period (1980-2004) and the two future periods (2011–2050 and 2051–2098). The results indicate insignificant increase in rainfall for the period 2011 to 2050 at both the stations (Figure 5). The variations vary from (-)8% to 1% at Domel and (-)12% to 7% in case of Garhi Dopatta for 2011-2050 series.

29. In contrast, towards the end of this century (2051–2098), the results indicate an increase of intensity for all extreme events for both stations with the only exception of CSM's 100 year return event for Garhi Doppata. The models estimated high rainfall variations (-2% to 27%) during the period from 2051 to 2100. One obvious result was low or insignificant variations until 2050 and high variations from 2051 to 2098. Among the three GCM models, CanESM2 showed less sensitivity than NorESM and CSM. The consistency of GCM projections for both stations for 2051–2098 indicates a strong likelihood that the extreme event intensity will increase along with global warming trends.



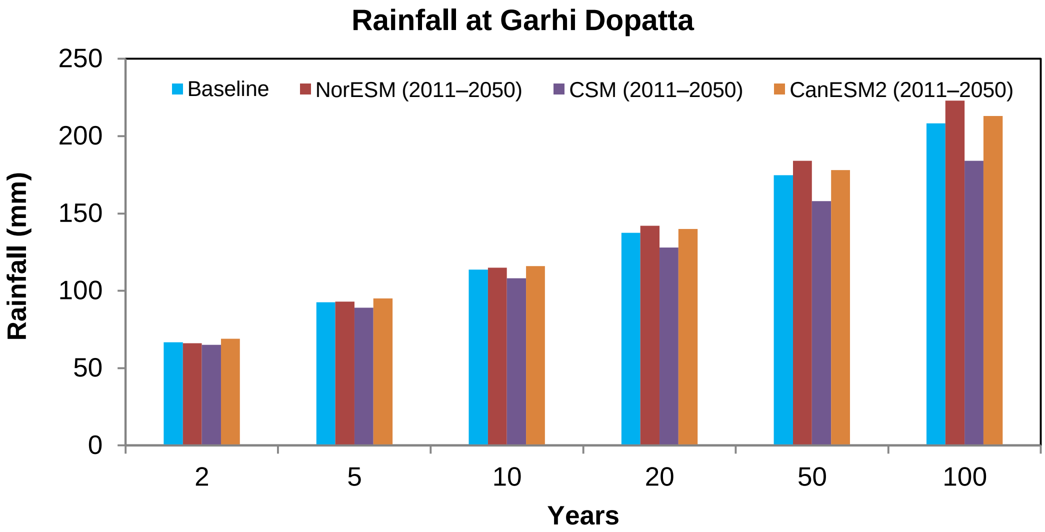


Figure 5. Projected Rainfall for Various Return Periods

D. River Flows and Sedimentation

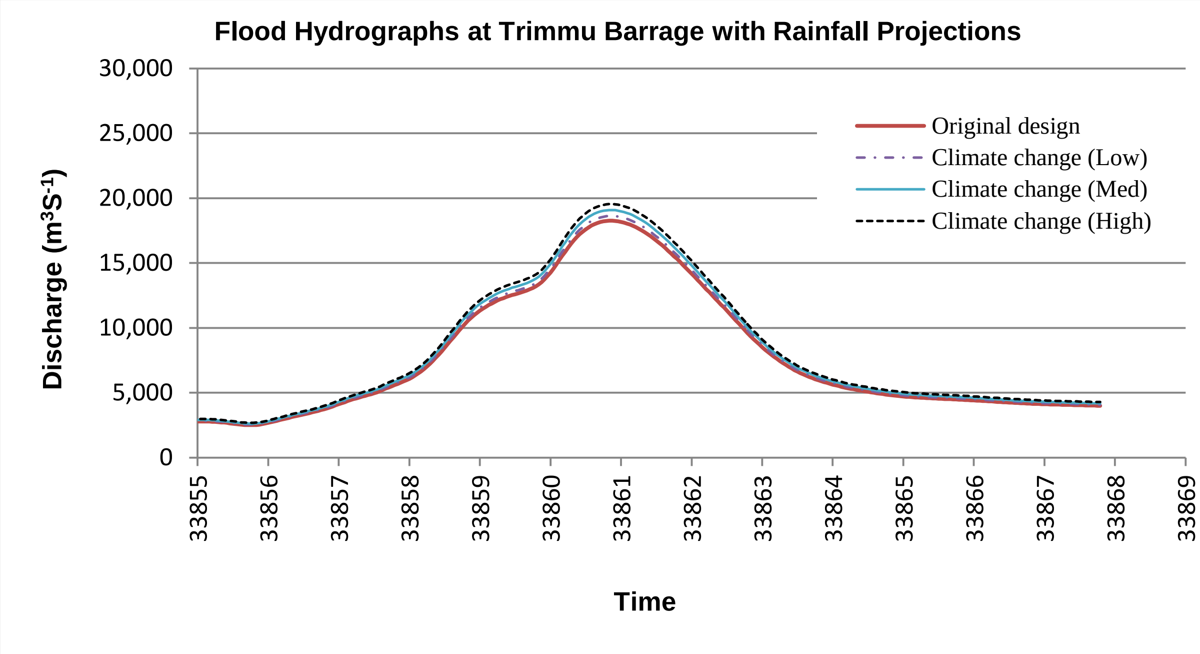
30. In the main Indus river, Ali et al. (2009)[9] identified neither a significant change in flow on the basis of the inflow into Tarbela (1961–2004) and at Kalabagh (1922–2002) nor of the Jhelum River measured at Mangla (1922–2004). An increasing trend was observed for the flow of Chenab measured at Marala (1922–2004) and a significant decreasing trend in the flow of Kabul River at Nowshehra (1961–2004).

31. The river flows projections can be made either on the basis of observed flow or from rainfall projections using hydrological modelling. The rainfall projections show large variations and do not show a clear trend. Increase in rainfall does not directly translate into increase in flow peaks due to several rainfall-runoff factors including rainfall uniformity, catchment area contribution, catchment conditions, antecedent moisture conditions etc. Further, stream flow routing and channel/off-channel storages also impact the flow peaks. Given the several uncertainties and data limitations,[10] a conservative approach is followed that considers scenarios (i) 2% increase in rainfall (low scenario); 4.5% increase in rainfall (medium scenario) and 7% increase in rainfall (worst case scenario); (ii) a linear translation of rainfall into runoff means percentage increase in rainfall corresponds to percentage increase in runoff; and (iii) insignificant change in flow peak due to routing for the projected increase in rainfall. The computed flow hydrographs for the two barrages with projected rainfall are in Figure 6.

32. Regarding sedimentation, the change in rainfall pattern combine together with the catchment degradation may increase the sediment flows. But a major part of this sediment will be trapped in the upstream Mangla reservoir and will reduce at the project location due to routing effect of the upstream structures. Nevertheless, contribution of downstream catchment and oblique flow phenomena at Trimmu barrage may change sediment pattern at upstream of the barrage and should be appropriately managed.

[9] G. Ali, S. Hassan, and A. Khan. 2009. Climate Change: Implications and Adaptation of Water Resources in Pakistan. Research Report 13. Islamabad: Global Change Impact Studies Centre.

[10] Chenab river is a transboudary river with most of its upper catchment is located in India and there was no access to the data.



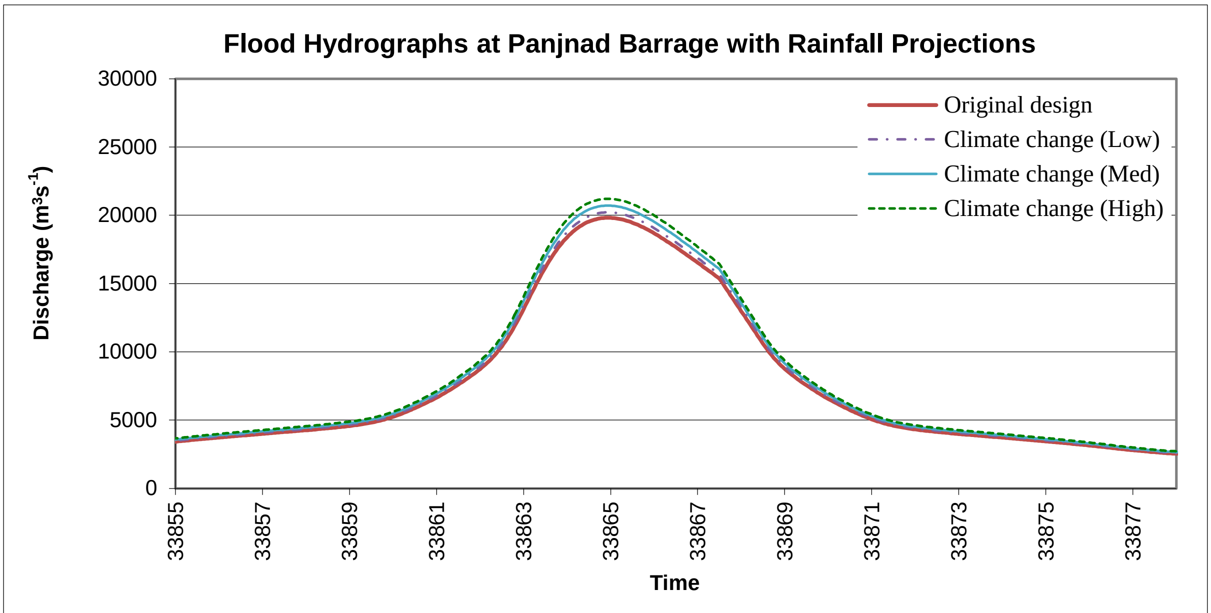


Figure 6. Computed Flow Hydrographs at Trimmu and Panjnad Barrages with Projected Rainfall

V. CLIMATE CHANGE IMPACTS AND ADAPTATION STRATEGY

A. Rationale for the Adaptation Strategy

33. The project aims at reliable irrigation supplies and reduced flood risks through enhancing barrages capacity and safety and safe passage of flood. The project is based on the concept of disaster risk management (DRM)—the barrages failure during flood may cause loss of crops for several seasons and high flood damage. In water resources projects in general, and this project in specific, DRM and climate change adaptation (CCA) overlap. For example; the climate change may affect the (i) barrage's structure and its performance due to water and sediment flow variability (part of this project); and (ii) crops in the command

area due to high evapotranspiration demands and imbalance between water supply and water demand (out of scope of this project). Therefore, existing barrages may require protection against climate change over normal flow conditions. However, the DRM requires protecting the barrages from and enhancing their capacities for extreme floods as governed by hydro-economic analysis. Protecting the barrages and enhancing their capacities for additional flows is needed for both the DRM and CCA. The protection requirements for the project in both cases will overlap (Figure 7). Therefore, the CCA strategy will require addressing the higher flows in a range of 2% to 7% and associated sedimentation issues as explained under climate change projections. However, the DRM will require managing 24% and 35% higher flows for Panjnad and Trimmu barrages, respectively to appropriately address the future flood risk management (FRM). So CCA interventions will be a subset of DRM interventions and the overlapping area will be important for the strategy. The non-overlapping area (Figure 7) for example; agriculture for CCA and drought for DRM are not part of this project and this strategy.

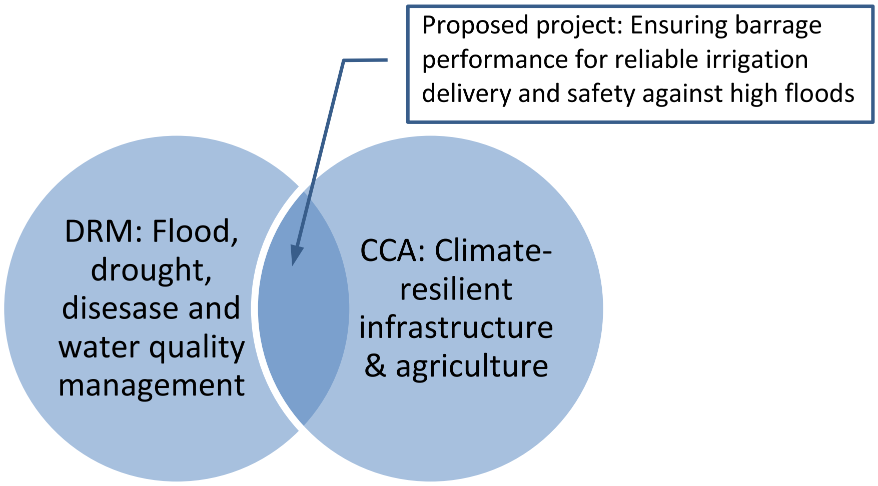


Figure 7. Disaster Risk Management and Climate Change Adaption Overlap

B. Climate Change Impact on the Project

34. The assessment does not show direct impacts of the projected temperature, glacial melt and precipitation rise on the barrages project. Nevertheless, the indirect impacts in terms of changes in flow and sediment pattern were assessed under the climate change projections. The climate change impacts on discharge hydrograph shows an increase of discharge beyond original design capacity of Trimmu barrage by 365 m^3s^{-1} (2%), 822 m^3s^{-1} (4.5%) and 1278 m^3s^{-1} (7%) for low, medium, and high rainfall projections (Table 4). The increase in discharge for Panjnad barrage was estimated at 396 m^3s^{-1} (2%), 892 m^3s^{-1} (4.5%) and 1387 m^3s^{-1} (7%). These additional flows may have implications to (i) sedimentation pattern at upstream of the barrages; (ii) protection works; and (iii) river training works. The existing barrages may also need additional capacity (over the original design capacity) to safely pass the additional flows due to climate change impacts. These impacts have been incorporated in the proposed climate change adaptation strategy for the existing barrages.

Table 4. Flood Peaks with Climate Change and Flood Management Scenarios

Barrage	Original Design Capacity (m^3s^{-1})	Peak Discharge with Projected Rainfall Increase		
		Peak Discharge with 2% Rainfall Increase (m^3s^{-1})	Peak Discharge with 4.5% Rainfall Increase (m^3s^{-1})	Peak Discharge with 7% Rainfall Increase (m^3s^{-1})
Trimmu barrage	18,265	18,630	19,087	19,543
Panjnad barrage	19,822	20,218	20,714	21,209

C. Adaptation Strategy for the Project

35. The probable impacts of climate change—rainfall and river flow variability, to the existing barrages could be the change in (i) flow frequency; (ii) flow pattern; and (iii) sedimentation distribution. The CCA strategy considers addressing these issues to improve performance of the barrages under existing conditions. The identified changes may require structural and non-structural measures. The structural measures could be (a) additional water ways, (b) improved training works, (c) strengthened protection works, and (d) periodic removal of the additional sediment, if needed. The non-structural measures are identified as enhanced O&M requirements, capacity building of communities and Punjab Irrigation Department (PID) in FRM and integrated water resource management (IWRM) approaches, strengthening PID's strategy and policy reform unit and Punjab Engineering Academy to help operationalizing IWRM and FRM approaches.

36. It is estimated that additional water way: one and half bay of 24 meters for low, 3 bays for medium, and 4.5 bays for high case scenario,[11] will be required. This strategy suggests incorporating interventions for medium rainfall projections. Stone protection of existing training works and strengthening of stone apron at downstream of the barrages will also be required. Trimming of existing bela at Trimmu barrage is also recommended as a part of CCA strategy.

37. For increased O&M requirements, the adaptation measures will be (a) revising the existing O&M manual by the project; and (b) periodic special inspections of these barrages by a panel of experienced and external experts every five years; one such inspection will be arranged during project implementation for demonstration purpose. Recommendations of the post-project inspections will be implemented by the Government, which can be physical works or adapting sound practices.

D. Adaptation Cost

38. The climate change adaptation cost was estimated at $17.0 million for low, $22 million for medium, and $28 million for high case scenarios of rainfall projections. For a medium case scenario, of the total cost of $22 million, $16 million will be required during the project implementation and $6.0 million will be spent by the Government after the project as an incremental cost for O&M during its design life. This will be in addition to the annual O&M expenditures, which the Government spends under standard operating practices. The loan will provide $13 million and the government will contribute $9 million of the total adaptation cost. Corresponding costs of structural and non-structural measures have been estimated as $12.2 million and $0.8 million. A cost summary is in Table 4 and a detailed cost estimate is in Appendix B.

[11] Addition of one bay at Trimmu and corresponding half bay at Panjnad barrage will be required for low rainfall projections.

Table 4. Summary of Climate Change Adaptation Cost

Description	Cost for Medium Rainfall Projections		
	Total Cost ($)	**ADB share ($)**	**Government Share ($)**
A. Cost to be incurred during project implementation			
Structural measures	15,000,000	12,200,000	2,800,000
Capacity building	1,000,000	800,000	200,000
Subtotal A	16,000,000	13,000,000	3,000,000
B. Recurrent or incremental cost by the Government (After the Project)			
Periodic inspections	1,200,000	0	1,200,000
Sediment removal	4,800,000	0	4,800,000
Subtotal B	6,000,000	0	6,000,000
Total (A+B)	22,000,000	13,000,000	9,000,000

VI. PROPOSED DESIGN BASIS FOR IMPROVEMENT OF THE BARRAGES

A. Climate Change Impacts

39. Four bases to improve the existing barrages have been analyzed. The climate change projections require increasing the existing flow capacity for Trimmu barrage from 18,265 m^3s^{-1} to 19,087 m^3s^{-1} and Panjnad barrage from 19,822 m^3s^{-1} to 20,714 m^3s^{-1} (4.5% higher than the original design). This is minimum rehabilitation requirement of the barrages for their performance as was originally envisaged at the time of their construction.

B. Flood Risk Management

40. Over the time, the activities of economic development significantly increased and important infrastructure is developed in the floodplain and command areas of these two barrages since their construction. Therefore, flood risks and associated damage cost is increased many folds and a higher level of protection is needed. However, the higher flood passage capacity may associate with high investment cost. Therefore, a hydroeconomic analysis to explore tradeoff between the investment and damage costs and optimize the barrages capacity was conducted (Figure 8). In Indus basin in general, a flood of 100 years return period was estimated to be the optimum flood for design of barrages.

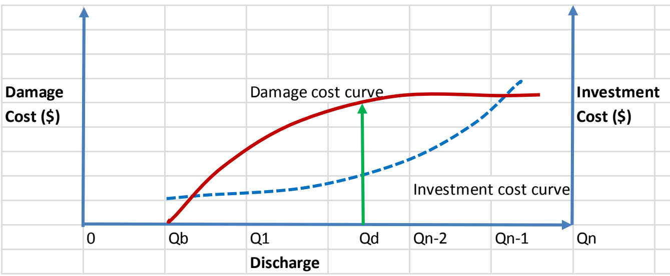


Figure 8. Decision Basis on Hydro-economic Analysis

C. Design Capacity of Upstream Barrages

41. As earlier noted, four major barrages and one dam exist upstream of Trimmu barrage.[12] These structures have significant impact on the flood peak at downstream. Also their flood passage capacity was considered as main guiding factor to decide flood passage

[12] Marala, Khanki, Qadirabad and Rasul barrages and Mangla dam exist upstream of Trimmu barrage.

capacity of Trimmu barrage. A flood peak higher than the flood passage capacity of the upstream structure cannot reach Trimmu barrage. Therefore, higher design discharge of Trimmu barrage than the corresponding discharges of upstream barrages may result in an investment without additional gain. Similarly, Panjnad barrage may not receive a bigger flood than the design capacities of its upstream barrages.[13] Thus, discharging capacities of upstream barrages played an important role in decision-making of the design discharges of Trimmu and Panjnad barrages.

D. Barrages Structural Safety

42. The design of main barrage structures considered high safety requirements and used adequate factors of safety (FOS) in analysis against sliding, overturning and undermining. Deep structures foundation, provision of sheet piles at upstream and downstream of concrete floors and reinforced concrete weirs, piers and abutments all follow sound engineering standards and practices. Fuse plug at upstream further ensures that high flow are not allowed to overtop the structures. Therefore, additional FOS ensures structural safety, reliability, and performance. This is a standard practice, which protect the barrages main structure from the negative impacts such as floods, climate change, or other unforeseen events.

43. The proposed design flood is optimized through hydroeconomic analysis and it follows logical upstream and downstream linkages of river flows as well as structural safety (Table 5). The proposed design flows are higher than the original barrages capacities (24% higher for Panjnad and 35% for Trimmu) and also 20%-30% higher than estimated requirements for climate change projections; no change in the project design and no additional cost is required.

Table 5. Flood Peaks with Climate Change and Flood Management Scenarios

Barrage	Original Design Capacity (m^3s^{-1})	Peak Discharge with Projected Rainfall Increase			Project's Proposed Peak Discharge (m^3s^{-1})
		Peak Discharge with 2% Rainfall Increase (m^3s^{-1})	Peak Discharge with 4.5% Rainfall Increase (m^3s^{-1})	Peak Discharge with 7% Rainfall Increase (m^3s^{-1})	
Trimmu barrage	18,265	18,630	19,087	19,543	24,777
Panjnad barrage	19,822	20,218	20,714	21,209	24, 495

VII CONCLUSIONS

44. The study is based on the limited available data. It used global and regional circulation models, which show high variability in climate projections. The hydrological assessment also is based on several assumptions. Therefore, the results and conclusions are based on these variations. However, a conservative approach has been used for design of the project, therefore, possible negative impacts either from climate change or flood risks have been adequately incorporated. The following relevant conclusions have been drawn from the study.

- The existing barrages require rehabilitation and upgrading to sustain their performance and avoid future risks.
- The country level studies show significant increase in temperature and precipitation.

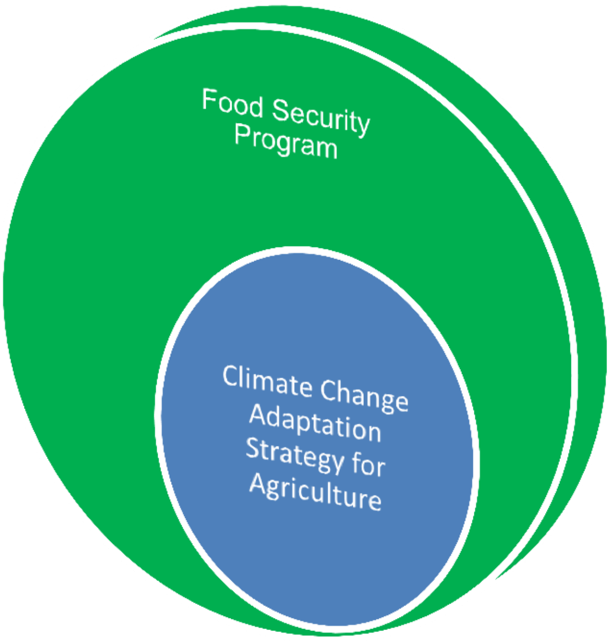
[13] Trimmu, Islam and Sidhnai barrages exist upstream of Panjnad barrage.

- Rainfall projections through downscaling of three GCMs do not show significant increase in rainfall during 2011 and 2050. However, it indicates an increase during a period from 2051 to 2098.
- Longtime flow data shows a decreasing trend in annual maximum flows, contradicting the results of climate change projections.
- Uncertainties in climate data, models the results of the climate projections, necessitates for adapting a conservative approach for design of barrages.
- The barrages design should follow an approach that optimizes design for flood risk management, probable damages, performance, climate change and structural safety.
- The proposed design of the barrages is sound and provide adequate safeguard against climate change.

VIII AGRICULTURAL PRODUCTION

A. General

45. Pakistan will need 40% to 50% additional food by 2025 to feed increased population from 180 million in 2011 to 221 million in 2025 and changed living standards.[14] This additional food will be produced through increased crop yield and expanded irrigated area, wherever opportunities exist. Government plans to revitalize agriculture and reduce postharvest losses to meet the additional food demand. Government's Food Security Program (FSP) focuses on (i) enhancing on-farm agricultural production; (ii) reduce crop losses; (iii) improve postharvest efficiency including reduction in grain loss, adding value chain and better marketing opportunities; and (iv) improving connectivity. Impact of climate change on crop production and strategy to address this impact is a subset of the overall FSP (Figure 6).



[14] Pakistan's Economic Survey 2011-2012.

46. As scope of this project is limited to the improvement of safety and performance of the two barrages, the climate change impact on the agriculture was broadly assessed.[15] Further, agricultural improvement involves bigger interventions than a project specific such as research in crop varieties, cropping patterns, and management practices, marketing, prices etc., a broader discussion has been presented to capture probable climate change impacts and related Government strategy.

B. Probable Impacts of Climate Change on Agriculture

47. Task Force on Climate Change, Planning Commission, Government of Pakistan based on a country scale studies using Decision Support System for Agro-technology Transfer (DSSAT) program and CERES-WHEAT and CERES-RICE crop simulation models to assess the impact of climate change on the productivity of wheat crop in four different agro-ecological zones[16] and on Basmati rice crop in semi-arid plains of Punjab[17] notes that:

(i) the growing season length for wheat will decrease with increase in average temperature in all the agro-ecological zones in Pakistan, the rate of reduction being larger in the mountainous regions than in the arid and semi-arid plains (GCISC 2009d). For temperature increases in the range 1°C to 5°C, the wheat yield will increase in the mountainous region but decrease in the sub-mountainous, arid and semi-arid regions. The increase in CO_2 concentration will have a positive effect on wheat yield in all the regions due to the fertilization effect of CO_2 but it could compensate for the adverse effect of rising temperature only to a certain extent. With the increase of ambient CO_2 from the current level of 380 ppm to 550 ppm, the baseline wheat yield in the arid and semi-arid plains could be sustained for temperature increases up to 3°C.

(ii) the growing season length of Basmati rice cultivated in the semi-arid plains of Punjab is also found to decrease with rise in temperature; it will decrease from 108 days to 102 and 89 days respectively for temperature increases of 1°C and 5°C over the baseline temperature (GCISC 2009e). At the current level of CO_2 concentration, the yield will have a decreasing trend with rise in temperature but increase in the CO_2 concentration level will be helpful in reducing the negative effect of temperature rise. Under the combined effect of temperature and CO_2, the baseline Basmati rice yield could be sustained for temperature increases up to 1°C provided the ambient CO_2 concentration level were to increase from 380 ppm to 550 ppm.

(iii) simulation modelling studies at GCISC show that the national wheat production in 2080s under the influence of the climatic factors of the IPCC high and low scenarios A2 and B2 will be 6-8% lower than the potential production if the climate were to remain unchanged. Rice, the other major food crop, is more sensitive to climate change; it is found that by 2080s Basmati rice production in the country will suffer a reduction of 15-18% due to climate factors anticipated under the A2 and B2 scenarios. The findings indicate that the cereal production in the northern mountainous areas will benefit from climate change. For example, the wheat yield in these areas will increase by 40-50% by 2080s under A2 and B2 scenarios. However, this will not be of much help at the national level as the contribution of the northern mountainous region to the national wheat production is merely 2%.

[15] Command area and agriculture is out of scope of the proposed project.
[16] Northern mountainous region, Northern sub-mountainous region, Southern semi-arid plains and Southern arid plains. The proposed project falls in the semi-arid plains.
[17] Sheikhupura district.

(iv) an expected increase in the frequency and intensity of precipitation events involving heavy rainfall within short periods of time may result in damage to crops and loss of top soil. Increased crop production losses on this account, together with those resulting from the expected more frequent and more intense floods and droughts caused by changes in average values of climatic parameters may further aggravate the declined production of the country resulting from productivity losses.

C. Government Strategy for Agricultural Improvement

48. Punjab has an estimated 8.4 million ha irrigation land, which produces over 80% of the total food requirement. The Government of Punjab has initiated a $433 million program in 2013 to enhance agricultural water productivity in Punjab including the command areas of Trimmu and Panjnad barrages.[18] The project, through improvement of crop productivity per unit of land and per unit of water, by increasing the efficiency of various agricultural inputs, in particular the input of irrigation water; improvement of farm practices by adopting modern techniques such as laser land levelling, crop diversification, proper cropping patterns, optimized planting dates etc.; and farmers' capacity building, will help in water demand management vis-à-vis improving agricultural production with less or same water use. The agricultural productivity enhancement program complements ADB's upstream investment in irrigation infrastructural improvement. Punjab is also working on sustainable groundwater management, which currently provides over 40% share of the total irrigation. A recent initiative to improve Basmati rice production and marketing with the technical assistance from ADB is also part of overall enhancement of agricultural production and contribution to food security.

49. As part of the FSP, the Punjab's strategy includes (i) developing heat and drought resistant crop varieties; (ii) upscaling high efficiency irrigation technologies for water conservation; (iii) better groundwater regulation to act as safeguard during peak irrigation demands and drought; (iv) capacity building of farmers and the extension services vis-à-vis encouraging private agricultural services; and (v) advancing the wheat sowing time by about two weeks (shift from 15 November to 1 November) and late sowing of cotton. The minor adjustments in sowing time of these two major crops will provide a reasonable safeguard against climate change. Punjab's strategy covers standard climate change adaptation practices against temperature rise and rainfall variability. The command areas of Trimmu and Panjnad barrages are part of the productivity enhancement program.

[18] This include $250 million loan from IDA and $183 million beneficiaries and government contribution.

Appendix A: Results of AWARE Model Study

The AWARE Model study rates the project as medium risk based on temperature increase, precipitation increase and flood, precipitation decrease, and water availability, and offshore category 1 storm. Summary of the main results is in Table A.1 below. A complete AWARE Model report is separately available.

Table A.1. AWARE Model Study Results for Project Risk Rating

Climate Parameters	AWARE Model Risk Rating	Acclimatize Commentary		Comments on the Model Functions and Results
		How climate parameters affect the Project	What does the science say could happen by the 2050s?	
Temperature increase	Low	• Heat waves stress to buildings • Warm weather can raise surface water temperatures. • Heat waves can impact agricultural productivity and growing seasons.	• Climate model projections do not agree that seasonal temperature will increase beyond 2˚C in the project location.	○ The model (Acclimatize) accepts that the seasonal temperature cannot raise more than 2ºC. ○ The barrages are mass reinforced concrete structure and use temperature steel. ○ The barrages are designed for extreme cases (much beyond than the seasonal phenomena). ○ No risk to the project due to the projected average temperature rise.
Precipitation increase	Medium	• Seasonal runoff may lead to erosion and siltation of water courses, lakes and reservoirs. • Flooding and precipitation induced landslide events.	• Climate model projections do not agree that seasonal precipitation will increase at the project locations, which could indicate a relatively high degree of uncertainty (see the section "Model agreement and uncertainty"	○ The climate model projections disagree with the results. ○ Local rainfall does not affect the barrage structure, which is designed for high floods. ○ The rainfall increase if any in catchment can generate high volume but probability of generating high peak is low as other contributing factor such as contributing area, rainfall duration and intensity, topography, antecedent moisture conditions and drainage density have role. ○ Therefore, risk due to rainfall increase is low.
Flood	High	Project is located in a region which has experienced recurring major flood events in the recent past.	Climate change is projected to influence the frequency and intensity of flood events. Existing engineering designs may not consider impact of climate change on the risks from flooding.	○ Climate change may influence frequency and intensity of flood but upstream structures, channel routing and flow regulation will reduce the flood peak. ○ A flood peak higher than the capacity of upstream structure cannot be passed on to the proposed barrages. ○ Due to flow regulation at Mangla flood peaks from Jhelum and Chenab rivers will not add up. ○ Therefore, risks to the project site will be medium (not high).
Water availability	High	The project is located in a region where there may be future water stress (2020s - 2050s).	Climate change may influence water availability in the regions that are already dry may suffer from increased evaporation and, seasonal variability.	○ Water stress will not affect the proposed project; however, it may impact on-farm agriculture, which is not in the scope of this project. ○ Therefore no risk due to water availability to the proposed project is expected.
Onshore	Low	On the Saffir-	Climate change may	○ Due to about 1000 kilometers

category 1 storms		Simpson Hurricane Scale a category 1 storm is characterized by sustained winds in excess of 119 km/hr (33 m/s).	influence the frequency and intensity of tropical storms and existing engineering designs may not take into consideration the impact of tropical or extra tropical storms.	distance onshore storm will not affect barrages.
Final risk rating	**Medium**			

Appendix B. Climate Change Adaptation Cost and Financing Plan

Item No	Description	Total cost for Low, Medium and High Projections Scenarios($)			ADB Share ($)	Government Share ($)	ADB Share ($)	Government Share ($)	ADB Share ($)	Government Share ($)
		Low	Medium	High	Low	Low	Medium	Medium	High	High
A	Cost to be incurred by the project									
1	Additional bays for two barrages (Low 2; Medium 4 and High 6)	6,000,000	11,000,000	17,000,000	5,000,000	1,000,000	9,000,000	2,000,000	14,000,000	3,000,000
2	Removing sediment and bela trimming	1,000,000	1,000,000	1,000,000	800,000	200,000	800,000	200,000	800,000	200,000
3	Strengthening protection works	3,000,000	3,000,000	3,000,000	2,400,000	600,000	2,400,000	600,000	2,400,000	600,000
	Subtotal	**10,000,000**	**15,000,000**	**21,000,000**	**8,200,000**	**1,800,000**	**12,200,000**	**2,800,000**	**17,200,000**	**3,800,000**
4	Capacity building of the communities	200,000	200,000	200,000	180,000	20,000	180,000	20,000	180,000	20,000
5	PID’s capacity building (IWRM & FRM)	200,000	200,000	200,000	180,000	20,000	180,000	20,000	180,000	20,000
6	Review of barrage manual	100,000	100,000	100,000	70,000	30,000	70,000	30,000	70,000	30,000
7	Improved discharge monitoring	300,000.00	300,000	300,000	270,000	30,000	270,000	30,000	270,000	30,000
8	Seminar and workshops on operationalizing IWRM practices	200,000	200,000.00	200,000	100,000	100,000	100,000	100,000	100,000	100,000
	Subtotal	**1,000,000**	**1,000,000**	**1,000,000**	**800,000**	**200,000**	**800,000**	**200,000**	**800,000**	**200,000**
	Total of A	**11,000,000**	**16,000,000**	**22,000,000**	**9,000,000**	**2,000,000**	**13,000,000**	**3,000,000**	**18,000,000**	**4,000,000**
B	**Recurrent or Incremental Cost by PID (After the Project)**									
1	Periodic inspection by the POE (One inspection)	100,000	100,000	100,000	0	100,000	0	100,000	0	100,000
2	Sediment removal and strengthening training works every five year	800,000	800,000	800,000	0	800,000	0	800,000	0	800,000
3	Government’s operational expenses for inspection	100,000	100,000	100,000	0	100,000	**0**	100,000	**0**	100,000
	Subtotal 5-yearly expenses	**1,000,000**	**1,000,000**	**1,000,000**	**0**	**1,000,000**	**0**	**1,000,000**	**0**	**1,000,000**
	Expenses during project life	**5,000,000**	**5,000,000**	**5,000,000**	**0**	**5,000,000**	**0**	**5,000,000**	**0**	**5,000,000**
	Total of B	**6,000,000**	**6,000,000**	**6,000,000**	**0**	**6,000,000**	**0**	**6,000,000**	**0**	**6,000,000**
	Total cost (A + B)	**17,000,000**	**22,000,000**	**28,000,000**	**9,000,000**	**8,000,000**	**13,000,000**	**9,000,000**	**18,000,000**	**10,000,000**