ISLAMIC REPUBLIC OF PAKISTAN
FEDERAL FLOOD COMMISSION (FFC)

TECHNICAL ADVISOR
ON
FLOOD MANAGEMENT
IN
ISLAMIC REPUBLIC OF PAKISTAN

FINAL REPORT
VOLUME-2
PRELIMINARY FEASIBILITY STUDY

September 2023

JAPAN INTERNATIONAL COOPERATION AGENCY

CTI ENGINEERING INTERNATIONAL CO., LTD.

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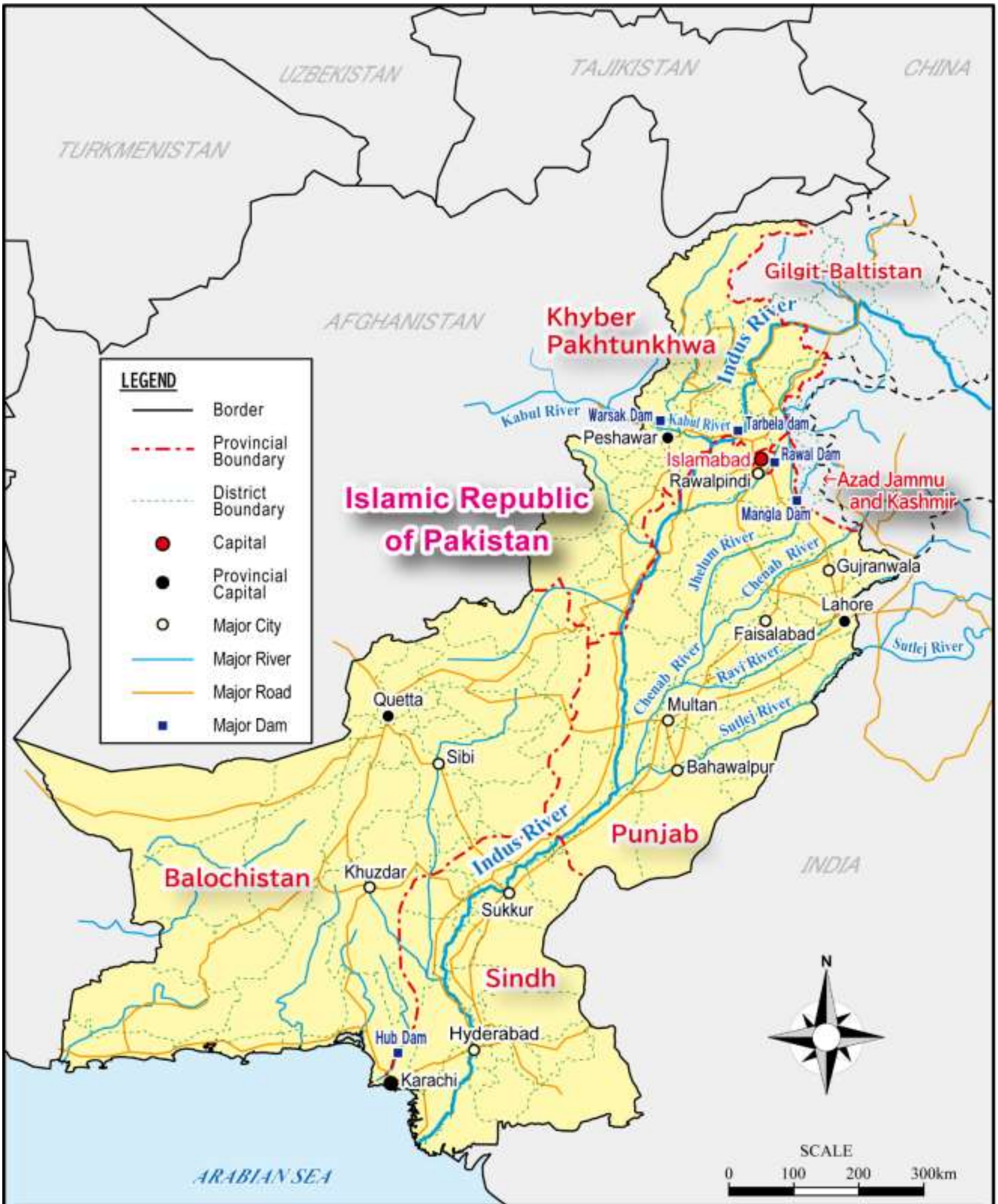
COMPOSITION OF FINAL REPORT

VOLUME-1：MAIN REPORT

VOLUME-2：Preliminary Feasibility Study

Exchange rate used in this report.
1USD=303.094PKR=146.164JPY
1PKR=0.482240JPY
As of September 2023.



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PROJECT LOCATION MAP

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ABBREVIATIONS AND ACRONYMS

ADB	Asian Development Bank
ADP	Annual Development Programme
AJ & K	Azad Jammu and Kashmir
D.G. Khan	Dera Ghazi Khan
D.I. Khan	Dera Ismail Khan
DRR	Disaster Risk Reduction
FATA	Federally Administrated Tribal Areas
FFC	Federal Flood Commission
FP	Flood Protection
FPSP	Flood Protection Sector Project
FPW	Flood Protection Works
GB	Gilgit-Baltistan
GIS	Geographical Information System
HFL	High Flood Level
HSSEU	Hydraulic Structures Safety Evaluation Unit
HWL	High Water Level
IRB	Indus River Basin
JICA	Japan International Cooperation Agency
KPK	Khyber Pakhtunkhwa
MCB	Manchar Containing Bund
MNVD	Main Nara Valley Drain
MoPS	Ministry of Planning, Development and Spatial Initiative
NDMP	National Disaster Management Plan
NFPP	National Flood Protection Plan
NGO	Non-Governmental Organization
NHA	National Highway Authority
NSL	Normal Surface Level
O&M	Operation and Maintenance
PC	Planning Commission
PDNA	Post Disaster Needs Assessment
PID	Provincial Irrigation Department
PIMU	Project Information Management Unit
PMD	Pakistan Meteorological Department
PRF	Project Readiness Financing
PSDP	Public Sector Development Program
RBOD	Right Bank Outfall Drain
SOP	Standard Operating Procedure
SFERP	Sindh Flood Emergency Rehabilitation Project
SLSC	Standard Least Squares Criterion
TOR	Terms of Reference
WAPDA	Water and Power Development Authority
WB	World Bank

CHAPTER 1 PRELIMINARY FEASIBILITY STUDY (PRE-F/S) OVERVIEW

1.1 Background of Pre-F/S

1.1.1 Selection of Target Areas

In the advisory activities, the advisor team participated in the Post Disaster Needs Assessment (PDNA) survey to analyze the damage caused by the large-scale flood in 2022. After analyzing the results of the PDNA survey, the past damage history, and bottlenecks in the natural and social characteristics of the Indus River system (see Section 2.4.2 of the main report), the advisory team selected target areas with a high DRR(Disaster Risk Reduction) potential by pre-investment of interventions. The target area was a low-lying area on the right bank of the Indus River in the Sindh province, which suffered the most damage during the 2022 Flood. This area is considered to be a high-risk area for flood damage due to the large number of people and industries that are exposed to hazards such as runoff from many rivers/nullahs on the Hill Torrent (seasonal rapids) areas, overflow due to the breach of the main bunds of the Indus River, and inland flooding due to local heavy concentrated rainfall. The above selection process of the Pre-F/S target area is by the Japan International Cooperation Agency (JICA) support policy in Pakistan as shown in Table 1.1.1.

Table 1.1.1 Draft JICA Support Policy for Pakistan

Items	Description
Overriding Principle	Develop supports that contribute to reducing economic losses in Pakistan through disaster risk reduction by flood protection measures in the Indus River Basin.
Policy for Project Formulation	【Approach】 ➢ Responding to the Sendai Framework for Disaster Risk Reduction focusing on economic development ➢ Intensive deployment according to the largest disaster risk of the Indus River ➢ Reduction of flood risk using existing assets ➢ Development of cooperation according to the flood mechanism
	【Narrative Description for the Approach】 ➢ Since considering disaster risk reduction as a development issue is essential for Pakistan along with the Sendai Framework for Disaster Risk Reduction, it is important to develop assistance that focuses on the reduction of economic damage. ➢ To this end, based on the actual damage caused by the 2022 and 2010 floods, JICA will concentrate his/her support on the main river of the Indus River system, which is considered to have a large concentration of assets to be protected and a high disaster risk in the event of a flood disaster. The relevance of expanding it systematically is high. ➢ JICA has prioritized flood risk reduction in Pakistan and is managing its existing programs. Therefore, since last year, JICA has conducted a preliminary survey of river basins that have a large macroeconomic impact and has already started technical cooperation for the "Review and Update of the National Disaster Management Plan" and "Flood Management Advisor," so these assets will also be utilized. ➢ In Pakistan, the causes and mechanisms of damage are different among upstream, midstream, and downstream, so cooperation should be considered accordingly.

Source: Advisor Team

1.2 Objectives of Pre-F/S

The purpose of the Pre-F/S is to reduce flood damage in the populated low-lying areas along the Indus River, which are most vulnerable to flood damage. As part of flood DRR measures to promote economic growth in Pakistan, the advisory team proposes projects that can be horizontally developed in the future based on the results of Pre-F/S. The advisory team also updated the implementation of measures in the Hill Torrent areas, which causes flooding in the lower plains on the right bank of the Indus River, through a review of the “Master Feasibility Studies For Flood Management of Hill Torrents of Pakistan (hereafter referred to as "M/F Study 1998")” conducted by Federal Flood Commission (FFC).

1.3 Pre-F/S Contents

1.3.1 Review and Update of the Hill Torrent Master-Feasibility Study

Review of the M/F Study1998 to understand the characteristics of the Hill Torrent areas and to update the implementation status of flood protection/control measures. Specifically, after confirming the progress of projects planned in M/F Study 1998 and understanding the current status of flood control/protection measures after the 2022 flood, the advisory team made recommendations on what FFC and Provincial Irrigation Department (PID) should implement at this stage. In addition, after consultation with FFC and PID, the target area for the Pre-F/S to be implemented in the advisory activity was determined.

1.3.2 Construction/Strengthening of the Indus River Bund and Drainage Capacity Enhancement of Lake Manchar

Based on the 2022 flood, the advisory team carried out an inventory survey to grasp the general current status of the Indus River bunds, assuming the risk of bunds' breach, and organizing issues and priority reaches to be rehabilitated or reconstructed. The inventory survey was carried out based on existing Indus River bunds Geographical Information System (GIS) data, satellite images, and the vulnerability survey by the Sindh province. As an output image, current issues, necessity and urgency of countermeasures, propositions of countermeasures, and investment effect of Indus River bunds in each place where it is necessary to respond in the short to medium term shall be summarized and arranged in a long list and location map of selected areas. In addition, measures for strengthening drainage capacity in the vicinity of Lake Manchar, where the damage was remarkable around its basin, were initially examined and Pre-F/S was conducted. Specific structures aimed at enhancing drainage capacity at the downstream edge of Lake Manchar shall be examined with the design criteria of 50 50-year scale. The results of Pre-F/S show the concept, method, scale, location, and estimated project cost of countermeasures on the premise of implementation of the JICA Grant Aid.

1.4 Design Policy (Plan size, socio-economic status, construction/procurement, adaptability to Pakistani companies, operation and maintenance (O&M) in implementing agencies, implementation schedule)

1.4.1 Plan Scale

In National Flood Protection Plan (NFPP) -IV, the flood control improvement scale of large rivers is set at a 100-year return period; however, other rivers are referred to the provinces. According to the M/F Study 1998, flood control/protection measures in the Hill Torrent areas are planned at a 25-year scale. Currently, 4 major PIDs use 25- to 40-year, and 40-year is used for more populous areas. In addition, the Irrigation Manual (supervised by the Panjab province) directs the development of irrigation facilities in low-lying areas at 50 years.

1.4.2 Socio-economic Conditions

This study does not conduct an economic evaluation of flood control measures, but its effects are qualitatively evaluated from the distribution of population and assets in the hazard area before and after implementation of the measures. Data on population and assets are from the 2017 Census (taken from the Pakistan Bureau of Statistics). For agricultural land, cropping areas/patterns and market price of products, etc. was determined by referring to the "Economic Survey 2021-2022".

Table 1.4.1 summarizes the population, representative cities, and population densities of the Sindh low-lying area, D.I. Khan (Dera Ismail Khan), and D.G. Khan (Dera Ghazi Khan), which are expected to be particularly damaged during floods in the right bank of Indus River. Although the population density in the low-lying areas including mountainous areas is almost homogeneous, the population of the Sindh low-lying area is larger than that of D.I. Khan and D.G. Khan. As for the maximum population density by region, the Sindh low-lying area is larger than that of D.I. Khan and D.G. Khan.

Table 1.4.1 Population, Representative Cities, and Population Density of Each Area

Area name	Population	Representative cities	Population density in Tehsil
Sindh Low Plains	11,409,933	Larkana(488,006), New Sukkur(268,942) Sukkur(231,459), Shikarpur(196,158) Jacobabad(191,098), Dadu(171,319) Shahdad kok(118,935), Kamber(100,970) *Only cities with a population of 100,000 or more There are 18 cities with a population of 50,000 or more	Total area: 248 people/km^2 Maximum: 1,766 people/km^2 200 people/km^2 or more Tehsil: 18
D.I.Khan	1,625,088	Dera Ismail Khan(212,324), Paharpur(66,745) *Only cities with a population of 50,000 or more	Area: 220 people/km^2 Maximum: 326 people/km^2 200 people/ km^2 or more Tehsil: 3
D.G.Khan	4,868,670	Dera Ghazi Khan(397,362), Rajanpur(99,097) Taunsa(97,193), Jampur(87,857) Fazalpur(76,809), Kot Chhutta(51,666) *Only cities with a population of 50,000 or more	Area: 201 people/km^2 Maximum: 547 people/km^2 200 people/km^2 or more Tehsil: 5

Source: Created by the Advisory Team based on Basic data provided by JICA and the Pakistan Bureau of Statistics

1.4.3 Construction and Procurement Capacity of Private Companies

In Pakistan, contractors participating in bidding for public works are ranked according to the size of the project cost as shown in Table 1.4.2.

Table 1.4.2 Standard of Bidding Participation Company by Project Cost Scale

Category	Project Cost limit (RS. in Millions)	Enlistment/Renewal Authority
C-A	No limit	Administrative Secretary
C-B	UP to 2,000 M	Administrative Secretary
C-1	UP to 1,000 M	Administrative Secretary
C-2	UP to 500 M	Administrative Secretary
C-3	UP to 250 M	Administrative Secretary
C-4	UP to 100 M	Administrative Secretary
C-5(Class-B)	UP to 30 M	Chife Engneer /DC
C-6(Class-C)	UP to 15 M	S.E/Director
Class-D	UP to 2 M	S.E/Director
Class-E	UP to 1 M	S.E/Director

Source: Punjab Bidding Standards

Generally, when selecting a contractor for public works, the relevant department calls for bids based on the scale of the project cost. When bidding, evaluations will be made based on the contractor's qualification standards, construction track record, experience, and cost. There are also contractors with a proven track record in river construction. There are no major problems with the contractor's procurement and construction capabilities. However, as a result of the site survey by the advisor team, it was determined that there were structural weaknesses in the design and issues with the management of construction accuracy during construction.

In the future, when bidding, it will be necessary to clarify the criteria and prepare a manual for selection, technical standards, etc. In addition, it is necessary to standardize construction planning and management.

1.4.4 Maintenance and Management Capacity of Executing Agencies

Currently, the FFC conducts technical examinations for public works, and if there are no problems, each provincial PID takes charge of the work. FFC conducts reviews at the planning and design stages. After the reviews and subsequent approval by Ministry of Planning, Development and Spatial Initiative (MoPS)-Planning Commission (PC), PIDs will handle the actual construction ordering, construction supervision, and construction inspection.

Some facilities are aging and are becoming difficult to properly maintain and manage; therefore, creating unified maintenance, management, and inspection manuals and deterioration diagnosis manuals are essential for the appropriate implementation of construction works. At the same time, safety evaluations will improve by improving the management system, and emergency response will become smoother.

The O&M of river structures are implemented as follows:

- The maintenance and management of the completed channels, water gates, weirs/barrages, and bunds will be carried out by PID.
- The water gates and barrages/weirs are operated 24 hours a day. Facility inspections are conducted from time to time.

1.4.5 Matters to be Noted in Construction Planning and Execution

The major issue is to build highly safe and strong channels, water gates, barrage/weirs, and bunds. It is necessary to create facilities that respond to regional characteristics from the design stage. Indicates the challenges faced during construction to create strong channels, water gates, barrages/weirs, bunds, etc.

- Material quality: Use of concrete, rip raps, revetment stones, etc. that meet design standards.
- Functionality of equipment; use of heavy machinery and vehicles that match the type of work based on specifications, etc.
- Ability of engineers and craftsmen; placement of proven personnel, etc.
- Reasonable construction plan; schedule creation considering non-workdays, monsoon season, etc.
- Maintaining construction accuracy based on standards; compliance with design standards, construction standards, etc.
- Safety management: daily safety checks, crisis management in processes, etc.

Ultimately, the accuracy of construction on-site will have a major impact on the safety of the facility. Relevant organizations should maintain close contact with the construction contractor and visit the site to assess the situation, allowing for quality construction work to be carried out.

CHAPTER 2 UPDATING INFORMATION ABOUT THE HILTRENT MANAGEMENT PROJECT

2.1 Overview of the Master Feasibility Study Report

In the M/F-Study1998 "Master Feasibility Studies for Flood Management of Hill Torrents of Pakistan (FFC, 1998)" (Hereinafter referred to as M/F Study1998), Hill Torrent projects were summarized by the province as shown in Figure 2.1.1. The projects mainly proposed structural measures for water conservation and/or flood control and were classified into core projects and sub-projects in each state. These Hill Torrent management projects have been implemented by the Pakistan provincial government and donor funds; however, as of 2023 most of the proposed core projects in Panjab and Sindh provinces have been implemented, and the proposals of other Hill Torrent management projects have been vague/rough and progress has been small or poorly managed. This may be because many projects are not cost-effective because of the nature of the Hill Torrent region. The cost-effective regions are where the nullahs mainly flow into the low-lying irrigation area along the right bank of the Indus River. Currently, flood control measures for the Hill Torrent regions and the low-lying areas are being closely focused after the 2022 flood damage including damage to public facilities.

FEDERAL AREAS	NORTH WESTERN FRONTIER PROVINCE (NWFP)	PUNJAB PROVINCE	SINDH PROVINCE	BALOCHISTAN PROVINCE
CORE PROJECT	CORE PROJECT	CORE PROJECT	CORE PROJECT	CORE PROJECT
- Nothing	- DI Khan Area	- DG Khan Area	- Khirthar Range Area	- Indus Basin Component including Quetta Region
SUB PROJECTS	SUB PROJECTS	SUB PROJECTS	SUB PROJECTS	SUB PROJECTS
- Northern Areas - FATA - AJK	- Hazara, Kabul & Bannu Basins - FATA	- Pothowar Area - Rachna and Chaj Doabs	- Karachi Area - Sehwan & Petaro Area	- Kharan Closed Desert Basin - Mekran Coastal Area

Source: M/F Study in 1998

Figure 2.1.1 State of Hill Torrent Project Proposals

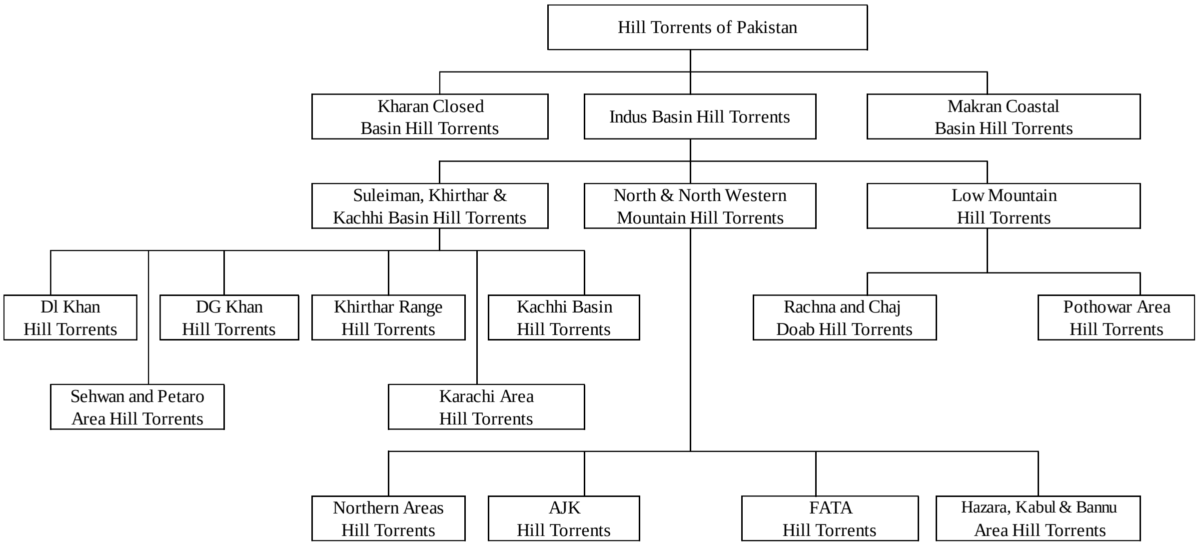
In most Hill Torrent areas, the following structures have been constructed for water conservation/use and flood control. Flowing water into/out from these structures is utilized through channels, karez, and dug wells. A common method of water use is to draw water into enclosed land, flood it for about 1.0 m, and then sow and cultivate it. The names used in the report are shown in parentheses.

- Dispersion Structure
- Diversion Structures
- Flood Carrier Channel
- Drainage Network
- Delay Action Dam
- Storage Dam/Pond
- Flood Wall
- Alluvial Fun excavated Pond (Depression)

2.2 Classification of Hill Torrent Area

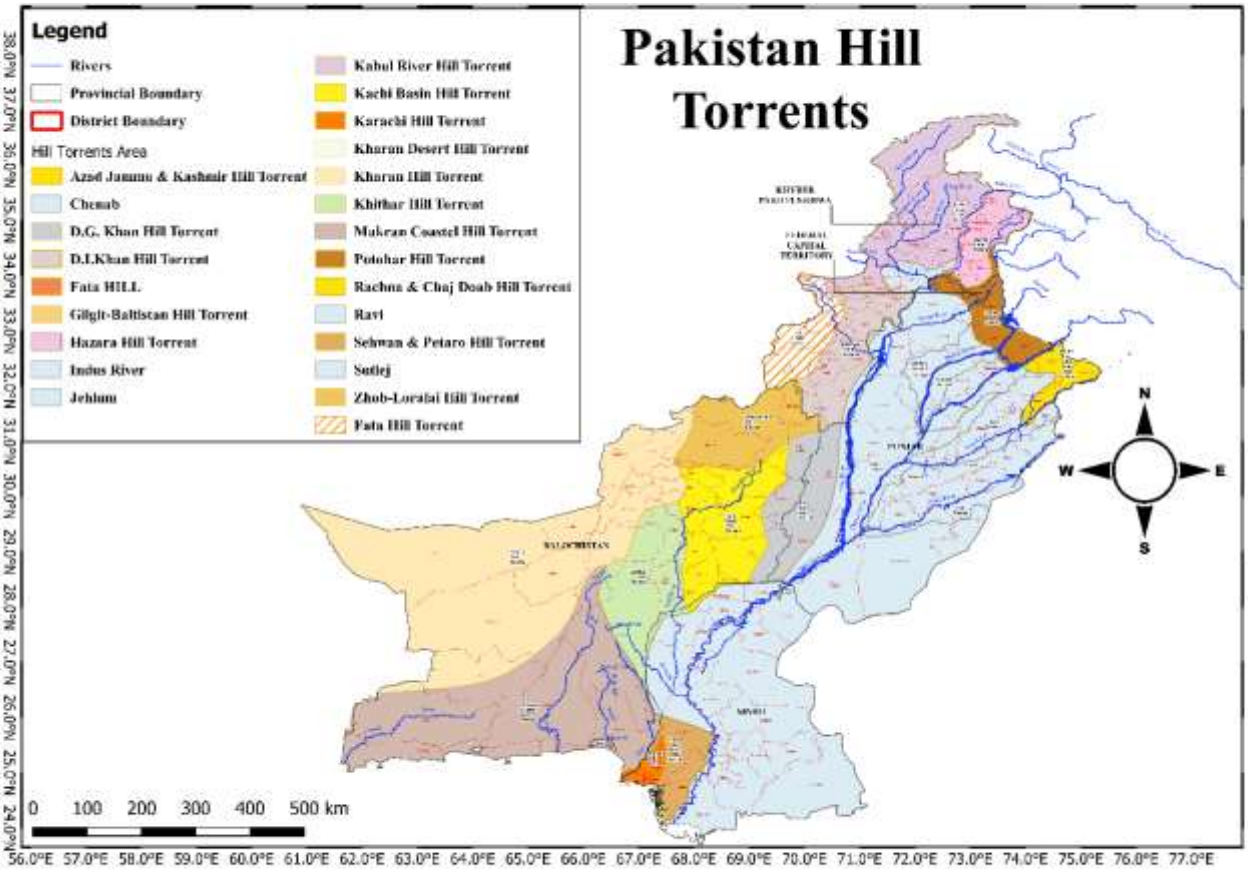
As shown in Figure 2.2.1, the Hill Torrent area is broadly classified into the following three categories based on the topographical characteristics and the locations to which the flood flowed. Figure 2.2.2 and Figure 2.2.3 show all the Hill Torrent areas and the IRB (Indus River Basin) areas directly flowing into the Indus River, respectively.

- Indus River Basin Hill Torrents.
- Kharan Closed Basin Hill Torrents
- Makran Coastal Basin Hill Torrents.



Source: M/F Study 1998

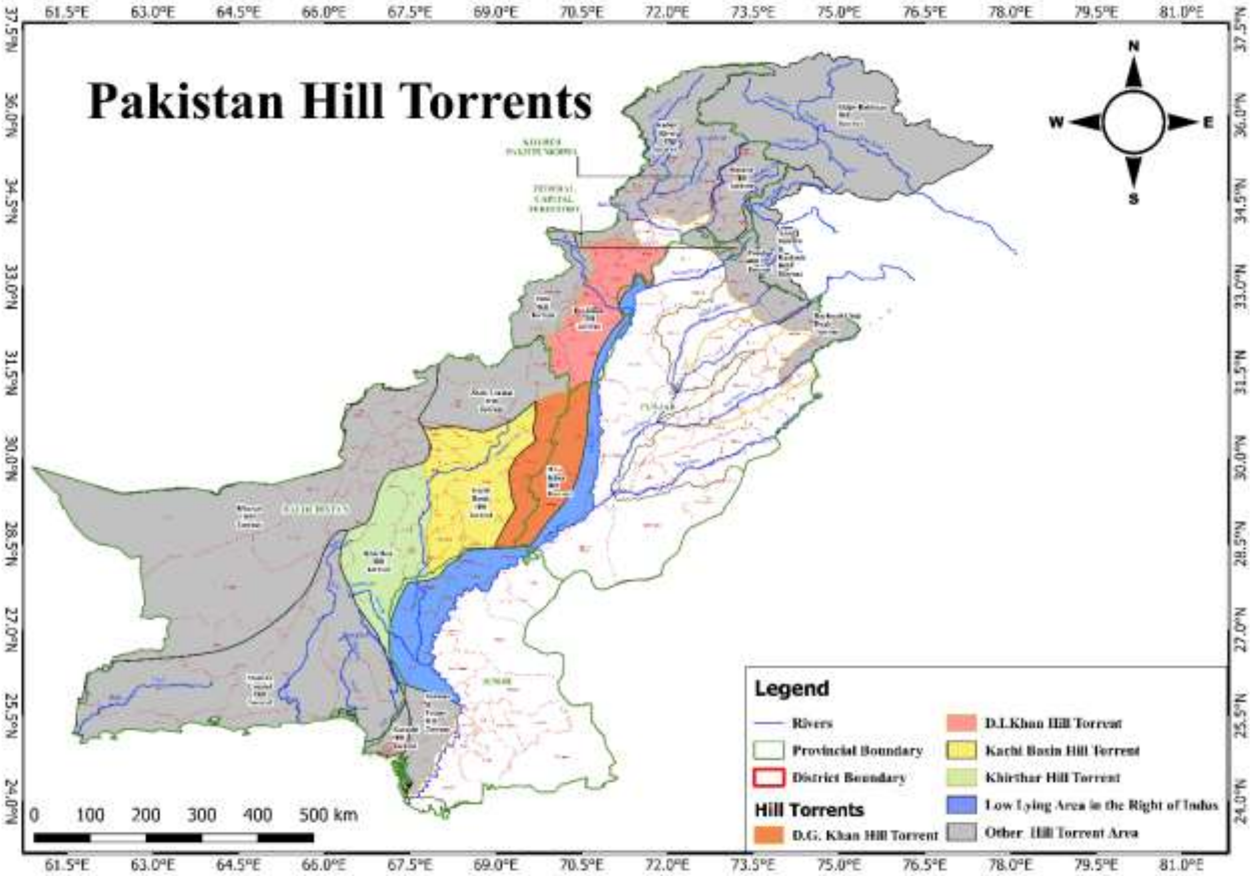
Figure 2.2.1 Classification of Hill Torrent Region



Source: M/F Study 1998 and Survey of Pakistan

Figure 2.2.2 Location map of all Hill Torrent areas

The Indus River Basin (IRB) Hill Torrent outfall eventually flows into the Indus River, and the most of others directly into the Arabian Sea. In particular, the IRB Hill Torrent area and the low-lying areas on the right bank of the Indus River that have been damaged over time by the Hill Torrent floods are shown in Figure 2.2.3



Source: Advisory team based on M/F Study 1998 and Survey of Pakistan

Figure 2.2.3 Location map of the IRB Hill Torrent area directly into the Indus River

The population- and property-accumulated low-lying area on the right (western) bank of the Indus River, which has a relatively high frequency of flood damage, received flood water from the IRB Hill Torrent area, namely, D.I. Khan in the KPK province, D.G. Khan in the Panjab-Balochistan province, and Kachhi and Khirthar Hill Torrent areas in the Sindh-Balochistan province, during not only the 2022 flood but others.

2.3 Progress and Status of 1998 M/F Study

The plan mainly deals with flood control, irrigation, and structural measures for power generation in each state. Progress and status of the IRB Hill Torrent area, i.e., D.I. Khan and D.G. Khan areas in Panjab-Balochistan and Kachhi and Khirthar Hill Torrent areas in Sindh-Balochistan are reviewed. Core projects and sub-projects are proposed in all provinces. In particular, it was difficult to ascertain the project status of the three regions mentioned above, because the progress of projects is not recognized clearly in PIDs.

2.3.1 Trends in Flood Control Development in the Hill Torrent Region

(1) Implementation of the Hill Torrent Project Proposed for M/F Study 1998

FFC and PIDs were interviewed and further requested to provide information on the progress of the project. However, FFC and PIDs do not have clear information for the old plan. Problems related to project management can also be seen in PIDs. In such cases, ADB (Asian Development Bank) conducts a Project Readiness Financing (PRF) survey for F/S and D/D studies around the target Hill Torrent areas. In general, the Hill Torrent projects have rarely been implemented due to budget shortfalls, according to FFC. However, based on the information and documents collected, the core projects appear to be almost complete.

(2) Trends in the national development of Hill Torrent as of NFPP-IV (2018)

It fully supported the development of "National Flood Protection Plan-IV (NFPP-IV)" in the Planning Commission's (MoPS-PC) 11th Five-Year Plan. NFPP-IV aims to protect public and private infrastructure and other socio-economic assets through flood bunds, barrages/weirs, flood forecasting, and early warning systems. However, since NFPP-IV was formulated in 2018, there have been few proposals for Hill Torrent projects considering the situation equivalent to the flood scale of 2022. Specifically, the Hill Torrent project in the northern KPK, which has relatively high precipitation and rapid rivers, has been proposed, but other states have not been specified as national protection plans in NFPP-IV.

(3) Movement after the 2022 Flood

On August 29, 2022, the Prime Minister directed to "Update the 2017 NFPP-IV to include measures to protect against rapid flows in mountainous areas." Based on this directive, FPSP-III has been updated and approved for its 1st edition (June 2023). In addition, FPSP-IV will be prepared. The updated FPSP-III includes priority sub-projects that had been proposed in the NFPP-IV survey process and reflects new projects that meet the emergency requirements of relevant agencies (PIDs, FLAs, WAPDA, PMD(Pakistan Meteorological Department), etc.) based on the 2022 flood damage.

Meanwhile, after the 2022 flood, development donors and the Government of Pakistan launched a Post Disaster Needs Assessment (PDNA) survey in September 2022, and MoPS produced a 4RF (Resilient, Recovery, Rehabilitation & Reconstruction) framework report at the beginning of January 2023, highlighting recovery, regeneration and reconstruction. In particular, the report highlights the BBB proposed in the Sendai Framework for Disaster Reduction as a financial requirement. Based on the requirement, development donors will finance/be financing PID and related institutions for recovery and reconstruction projects.

(4) Measures for the Hill Torrent Area Proposed in the Updated FPSP-III (June 2022)

The flood control targets for the updated FPSP-III (June 2022version) have been revised as shown in Table 2.3.1 Looking at these 12 flood control targets, structural and non-structural measures for rapid-flowing rivers stand out in light of the characteristics of the 2022 floods. Improvements to drainage measures in the low-lysing area of Sindh province, which is subject to this Pre-F/S, were also incorporated.

As will be described later, after the Hill Torrent measures and the strengthening of the main Indus River bunds, it is necessary to address inland water drainage issues in consideration of the water balance during flooding in the low-lying areas, especially around the low-lying areas on the right bank of Indus River in the Sindh province.

Table 2.3.1 Flood control improvement targets for FPSP-III updated

1.	To strengthen a small number of existing flood control facilities through additional/new interventions.
2.	Improvement of the drainage network in Sindh (rehabilitation and renovation of drainage channels, etc.).
3.	The establishment of a Flood Remote Observation Network that observes all rivers/small rivers/channels in the country at a scale corresponding to the major, secondary, and tertiary levels and helps to predict and warn of accurate and robust river floods.
4.	The establishment of fixed/mobile weather radars for flood monitoring, especially in response to sudden floods through current forecasting.
5.	The establishment of flood early warning centers in Quetta, Karachi, Hyderabad, Peshawar, Gilgit, Multan and Muzaffarabad.
6.	Strengthening and capacity-building of institutions, including the establishment of PIMUs (Project Information Management Unit) for the implementation of FPSP-III and NFPP-IV.
7.	Integrated flood management in the mountainous areas of Koh-e-Suleiman and Khirthar Range through water dispersion/water commutation structures, seepage control measures, etc. with the introduction of Nature-Based solutions and the latest technology.
8.	Installation of flood telemetry along Hill Torrents (D. G. Khan, Rajanpur & Khirthar Range).
9.	Construction of water storage and flood dispersion structures at Hill Torrents.
10.	Research and structural measures to improve flood resilience in major cities and renovation of existing flood prevention facilities/information.

11.	Measures to deal with urban flooding, including groundwater recharge rainwater retention, and dipping measures.
12.	Development of guidelines/SOPs for routing urban flooding through existing canal, drainage/river systems.

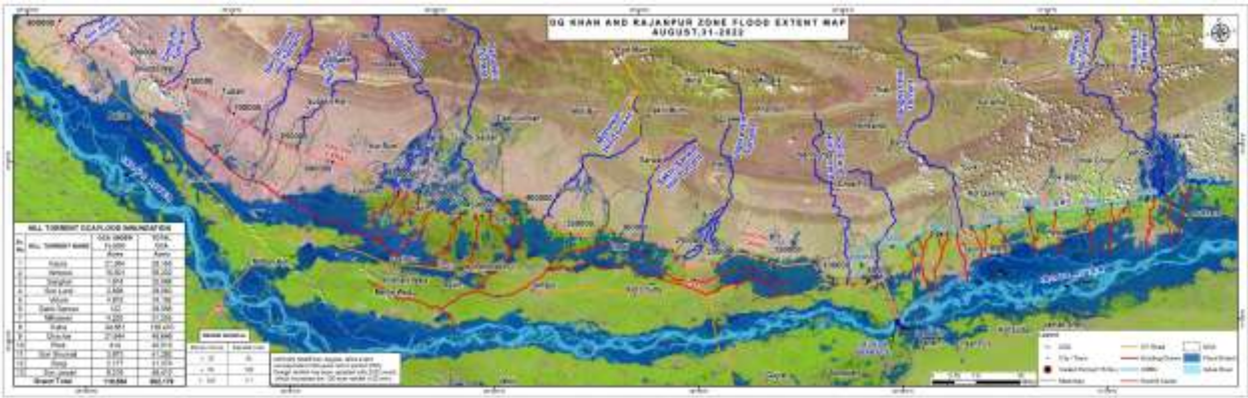
Source: Updated FPSP-III Report (Jun. 2023)

2.4 D.G Khan Hill Torrent Region

2.4.1 Landforms and Flood Characteristics of D.G Khan Hill Torrent Region

In the D.G. Khan Hill Torrent region, houses/buildings, irrigation areas, and other industries are concentrated in the low-lying areas extending from the north to the south on the right bank of the Indus River. Because the elevation of D.G. Khan's low plain is generally higher than that of the Indus River, the surface water from the upper Hill Torrent rivers drains naturally to the Indus River. In the vicinity of Rajaput, which is adjacent to D.G. Khan, bunds are constructed along the Indus River. In D.G. Khan's low plain, bunds are built individually around cities, towns, or other settlements to protect against the outflow from the upper Hill Torrent.

One of the two nuclear power plants in Pakistan is constructed in the Chashma district of the D.G. Khan Hill Torrent region.



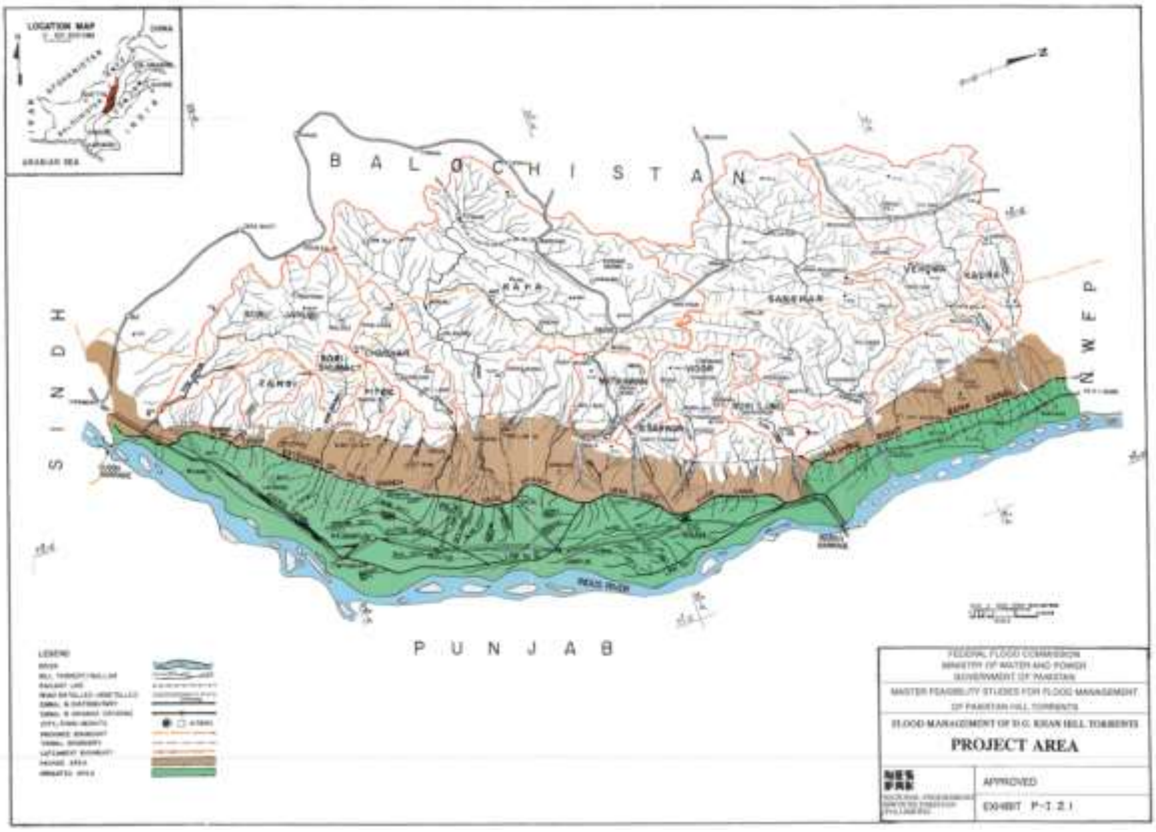
Source: Panjab-PID (2023)

Figure 2.4.1 D.G. Hill Torrent Area

2.4.2 Proposed Plans in M/F Study 1998 in Panjab-D.G. Khan

2.4.2.1 Description of the Plans

The total area of the D.G. Khan Hill Torrent area is about 24,500 km2 and is divided into 13 major Hill Torrent basins as shown in Figure 2.4.2. In 1998, 15 diversion/dispersion systems were built. The diversion/dispersion system consists of weirs and channels leading water to irrigated areas and is constructed as appropriate to meet water rights. Flood irrigation, a traditional method of irrigation, is also used to distribute river water to farmland during low-water periods by placing soil bunds in small rivers at right angles to the current. Some of these structures have flood-diversion functions.



Source: M/F Study 1998

Figure 2.4.2 Watershed Classification in D.G. Khan Hill Torrent Area

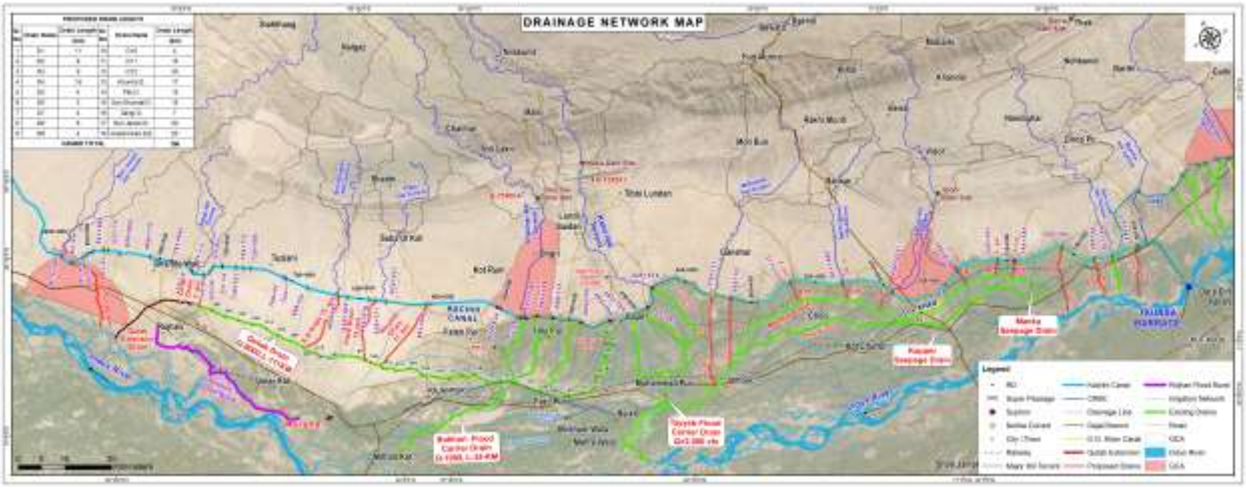
In 1998, the core project in the D.G. Khan Hill Torrent area was proposed as the most effective flood control and water utilization facility construction project in all the Hill Torrent areas and was supported by development donors. The projects were judged to have a high return on investment by development donors and to be bankable projects.

The projects are proposed in around 11 watersheds and detailed design has been carried out. Specifically, 25 weirs and dispersion/diversion facilities were to be installed at approximately 1.1 bil. PKR at that time (see Table 2.4.1). FFC and Panjab-PID did not clearly understand the progress of the core project; however, Panjab-PID mentioned that the progress was very slow due to the financial deficit.

Table 2.4.1 List of Priority Projects in 1998

No	Hill Torrent basin	Cost						
		Land acquisition	Civil Works		Total civil works cost including physical contingency	Detail design & construction supervision (5% of civil works)	Engineering and Admin. (3% of civil works)	Total
			Flood management structures	Flood carrier channels				
1	Kaura	2	40	-	44	2	1.2	49.2
2	Vehowa	4	67	-	73.7	3.35	2.01	83.06
3	Sanghar	3	68	-	74.8	3.4	2.04	83.24
4	Sori Lund	8	75	8	91.3	4.15	2.49	105.94
5	Vidore	7	180	30	231	10.5	6.3	254.8
6	Sakhi Sarwar	4	40	12	57.2	2.6	1.56	65.36
7	Chachar	6	68	20	96.8	4.4	2.64	109.84
8	Pitok	7	Nil	65	71.5	3.25	1.95	83.7
9	Sori Shumali	-	-	-	-	-	-	-
10	Zangi	5	52	30	90.2	4.1	2.46	101.76
11	Sori Janubi	4	60	20	88	4	2.4	98.4
Total		**50**	**650**	**185**	**918.5**	**41.75**	**25.05**	**1,035.3**
Provision for purchase of maintenance equipment								**20**
GRAND TOTAL								**1,055.3**

Source: M/F Study 1998

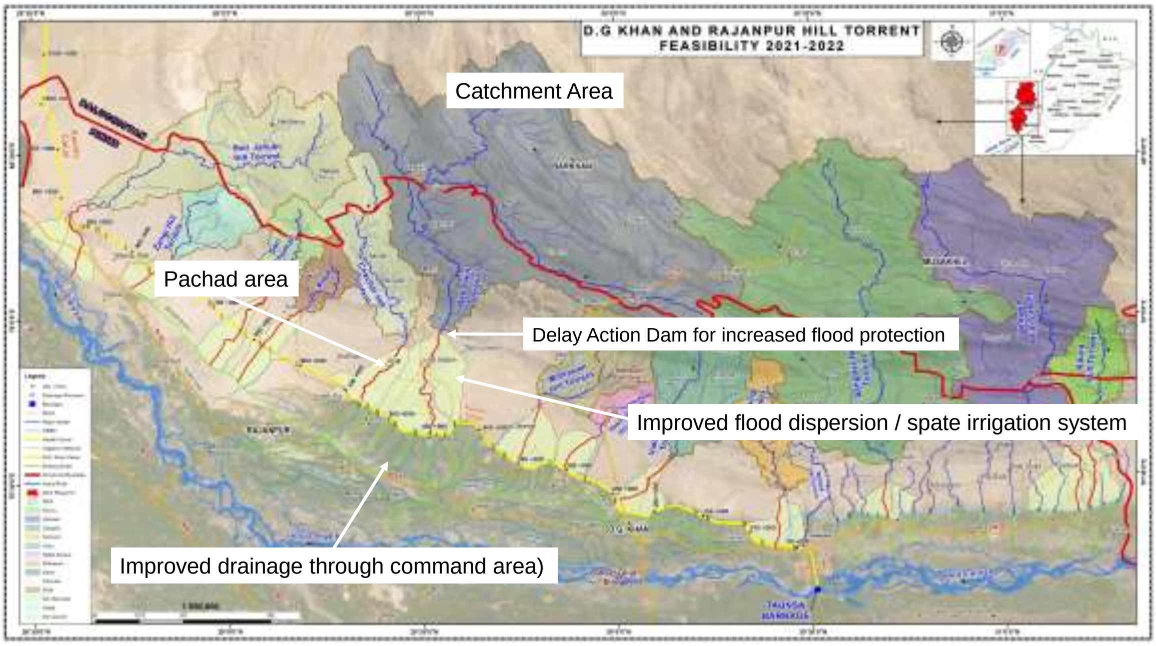


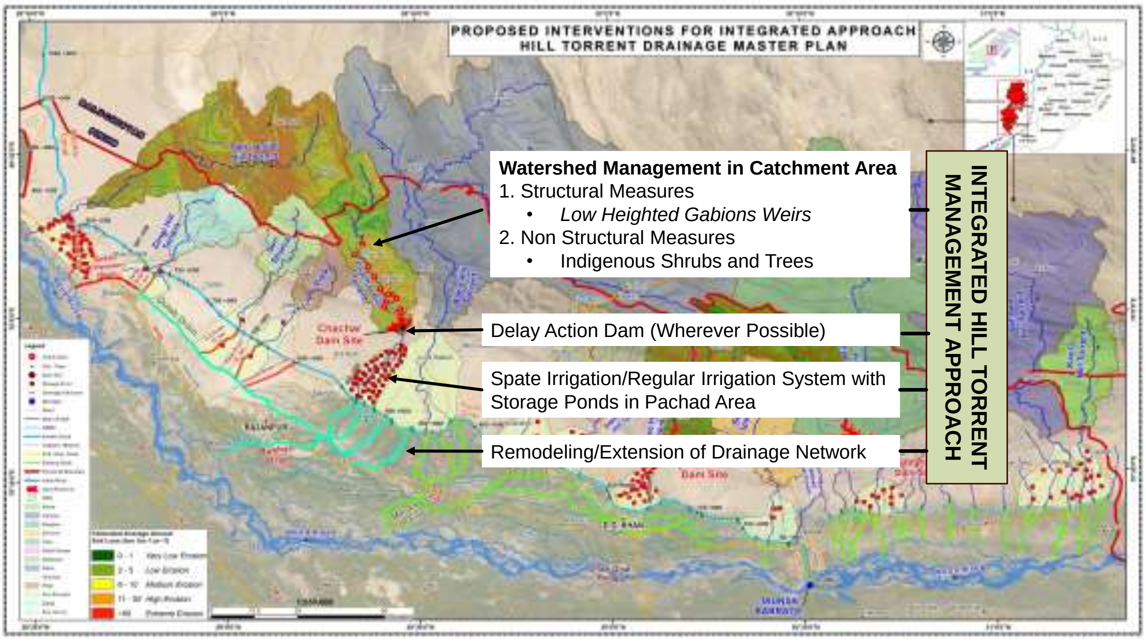
Source: Panjab-PID (2023)

Figure 2.4.3 Drainage network in the D.G. Khan Hill Torrent area (existing and planned)

2.4.2.2 Current Planning Status

Panjab-PID presented the following Hill Torrent management concept as of July 2023 as shown in Figure 2.4.4 (2 maps). There is no overall Hill Torrent management plan; however, it appears that projects are being planned and implemented with appropriate research for the target area, funded by development donors. Specifically, Panjab-PID is conducting a “Project Readiness Financing (PRF) study (until December 2024) funded by ADB for water resources management, and the D.G. Khan and Rajanpur District to identify potential projects. The study will carry out 7-8 F/S surveys and 4-5 detailed designs, and will also add a scope to comprehensively solve the drainage problems of the Koh-e-Sulaiman Mountains.





Source: Panjab-PID (2023)

Figure 2.4.4 Example of Integrated Management in the D.G. Khan Hill Torrent Region

2.5 Kachhi and Khirthar Hill Torrent Regions and RBOD District

2.5.1 Geomorphology and Flood Characteristics of the Target Area

The target area is generally divided into Hill Torrent mountainous area (Mula River Basin and GAJ districts comprising the Kachhi and Khirthar Hill Torrents of Figure 2.5.1) in the Balochistan province and low-level area in the Sindh province (Right Bank Outfall Drain area: RBOD area). Flooding in Balochistan-Hill Torrent mountainous area will flow into low-level areas in the Sindh province. To be exact, there is the Nari river basin in the lower GAJ area, and the two are called Gaj-Nari Hill Torrent.

On the Sindh province side, the Flood Protection (FP)-Bund has been constructed and maintained along the Hill-Torrent foothills from north to south, and the flood water from the western Hill Torrent mountains is stored around the foothills, and the FP-Bund is channeled into Lake Manchar. After that, the flood water is discharged from Lake Manchar into the Indus River through the sluice gates and spillway.

Source: Balochistan-PID (2023)

Figure 2.5.1 RBOD Area

Based on the information of the 2010 and 2022 floods in this area, it can be said that the natural causes of the flooding of the low-lying areas are (1) overflow from the Indus River due to the bund breach, (2) flood flowing from Hill Torrent mountains, and (3) direct heavy rainfall. The current (2023) drainage capacity of Lake Manchar is designed below the 50-year flood probability mentioned in the Irrigation Manual. In addition, the flood flows from Hill Torrent have frequently damaged FP-Bund and other public facility. Overflowing water from Lake Manchar and damage to FP-Bund cause great damage to residential and irrigation areas in Sindh. Therefore, flood control measures in the Hill Torrent area in Balochistan should be carried out in consideration of the water balance and drainage capacity of low-lying areas in Sindh especially during floods.

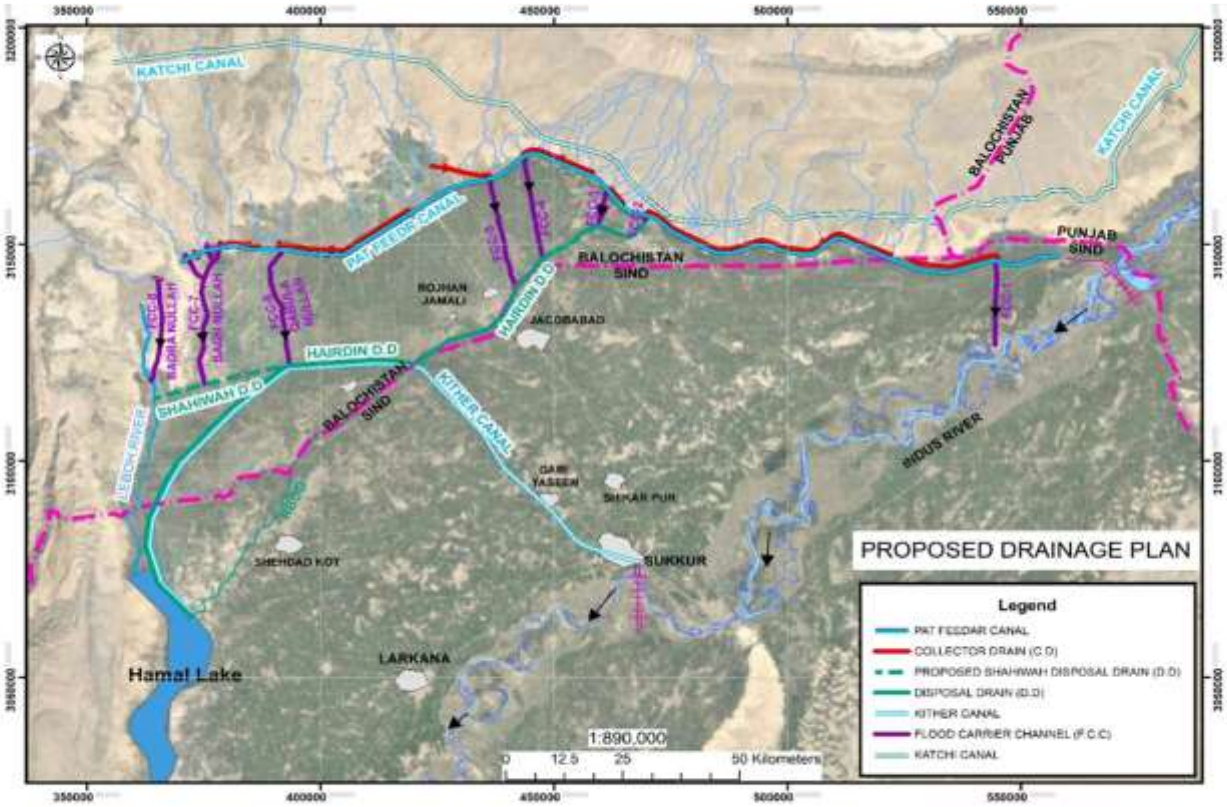
2.5.2 Plan Contents and Progress in 1998

The Hill Torrent flood control in/around the RBOD was not proposed in the 1998 M/F Study. The reason for this is that Balochistan has a relatively low priority for the area from an economic point of view. In the Sindh province, projects related to irrigation channels, FP-Bund, and drainage system of Lake Manchar have been carried out; however, they have not been fully examined in terms of future treatment of floods from the Balochistan province, impacts of climate change, and future land use.

2.5.3 Current Planning Status

The Balochistan province has proposed the concept of directing floodwaters from the Hill Torrent region into the Indus River and irrigation canals within the Sindh Province through multiple Flood Carrier Channels (FCC: see Table 2.5.1) directly into the Indus River and irrigation channels in the Sindh province. The Balochistan province has proposed the projects shown in Table 2.5.2 and Figure 2.5.2 which will affect the Sindh province including FFC.

Most of the flood flows into Lake Hamal and eventually Lake Manchar through irrigation channels and natural water courses. The abovementioned situations should be recognized as an inter-provincial issue; therefore, comprehensive planning by FFC steering is required. It is also necessary to consider the treatment of runoff from the northern Hill Torrent area flowing into or overflowing the Pat Feeder Canal.



Source: Balochistan-PID (2023)

Figure 2.5.2 Propositions by Balochistan in/around RBOD Area

Table 2.5.1 Proposed FCC in the Inter-Provincial Area

No.	FFC channel	Extension (km)	Flow capacity (m3/s)	Width (m)	Depth (m)
1	FCC-01	17.4	340	106.68	1.2
2	FCC-02	2.2	170	68.58	1.0
3	FCC-03	8.3	170	68.58	1.0
4	FCC-04	23.9	396	137.16	1.1
5	FCC-05	26.4	512	137.16	1.3
6	FCC-06	30.1	349	121.92	1.1
7	FCC-07	34.7	641	182.88	1.2
8	FCC-08	26.5	116	45.72	1.0

Source: Balochistan-PID (2023)

Table 2.5.2 Other Projects proposed by Balochistan

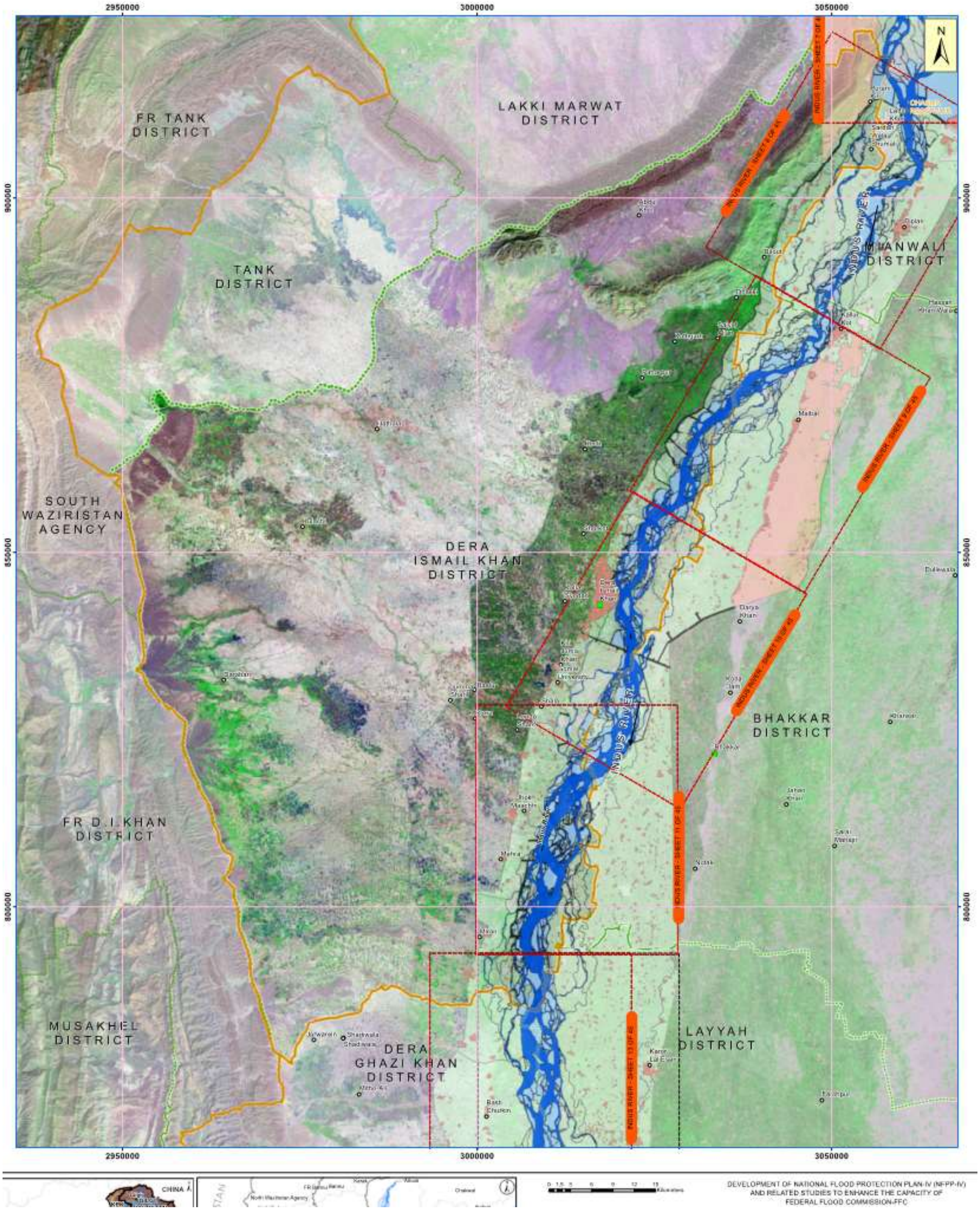
1.	Small dams in mountainous areas
2.	Transverse drainage structures of the Kacchi River and Pat Feeder Canal.
3.	Levee on the right bank (north) of the Kacchi River and Pat Feeder Canal.
4.	FCC construction from the right bank of Pat Feeder Canal.
5.	FCC Construction in Pat Feeder Canal’s Distribution Irrigation Area
6.	Conversion of Hairdin Underground Drainage to Flood Drainage
7.	Connecting Shahiwah Drainage to Lebohu River

Source: Balochistan-PID (2023)

2.6 D.I. Khan Hill Torrent Region

2.6.1 D.I. Landforms and Flood Characteristics of Khan Hill Torrent Region

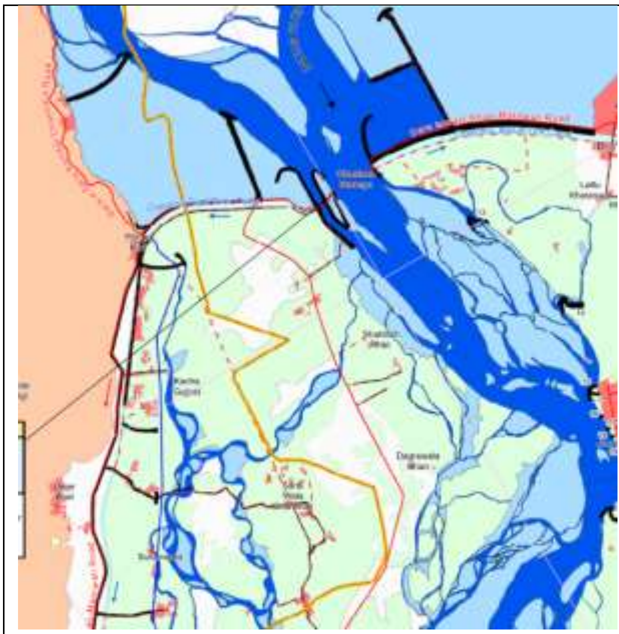
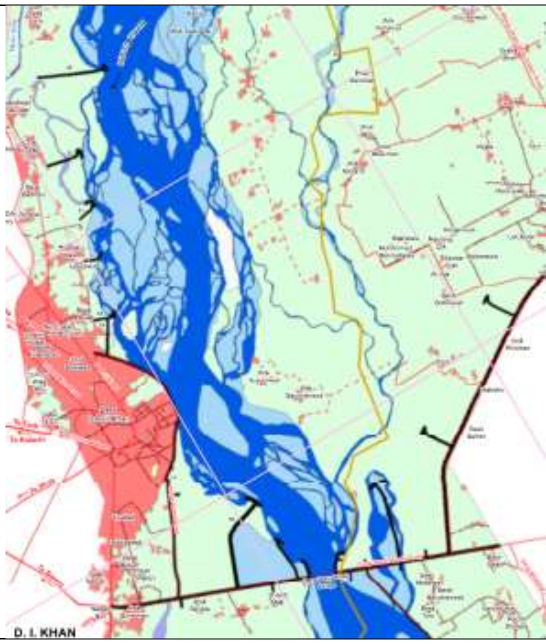
Since the D.I. Khan Hill Torrent area has roughly the same topographic characteristics as the D.G. Khan Hill Torrent area, it is assumed that the flood characteristics are also similar. Many municipalities, including D.I Khan (red hatch near the center of Figure 2.6.1), a major city in the area, are located in the Indus River floodplain (light green area along the Indus River in Figure 2.6.1).



Source: NFPP-IV

Figure 2.6.1 D.I. Khan Landforms

A national road (Dera Ismael Khan-Mainwari Road) runs north to south on the boundary between the riverine area and the low-lying areas, and it seems that spur dikes extending from the national road towards the Indus River protect other cities and towns. On the other hand, the central city of D.I. Khan is only protected by a ring dike surrounding the city. An irrigated land (dark green area in the figure) extends west from the national road, and the Chashma Right Bank Canal (CRBC: irrigation canal) extending about 270 km is set up at the western end of the irrigated land (drawn from Chashma Barrage).

	
Spur dike works extending from the national road (the left black line) protect towns and villages in the riverine area.	Major city D.I. Khan (the red hatch portion) is protected from the Indus River by the bands.

Source: NFPP-IV

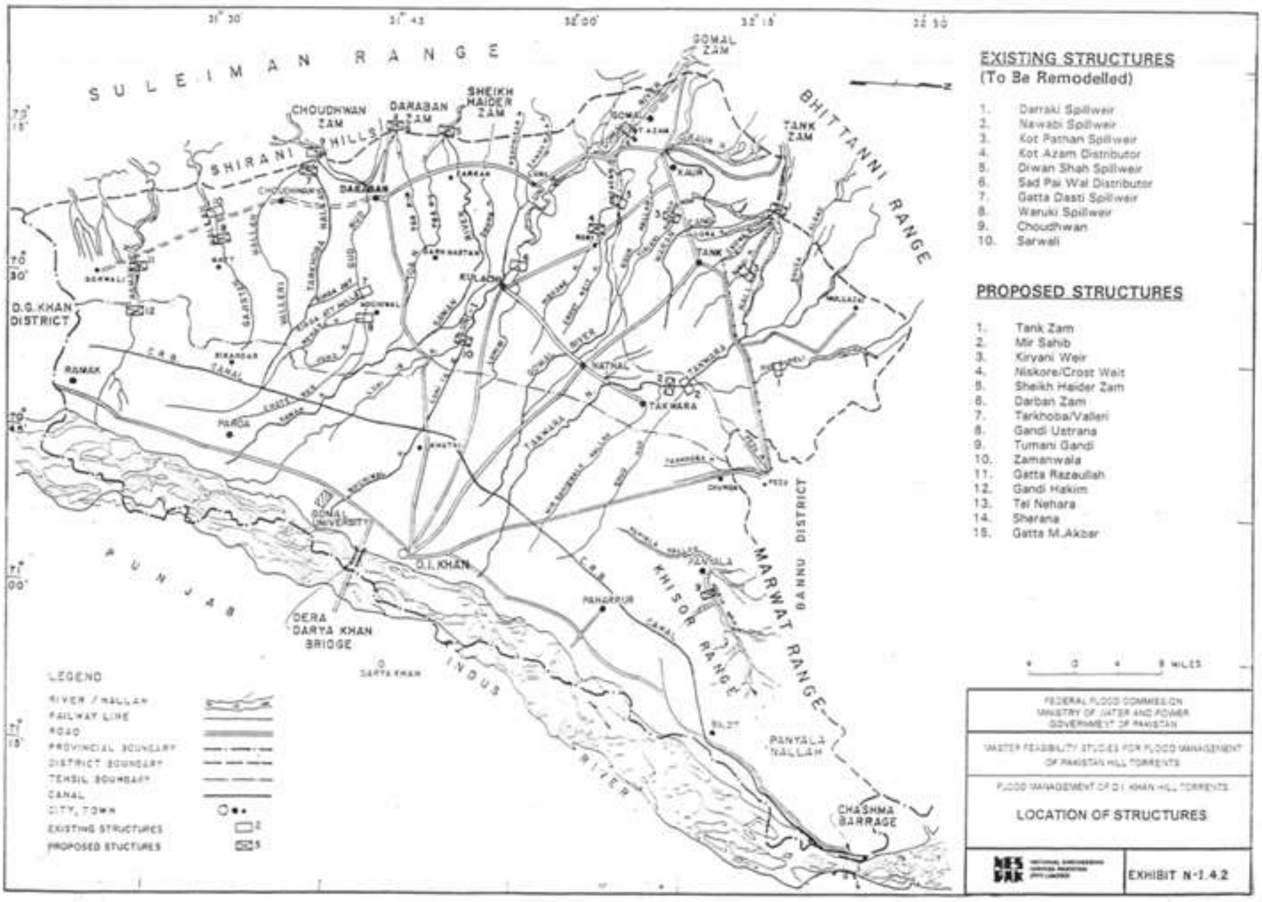
Figure 2.6.2 City and Towns of D.I. Khan Area Protected by Spurs and Bunds

2.6.2 Proposed Plans in the M/F Study 1998 in D.I Khan Areas and the Current Situation

2.6.2.1 Plans in 1998 and Progress of Projects

At the time of 1998, two (2) core projects were proposed; but, details of their contents were not described in the M/F Study 1998. According to the documents compiled after the constructions and websites, the core projects were the construction of the Chashma Right Bank Canal (CRBC: a gravitational irrigation canal that draws water from the Chashma barrage on the Indus River) of about 274 km across 72 districts and the construction of the Gomal zam dam (multipurpose gravity concrete dam for flood control, power generation and irrigation in the Gomal River basin) with a total storage capacity of 1.4 BCM. The former was already completed with a 450mil.USD loan from ADB (the loan expired in December 2003), and the latter was constructed in 2011 by the KPK Province with about 12 bil. PKR is funded by Public Sector Development Program(PSDP) and United States Agency for International Development (USAID) funds.

Other projects included the rehabilitation of 10 weirs shown in Figure 2.6.3 and the construction of 15 Distributors. The total project cost was 354 mil. PKR; however, there was no clear information from the KPK province regarding the status and progress. FPSP-III does not list the Hill Torrent project in the KPK province. This means that they are not recognized as urgent national projects. On the other hand, about 10 projects are proposed for NFPP-IV, including the construction of a spur dike and bunds on the main Indus River around D.I. Khan.



Source: M/F Study 1998

Figure 2.6.3 Proposed **Sub-Project in D.I. Khan Area in 1998**

2.6.2.2 Planning Situation at Present

In the KPK province, although non-structural measures have been implemented by WAPDA, PMD, PID, etc. along with NFPP-IV and their plans for early warning system (EWS) and river management, total investment cost for flood control facilities in the Hill Torrent area since 1998 is estimated to be relatively small compared to other provinces based on the budget investment so far (see Table 2.6.1). In NFPP-IV, In the D.I. Khan Hill Torrent region, the project for the construction of flood protection works (FPW) for 4 rivers and their branches, including the Gomal basin, is proposed at a total project cost of 4.6 bil. PKR; however, is not covered in the updated FPSP-III as of June 2023.

Table 2.6.1 General budget allocations

No.	State/Region	Distribution Ratio
1.	Punjab	45%
2.	Sindh	31%
3.	Khyber Pakhtunkhwa	11%
4.	Balochistan	08%
5.	Gilgit-Baltistan	01%
6.	Merged Area (Ex-FATA(Federally Administrated Tribal Areas))	03%
7.	Azad Jammu & Kashmir	01%

Source: FFC (November 2021)

After the 2022 floods, rehabilitation of river structures damaged by floods has been underway with the support of development donors such as ADB, JICA, etc. However, since 1998, in the D.I. Khan Hill Torrent area of the KPK province, a specifically articulated proposal is one in the NFPP-IV as mentioned above (details not described in NFPP-IV). On the other hand, as a result of the remote and face-to-face hearings, the KPK province is reviewing the construction plan of the following 12 dams for flood control, water utilization, and power generation. Of these dams, three (3) dams are supposed to be constructed in the D.I. Khan area.

Table 2.6.2 Dam Proposals by KPK-PID

Name	Sh. Haider Zam	Tank Zam	Chowdwan Zam	Surkhawai	Sher Dara	KORA nullah	Sumari Payan	Barwasa	Shaheed Banda	Nakai	Torawari	PANJTAR
Location District	**D.I Khan**	Tank	**D.I.Khan**	Mardan	SWABI	**D.I. Khan**	Kohat	Haripur	Charsada	Noshera	Hangu	Bunir
Type	Earth core Rock fill	Zoned Embankment	Rockfill	Earth core Rock fill	RCC	Roller compact concrete	Earth core Rockfill	Earth core Rockfill	Roller compact concrete	Earth core Rockfill	Earth core Rock fill	Earth core Rock fill
Gross storage Acr ft.	89,910	345,000	51,835	2,214	3,107	15,733	6,218	1,111	1,168	835	7,369	8,574
Live storage Acr Ft	62,856	295,000	41,361	1,800	2,754	9,885	5,507	821	1,045	733	6,323	7,234
Dead Storage Acr ft.	27,832	50	10,474	414	353	5,848	710	290	123	102	1,046	1,340
Dam Height Ft.	190	292	2,000	133	219	120	71	105	151	110	160	115
Dam Crest Length ft.	1,536	1,600	1,936	1,073	781	583	2,066	716	680	643	1,464	510
Dam Crest Level asl	1,257	2,297	1,319	1,620		1,000	1,825	1,505	105	2,085	3,880	1,444
Command area Acres	19,398	70,000	17,300	1,622	1,600	6,500	2,200	1,110	1,000	650	7,000	1,600
Reservoir Catchment area Sq.mile		840	394	11	7	192	36	5	4	5	37	51
Cost (mil. PKR)	53	10,282	14,000	2,142	2,611	640	1,968	1,253	1,065	1,315	4,406	3,802

Source: KPK-PID (2023)

2.7 Trends in Flood Control in Hill Torrent Area by FFC

2.7.1 Development of Hill Torrent Master Plan (M/P)

Through the M/F Survey 1998 (FFC) review, the status and progress of flood control projects in the target areas have been investigated in this advisory work, but it is found that the states have not followed up much by related organizations. As is the case with NFPP-IV, since the purpose of the survey was just to secure funds, it seems that after the end of the M/F Survey 1998, the provinces have acted on their project information of each province and have not provided feedback to the M/F Survey 1998.

To resolve this situation, FFC held FMC meetings on "Formulation of Master Plan of National Drainage" in July and August 2023 to discuss the preparation of flood control M/Ps for the Hill-Torrent region nationwide. Currently, through local consultants, FFC is preparing Terms of Reference (TOR) for the formulation of M/Ps for each Hill-Torrent region. The advisor participated in both meetings as the FFC-JICA advisor, and development donors such as WB, ADB, JICA Pakistan office were also invited to participate in the second meeting. In the FFC meeting room, the FFC chairman informally requested the JICA Pakistan office to participate in the M/P.

2.7.2 M/P development in each Hill Torrent region

Flood protection and control in the Hill Torrent region is listed as a priority project under the National Disaster Management Plan (NDMP 2012). Under the NFPP-IV (2018) established based on NDMP, national projects included such as (a) Flood Protection Work (FPW) in the Kabul River basin in the north and Hill Torrent management projects; (b) FPW in the Chitral and Swat basins and Hill Torrent management projects, where severe flood damage occurred in 2022; and (c) Flood control projects such as FPW (including FCC) in several Hill Torrent basins in D.I. Khan region.

After the 2022 flood, projects based on 4RF and those based on FPSP-III have been proposed and implemented. However, the following administrative and technical issues were clarified in this survey.

① For the formation, implementation, and management of Hill Torrent projects properly by FFC and PIDs, it is necessary to develop a rational system and improve the efficiency of selecting priority projects. Examples include projects listed in FPSP-III that are being implemented by other World Bank projects, and the inability to adequately show the progress and status of past projects. On each occasion, ADB conducts a Project Readiness Financing (PRF) survey to form and implement new projects and perform partial optimization.

② In the Hill Torrent region, which has inter-provincial challenges, the challenges need to be addressed, especially considering both the mountainous areas where flooding occurs and the low-lying areas where flooding intrudes. An example is the resolution of integrated challenges in the Balochistan province on the flood side and the Sindh and Panjab provinces on the receiving side in the IRB Hill Torrent regions. In addition, there is no basic plan for comprehensive management of the Hill Torrent region or its constituent watersheds.

To solve these problems, the FFC proposed FPSP-III (a) to improve the capabilities and functions of the FFC organization and prepared TORs for the formation of each Hill-Torrent M/P (2). The FFC requested the JICA Pakistan Office to conduct both projects.

CHAPTER 3 BUND IMPROVEMENT PROJECT

3.1 Features of the Indus River from Sukkur to Manchar

3.1.1 Satellite Image Analysis

3.1.1.1 Identification of Vulnerable Points by Satellite Image Analysis

In this section, the transition of the river channel by satellite image was confirmed, and possible vulnerable points were extracted from the result. For the Sukkur to Lake Manchar section of the Indus River, since satellite images (taken in December every year) every 1 year from 1984 to 2020 can be obtained by Google Earth, the points where the mainstream line of the river and bunds are approaching in the present or past were extracted as vulnerable points from the satellite images in this period. The list of the extracted vulnerable points is shown in Table 3.1.1, the location map of the vulnerable points is shown in Figure 3.1.1, the satellite image is shown in Figure 3.1.2 from the upstream side, and the surrounding map and elevation map is shown in Figure 3.1.3 from the upstream side.

The target points are chosen from the right bank areas (No. 1 to 6), which are densely populated areas and have cities including Sukkur and Larkana.

No. 1 to 3 are located upstream area of Larkana, and there are cities like Ratodero and Qamber near the vulnerable points. The ground level of some parts of these cities is lower than the ground level near the vulnerable points, so if the bund is broken, there are risks of flooding damage. The mainstream line of the river and the bund are always close to each other for No. 1 and 3, and they used to close to each other for No. 2. There are spur dikes for No.1 and double bunds for No. 2 and 3, however it should be noted that the second bund is not as strengthened as the first bund.

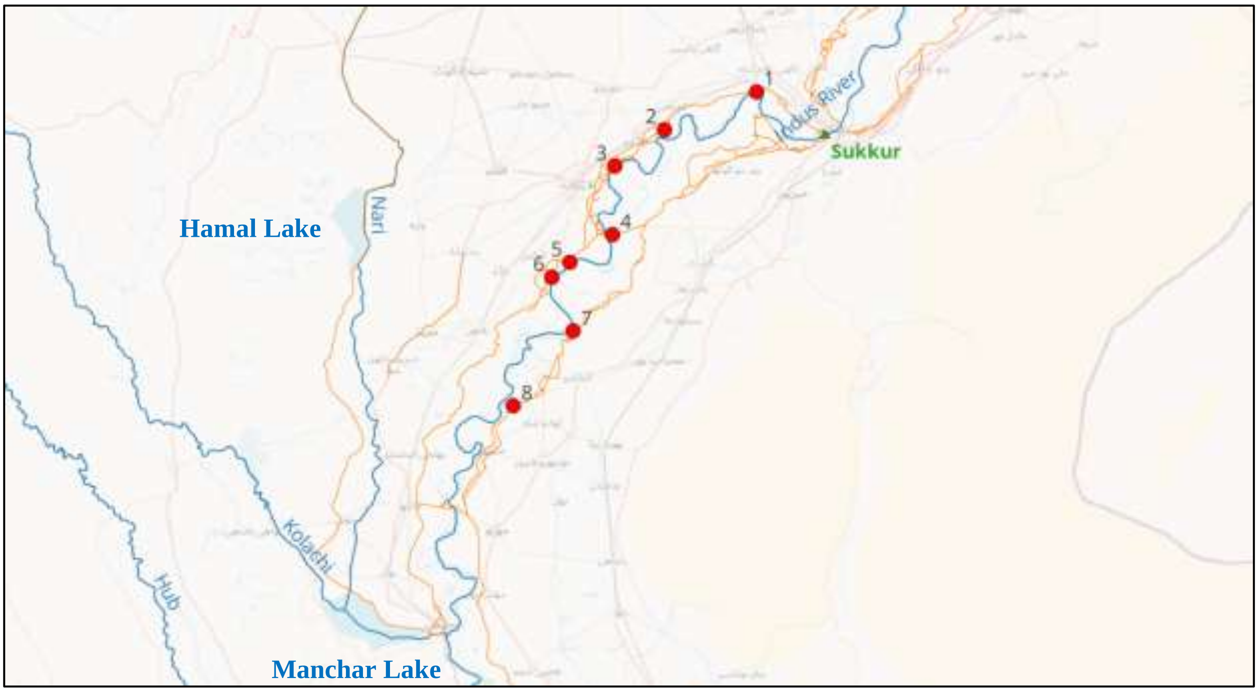
No. 4 is located on the Larkana Khairpur Bridge, if the bund is broken, there are risks of affecting the transport of right bank areas and left bank areas of Indus River. Construction of the bund changed the mainstream line, and it should be monitored because the original mainstream was different from current one.

No. 5 and 6 are located downstream area of Larkana, and there are cities like Dokri, Badar and Mehar near the vulnerable points. The ground level of some parts of these cities is lower than the ground level near the vulnerable points, so if the bund is broken, there are risks of flooding damage. The mainstream line of the river and the bund are always close to each other for both No. 5 and No. 6. There are double bunds for No.5 and 6, however it should be noted that the second bund is not as strengthened as the first bund.

Table 3.1.1 List of Extracted Vulnerable Points

No	Mainstream and Bund	Bund Status	Nearby Cities	Latitude	Longitude
1	Always approacing to bund	Existing spur dike	Larkana, Ratodero, Qamber	27.790	68.669
2	Approaching in 1984-2013	Double bunds	Larkana, Ratodero, Qamber	27.693	68.433
3	Always approacing to bund	Double bunds	Larkana, Ratodero, Qamber	27.600	68.305
4	Mainstream has changed after building bund	—	—	27.423	68.299
5	Always approacing to bund	Double bunds	Dokri, Badar, Mehar	27.353	68.190
6	Always approacing to bund	Double bunds	Dokri, Badar, Mehar	27.314	68.144
7	Approaching from 1995	Double bunds	Kandiaro, Tharu Shah	27.175	68.198
8	Approaching in 1992-1999	Single bund	Kandiaro, Tharu Shah	26.983	68.045

Source: Advisory Team



Source: Advisory Team

Figure 3.1.1 Location Map of Extracted Vulnerable Points

○ : Vulnerable Points

Source: Created by the Advisory Team from Google Earth

Figure 3.1.2 (1) Satellite Image of Sukkur to Lake Manchar Section of the Indus River

○ : Vulnerable Points
○ : The mainstream line of the river and the bund are not close to each other at that time.

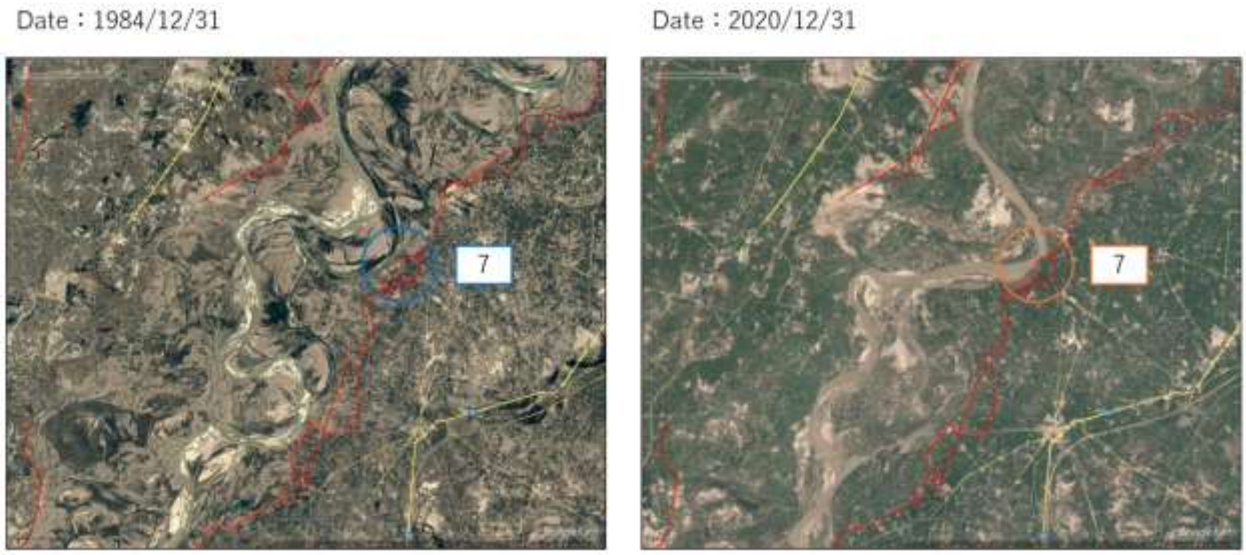
Source: Created by the Advisory Team from Google Earth

Figure 3.1.2 (2) Satellite Image of Sukkur to Lake Manchar Section of the Indus River

○ : Vulnerable Points

Source: Created by the Advisory Team from Google Earth

Figure 3.1.2 (3) Satellite Image of Sukkur to Lake Manchar Section of the Indus River



○ : Vulnerable Points
○ : The mainstream line of the river and the bund are not close to each other at that time.

Source: Created by the Advisory Team from Google Earth

Figure 3.1.2 (4) Satellite Image of Sukkur to Lake Manchar Section of the Indus River

○ : Vulnerable Points
○ : The mainstream line of the river and the bund are not close to each other at that time.

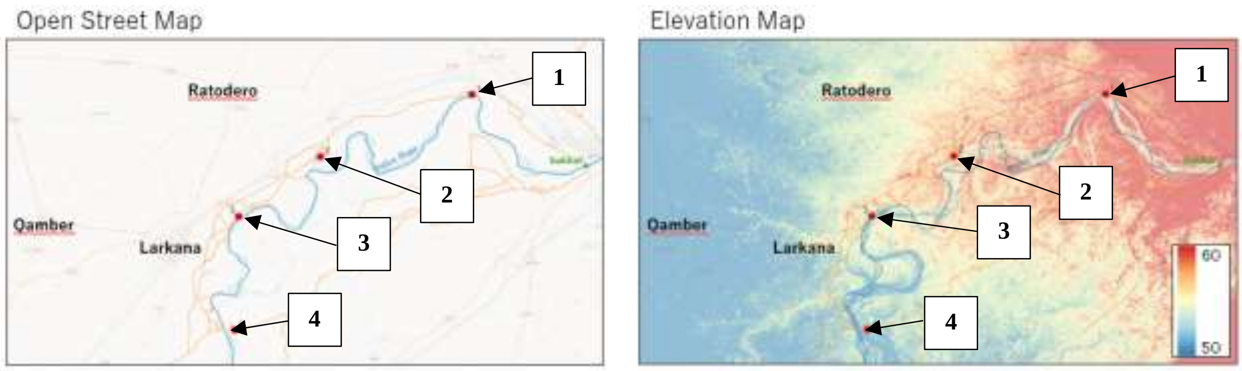
Source: Created by Advisory Team from Google Earth

Figure 3.1.2 (5) Satellite Image of Sukkur to Lake Manchar Section of the Indus River

※There are no vulnerable points in this section

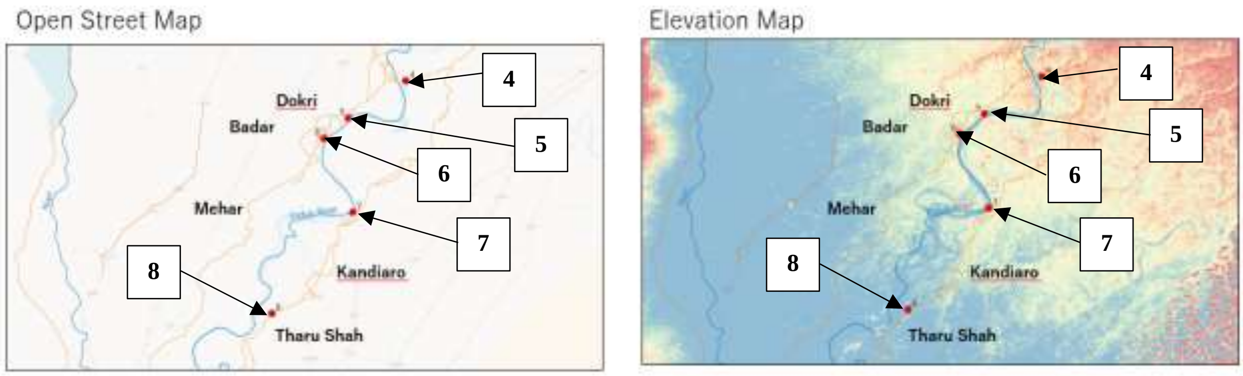
Source: Created by Advisory Team from Google Earth

Figure 3.1.2 (6) Satellite Image of Sukkur to Lake Manchar Section of the Indus River



Source: Created by the Advisory Team from Open Street Map and Mapzen Global Terrain

Figure 3.1.3 (1) Surrounding Map and Elevation Map of Vulnerable Points



Source: Created by the Advisory Team from Open Street Map and Mapzen Global Terrain

Figure 3.1.3 (2) Surrounding Map and Elevation Map of Vulnerable Points

3.1.1.2 Transition of River Channel near Old Abad Bund

Table 3.1.3 shows the list of vulnerable points identified by Sindh-PID, and Figure 3.1.4 shows the location map of vulnerable points.

Among them, Old Abad Bund has changed its vulnerable points due to the major change in the river channel between 2003 and 2023. Figure 3.1.5 shows a satellite image of the area near Old Abad Bund from 2003 to 2023, and Figure 3.1.6 shows a more extensive satellite image.

By Figure 3.1.5, the Old Abad Bund and the New Abad Bund conditions can be summarized as shown in Table 3.1.2, indicating that the vulnerability of the Old Abad Bund has increased in recent years. This may be due to the establishment of the J-head Spur between 2003 and 2013. In addition, a more extensive satellite image (Figure 3.1.6) shows that the upstream mainline has changed significantly over the 10 years from 2003 to 2013 and from 2013 to 2023, and these changes may also have affected the erosion of the bund near the Old Abad Bund.

Table 3.1.2 Changes in the Status of the Old Abad Bund and the New Abad Bund

Year	Old Abad Bund	New Abad Bund
2003	No erosion has occurred	Erosion is progressing
2013	Erosion is progressing	Erosion situation has improved
2023	Erosion has further progressed	Erosion situation has further improved

Source: Advisory Team

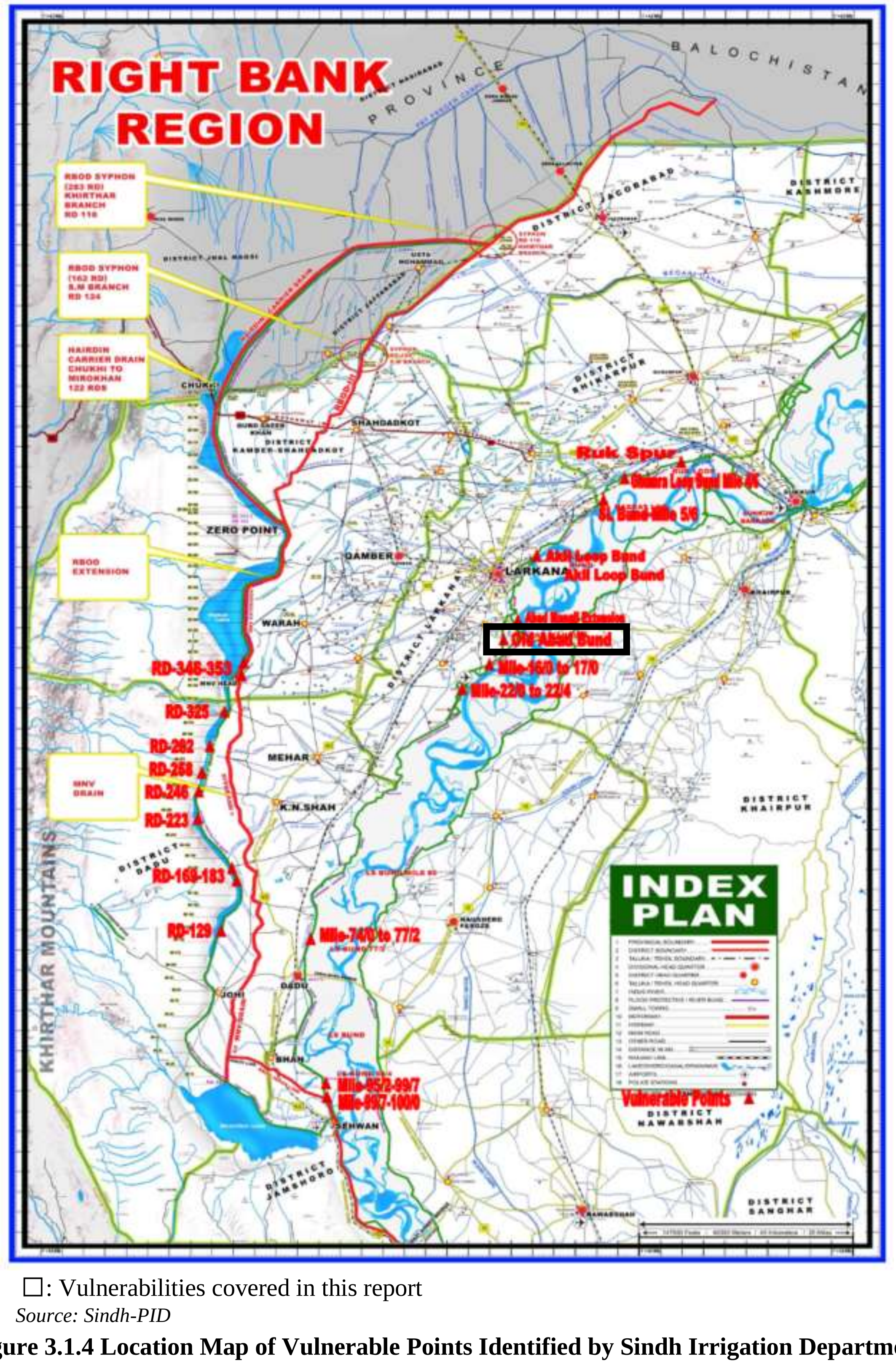
Table 3.1.3 List of Vulnerable Points Identified by Sindh Irrigation Department

No. in NFPP-IV	No in SID Contingency Plan 2023	Name	Detailed Location on MAPs (Co-ordinates/ Landmark, etc.)	Verification	Remarks
214	53	S.L Bund Mile 5/6 Near Bachal Shah Miani (V.P)	27°43′39.87″N 68°45′45.36″E	There is no any past History of this reach, but during flood 2022 the leak and seepage has been observed.	This reach is needed proper treatment and raising and widening of Bund.
251	54	Ghumra Loop Bund Mile 4/6 (V.P)	27°47′38.74″N 68°40′48.48″E	During 1960-61 as there was active erosion opposite Ghumra Loop Bund, and the reach of Ghumra Loop Bund Mile 4/6 to 6/3 became de-commissioned as such Ruk Loop Bund is acting as 1st Line of defense since then	During flood 2022, River Indus was striding towards this reach very rapidly. So the scheme has been initiated for construction stone apron along this reach.
216	55	Ruk Spur, mile 0/5, 1/1, 1/6 & 2/3 (V.P)	27°47′39.05″N 68°40′42.44″E	During flood 1976 heavy erosion was observed along Ruk Loop Bund, these four spurs was constructed in 1978-79.	During flood 2022 the river became very active against ruk loop bund mile 0/0. The new scheme for construction new T-Head Spur has been initiated at this reach.
106	56	Moria Loop Bund Mile 0/0 To 1/0 (M.V.P)	27°37′7.12″N 68°20′55.52″E	During flood 2017 heavy scouring and erosion was observed and controlled by flood fighting works.	The scheme was approved for construction of river training works viz: spurs, stone apron, which was completed. During flood and rain 2022, this reach is again affected, which need proper treatment.
223	57	Akil Loop Bund Mile 0/0 To 0/7 (V.P)	27°34′39.06″N 68°17′23.41″E	These bunds are historically coming under the direct hit of River Indus at right angle, since30 years these bunds faces erosion and heavy scouring. Many river training works carried out along this bund, in which spurs, stone apron, stone pitching and widening of the bund.	During flood 2015 some river raining works was disturbed, for which scheme is intimated which is in progress.
232	58	Abad Mangli Extension Mile 0/0 To 1/5 (V.P)	27°26′37.99″N 68°15′28.85″E	This reach is located immediately at up stream of Khairpur Larkana bridge and huge river training works was carried out as allied structures of above bridge.	This bund was un-safe / vulnerable up to 2019. At present this bund is quite safe.

No. in NFPP-IV	No in SID Contingency Plan 2023	Name	Detailed Location on MAPs (Co-ordinates/ Landmark, etc.)	Verification	Remarks
	59	Old Abad Bund (V.P)	27°27′15.75″N 68°15′41.33″E	The river have remained very active along Old Abad / New Abad bund since last half century, but specially after construction of Khairpur Larkana bridge. This reach was over toped in flood 2010 and 2022, the river water was cordoned by Abad Manguli Bund.	The old / new bund is needed immediate repair and rehabilitation work.
233	60	L.S Bund 16/0 To 17/0 (Hakra Point) (M.V.P)	27°21′49.93″N 68°11′43.53″E	In flood 2015 the river came near at 200 ft so in 2017 the scheme was initiated for construction of T-Head spur and Stone apron along this reach.	The earthen shank of newly constructed T-Head Spur at Mile 16/1 is need to be raising and providing stone pitching.
233	61	L.S Bund Mil 22/0 To 22/4 Opposite Moen Jo Daro (V.P)	27°18′46.07″N 68°8′36.84″E	The reach remained in direct hit of River since last three decade. In eighties river training works viz: spurs, stone pitching and stone apron were constructed.	During flood 2017, this reach and T-Head Spur at L.S Bund 22/0 was in direct hit, which caused heavy damages. Which need to be recouped.
-	-	S.L Bund Mile 0/2 To L.S Bund Mile 36/5	-	During heave rains in 2022 whole reach has been affected badly. The side slopes were slipped down.	These 86 miles of river bund need raising, strengthening and Stone pitching along earthen river side slopes.

□: Vulnerabilities covered in this report

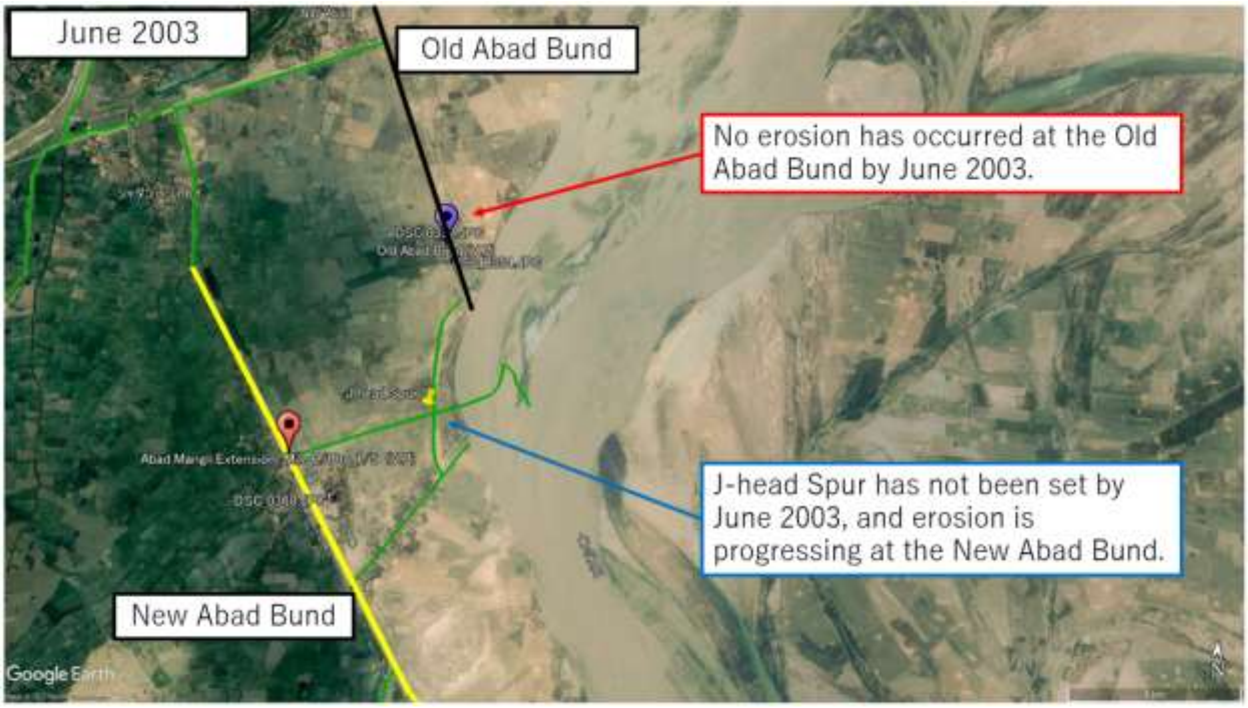
Source: Sindh-PID



☐: Vulnerabilities covered in this report

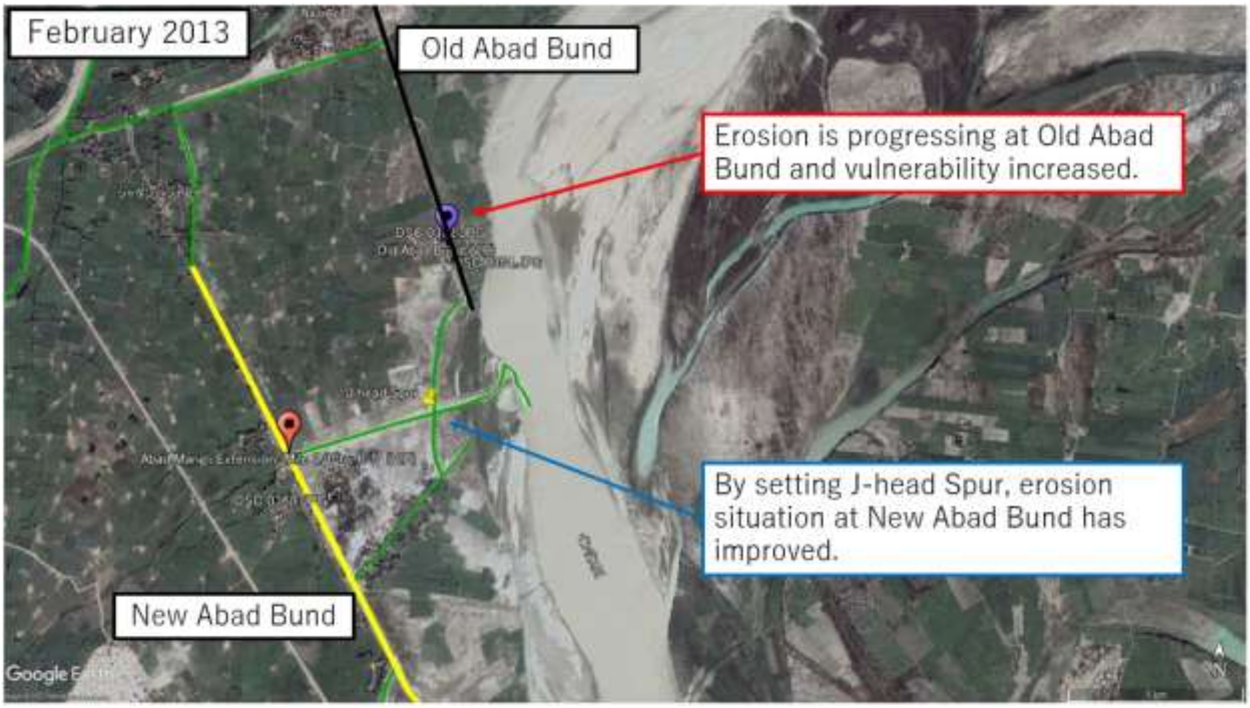
Source: Sindh-PID

Figure 3.1.4 Location Map of Vulnerable Points Identified by Sindh Irrigation Department



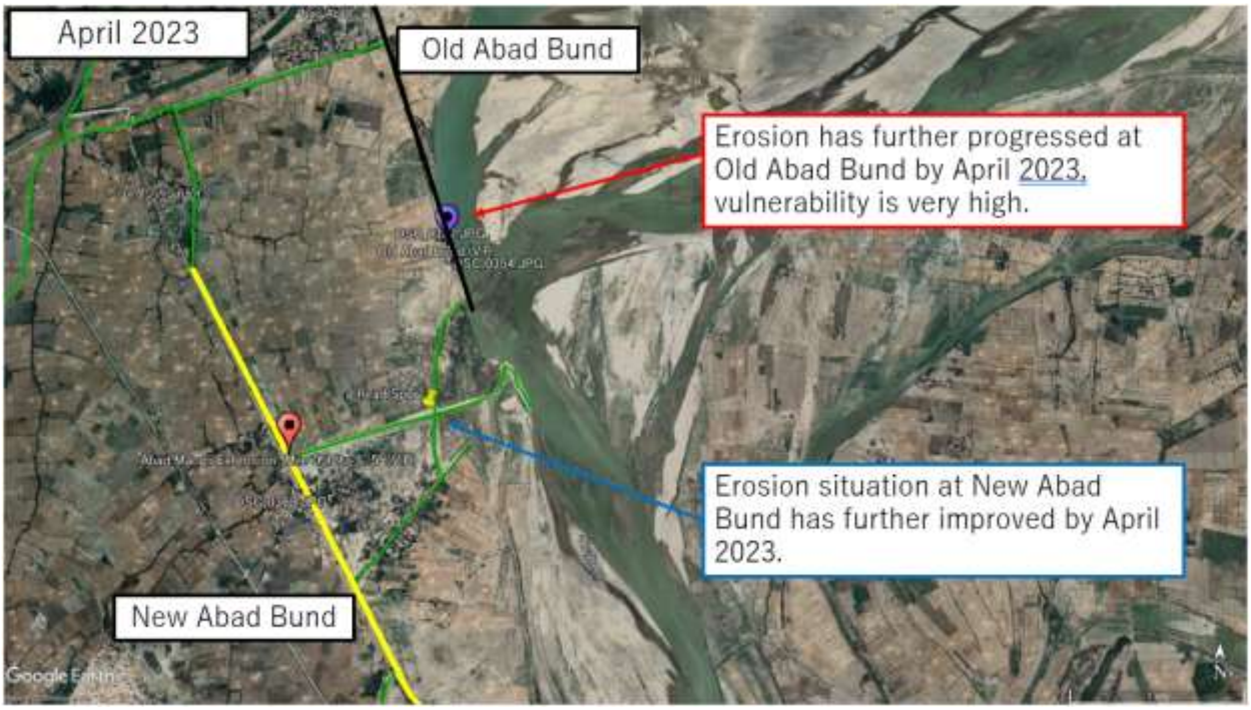
Source: Created by Advisory Team from Google Earth

Figure 3.1.5 (1) Satellite Image of the Area near the Old Abad Bund as of June 2003



Source: Created by Advisory Team from Google Earth

Figure 3.1.5 (2) Satellite Image of the Area near the Old Abad Bund as of February 2013

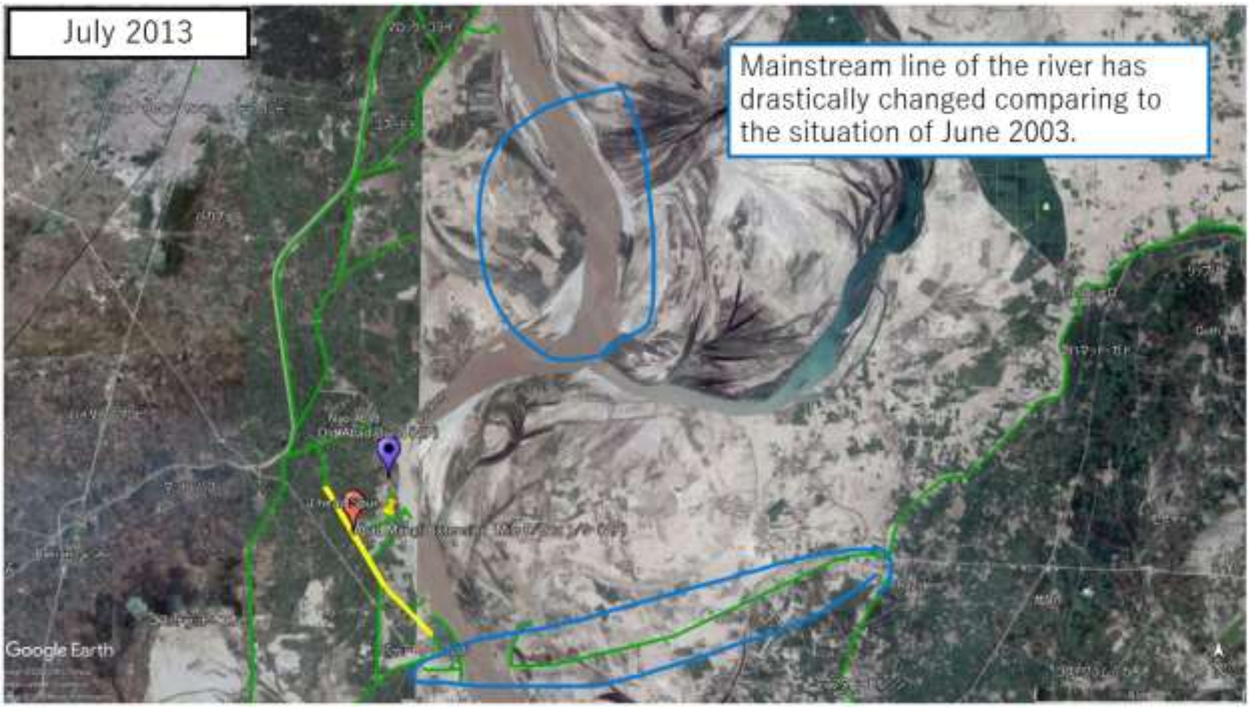


Source: Created by Advisory Team from Google Earth

Figure 3.1.5 (3) Satellite Image of the Area near the Old Abad Bund as of April 2023

Source: Created by Advisory Team from Google Earth

Figure 3.1.6 (1) Extensive Satellite Image of the Area near the Old Abad Bund as of June 2003



Source: Created by Advisory Team from Google Earth

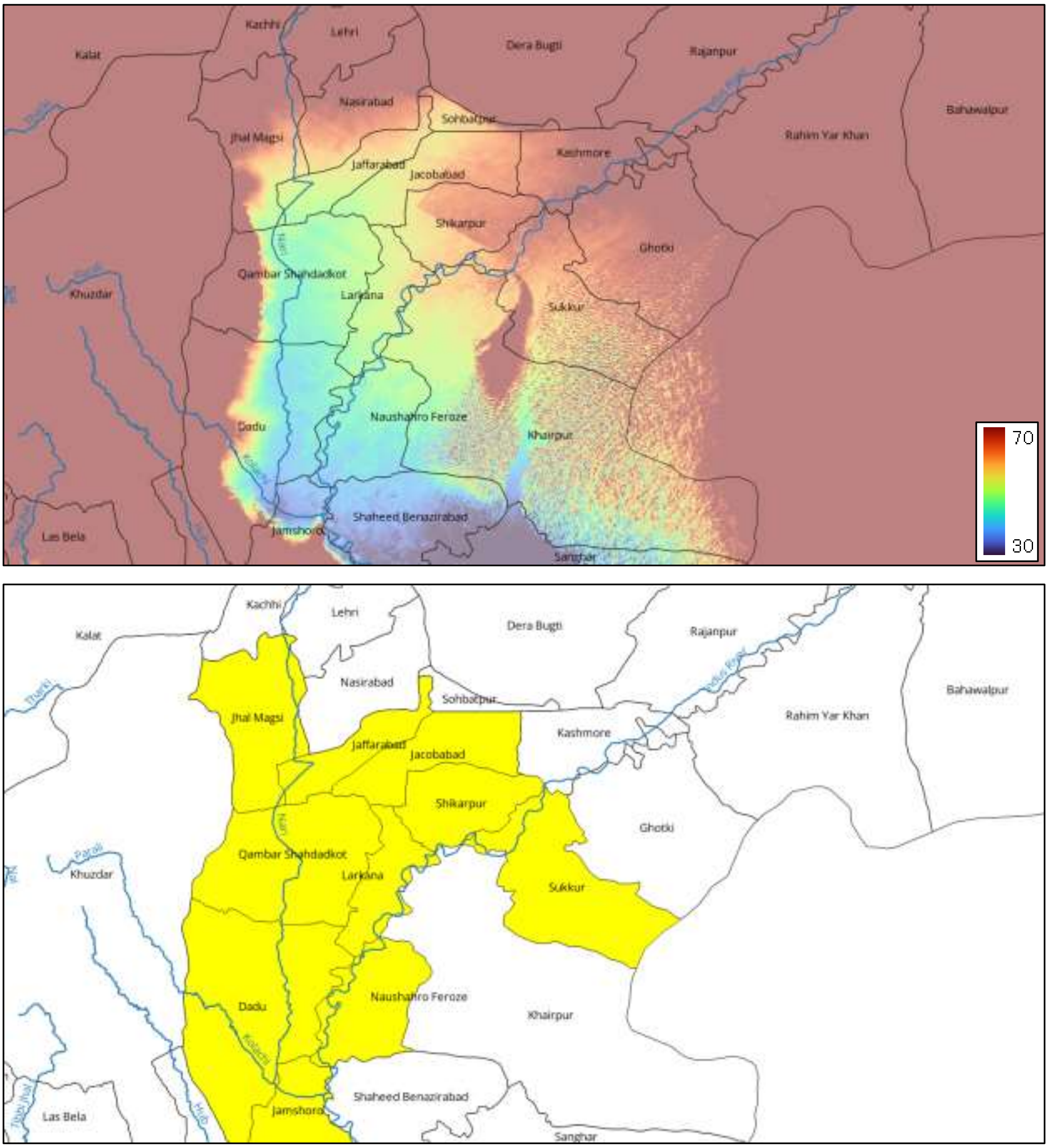
Figure 3.1.6 (2) Extensive Satellite Image of the Area near the Old Abad Bund as of July 2013

Source: Created by Advisory Team from Google Earth

Figure 3.1.6 (3) Extensive Satellite Image of the Area near the Old Abad Bund as of April 2023

3.1.2 Development Status of the Study Area

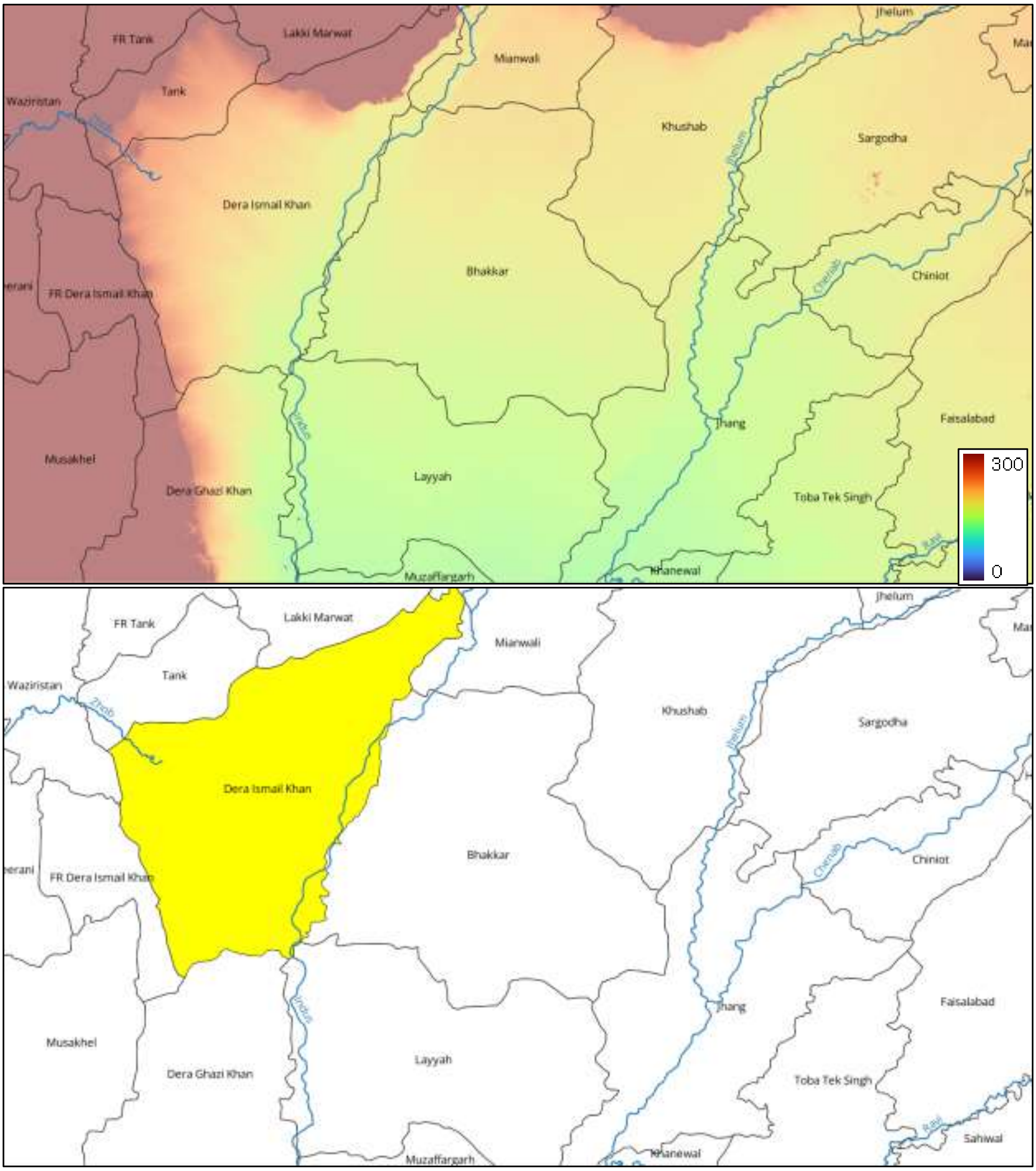
This section summarizes the development status of the lowland in Sindh (Sukkur to Lake Manchar section of the Indus River), including area, population, and property status (houses and crops). The target area is only for districts and tehsils that may be damaged by the flood from bund breach near Sukkur (shown in Figure 3.1.7). As a reference, the same figures for D. I. Khan and D. G. Khan are also summarized.



■ : Districts can be damaged by flood from bund breach near Sukkur

Source: Advisory Team

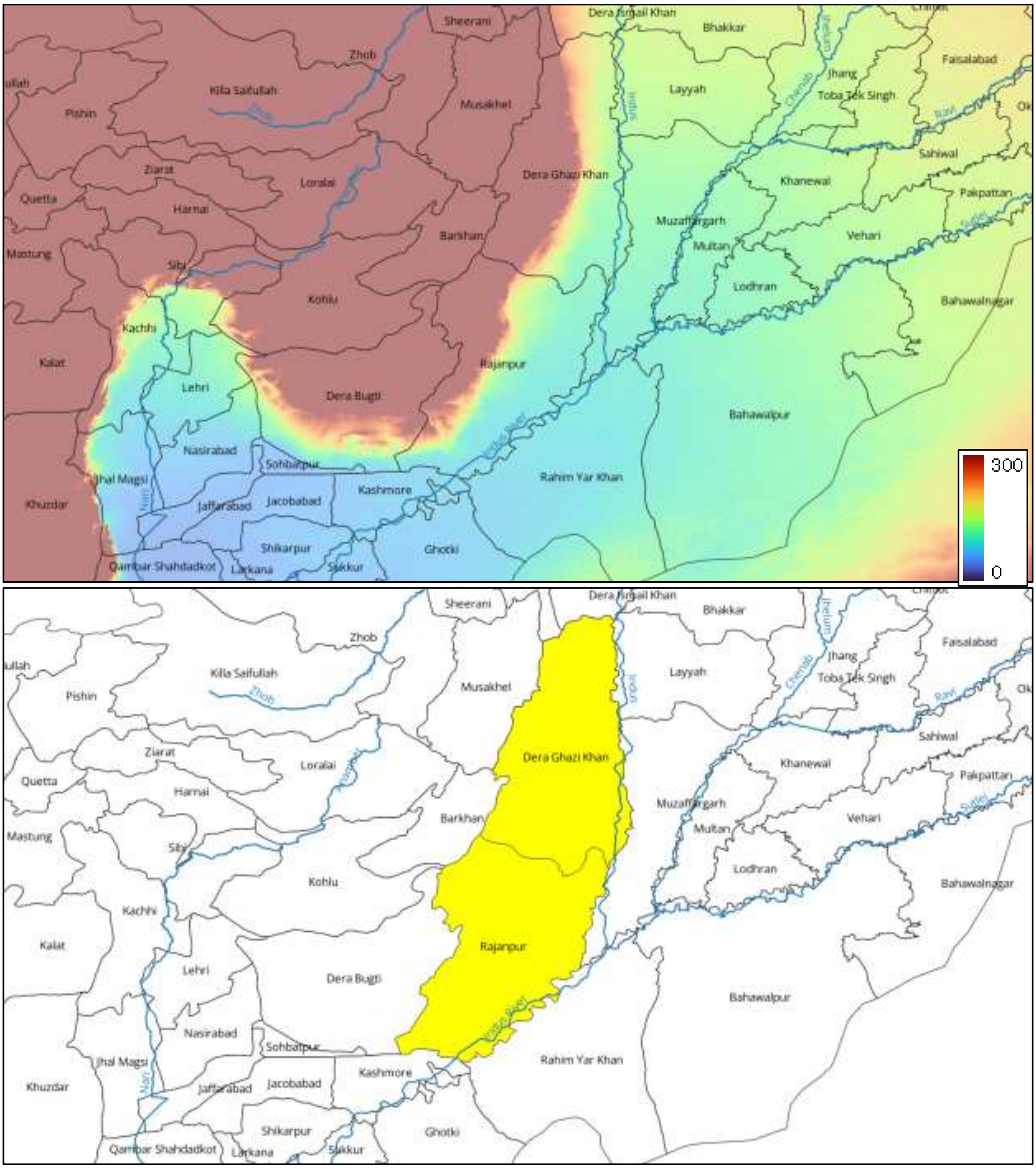
Figure 3.1.7 (1) Districts Can Be Damaged by Flood from Bund Breach near Sukkur



■ : Districts can be damaged by flood from bund breach in D. I. Khan

Source: Advisory Team

Figure 3.1.7 (2) Districts Can Be Damaged by Flood from Bund Breach in D. I. Khan



■ : Districts can be damaged by flood from bund breach in D. G. Khan

Source: Advisory Team

Figure 3.1.7 (3) Districts Can Be Damaged by Flood from Bund Breach in D. G. Khan

3.1.2.1 Total Area and Population

Based on basic data (polygon data) provided by JICA, the total area and population were summarized. The total area and population per district is shown in Table 3.1.4 and that per tehsil is shown in Table 3.1.5. The population density is distributed as shown in Figure 3.1.8. The cities in the study area are also summarized in Table 3.1.6 and Figure 3.1.9.

As a reference, the same figures for D. I. Khan and D. G. Khan are also summarized in Table 3.1.7, Table 3.1.8, Figure 3.1.10, and Figure 3.1.11.

Table 3.1.4 Total Area and Population by District (Lowland in Sindh)

Province	District	Total Area (km2)	Total Area (mi2)	Population
Sindh	Qambar Shahdadkot	5,608	2,165	1,341,042
	Jacobabad	2,771	1,070	1,006,297
	Shikarpur	2,577	995	1,231,481
	Sukkur	5,205	2,010	1,487,903
	Larkana	1,910	737	1,524,391
	Dadu	7,994	3,086	1,550,266
	Naushahro Feroze	3,036	1,172	1,612,373
	Jamshoro	11,264	4,349	993,142
Balochistan	Jhal Magsi	3,841	1,483	149,225
	Jaffarabad	1,796	693	513,813
Total		46,001	17,761	11,409,933

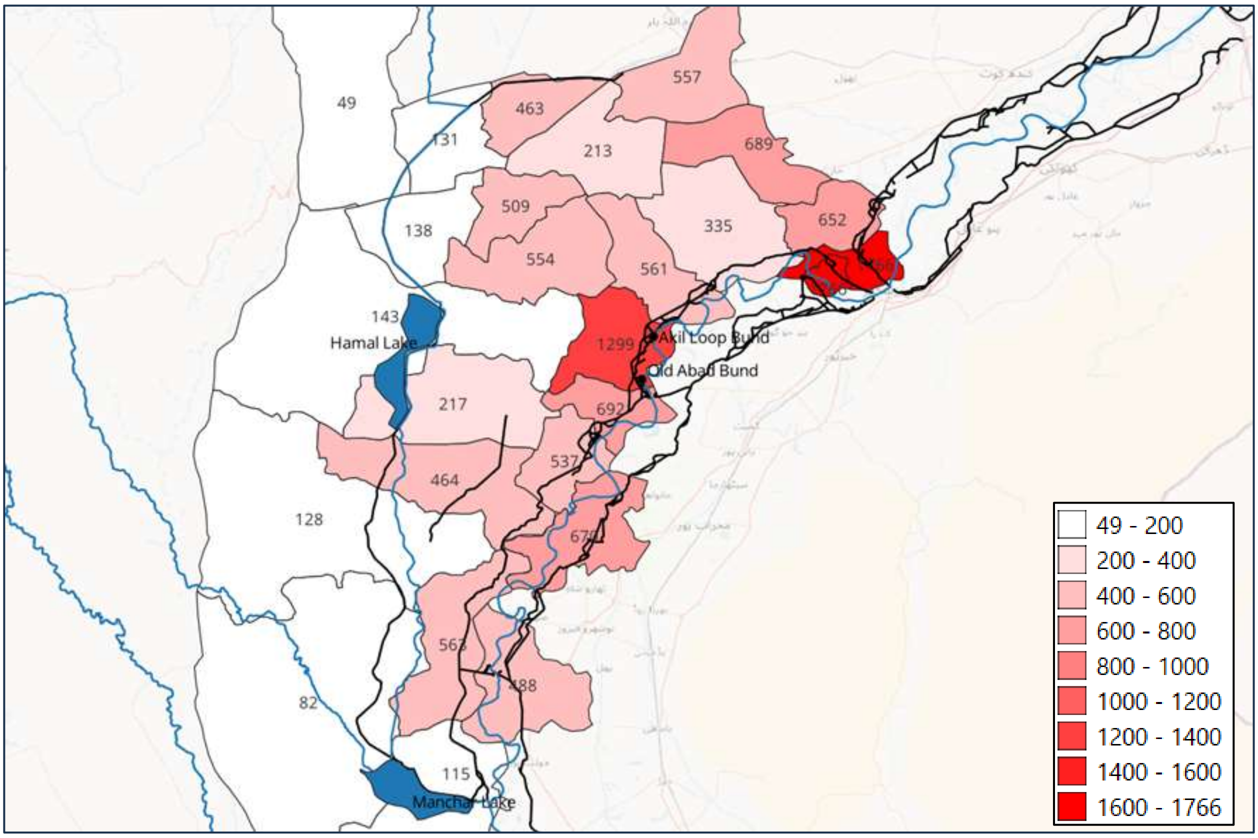
Source: Basic data provided by JICA

Table 3.1.5 Total Area and Population by Tehsil (Lowland in Sindh)

Province	District	Tehsil	Total Area (km2)	Population
Sindh	Qambar Shahdadkot	Qubo Saeed Khan	623	85,970
		Shahdadkot	398	202,745
		Miro Khan	772	427,150
		Kambar Ali Khan	2,755	395,206
		Warah	1,059	229,971
	Jacobabad	Garhi Khairo	744	158,360
		Jacobabad	686	382,513
		Thul	1,341	465,424
	Shikarpur	Garhi Yasin	943	315,883
		Shikarpur	568	391,172
		Lakhi	685	248,143
		Khanpur	381	276,283
	Sukkur	Sukkur	312	551,357
		Pano Aqil	900	435,823
		Rohri	1,049	371,104
		Salehpat	2,943	129,619
	Larkana	Ratodero	591	331,584
		Larkana	568	738,069
		Bakrani	332	229,444
		Dokri	419	225,294
	Dadu	Mehar	993	460,679
		Khairpur Nathan Shah	2,605	334,258
		Dadu	818	460,481
		Johi	3,577	294,848
	Naushahro Feroze	Kandiaro	666	446,079
		Moro	755	368,789
		Mehrabpur	484	—
		Bhiria	398	424,684
		Naushahro Feroze	733	372,821
	Jamshoro	Sehwan	2,342	269,291
		Thano Bula Khan	5,275	145,450
		Manjhand	2,429	140,840
		Kotri	1,218	437,561
Balochistan	Jhal Magsi	Jhal Magsi	1,806	88,575
		Gandawa	2,035	60,650
	Jaffarabad	Gandakha	572	74,976
		Usta Muhammad	402	186,226
		Jhat Pat	822	252,611
Total			46,001	11,409,933

*There is no population data for Mehrabpur Tehsil,
but it is outside the expected inundation range, so this does not affect the study.

Source: Basic data provided by JICA



Source: Advisory Team

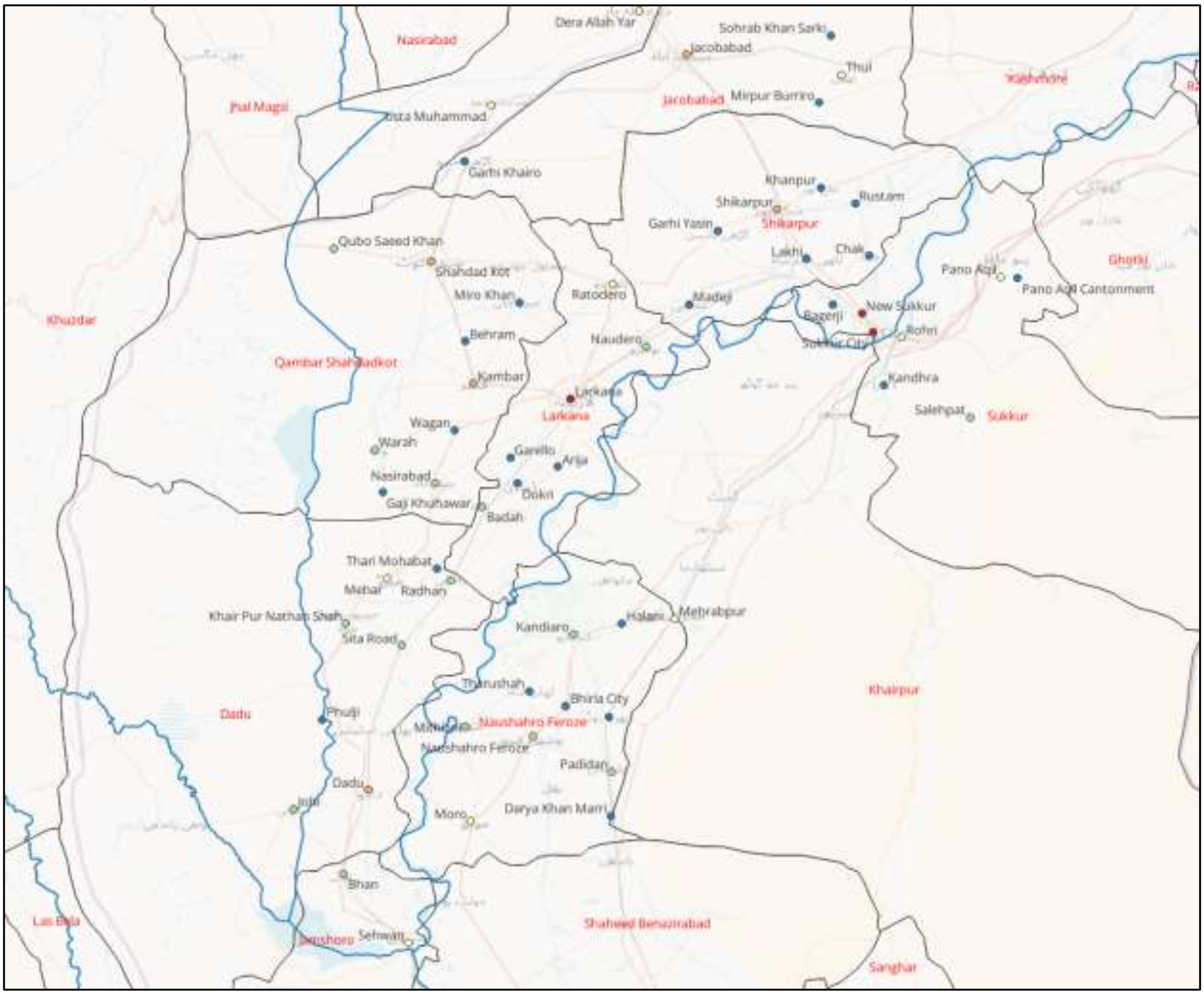
Figure 3.1.8 Population Density Distribution by Tehsil (Lowland in Sindh)

Table 3.1.6 City Population (Lowland in Shind)

Province	District	City	Population	Province	District	City	Population
Sindh	Larkana	Larkana	488,006	Sindh	Qamber Shahdadkot	Qubo Saeed Khan	27,623
Sindh	Sukkur	New Sukkur	268,942	Sindh	Sukkur	Salehpat	26,925
Sindh	Sukkur	Sukkur City	231,459	Sindh	Naushahro Feroze	Padidan	25,301
Sindh	Shikarpur	Shikarpur	196,158	Sindh	Shikarpur	Khanpur	24,919
Sindh	Jacobabad	Jacobabad	191,098	Sindh	Naushahro Feroze	Bhiria Road	24,741
Sindh	Dadu	Dadu	171,319	Sindh	Sukkur	Pano Aqil Cantonment	24,094
Sindh	Qamber Shahdadkot	Shahdad kot	118,935	Sindh	Shikarpur	Lakhi	23,405
Sindh	Qamber Shahdadkot	Kambar	100,970	Sindh	Naushahro Feroze	Halani	23,380
Sindh	Naushahro Feroze	Moro	95,448	Sindh	Naushahro Feroze	Tharushah	23,259
Balochistan	Jaffarabad	Dera Allah Yar	80,958	Sindh	Larkana	Dokri	22,164
Balochistan	Jaffarabad	Usta Muhammad	76,753	Sindh	Qamber Shahdadkot	Miro Khan	21,270
Sindh	Sukkur	Pano Aqil	76,015	Sindh	Qamber Shahdadkot	Behram	21,042
Sindh	Jacobabad	Thul	70,245	Sindh	Larkana	Arija	20,608
Sindh	Sukkur	Rohri	69,944	Sindh	Shikarpur	Madeji	19,817
Sindh	Larkana	Ratodero	67,502	Sindh	Shikarpur	Garhi Yasin	16,120
Sindh	Jamshoro	Sehwan	66,898	Sindh	Sukkur	Kandhra	15,798
Sindh	Dadu	Mehar	56,200	Sindh	Qamber Shahdadkot	Wagan	15,763
Sindh	Naushahro Feroze	Mehrabpur	53,608	Sindh	Qamber Shahdadkot	Gaji Khuhawar	15,455
Sindh	Larkana	Naudero	48,983	Sindh	Shikarpur	Chak	14,688
Sindh	Dadu	Khair Pur Nathan Shah	41,320	Sindh	Dadu	Thari Mohabat	14,282
Sindh	Larkana	Badah	40,038	Sindh	Naushahro Feroze	Bhiria City	14,089
Sindh	Naushahro Feroze	Kandiaro	38,869	Sindh	Jacobabad	Garhi Khairo	12,619
Sindh	Naushahro Feroze	Naushahro Feroze	38,204	Sindh	Jacobabad	Sohrab Khan Sarki	12,525
Sindh	Qamber Shahdadkot	Warah	37,926	Sindh	Naushahro Feroze	Darya Khan Marri	11,942
Sindh	Qamber Shahdadkot	Nasirabad	37,819	Sindh	Larkana	Garello	11,597
Sindh	Jamshoro	Bhan	37,452	Sindh	Dadu	Phulji	11,261
Sindh	Dadu	Sita Road	31,093	Sindh	Jacobabad	Mirpur Burriro	10,731
Sindh	Naushahro Feroze	Mithiani	30,392	Sindh	Shikarpur	Rustam	9,334
Sindh	Dadu	Johi	29,031	Sindh	Sukkur	Bagerji	7,629
Sindh	Dadu	Radhan	28,900				

■ : Population more than 200,000
■ : Population more than 100,000 and less than 200,000
■ : `Population more than 50,000 and less than 100,000
■ : Population more than 25,000 and less than 50,000
■ : Population less than 25,000

Source: Created by Advisory Team from Pakistan Bureau of Statistics



Red: District name, Black: City name

■ : Population more than 200,000

■ : Population more than 100,000 and less than 200,000

■ : Population more than 50,000 and less than 100,000

■ : Population more than 25,000 and less than 50,000

■ : Population less than 25,000

Source: Created by Advisory Team from Pakistan Bureau of Statistics

Figure 3.1.9 City Population (Lowland in Sindh)

Table 3.1.7 (1) Total Area and Population by Tehsil (D. I. Khan)

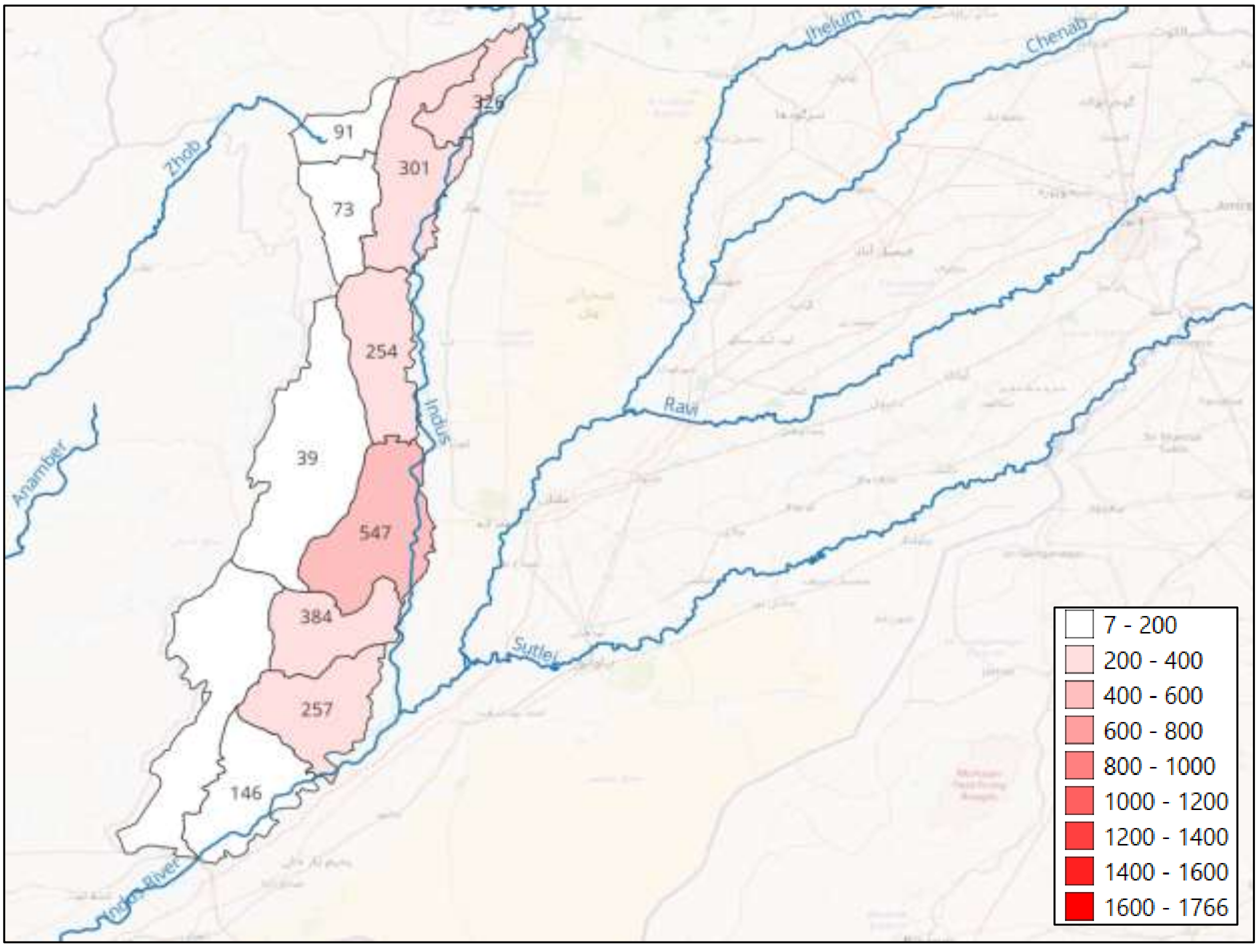
Province	District	Tehsil	Total Area (km2)	Total Area (mi2)	Population
Khyber Pakhtunkhwa	Dera Ismail Khan	Paharpur	1,169	451	381,086
		Dera Ismail Khan	3,384	1,306	1,017,792
		Kulachi	1,120	432	101,892
		Daraban	1,708	660	124,318
Total			7,381	2,850	1,625,088

Source: Advisory Team

Table 3.1.7 (2) Total Area and Population by Tehsil (D. G. Khan)

Province	District	Tehsil	Total Area (km2)	Total Area (mi2)	Population
Punjab	Dera Ghazi Khan	Taunsa	2,665	1,029	677,785
		Dera Ghazi Khan	3,622	1,398	1,982,194
		De-excluded Area D.G.Khan	5,404	2,086	212,652
	Rajanpur	Jampur	2,213	854	849,389
		Rajanpur	2,745	1,060	706,770
		Rojhan	2,774	1,071	405,689
		De-excluded Area Rajanpur	4,797	1,852	34,191
Total			24,221	9,352	4,868,670

Source: Advisory Team



Source: Advisory Team

Figure 3.1.10 Population Density Distribution by Tehsil (D. I. Khan and D. G. Khan)

Table 3.1.8 (1) City Population (D. I. Khan)

Province	District	City	Population	lat	lon
Khyber Pakhtunkhwa	Dera Ismail Khan	Dera Ismail Khan	212,324	31.86568	70.90051
Khyber Pakhtunkhwa	Dera Ismail Khan	Paharpur	66,745	32.1042	70.97544
Khyber Pakhtunkhwa	Dera Ismail Khan	Paroa	39,881	31.55623	70.76122
Khyber Pakhtunkhwa	Dera Ismail Khan	Kulachi	24,753	31.93331	70.4601
Khyber Pakhtunkhwa	Dera Ismail Khan	Panyala	10,821	32.24372	70.88688
Khyber Pakhtunkhwa	Dera Ismail Khan	Dera Ismail Khan Cantonment	5,694	31.8209	70.91718

■ : Population more than 200,000
■ : Population more than 100,000 and less than 200,000
■ : Population more than 50,000 and less than 100,000
■ : Population more than 25,000 and less than 50,000
■ : Population less than 25,000

Source: Created by Advisory Team from Pakistan Bureau of Statistics

Table 3.1.8 (2) City Population (D. G. Khan)

Province	District	City	Population	lat	lon
Punjab	Dera Ghazi Khan	Dera Ghazi Khan	397,362	30.04977	70.64559
Punjab	Rajanpur	Rajanpur	99,097	29.10596	70.33014
Punjab	Dera Ghazi Khan	Taunsa	97,193	30.71259	70.6498
Punjab	Rajanpur	Jampur	87,857	29.64654	70.59375
Punjab	Rajanpur	Fazalpur	76,809	29.29274	70.45169
Punjab	Dera Ghazi Khan	Kot Chhutta	51,666	29.88904	70.65141
Punjab	Rajanpur	Kot Mithan	36,755	28.96011	70.36621
Punjab	Rajanpur	Dajal	22,233	29.56141	70.37807
Punjab	Rajanpur	Rojhan	14,545	28.69241	69.95216

■ : Population more than 200,000
■ : Population more than 100,000 and less than 200,000
■ : Population more than 50,000 and less than 100,000
■ : Population more than 25,000 and less than 50,000
■ : Population less than 25,000

Source: Created by Advisory Team from Pakistan Bureau of Statistics

Red: District name, Black: City name

■ : Population more than 200,000
■ : Population more than 100,000 and less than 200,000
■ : Population more than 50,000 and less than 100,000
■ : Population more than 25,000 and less than 50,000
■ : Population less than 25,000

Source: Created by Advisory Team from Pakistan Bureau of Statistics

Figure 3.1.11 City Population (D. I. Khan and D. G. Khan)

3.1.2.2 Property Value of Houses

The property value of houses in the study area is about 16 tri. PKR as shown in Table 3.1.9 The value of house assets was estimated as "the property value by 1 house × number of households".

According to the article named "House price inflation in Pakistan" published by Modern Diplomacy on April 17, 2023, the average loan amount when buying a house was 2 mil. PKR to 8 mil. PKR, so in this study the property value by 1 house is set as 8 mil. PKR.

As shown in Table 3.1.10, the number of households was estimated as "the population of the target district ÷ the number of persons per household". Based on "Salient Features of Final Results Census 2017", the number of persons per household was set as 5.55 in Sindh Province and 6.87 in Balochistan Province. (See Figure 3.1.12)

Table 3.1.9 Property Value of Houses in the Study Area

Contents	Price	Unit
House asset	8,000,000	PKR
No of household	2,032,890	-
Total	16,263,120,000,000	PKR

Source: Advisory Team

Table 3.1.10 Number of Households in the Study Area

Province	District	Total Area (km2)	Total Area (mi2)	Population	People per Household	Household
Sindh	Qambar Shahdadkot	5,608	2,165	1,341,042	5.55	241,629
	Jacobabad	2,771	1,070	1,006,297	5.55	181,315
	Shikarpur	2,577	995	1,231,481	5.55	221,888
	Sukkur	5,205	2,010	1,487,903	5.55	268,091
	Larkana	1,910	737	1,524,391	5.55	274,665
	Dadu	7,994	3,086	1,550,266	5.55	279,327
	Naushahro Feroze	3,036	1,172	1,612,373	5.55	290,518
	Jamshoro	11,264	4,349	993,142	5.55	178,945
Balochistan	Jhal Magsi	3,841	1,483	149,225	6.87	21,721
	Jaffarabad	1,796	693	513,813	6.87	74,791
Total		46,001	17,761	11,409,933	—	2,032,890

Source: Advisory Team

POPULATION DENSITY AND HOUSEHOLD SIZE BY ADMN UNITS

ADMN UNIT	POPULATION (MILLION)	POPULATION DENSITY (SQ. KM)	HOUSEHOLD SIZE 1998	HOUSEHOLD SIZE 2017
PAKISTAN	207.68	260.88	6.8	6.39
KP	30.51	409.40	8.0	7.83
FATA	4.99	183.43	9.3	8.60
PUNJAB	109.99	535.63	6.9	6.38
SINDH	47.85	339.60	6.0	5.55
BALOCHISTAN	12.34	35.53	6.7	6.87
ICT	2.00	2211.22	6.2	5.86

Source: Salient Features of Final Results Census 2017

Figure 3.1.12 Number of People per Household for Each Province

3.1.2.3 Asset Value of Crops

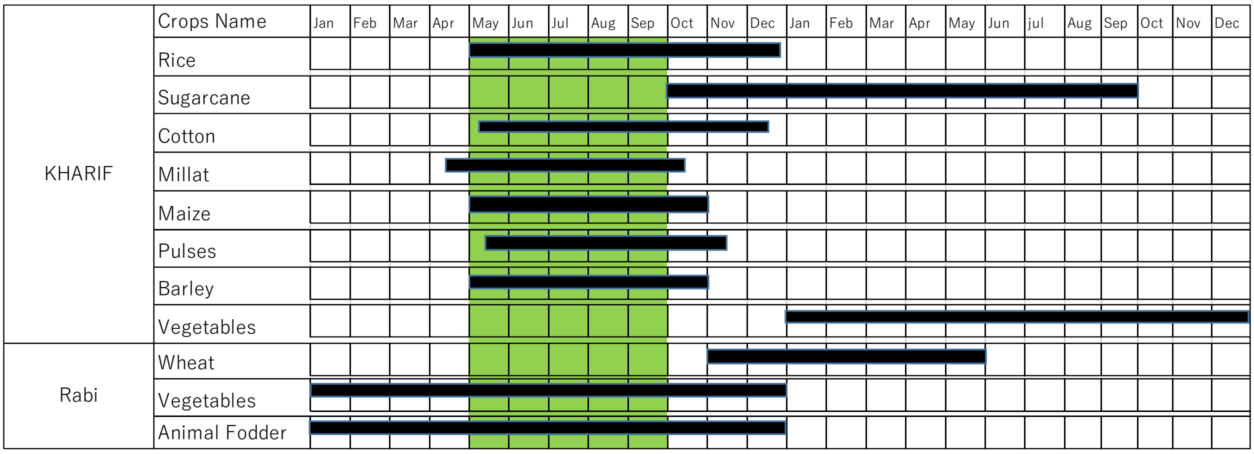
(1) Major Crops

Cropping pattern in Pakistan are shown in Table 3.1.11 The crops grown during flood season (May to September) are the target of this study.

Table 3.1.12 shows the agricultural land area for each crop by district. The target crops in this study are only the crops that occupy 10% or more of the agricultural area in the district.

3 types of crops (cotton, rice, and wheat) meet the above conditions, and the asset value of these crops and the estimated damage during flood events are estimated.

Table 3.1.11 Cropping Pattern in Pakistan



: Estimated Seasons (May to September)

Source: Sindh-PID

Table 3.1.12 (1) Agricultural Land Area for Each Crop (ha)①

Province	District	Kharif											Total
		Cotton	Rice	Sugarcane	Maize	Sorghum	Groundnut	Sunflower	Sesame	Mashbean	Mungbean	O.K.Pulses	
Sindh	N. Feroze	36208.4	9395.0	21723.8	70.7	469.3	0.0	125.0	1889.7	0.0	83.8	0.0	178390.9
	Jacobabad	0.0	73020.0	152.0	0.0	217.0	0.0	1005.0	0.0	0.0	0.0	0.0	120687.0
	Shikarpur	41.6	107171.0	339.8	2.7	13.0	0.0	933.0	28.7	0.0	0.0	0.0	149946.5
	Larkana	1373.2	98009.0	610.8	0.0	75.7	0.0	116.0	1599.7	0.0	0.0	0.0	159366.3
	Qamber	0.0	80929.0	126.0	0.0	855.0	0.0	0.0	0.0	0.0	0.0	0.0	136422.2
	Dadu	11196.2	44731.0	4865.2	49.7	485.7	0.0	1530.0	1139.0	0.0	7.7	0.0	144116.2
	Jamshoro	15604.4	441.0	653.2	83.0	472.3	0.0	66.0	559.7	16.0	10.7	3.8	62901.6
Balochistan	Jafferabad	2.6	110500.0	42.0	0.7	85.0	0.0	0.0	37.0	0.0	2.3	0.0	258337.1
	Jhal Magsi	21.8	59.0	0.0	0.0	5275.0	0.0	105.0	4797.0	60.0	338.0	29.4	93990.0

(yellow): Crops with agricultural land area exceeding 10%

Source: Cropping Pattern Zonation of Pakistan

Table 3.1.12 (2) Agricultural Land Area of Each Crop (ha)②

Province	District	Rabi														Total
		Wheat	Rapeseed & Mustard	Chickpea	Barley	Potatoe	Onion	Lentil	Tobacco	Garlic	Green peas	O.R Pulses	Corriander	Lin-seed	Sugar-beet	
Sindh	N. Feroze	105878.6	893.0	197.0	12.8	180.8	879.0	47.2	5.8	10.6	293.4	0.0	27.0	0.0	0.0	178390.9
	Jacobabad	31356.8	4409.0	2133.0	161.8	0.0	839.0	430.8	0.0	0.0	6927.4	0.0	27.0	8.2	0.0	120687.0
	Shikarpur	37988.8	995.0	1818.0	26.0	33.4	199.0	76.6	0.0	11.4	43.4	0.0	181.3	43.8	0.0	149946.5
	Larkana	48642.4	3998.0	838.0	1005.0	0.0	611.0	0.0	0.0	70.6	424.8	0.0	266.3	1725.8	0.0	159366.3
	Qamber	51863.2	409.0	154.0	118.6	0.0	264.0	196.8	0.0	0.0	993.2	0.0	0.0	513.4	0.0	136422.2
	Dadu	74046.4	1594.0	590.0	114.6	38.8	3285.0	0.0	0.0	65.4	347.0	0.0	30.5	0.0	0.0	144116.2
	Jamshoro	37408.4	577.0	927.0	114.0	4.2	5594.0	81.6	4.2	99.6	98.0	0.0	83.5	0.0	0.0	62901.6
Balochistan	Jafferabad	112550.8	6535.0	22250.0	10.0	0.0	1270.0	6.4	0.0	32.2	4573.3	0.0	439.8	0.0	0.0	258337.1
	Jhal Magsi	82187.0	677.0	0.0	195.0	0.0	72.0	0.0	86.2	0.0	0.0	0.0	87.6	0.0	0.0	93990.0

(yellow): Crops with agricultural land area exceeding 10%

Source: Cropping Pattern Zonation of Pakistan

(2) Crop Assets

For the three types of crops (cotton, rice, and wheat), the yields of each crop are shown in Table 3.1.13 and the assets of each crop are shown in Table 3.1.14. From these tables, the crop yields of the study area are estimated as approximately 3.06 bil. kg and the crop assets are also estimated at approximately 222 bil. PKR.

Here, the yields of each crop were estimated by “the agricultural land area of each crop x the yields per unit agricultural land of each crop”, and the assets of each crop were estimated by ”the yields of each crop × the unit market prices of each crop”.

Based on the information from “Economic Survey 2021-2022”, the yields per unit of agricultural land for each crop are estimated in Table 3.1.15 by taking the average crop yield of 5 years from 2017 to 2022.

Also, based on the information from “The Pakistan Bureau of Statistics”, the unit market prices of each crop for 2021-2022 are shown in Table 3.1.16 by confirming the unit market prices of each crop around 2010 and the rate of increase in prices.

Table 3.1.13 Yields of Each Crop (kg)

Province	District	Crop	Cotton	Rice	Wheat
		Yield(kg/ha)	677	2,547	2,892
Sindh	N. Feroze		24,527,570	23,929,065	306,222,087
	Jacobabad		0	185,981,940	90,690,137
	Shikarpur		28,180	272,964,537	109,871,207
	Larkana		930,206	249,628,923	140,683,549
	Qamber		0	206,126,163	149,998,747
	Dadu		7,584,306	113,929,857	214,156,998
	Jamshoro		10,570,421	1,123,227	108,192,574
Balochistan	Jafferabad		1,761	281,443,500	325,519,424
	Jhal Magsi		14,767	150,273	237,701,241
Total			43,657,211	1,335,277,485	1,683,035,965
					3,061,970,661

Source: Advisory Team

Table 3.1.14 Assets of Each Crop (PKR)

Province	District	Crop	Cotton	Rice	Wheat
		Price(PKR/kg)	111.40	81.34	64.55
Sindh	N. Feroze		2,732,322,905	1,946,440,081	19,765,894,497
	Jacobabad		0	15,128,159,098	5,853,828,824
	Shikarpur		3,139,179	22,203,505,049	7,091,920,491
	Larkana		103,623,077	20,305,337,510	9,080,782,580
	Qamber		0	16,766,732,233	9,682,056,048
	Dadu		844,876,706	9,267,292,312	13,823,315,857
	Jamshoro		1,177,523,987	91,365,628	6,983,568,802
Balochistan	Jafferabad		196,199	22,893,201,593	21,011,490,881
	Jhal Magsi		1,645,050	12,223,519	15,343,039,774
Total			4,863,327,102	108,614,257,023	108,635,897,755
					222,113,481,880

Source: Advisory Team

Table 3.1.15 Yields per Unit Agricultural Land of Each Crop (kg/ha)

Year	Kharif					Rabi					
	Cotton	Rice	Sugarcane	Maize	Mashbean	Wheat	Rapeseed & Mustard	Barley	Potatoe	Onion	Tobacco
2017-2018	753	2,568	62,096	4,718		2,851					
2018-2019	707	2,563	60,956	4,968		2,806					
2019-2020	618	2,444	63,841	5,614		2,868					
2020-2021	578	2,525	69,534	6,305	627	2,996	1,321	1,000	25,066	14,992	3,055
2021-2022(P)	731	2,635	70,314	6,436	763	2,940	1,354	1,077	25,293	14,956	3,055
Average	677	2,547	65,348	5,608	695	2,892	1,338	1,038	25,180	14,974	3,055

Source: Economic Survey 2021-2022

Table 3.1.16 Unit Market Prices of Each Crop (PKR/kg)

Crop	Data Year	PKR/40kg	Unit Price at Data Year (PKR/kg)	Estimated Year	Growth rate	Unit Price at Estimated Year (PKR/kg)	Data Area
Cotton	2008-2009	1465	36.63	2021-2022	3.04	111.40	Pakistan
Rice	2010-2011	1269.4	31.74	2021-2022	2.56	81.34	Sukkur
Sugarcane	2010-2011	127	3.18	2021-2022	2.56	8.14	Sindh
Maize	2010-2011	805.5	20.14	2021-2022	2.56	51.62	Hyderabad
Wheat	2010-2011	1007.31	25.18	2021-2022	2.56	64.55	Hyderabad

Source: Pakistan Bureau of Statistics

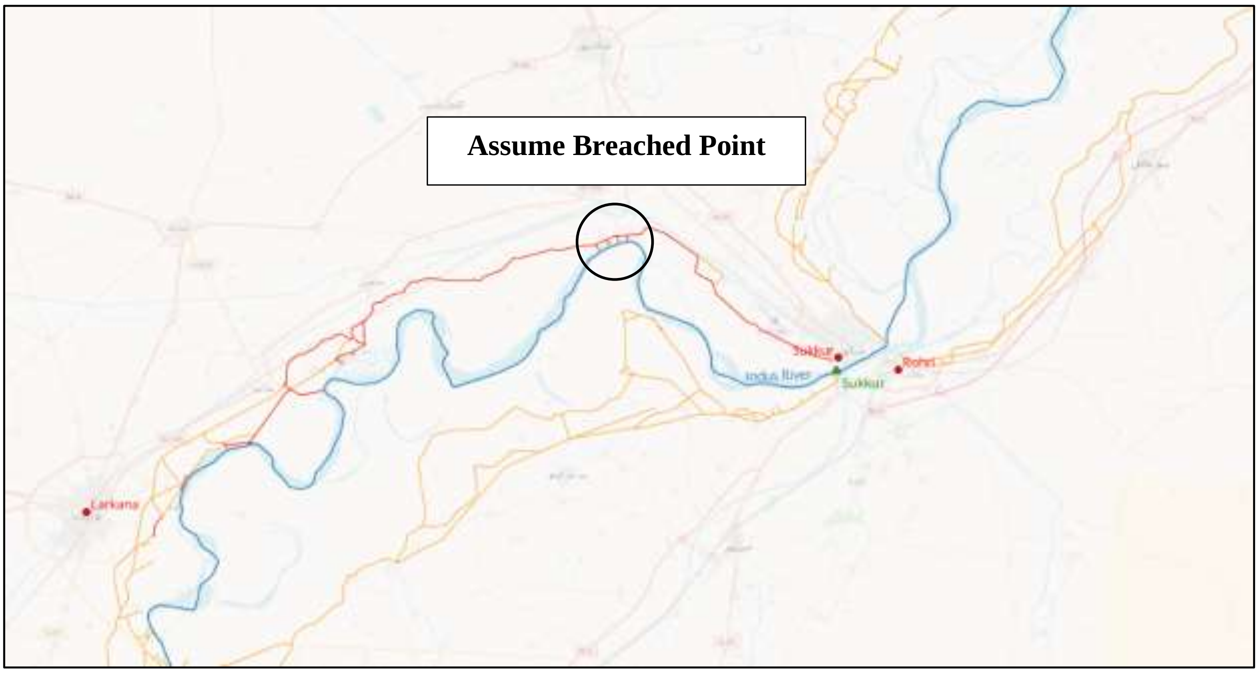
3.1.3 Assumption of Maximum Flood Damage

3.1.3.1 Assumption of Flooded Area

In this study, maximum flood damage was considered when the right bund near Sukkur was breached. The assumed breached point is shown in Figure 3.1.13 (No. 1 vulnerable point in satellite image analysis).

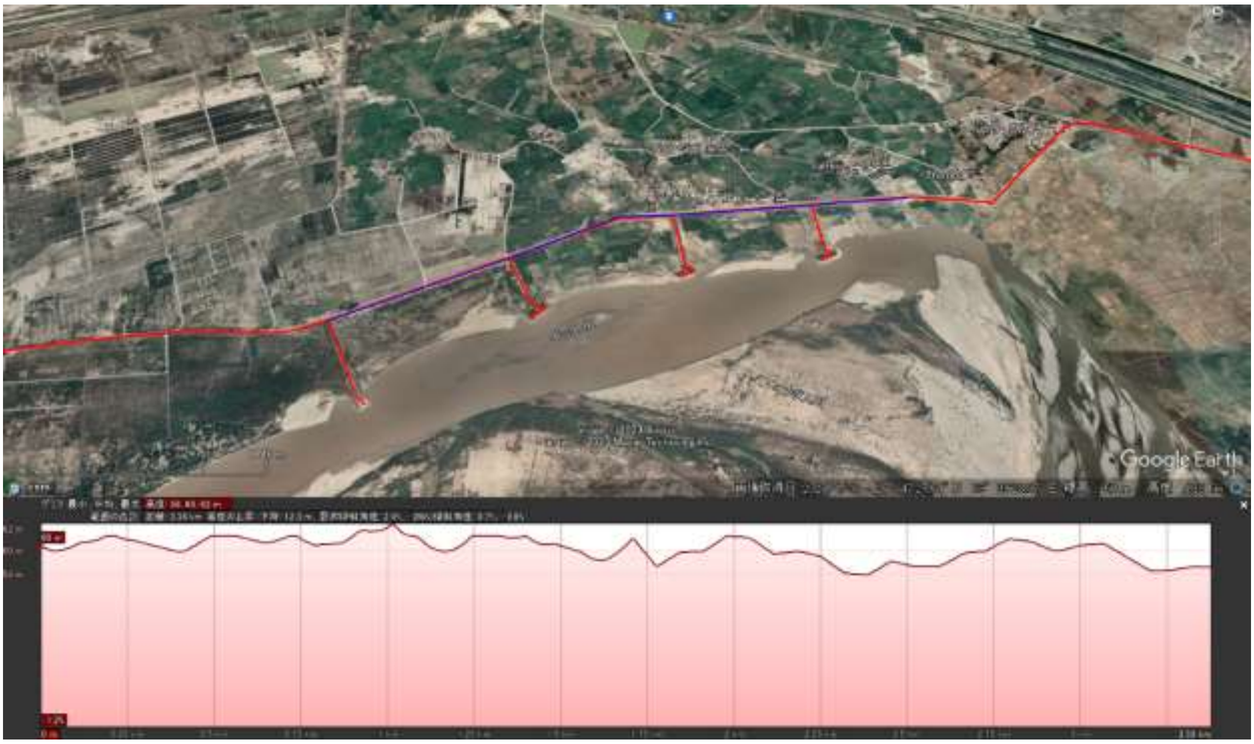
According to Google Earth (see Figure 3.1.14), the elevation near the assumed breached point is more than about 58 m, and it is considered that areas with ground elevations lower than that will be inundated. Figure 3.1.15 shows an elevation map of the study area. In many areas, ground elevations are lower than the elevation near bunds of the Indus River, and flood damage is likely to spread over a wide area of the study area.

Figure 3.1.16 shows an overlay of the elevation map and the flood record map in the 2022 flood. This figure shows that the area with an elevation of less than 58 m and the flooded area in the 2022 flood is almost the same. Therefore, the maximum flooded area from the breached point should be almost the same as the flooded area in the 2022 flood. So, the assumed flooded area in this study is set as the flooded area in the 2022 flood.



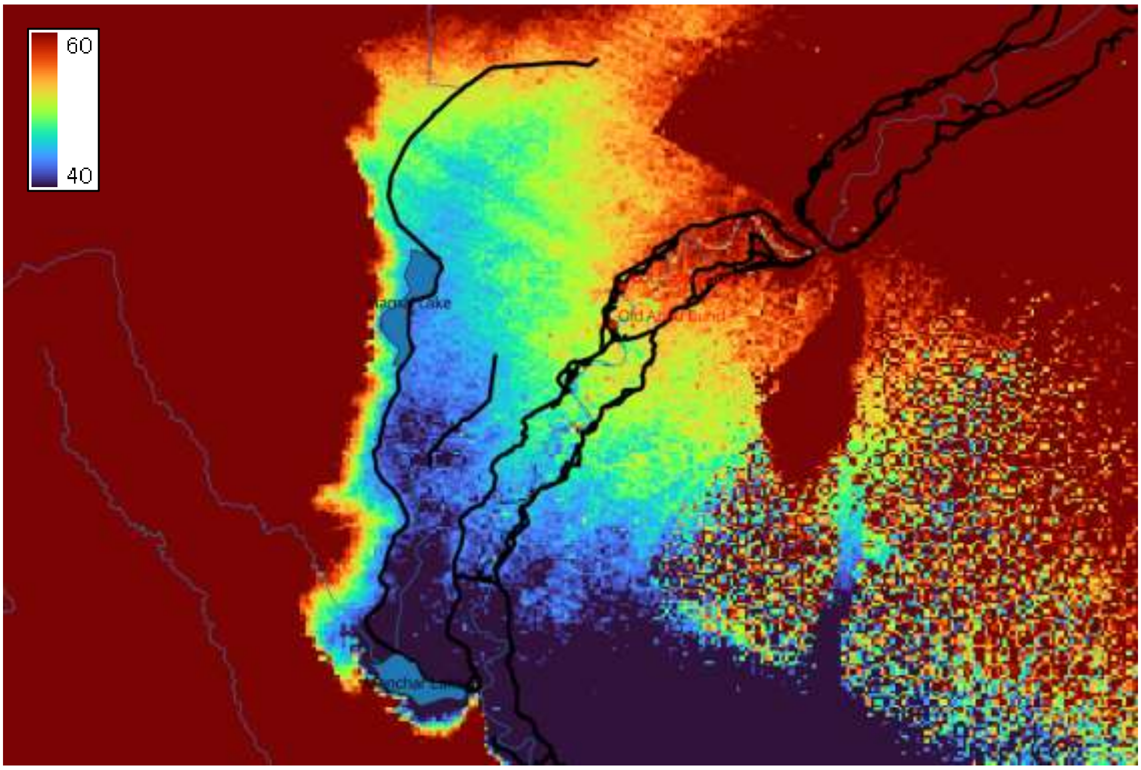
Source: Basic data provided by JICA

Figure 3.1.13 Assumed Breached Point



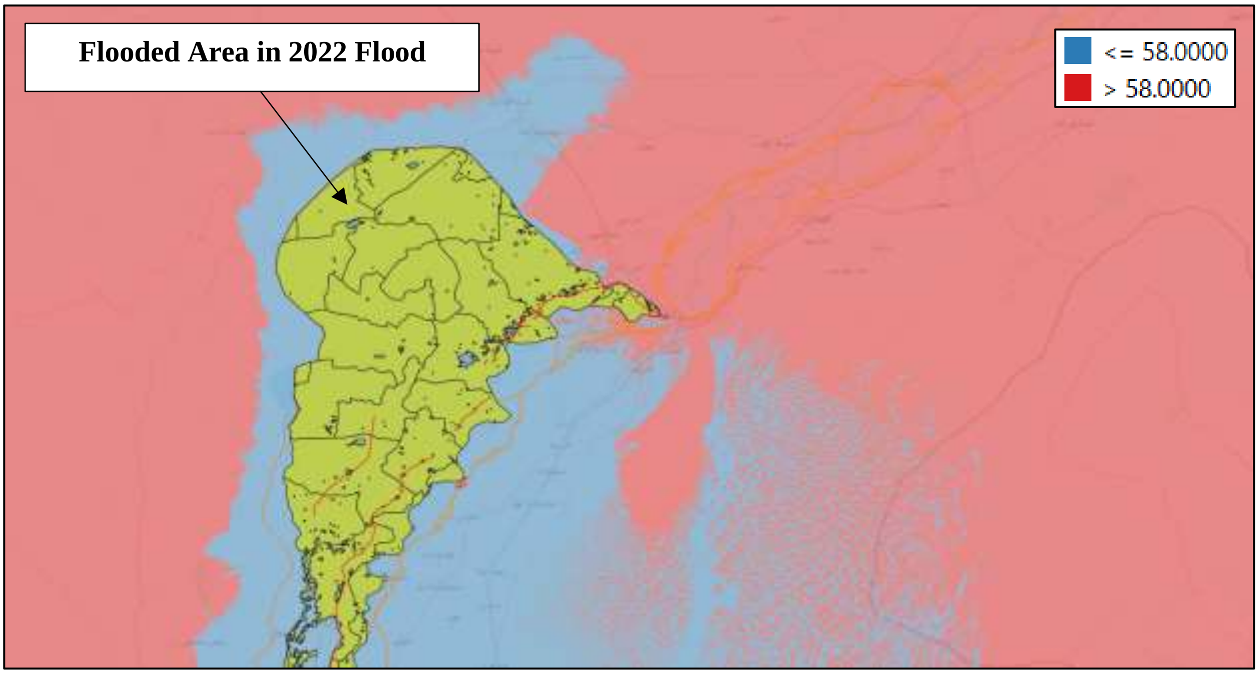
Source: Created from Google Earth

Figure 3.1.14 Elevation near Assumed Breached Point



Source: Advisory Team

Figure 3.1.15 Ground Elevation of the Study Area



Source: Basic data provided by JICA

Figure 3.1.16 Overlay of the Elevation Map and the Flood Record Map in 2022 Flood

3.1.3.2 Estimated Amount of Damage to Houses

The estimated amount of damage to houses in the study area is about 3.6 tri. PKR is shown in Table 3.1.17. Here, the estimated amount of damage to houses was estimated by "the estimated value of unit house × the number of affected households × the damage rate."

The estimated value of the unit house was 8 million. PKR is the same as the amount set in the preceding section.

The damage rate was set according to the “Flood Control Economic Survey Manual”, assuming that the inundation depth was 2 m. Table 3.1.18 shows the description of the “Flood Control Economic Survey Manual”. Since the ground slope is less than 1/1,000, Group A and the inundation depth is assumed to be 2 m, the damage rate of this study is 0.592.

The number of affected households was estimated for each tehsil as follows. Table 3.1.19 shows the estimation results, and it is assumed that approximately 763,000 households will be affected.

・Inundation Ratio = Inundated Area ÷ Total Area

・Number of Disaster Victims = Population × Inundation Ratio

・Number of Affected Households = Number of Disaster Victims ÷ Number of People per Household

Table 3.1.17 Estimated Damage to Houses

Contents	Price	Unit
House asset	8,000,000	PKR
No of affected household	763,021	-
Total price of affected house	6,104,168,000,000	PKR
Damage Rate	0.592	-
Amount of Damage	3,613,667,456,000	PKR

Source: Advisory Team

Table 3.1.18 Damage Rate in "Flood Control Economic Survey Manual"

Ground Slope	Under the floor	Above the floor (cm)					Sediment deposition	
		~50	50~99	100~199	200~299	300~	~50cm	50~cm
Group A	0.047	0.189	0.253	0.406	0.592	0.800	0.430	0.785
Group B	0.058	0.219	0.301	0.468	0.657	0.843		
Group C	0.064	0.235	0.325	0.499	0.690	0.865		

Group A: Less than 1/1,000, Group B: 1/1,000~1/500, Group C: More than 1/500

Source: Flood Control Economic Survey Manual

Table 3.1.19 Estimation Result of the Number of Flood-Affected Households

Province	District	Tehsil	Total Area (km2)	Total Area (mi2)	Flooded Area (km2)	Flooded Area (mi2)	Inundation Rate (%)	Population	People per Household	Household	Affected People	Affected Household
Sindh	Qambar Shahdadkot	Qubo Saeed Khan	623	241	476	184	76.35	85,970	5.55	15,490	65,637	11,826
		Shahdadkot	398	154	395	152	99.17	202,745	5.55	36,531	201,062	36,227
		Miro Khan	772	298	770	297	99.82	427,150	5.55	76,964	426,397	76,828
		Kambar Ali Khan	2,755	1,064	640	247	23.22	395,206	5.55	71,208	91,756	16,533
		Warah	1,059	409	863	333	81.46	229,971	5.55	41,436	187,343	33,755
	Jacobabad	Garhi Khairo	744	287	735	284	98.80	158,360	5.55	28,533	156,454	28,190
		Jacobabad	686	265	58	22	8.45	382,513	5.55	68,921	32,309	5,821
		Thul	1,341	518	0	0	0.00	465,424	5.55	—	—	—
	Shikarpur	Garhi Yasin	943	364	734	283	77.86	315,883	5.55	56,916	245,933	44,312
		Shikarpur	568	219	32	12	5.68	391,172	5.55	70,481	22,221	4,004
		Lakhi	685	264	0	0	0.00	248,143	5.55	—	—	—
		Khanpur	381	147	0	0	0.00	276,283	5.55	—	—	—
	Sukkur	Sukkur	312	121	131	50	41.84	551,357	5.55	99,344	230,679	41,564
		Pano Aqil	900	347	0	0	0.00	435,823	5.55	—	—	—
		Rohri	1,049	405	0	0	0.00	371,104	5.55	—	—	—
		Salehpat	2,943	1,136	0	0	0.00	129,619	5.55	—	—	—
	Larkana	Ratodero	591	228	569	220	96.25	331,584	5.55	59,745	319,164	57,507
		Larkana	568	219	537	207	94.56	738,069	5.55	132,985	697,904	125,748
		Bakrani	332	128	332	128	100.00	229,444	5.55	41,341	229,444	41,341
		Dokri	419	162	410	158	97.75	225,294	5.55	40,594	220,233	39,682
	Dadu	Mehar	993	384	746	288	75.12	460,679	5.55	83,005	346,044	62,350
		Khairpur Nathan Shah	2,605	1,006	393	152	15.09	334,258	5.55	60,227	50,451	9,090
		Dadu	818	316	550	212	67.19	460,481	5.55	82,970	309,400	55,748
		Johi	3,577	1,381	0	0	0.00	294,848	5.55	—	—	—
	Naushahro Feroze	Kandiaro	666	257	185	71	27.79	446,079	5.55	80,375	123,972	22,337
		Moro	755	292	185	71	24.48	368,789	5.55	66,448	90,264	16,264
		Mehrabpur	484	187	0	0	0.00	—	5.55	—	—	—
		Bhiria	398	154	0	0	0.00	424,684	5.55	—	—	—
		Naushahro Feroze	733	283	0	0	0.00	372,821	5.55	—	—	—
	Jamshoro	Sehwan	2,342	904	151	58	6.46	269,291	5.55	48,521	17,393	3,134
		Thano Bula Khan	5,275	2,037	0	0	0.00	145,450	5.55	—	—	—
		Manjhand	2,429	938	0	0	0.00	140,840	5.55	—	—	—
		Kotri	1,218	470	0	0	0.00	437,561	5.55	—	—	—
Balochistan	Jhal Magsi	Jhal Magsi	1,806	697	20	8	1.13	88,575	6.87	12,893	1,001	146
		Gandawa	2,035	786	0	0	0.00	60,650	6.87	—	—	—
	Jaffarabad	Gandakha	572	221	326	126	56.98	74,976	6.87	10,914	42,721	6,219
		Usta Muhammad	402	155	362	140	89.99	186,226	6.87	27,107	167,585	24,394
		Jhat Pat	822	318	0	0	0.00	252,611	6.87	—	—	—
Total			46,001	17,761	9,600	3,706	20.87	11,409,933	—	1,312,949	4,275,367	763,021

Source: Advisory Team

3.1.3.3 Estimated Crop Damage

The estimated crop damage in the study area is approximately 83 bil. PKR is shown in Table 3.1.20. Here, the estimated amount of crop damage was estimated for each district as "the crop asset value × inundation rate."

Table 3.1.20 Estimated Amount of Crop Damage

Province	District	Inundation Rate(%)	Cotton	Rice	Wheat	Total
Sindh	N. Feroze	12.18	332,796,930	237,076,402	2,407,485,950	2,977,359,281
	Jacobabad	28.62	0	4,329,679,134	1,675,365,810	6,005,044,943
	Shikarpur	29.74	933,592	6,603,322,402	2,109,137,154	8,713,393,147
	Larkana	96.73	100,234,602	19,641,352,974	8,783,840,990	28,525,428,566
	Qamber	56.06	0	9,399,430,090	5,427,760,621	14,827,190,710
	Dadu	21.13	178,522,448	1,958,178,865	2,920,866,641	5,057,567,954
	Jamshoro	1.34	15,778,821	1,224,299	93,579,822	110,582,943
Balochistan	Jafferabad	38.27	75,085	8,761,228,250	8,041,097,560	16,802,400,895
	Jhal Magsi	0.53	8,719	64,785	81,318,111	81,391,614
Total		-	628,350,197	50,931,557,200	31,540,452,657	83,100,360,054

Source: Advisory Team

3.1.3.4 Total Estimated Flood Damage

The estimated flood damage in case of flooding is shown in Table 3.1.21 by summing the estimated amount of damage to houses and crops outlined in the preceding section.

Table 3.1.21 Total Estimated Flood Damage

Contents	Damage	Unit
Amount of House Damage	3,613,667,456,000	PKR
Amount of Crop Damage	83,100,360,054	PKR
Total Amount of Damage	3,696,767,816,054	PKR

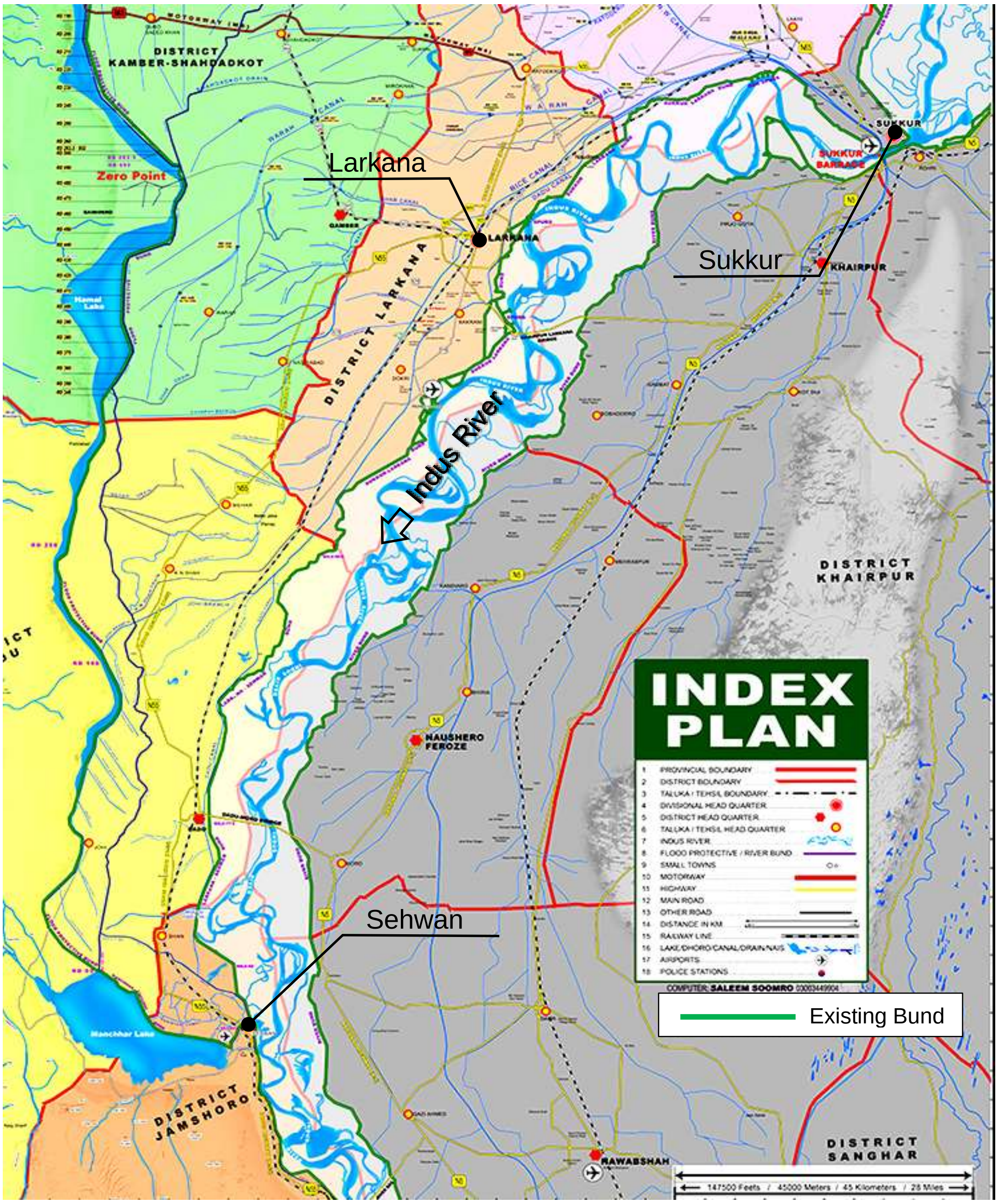
Source: Advisory Team

3.2 Situation of Indus Bunds

3.2.1 Overview of Existing Bund

(1) Development of Bund

On the right bank of the Indus River in the Sukkur-Larkana Region, which is the target area of this study, bunds have been developed in the whole stretch, and at most of the sites, the bunds are double or triple-layered. According to the information based on NFPP-IV and the Sindh Irrigation Department, there is no site where the bund has not been developed at all (see Figure 3.2.1).



Source: Added on Sukkur Barrage Right Bank Region Index Map, Sindh Irrigation Department

Figure 3.2.1 Index Map of Sukkur Barrage Right Bank Region

(2) Basic Specifications (Bund Height, Top Width, etc.)

1) Bund Height

The bund height has been improved by securing the necessary freeboard for the 2010 HFL. However, the freeboard seems to vary depending on the site and is 5 to 6 ft(1.52 to 1.83 m).

2) Top Width

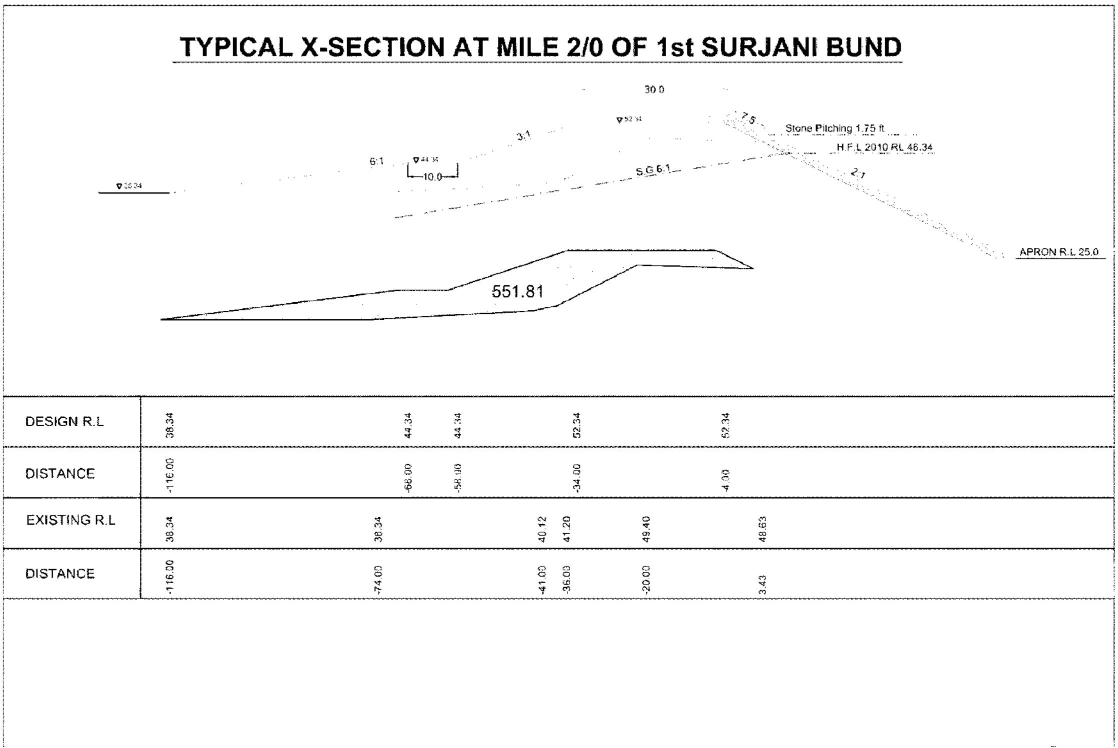
The value of the top width varies from the planned value of 20 ft to 30 ft(6.01~9.15 m) even in the bund located along the same Indus River, and it seems that some locations have 20 ft width or less as of now. Riprap is stored on the top of bunds as a stockpiling material at the locations that are particularly concerned with erosion, and the top of the bund is widened in such places (see Photo 3.2.1).

3) Side Slope

The proposed side slope varies from 2.0:1 to 3.0:1 on the riverside and from 3.0:1 or 2.0:1 on the land side with a berm (width: 5 to 10 ft). The side slope of the existing bunds seems to be 2.0:1 in many places.

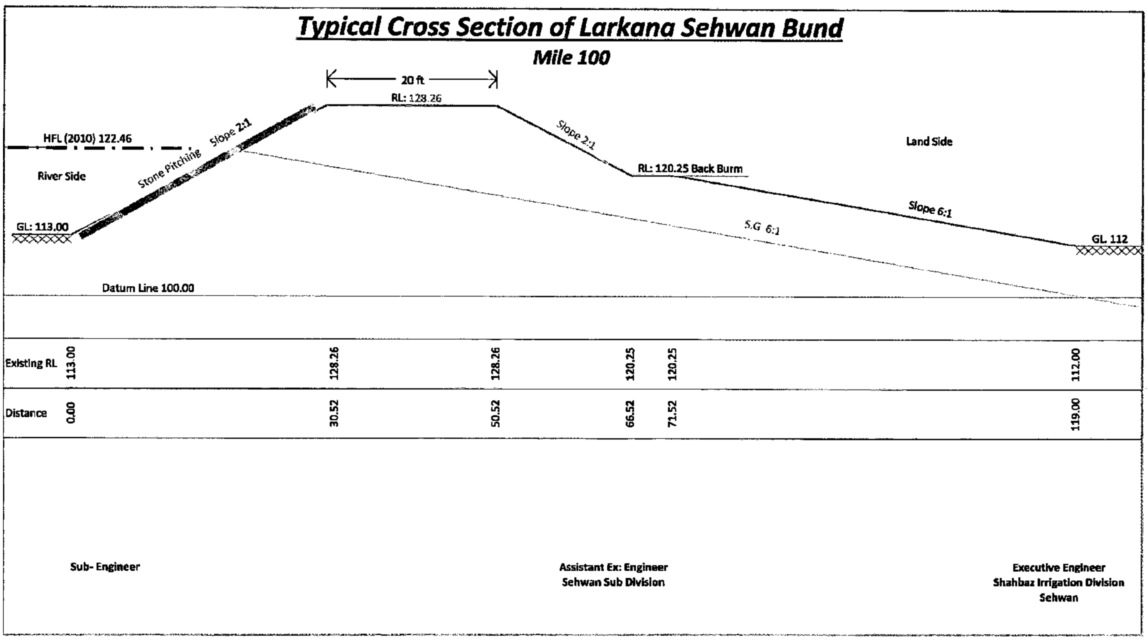
Source: Sindh-PID

Photo 3.2.1 Stockpiled Materials on a Bund



Source: Sindh PID

Figure3.2.2 Example of Typical Section of a Bund (1)



Source: Sindh PID

Figure 3.2.3 Example of Typical Section of a Bund (2)

(3) Common Issues

A joint site inspection was conducted between 2/8/2023 and 4/8/2023 with engineers from the Sindh Irrigation Department. Based on the site inspection results, the following issues were identified in the existing bunds.

- There are many locations where the top of the bund is not paved, and unevenness and bad runnability for vehicles were nb observed in such locations. Such a situation hurts the smooth inspection of bunds and rivers.
- Most areas of the riverside slope are covered with stone pitching, but there are many areas where the soil materials of the bund are washed out from the slope due to no anti-suction material such as filter fabrics being laid.
- The landside slope is not covered at most of the sites. There seems to be no expansion of the bund body in addition to the required section considering erosion. Hence, the required section is gradually eroded and decreased by rainwater.
- Since the protection of the shoulder is insufficient, the shoulder is damaged in many locations.

3.2.2 Vulnerable Points of the Existing Bund

(1) Vulnerable Points Listed by the Local Government

"Contingency Plan 2023, Government of Sindh Irrigation Department" provides a list of vulnerable points of existing bunds. Listed in Table 3.2.1 are the vulnerable points specified for the right bank bund at Larkana from Sukkur Barrage. Figure 3.2.4 shows the location map of each vulnerable point along the right bank bund of the Indus River.

According to information from the Sindh Irrigation Department, the main reasons[1] why the listed points were identified as vulnerable points are as follows:

1. Any history of cut or breach.
2. Total number of populations to be affected or living along the site.

1 Based on interviews with the Sindh Irrigation Department

3. Huge public or private important infrastructure around the site.
4. Existing site & local soil conditions and available flood protection works.
5. Underground water levels to bunds.
6. Any major road networks etc.
7. Condition of flood bunds such as its cross-section, top levels, side slopes, and quality of soil consisting of the bund body

Table 3.2.1 lists 22 vulnerable points. 17 points are on the bunds along the Indus River (Location No.53 to 68) and the remaining 5 are on FP Bund or Superio Bund for protection against Hill Torrent.

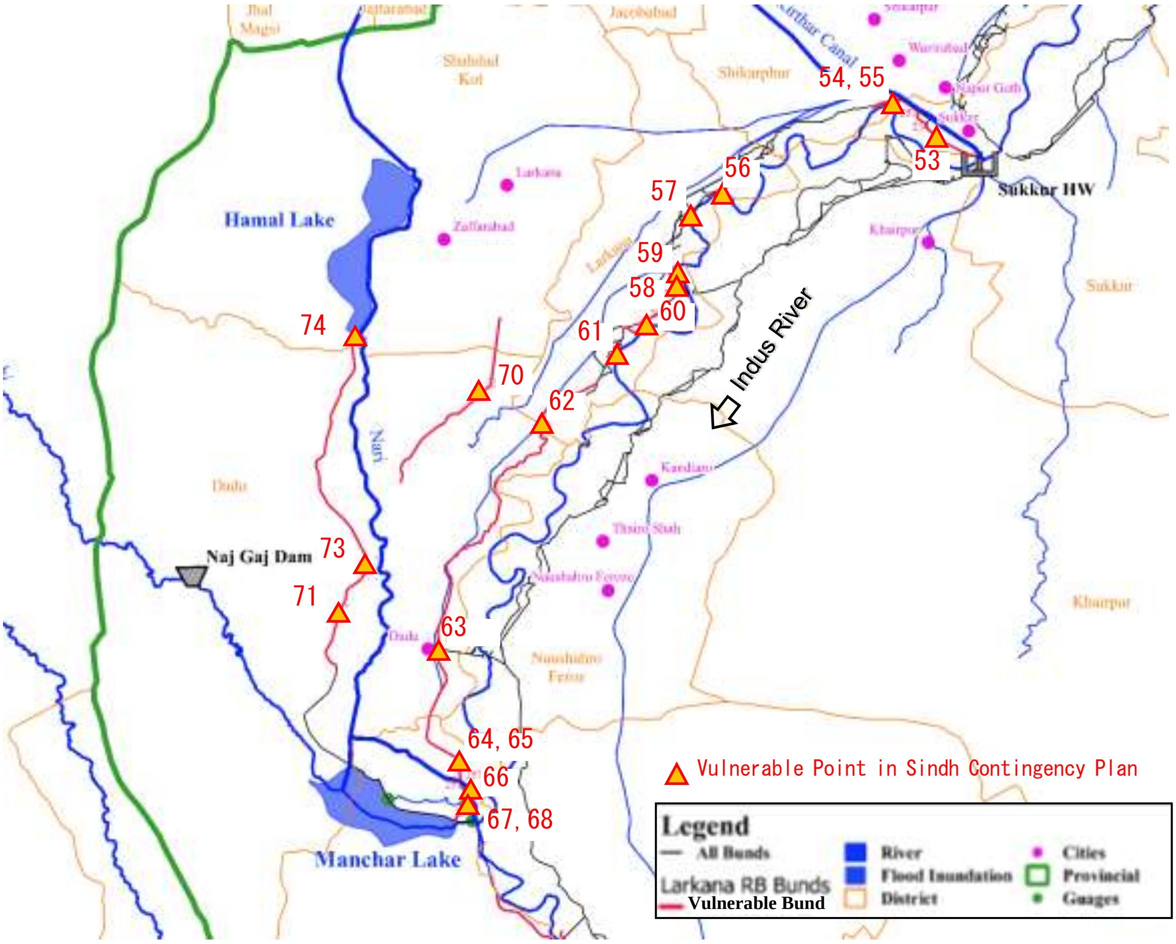
Also shown in red color in the Opinion column of Table 3.2.1 are 5 of the 17 vulnerable points along the Indus River for which the need for early rehabilitation and repair is recognized but not action has not yet been taken before the joint site inspection conducted with Engineers from Sindh Province in this study (3/8/2023). Therefore, these 5 points would be considered as priority points for the site inspection.

Table 3.2.1 List of Bund Vulnerable Points in Sukkur Barrage Right Bank Region, Larkana

No.		Description	Verification	Opinion
In NFPP-IV	In the Sindh Contingency Plan			
214	53	S.L Bund Mile 5/6 Near Bachal Shah Miani (V.P)	There is no History of this reach, but during the flood in 2022, the leak and seepage have been observed.	This reach is needed for proper treatment and raising and widening of Bund.
251	54	Ghumra Loop Bund Mile 4/6 (V.P)	During 1960-61 as there was active erosion opposite Ghumra Loop Bund, and the reach of Ghumra Loop Bund Mile 4/6 to 6/3 became decommissioned as such Ruk Loop Bund has acted as 1st Line of defense since then	During the flood of 2022, the River Indus was striding towards this reach very rapidly. The scheme has been initiated for the construction stone apron along this reach.
216	55	Ruk Spur, mile 0/5, 1/1, 1/6 & 2/3 (V.P)	During the flood of 1976 heavy erosion was observed along Ruk Loop Bund, these four spurs were constructed in 1978-79.	During the flood in 2022, the river became very active against Ruk Loop Bund mile 0/0. The new scheme for construction New T-Head Spur has been initiated at this reach.
106	56	Moria Loop Bund Mile 0/0 to 1/0 (M.V.P)	During flood 2017 heavy scouring and erosion were observed and controlled by flood fighting works.	The scheme was approved for the construction of river training works viz: spurs, stone apron, which was completed. During flood and rain in 2022, this reach is again affected, which needs proper treatment.
223	57	Akil Loop Bund Mile 0/0 to 0/7 (V.P)	These bunds have historically come under the direct hit of River Indus at a right angle, For 30 years these bunds have faced erosion and heavy scouring. Many river training works were carried out along this bund, including spurs, stone apron, stone pitching, and widening of the bund.	During the flood of 2015, some river training works were disturbed, for which the scheme is intimated which is in progress.
-	58	Abad Mangli Extension Mile 0/0 to 1/5 (V.P)	This reach is located immediately upstream of Khairpur Larkana bridge and huge river training works were carried out as allied structures of the above bridge.	This bundle was unsafe/vulnerable up to 2019. At present this bundle is quite safe.
233	59	Old Abad Bund (V.P)	The river has remained very active along the Old Abad/New Abad bund for the last half century, but especially after the construction f Khairpur Larkana bridge. This reach was overtopped in floods in 2010 and 2022, the river water was cordoned off by Abad Manguli Bund.	The old/new bad bund needs immediate repair and rehabilitation work.

No.		Description	Verification	Opinion
In NFPP-IV	In the Sindh Contingency Plan			
233	60	L.S Bund 16/0 to 17/0 (Hakra Point) (M.V.P)	In flood 2015 the river came nearly 200 ft so 1n 2017 the scheme was initiated for the construction of a T-Head spur and Stone apron along this reach.	The earthen shank of the newly constructed T-Head Spur at Mile 16/1 needs to be raised and provide stone pitching.
257	61	L.S Bund Mile 22/0 to 22/4 Opposite Moen Jo Daro (V.P)	The reach remained in a direct hit of River since last three decade. In the eighties river training works viz: spurs, stone pitching, and stone aprons were constructed.	During flood 2017, this reach and T-Head Spur at L.S Bund 22/0 was in direct hit, which caused heavy damages. Which need to be recouped.
257	62	LS Bund mile 38/6 to 58/0 & 62/0 (V.P)	River Course Direct hits this Point	Proper watching and vigilance during floods.
257	63	LS Bund, mile 74/0 to 77/2 (V.P)	Leakage in Flood 1976	Same as above.
257	64	LS Bund, mile 95/2to 99/7 (V.P)	River Course Direct hits this Point	Same as above.
257	65	LS Bund, mile 95/2 (V.P)	Breach Accord in Flood 1976	Same as above.
257	66	LS Bund, mile 99/7(V.P)	Relief cut points for Drains Manchhar Flood water from the Barrage area of Taluka Sehwan.	Same as above.
257	67	LS Bund, mile 100/0 (V.P)	River Course Direct hits this Point	Same as above.
191	68	Sehwan Protective Bund mile 0/0 (V.P)	When Manchhar Flood Water Drains through the Aral Head Regulator the water hits this point.	Same as above.
261	69	Sann Veehdari Bund mile 11/6 (V.P)	Hill torrents Direct hits to this Point	Same as above.
258	70	Superio Bund RD 49 (PUO)	Breach Point during flood 2010. The whole reach of Suprio Bund always overtopped after the occurrence of bread in F.P Bund.	Same as above.
-	71	FP Bund RD 129 (PUO)	Hill torrents Direct hits to this Point	Same as above.
-	72	FP Bund RD 223, 246, 258, 282 and 325 (PUO)	A direct hit of Hamal Lake.	Same as above.
-	73	FP Bund RD 169 to 183 (PUO)	Hill torrents Direct hits to this Point	Same as above.
-	74	FP Bund RD 346 to 353 (PUO)	A direct hit of Hamal Lake	Same as above.

Source: Contingency Plan 2023, Government of Sindh Irrigation Department and Interview from Sindh Irrigation Department



Source: Advisory Team extracted from information by Sindh Irrigation Department information

Figure 3.2.4 Location of Bund Vulnerable Points Listed by Sindh Irrigation Department

The above five points are summarized in Table 3.2.2. According to the Sindh Irrigation Department, the need for early repair and reconstruction is recognized for these five points. Repairs to existing spurs are considered necessary in Locations No.60 and 61. On the other hand, repairs to the existing bund bodies are considered necessary in Locations No.53, 56, and 59.

Table 3.2.2 List of Vulnerable Points that Need Immediate Action in Sukkur Barrage Right Bank Region, Larkana

No.		Description	Location	Necessary Work by Sindh Irrigation Department
In NFPP-IV	In the Sindh Contingency Plan			
214	53	S.L Bund Mile 5/6 Near Bachal Shah Miani (V.P)	27°43'39.87"N, 68°45'45.36"E	Countermeasure against Seepage
106	56	Moria Loop Bund Mile 0/0 to 1/0 (M.V.P)	27°37'7.12"N, 68°20'55.52"E	Countermeasure against Scouring & Erosion
233	59	Old Abad Bund (V.P)	27°27'15.75"N, 68°15'41.33"E	Rehabilitation of the Bund
233	60	L.S Bund 16/0 to 17/0 (Hakra Point) (M.V.P)	27°21'49.93"N, 68°11'43.53"E	Rehabilitation of Spurs
257	61	L.S Bund Mile 22/0 to 22/4 Opposites Moen Jo Daro (V.P)	27°18'46.07"N, 68° 8'36.84"E	Same as Above

Source: Advisory Team extracted from information by Sindh Irrigation Department information

1) Location No.53: S.L Bund Mile 5/6 Near Bachal Shah Miani (V.P)

Figure 3.2.5 shows the situation around Location No.53.

The waterway during the ordinary time is apart from the bund and the direction of the waterway is almost parallel with the alignment of the existing bund. According to the Sindh Contingency Plan 2022, leakage and seepage flow were observed at this location during the 2022 Flood.

The bund here is only a single line and Sukkur Airport is located behind it. Hence, a breach or collapse of the bund in this stretch may hurt transportation.

Based on the joint site inspection with the engineers from PID-Sindh from 2/8/2023 to 4/8/2023, the engineer mentioned that there is no vulnerable concern at this point and this point can be disregarded.

Hence, this point is considered safe, and further study on this point would not be conducted anymore.

Source: Google Earth

Figure 3.2.5 Situation around Location No.53

Source: Advisory Team

Photo 3.2.2 Situation of Existing Bunds (1) (S.L Bund Mile 5/6 Near Bachal Shah Miani (V.P))

Source: Advisory Team

Photo 3.2.3 Situation of Existing Bunds (2) (S.L Bund Mile 5/6 Near Bachal Shah Miani (V.P))

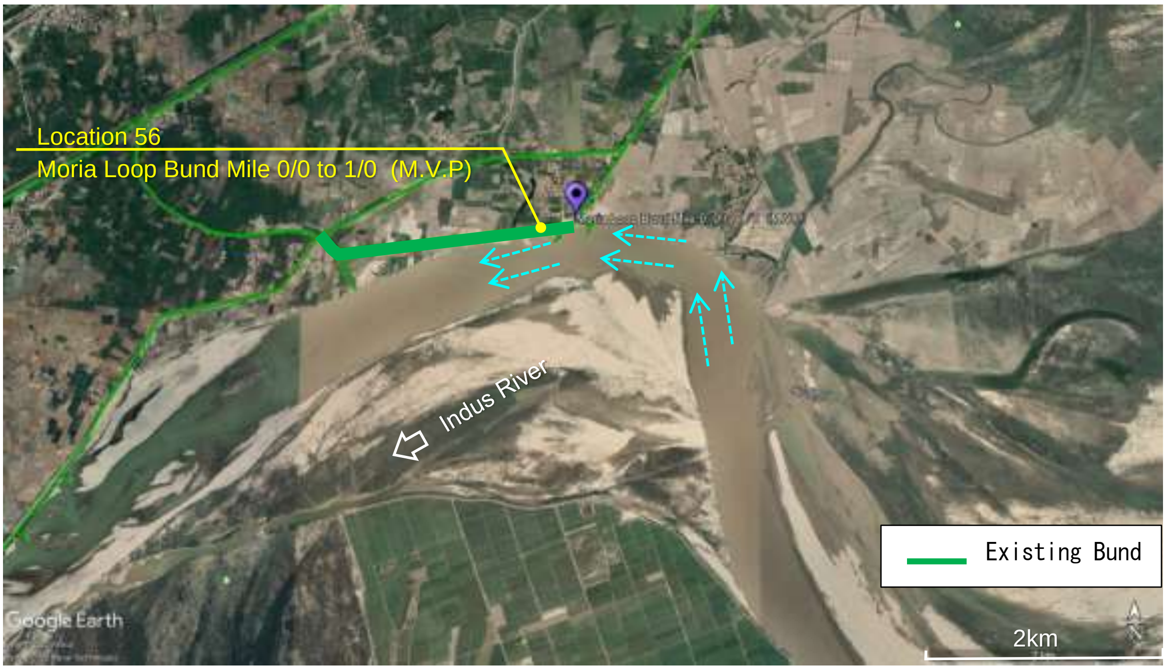
2) Location No.56: Moria Loop Bund Mile 0/0 to 1/0 (M.V.P)

Figure 3.2.6 shows the situation around Location No.56.

The waterway during the ordinary time is in front of the existing bund. The bund is located on the outer side of the steep curve of the waterway. Due to such a situation, erosion and scouring around the riverbank have been serious issues and it was damaged also during the 2022 Flood.

The bund here is double-layered. Hence, although a breach or collapse of the bund in this stretch occurs, the inundation due to the overflow from the Indus River may not expand significantly. Some residential area exists between the first and send lines of the bunds.

Based on the joint site inspection with the engineers from PID-Sindh from 2/8/2023 to 4/8/2023, the rehabilitation work for the existing spur was ongoing.



Source: Google Earth

Figure 3.2.6 Situation around Location No.56

Source: Advisory Team

Photo 3.2.4 Situation of Existing Bund (Moria Loop Bund)

Source: Advisory Team

Photo 3.2.5 Situation of Spur (Moria Loop Bund)

3) Location No.59: Old Abad Bund (V.P)

Figure 3.2.7 shows the situation around Location No.59.

The waterway during the ordinary time is in front of the existing bund. The bund is located on the outer side of the steep curve of the waterway. There is a J-head spur and it seems to help to keep some distance between the waterway and the existing bund.

The bund here is double layered and the bund namely Abad Mangli Extension is evaluated safe by the information in Table 3.2.1. Hence, although a breach or collapse of the bund in this stretch occurs, the inundation due to the overflow from the Indus River may be stopped by the second line bund. However, if a flood on the same scale as the 2010 Flood, the second line bund, which does not have the same strength and resistance as the first line bund, may break.

The area between the first line bund and the second line bund is used as agricultural land. although the population concentration area is not located close to the second-line bund, the urban area of Larkana is located only about 10 km upstream of the second-line bund.

A joint site inspection was conducted between 2/8/2023 and 4/8/2023 with engineers from the Sindh Irrigation Department. The bund height at this location was about 1m from the ground in the land side, and the bund height was significantly lower than the bund on the upstream and downstream sides. Protective structures using straw and wood were installed in front of the bund to prevent erosion of the existing bund by waves.

Source: Google Earth

Figure 3.2.7 Situation around Location No.59

Source: Advisory Team

Photo 3.2.6 Situation on the River Side of Existing Bund (Old Abad Bund)

Source: Advisory Team

Photo 3.2.7 Situation Behind the Existing Bund (Old Abad Bund)

4) Location No.60: L.S Bund 16/0 to 17/0 (Hakra Point) (M.V.P)

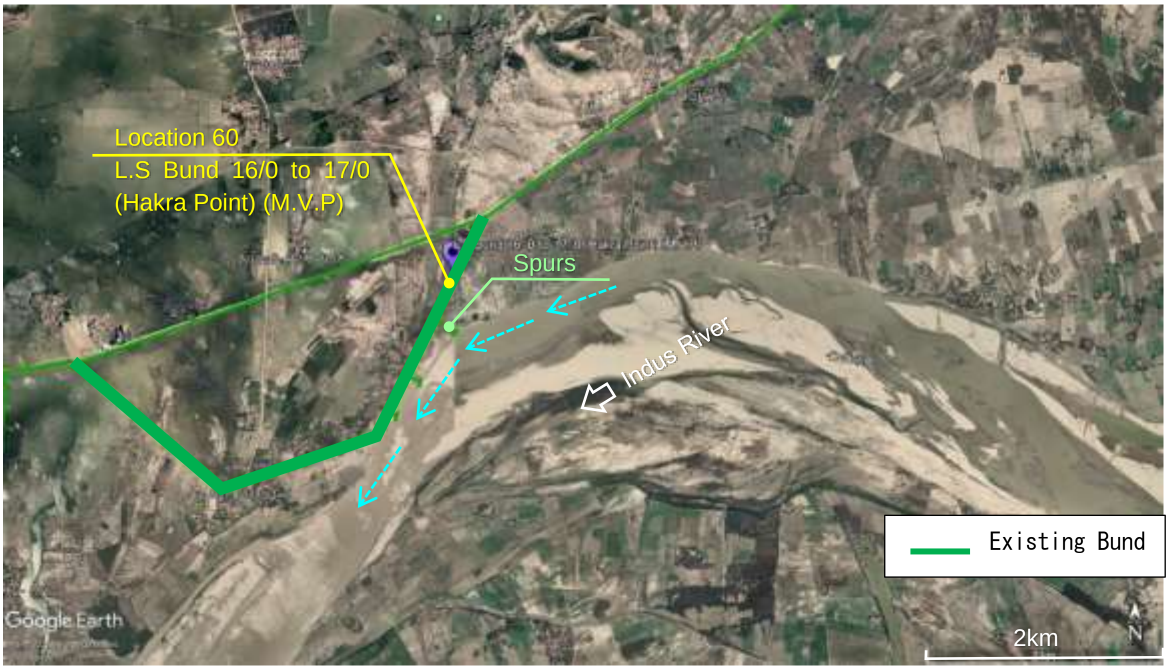
Figure 3.2.8 shows the situation around Location No.59

The waterway during the ordinary time is in front of the existing bund. The bund is located on the outer side of the steep curve of the waterway. Furthermore, the direction of the waterway is hitting the upstream side of this point.

There are 3 spurs here, however ground around the spur located on the downstream side is not seen with the satellite images and the effect of the spurs seems to be insufficient. Also, the necessity of the rehabilitation of the spurs is recognized by PID-Sindh(See Table 3.2.1)

The bund here is double-layered. Hence, although a breach or collapse of the bund in this stretch occurs, the inundation due to the overflow from the Indus River may not expand significantly. Some residential area exists between the first and send lines of the bunds.

From 2/8/2023 to 4/8/2023, a joint site inspection was conducted with engineers from the Sindh Irrigation Department. According to the information of the Sindh Irrigation Department at the site, the front side of the existing spur needed repair. However, when it was inspected at the site, there was no noticeable damage at present, and it seems to have already been repaired.



Source: Google Earth

Figure 3.2.8 Situation around Location No.60

Source: Advisory Team

Photo 3.2.8 Status of Existing Bund (L.S Bund 16/0 to 17/0 (Hakra Point)

Source: Advisory Team

Photo 3.2.9 Status of Existing Spur (L.S Bund 16/0 to 17/0 (Hakra Point)

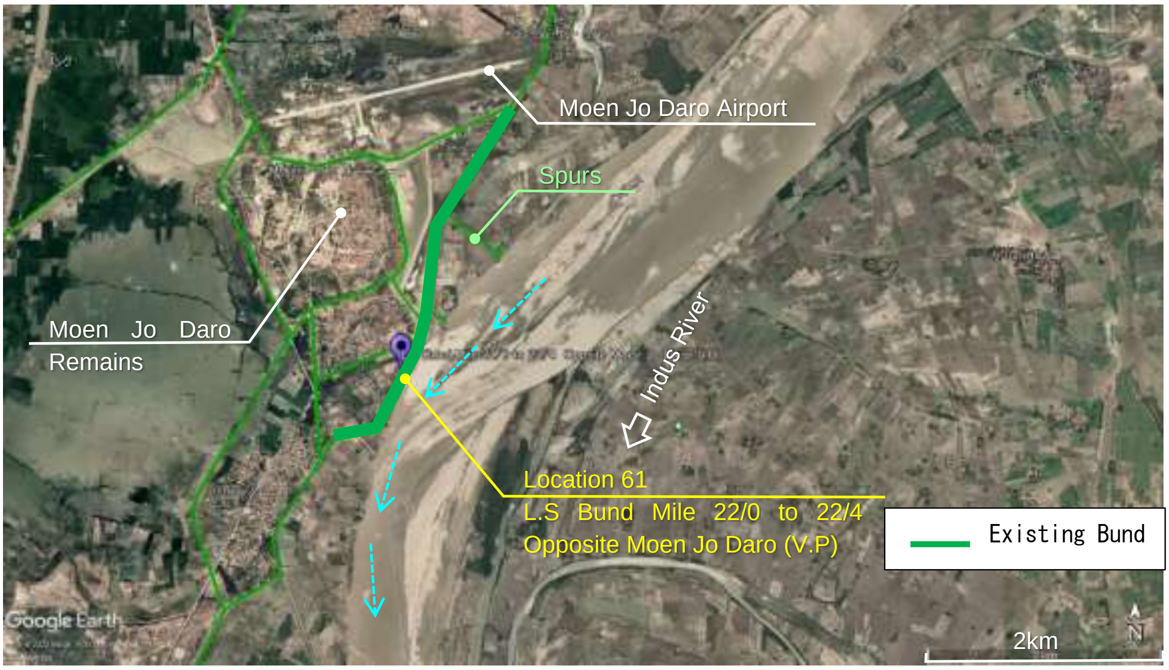
5) Location No.61: L.S Bund Mile 22/0 to 22/4 Opposite Moen Jo Daro (V.P)

Figure 3.2.9 shows the situation around Location No.61.

The waterway during the ordinary time is in front of the existing bund. The bund is located on the outer side of the curve of the waterway. There are spurs and it seems to help to keep some distance between the waterway and the existing bund in the upstream and downstream sides. However, there is a stretch without spurs and the waterway is located near the existing bund. This area seems to suffer from severe erosion and scouring. The necessity of the rehabilitation of existing spurs is recognized by PID-Sindh.

The bund here is more than double-layered. Hence, although a breach or collapse of the bund in this stretch occurs, the inundation due to the overflow from the Indus River may not expand significantly. Some residential area exists between the first and send lines of the bunds.

From 2/8/2023 to 4/8/2023, a joint site inspection was conducted with Sindh Irrigation Department engineers. According to the information from the Sindh Irrigation Department, the front side (apron part) of the existing spur was damaged by the scouring and needed to be repaired.



Source: Google Earth

Figure 3.2.9 Situation around Location No.61

Source: Advisory Team

Photo 3.2.1 Status of Existing Bund (L.S Bund Mile 22/0 to 22/4 Opposite Moen Jo Daro (V.P))

Source: Advisory Team

Photo 3.2.2 Situation of Existing Spur (L.S Bund Mile 22/0 to 22/4 Opposite Moen Jo Daro (V.P))

(2) Vulnerable Points Extracted from Joint Site Inspection Results

1) Akil Link Bund

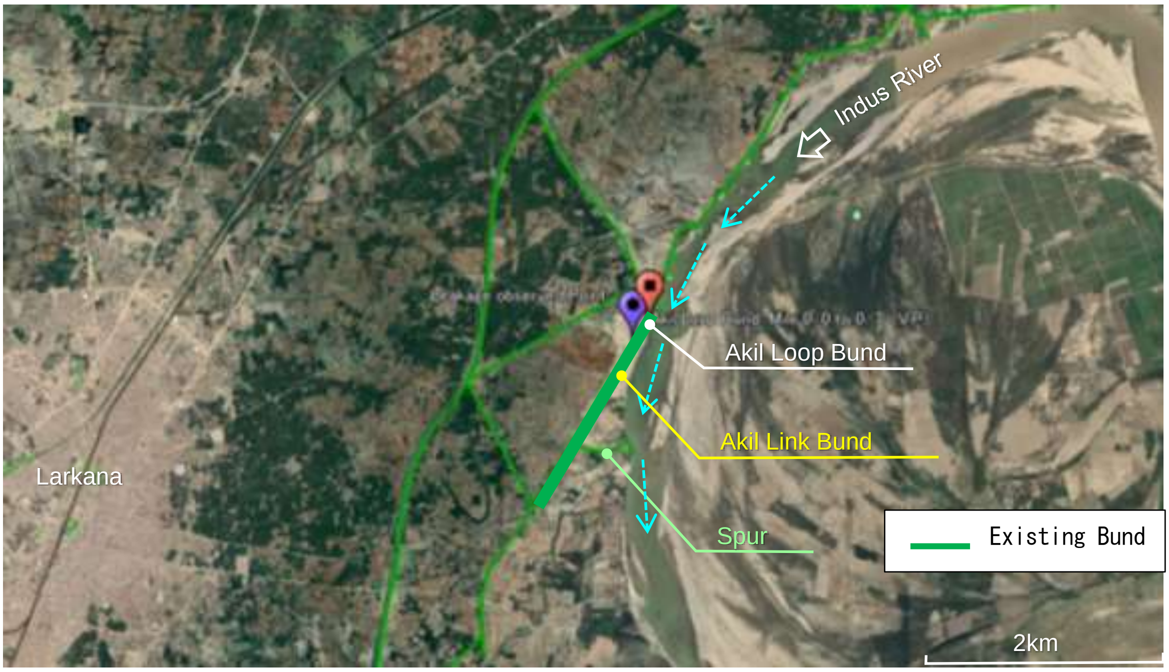
A joint site inspection was conducted between 2/8/2023 and 4/8/2023 with Sindh Irrigation Department engineers. The adjacent Akil Loop Bund was listed by the Sindh Irrigation Department as a vulnerable point due to erosion. At the Akil Link Bund adjacent to the Akil Loop Bund, the occurrence of water leakage was observed around the toe of the bund. At the site inspection, the situation was announced as Medium Flood, and the most of flood plain in front of the bund was inundated.

Figure 3.2.10 shows the situation near Akil Link Bund.

In ordinary times, the main channel is in front of the existing bund, and the bund is located outside the curve of the main channel. The distance between the existing bund and the main channel is assured except for the area around the upstream end which is connecting with the Akil Loop Bund due to the effect of the spur in the downstream side.

The bund at this location is double-layered. Therefore, even if a breach occurs in this section, there is a possibility that the inundation caused by the flooding of the Indus River will not be stopped by the second line bund. However, if a flood on the same scale as the 2010 Flood, the second line bund, which does not have the same strength and resistance as the first line bund, may break.

According to the results of rough hydraulic analysis, if the first and second bund breach, the flood flow will reach the major city of Larkana and other cities, causing great damage to the hinterland.



Source: Google Earth

Figure 3.2.10 Situation around Akil Link Bund

Source: Advisory Team

Photo 3.2.3 Status of Existing Bund (Akil Link Bund)

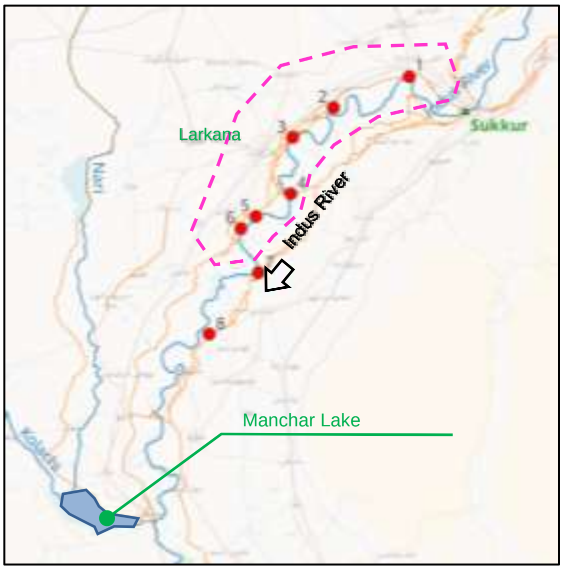
Source: Advisory Team

Photo 3.2.4 Situation of Water Leakage at the Toe of Existing Bund (Akil Link Bund)

(3) Vulnerable Points based on Satellite Image Analysis

Based on the aforementioned satellite image analysis, six points (No.1~6) shown in Figure 3.2.11 are considered vulnerable points in the stretch from Sukkur to the vicinity of Larkana. The vulnerable points are extracted considering the following points.

1. The distance between the channel and the bund is close or the channel is moving and getting closer to the existing bund.
2. The flow direction of the channel is hitting the existing bund.
3. There is a developed area behind the existing bund.
4. The elevation of the land side is relatively low, and it is easy for river water to flow into the developed area.



Source: Advisory Team

Figure 3.2.11 Location of Bund Vulnerable Points Based on Satellite Image Analysis

The names of the bunds at the six sites are as follows respectively.

1. S.L Bund~Ghumra Loop Bund → Implemented (ongoing), Less Urgent
2. S.L Bund → Less Urgent
3. Moria Loop Bund → Sindh Province recognizes the need for action
4. Old Abad Bund → Same as above
5. L.S Bund (16/0 to 17/0) → Same as above
6. L.S Bund (22/0 to 22/4) → Same as above

Five out of the above six points, except Location No.2, are also listed as vulnerable points extracted by the local government, which will be described later.

Regarding Location No.2, although satellite photographs in the past showed the main river channel approaching the existing bund, since 2013, the main river channel has been shifting to the left side of the bund, and as of August 2023, the vulnerability is low, and the countermeasure for this part is considered to be less urgent.

In addition, analysis with satellite images shows that only point 1 has a single-layered bund(see Figure 3.2.12), and the vulnerability appears to be higher than that of other points Location No.2~6. However, as shown in the summary of Location No.54 and 55 in Table 3.2.1, countermeasures by Sindh Province have been continuously implemented at this point, and certain effects have been obtained.

As for other Locations No.3~6, the necessity of countermeasures are recognized by Sindh Province. The situation of these 4 points will be described as mentioned above.

Source: Google Earth (The image is as of 4/20/2023)

Figure 3.2.12 Situation around Location No.1

(4) Summary

Table 3.2.3 summarizes the vulnerable points identified in this study with the urgency of countermeasures based on the situation as of August 2023. The table shows that the Old Abad Bund (V.P) and the Akil Link Bund has the higher urgency of countermeasures due to the no ongoing/proposed rehabilitation or improvement of the bunds. The other sites have relatively low urgency because the river channel has changed, countermeasures are being implemented, and the damage is only to the front spur, not the bund itself.

Table 3.2.3 Current Status of Extracted Sites and Urgency for Countermeasures

Source for Pick up[1)]	Description	Location	Current State	Urgency for Bund Rehabilitation/Improvement
1	S.L Bund~Ghumra Loop Bund	27°47'38.74"N 68°40'48.48"E	Rehabilitation of the existing spurs was ongoing.	Low
1	S.L Bund	27°41'27.91"N 68°25'57.76"E	Less Vulnerable	Low
2	S.L Bund Mile 5/6 Near Bachal Shah Miani (V.P)	27°43'39.87"N, 68°45'45.36"E	Not Vulnerable	None
1,2	Moria Loop Bund Mile 0/0 to 1/0 (M.V.P)	27°37'7.12"N, 68°20'55.52"E	Rehabilitation of the existing spurs was ongoing.	Low
1,2	Old Abad Bund (V.P)	27°27'15.75"N, 68°15'41.33"E	Not yet Rehabilitated	High
1,2	L.S Bund 16/0 to 17/0 (Hakra Point) (M.V.P)	27°21'49.93"N, 68°11'43.53"E	Rehabilitation of the existing spurs was completed.	Low
1,2	L.S Bund Mile 22/0 to 22/4 Opposite Moen Jo Daro (V.P)	27°18'46.07"N, 68° 8'36.84"E	Rehabilitation of the existing spurs(Only the apron) is needed.	Low
3	Akil Link Bund	27°34'31.09"N 68°17'15.03"E	Not yet Improved	High

1) 1: Analysis from Satellite Image, 2: Sindh Contingency Plan 2023, 3:Site Inspection in Aug. 2023.

3.3 O&M of the Indus Bunds

3.3.1 General

Flood control facilities are structures constructed to reduce the risk of flood damage, especially in the hinterland. Flood control facilities and associated waterways will be designed to sustainably discharge floodwaters to protect people and other infrastructure. It is one of the flood control facilities. Flood bunds are man-made structures, usually earthen embankments designed and constructed to contain or control the flow of water to protect from inundation, and are considered to act as a barrier between flood water and protected areas. Flood bunds may provide not only a reduction in hazard of flooding, but also zero risk of the flood risk. However, since bunds are generally made of earthen materials, appropriate measures are required to prevent damage to the bund body in the event of water flow hitting in the long run.

In NFPP-IV, a 100-year return period scale is set as a planning and design condition for the construction scale of the main river embankment of the Indus River. According to PIDs, the HWL(High Water Level) is set based on the 2010 Flood water level, which is understood to be equivalent to a 100-year return period. In particular, the diversion bunds around the barrages along Indus River are designed on a 100-year return period.

Presently flood protection bunds in vulnerable reaches are designed for a return period of 50 years. Similarly on Hill Torrents with flashy flows, a return period of 25 years is used.

3.3.2 Present Practice in Pakistan

(1) Offices and Guidelines Regulating Bunds

Generally, FFC has the role of project inspection through FMC, so it can be said that it supervises the design conditions of flood control works. All PIDs follow the FFC, while only the Sindh Province, supplements with the guidelines of its own Indus River Commission laid down in the Sindh Bund Manual, these condition does not conflict with the FFC’s suggestion.

(2) Length and Population of Flood Bunds and River Training Works

A large number of flood protection works and river training works were constructed after the 2010 and 2022 floods which is tabulated in Table 3.3.1.

Flood Protection Bunds and River Training works under their role of protecting the structure are the first line of defense against the erosive capabilities of a river channel and thus need to be designed and maintained with care and due diligence. Under-designed or inadequately maintained works structures may fail and result in significant damages to embankments or important salient components, which necessitate:

- Control the Flow Pattern in River Channels.
- To Protect Flood Bunds Against River Flood Spills and Rain Water
- To Guide the River Flow to Pass Smoothly Within a Defined River Channel
- Regulate the river area so that floodwaters can flow smoothly.

Table 3.3.1 Population and Length of Bunds in Pakistan

	Name Province	Bund / Dike / Embankment		River Training Works (Spur, Stud, Groyen)	
		Numbers	Length (KM)	Numbers	Length (KM)
1	PUNJAB	405	2966	878	590
2	SINDH	120	1490	160	570
3	KPK	75	75	390	97
4	Baluchistan	-	-	-	-
5	AJ & K (Azad Jammu and Kashmir)	15	1.68	-	-
6	GB(Gilgit-Baltistan)	32	29.6	-	-
7	FATA	65	51.5	-	-
8	Pak Railway	23	24	-	-
9	NGO(Non-Government Organization)s	197	270	-	-
	Grand Total	**932**	**4907.78**	**1428**	**1257**

Source: The Advisory Team summarized based on the information from each province.

(3) Necessity of Flood Protection Works (FPW)

The construction of Flood protection works is required to protect Irrigation Infrastructures and to safeguard the adjacent agricultural lands and human bodies (towns) from the onslaught of floods in Pakistan. PID activities in this regard include both short-term measures (flood fighting) and long-term measures (River flow training). To get the optimum results precise planning of flood Protection works between the river control points based on model studies is important. Unfortunately, due to financial constraints, most of the Flood protection projects cannot be implemented completely, which ultimately restricts the usefulness of the projects. PIDs are responsible for proper upkeep and maintenance of existing FP Works, Flood fighting, flood watching, and flood restoration of flood damages after monsoon season.

(4) Flood Bunds Maintenance

1) Causes of Damages

The major causes of damage to bunds are as follows.

- Topping Due Inadequacy of Design Parameters.
- Local Obstruction in the Vicinity of Flood Bunds Causes Heading Up.
- Flood Heights Increased Due to Change in River Morphology.
- Seepage Through the Body of Bunds.
- Erosion Due to River Current Attack.
- Settlement on Prolonged Saturation of Bunds Earthen Body
- Old Tree Roots with Soil of the Bund Body Create Runnels
- Piping Action
- Erosion Through Parallel Flows of River Current Along Bunds Slopes.
- Erosion Through Wave Action During Blow of Wind.
- Earthquake Which May Cause Liquefaction of the Bund Body
- Rain Cuts or Ravines Caused by Heavy Rain Fall.
- Cracking and Slope Failure

2) Overall Surveillance

Since the shanks of training works on rivers in Pakistan remain dry for the most of time (about 9 months a year 15th September to 15th June), they are prone to develop all sorts of weaknesses. Therefore, to ensure their safety effective surveillance is required which includes in-depth regular inspections and proper and timely maintenance works.

Based on the above-said surveillance a casual random inspection arranged by PIDS by a picked teams throughout the year is usually considered as adequate. keeping in view the importance of flood works it's not adequate there should be a thorough and detailed inspection by a competent expert team, in March /April each year and necessary maintenance works based on team findings should be completed before the 15th of June (start of moon soon).

During pre and post-flood inspections, the expert team may collect the following information,

- Approved L-Section and Designed X-Sections of the Bunds.
- Top Levels, Top Width, Side Slopes, Water Level at Various Discharges.
- Normal Surface Level (NSL) Both Sides of Bunds
- Unwanted Vegetation and Encroachment on Top of Bund and Side Slopes.
- Damaged Stone Riprap and Apron in Case of Armored Spurs
- Settlement of the TOP of the Bunds.

3) Maintenance of Flood Bunds

Maintenance Considerations

- Design Section of Flood Protection Structures Should Be Maintained.
- Weathering Action Over the Flood Bunds on Account of the Normal Wind, Local Traffic, Trespass, Settlement of Top Due to Heavy Traffic, and Washing Away the Soil from Top and Side Slopes Due to Rains.
- Rat Holes and Porcupine Holes Are Normally Responsible for Breach of the Bunds During Flood.
- Laying of Sheet Pile Along River Side Slopes.

The total allocation of the Annual O&M budget for flood bunds and River Training works is collected from the Provincial PIDs and tabulated in Table 3.3.2.

Table 3.3.2 Annual O&M Cost of Indus River System Flood Protection Works

	Name of Province	Annual O&M Budget for Drainage and Flood (Million PKR)		
		2021-22	2022-23	2023-24
1	Punjab	2,200	2,700	3,000
2	Sindh	1,500	1,700	2,000
3	KPK	Not Obtained	Not Obtained	Not Obtained
4	Balochistan	Not Obtained	Not Obtained	Not Obtained

Source: The Advisory Team summarized based on the information from each province.

3.4 On-going River Improvement Works

By "Sindh Contingency Plan 2023", "Flood Contingency Plan - 2022" and "SINDH FLOOD EMERGENCY REHABILITATION PROJECT (IRRIGATION COMPONENT)", the ongoing river improvement works in Sukkur -Barrage Right Bank Region are summarized in Table 3.4.1 and Table 3.4.2. As of August 2023, the details on the progress of each project could not obtained.

Table 3.4.1 List of Projects in Sukkur Barrage Right Bank Region (1)

Sr# in the Source	Name of Scheme REVISED LIST OF SCHEMES OF SINDH FOR THE UMBRELLA PC-I OF FLOOD PROTECTION SECTOR PROJECT-III (FPSP-III)
17	Construction of New T-Head Spur along Ruk Loop Bund at Mile 0/0+20, Providing Stone Pitching, Stone Apron along Ruk Loop Bund Mile 0/0 to 0/5 and Ghumra Loop Bund Mile 4/6 and Providing Stone Pitching and Apron at Remaining Portions of T-Spur Mile 0/5, 1/1, 1/6 and 2/3. (Western Sindh Circle)
18	Raising and strengthening and stone pitching along L.S Bund from mile 36/5 to 77/2 in Southern Dadu Division Dadu
19 (Not Along Indus River)	Strengthening / Earthwork from RD.) to 20.0 and RD 75.0 to 220.0 & stone pitching from RD.0.0 to 20.0 & RD.75.0 to 220.0 along F.P bund in Southern Dadu Division Dadu.
20	Restoration Works along S.L Bund mile 38/0 to 40/5, Akil Link Bund, Ilyas loop bund, Recoupment of the damaged apron of J-SPUR Akil Link Bund, and Construction of Protection Wall between Phulpota Minor and first defense line of River Bund and Reconstruction of Gauge Pillars in Northern Dadu Division Larkana.
21	Recoupment of damaged stone apron along L.S Bund Mile 22/3 to 22/4, damaged apron of T-SPUR at L.S Bund Mile 22/0, and raising strengthening of Hassan Wahan loop and Moen-Jo-Daro protection bund and providing stone pitching along Gaji Derolind bund Northern Dadu Division Larkana.
22	Restoration of old/new Abad Bund Mile 0/0 to 1/3 + 410, Providing Stone Pitching and Stone Apron along Old / New Abad Bund and Abad Ring Bund Mile 2/0 in Northern Dadu Division Larkana.

Source: Sindh Contingency Plan 2023

Table 3.4.2 List of Projects in Sukkur Barrage Right Bank Region (2)

Sr# in the Source	Name of Scheme
1	Providing stone apron, stone pitching, and earthwork along L.S Bund Mile 18/0 to 20/0 in Northern Dadu Division, Larkana (ADP (Annual Development Programme) No.1157).
2	Recoupment of Damaged T-Head Spur along Agani Akil Loop Bund 2/6+250, Mole of 0/4 and 0/7 Mole Spur and 09 Nos. Stone Studs in Larkana Sub-division (ADP No: 1158/2021-22).
3	Providing stone apron, stone pitching, and earthwork along L.S Bund Mile 16/7 to 17/2 in Northern Dadu Division, Larkana (Non-ADP).
4 (Not Along Indus River)	Retaining Wall along Gaj Diversion Bund in Southern Dadu Division
5 (Not Along Indus River)	Strengthening / Earthwork from RD-20.0 to 75.0 & Stone Pitching from RD-20.0 to 75.0 along F.P Bund in Southern Dadu Division Dadu

Source: Flood Contingency Plan – 2022

Table 3.4.3 List of Projects in Sukkur Barrage Right Bank Region (3)

Sr# in the Source	Name of Scheme EMERGENT REHABILITATION WORKS UNDER SFERP
17	Rehabilitation of Karampur Ring Bund
20	River Training Works at Ruk Loop Bund (Indus River)

Source: SINDH FLOOD EMERGENCY REHABILITATION PROJECT (IRRIGATION COMPONENT), June 2023

3.5 Hydrological condition of the Indus River

3.5.1 Discharge of the Indus River by Probability Scale

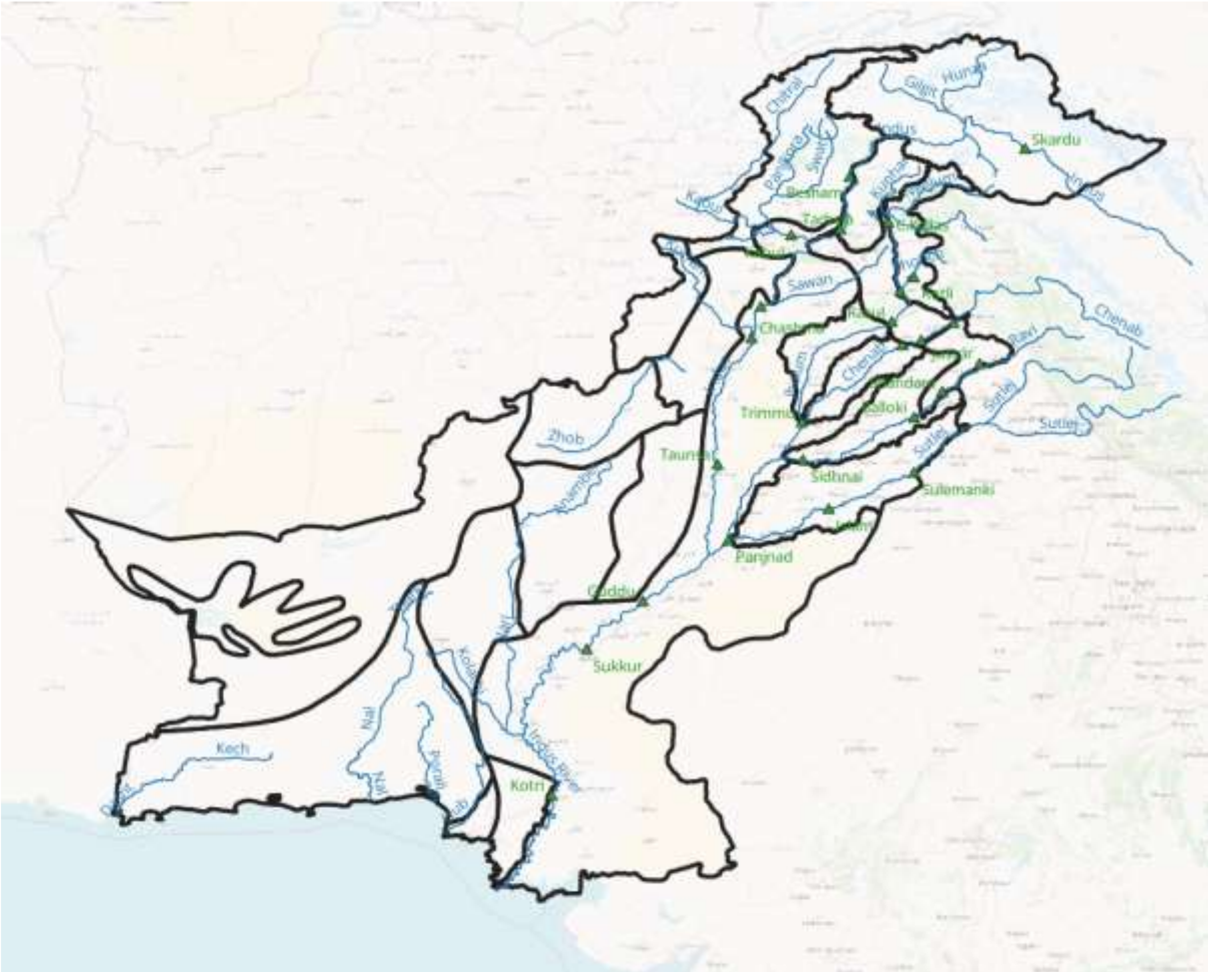
The discharge of each discharge station in the Indus River basin by probability scale is shown in Table 3.5.1, the location map of each discharge station is shown in Figure 3.5.1, and the discharge of each discharge station during the 50-year probability flood is shown in Figure 3.5.2.

The area targeted by the bund improvement project is the area downstream of Sukkur Station on the Indus River, and the discharge will be about 34,000m$^{3/}$s during the 50-year probability flood. It may be more than 34,000 m^3/s for 50-year probability flood if the overflow from Guddu barrage or the other barrages in the 2010 flood is considered.

Table 3.5.1 Discharges by Probability Scale for Each Discharge Station in the Indus River Basin

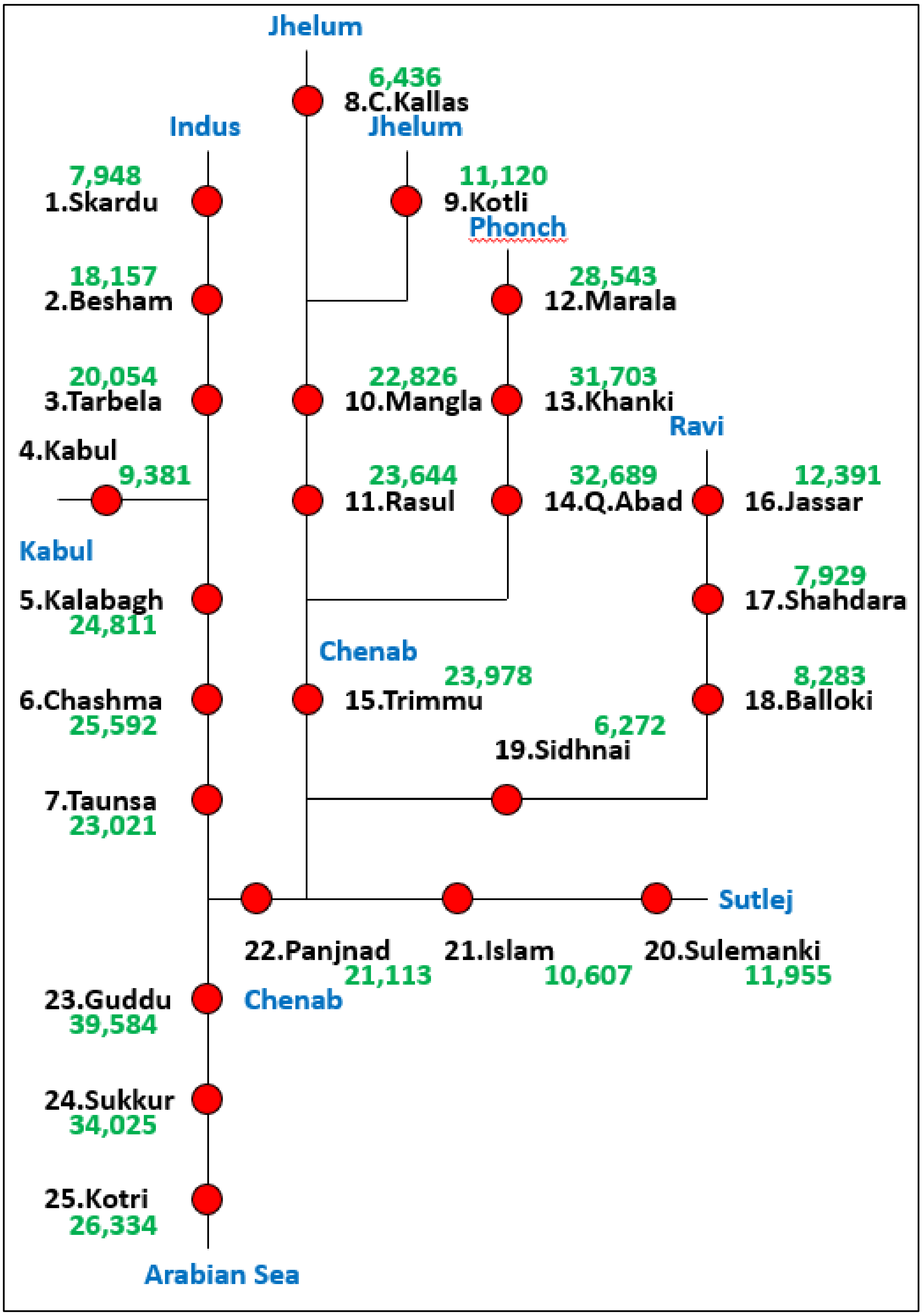
No	River	Observatory	Analysis		X-years Discharge						
			Available Data	Probability Distribution	5-years	10-years	20-years	30-years	50-years	80-years	100-years
1	Indus	Skardu	35	Gumbel	6,029	6,629	7,204	7,535	7,948	8,328	8,509
2	Indus	Besham	35	SqrtEt	12,640	14,263	15,905	16,888	18,157	19,354	19,932
3	Indus	Tarbela	49	Gev	12,371	14,255	16,463	17,947	20,054	22,262	23,415
4	Kabul	Kabul	37	Gev	4,703	5,881	7,235	8,130	9,381	10,675	11,341
5	Indus	Kalabagh	95	Gumbel	17,168	19,555	21,846	23,163	24,811	26,317	27,031
6	Indus	Chashma	52	SqrtEt	16,455	19,111	21,829	23,466	25,592	27,611	28,594
7	Indus	Taunsa	63	Gumbel	15,557	17,890	20,127	21,413	23,021	24,494	25,193
8	Jhelum	C.Kallas	10	LN3Q	2,665	3,574	4,664	5,400	6,436	7,507	8,056
9	Phonch	Kotli	10	Gev	2,050	3,491	5,794	7,742	11,120	15,478	18,100
10	Jhelum	Mangla	96	Gev	8,291	11,562	15,656	18,547	22,826	27,515	30,035
11	Jhelum	Rasul	97	Gev	7,323	10,840	15,387	18,675	23,644	29,206	32,241
12	Chenab	Marala	97	Gev	12,244	16,183	20,858	24,018	28,543	33,320	35,820
13	Chenab	Khanki	97	Gev	12,609	17,083	22,517	26,264	31,703	37,545	40,637
14	Chenab	Q.Abad	53	LN3Q	13,646	18,612	24,199	27,793	32,689	37,582	40,042
15	Chenab	Trimmu	93	Gev	10,800	14,240	18,080	20,563	23,978	27,442	29,203
16	Ravi	Jassar	74	Gev	4,550	6,448	8,696	10,217	12,391	14,688	15,888
17	Ravi	Shahdara	95	Gev	2,857	3,964	5,383	6,400	7,929	9,628	10,551
18	Ravi	Balloki	97	Gev	3,381	4,508	5,895	6,864	8,283	9,820	10,639
19	Ravi	Sidhnai	97	Gev	2,251	3,135	4,262	5,066	6,272	7,611	8,334
20	Sutlej	Sulemanki	97	Gumbel	6,162	7,971	9,707	10,706	11,955	13,096	13,637
21	Sutlej	Islam	97	LogP3	5,125	7,082	8,772	9,639	10,607	11,389	11,723
22	Chenab	Panjnad	97	Gev	11,689	14,654	17,480	19,097	21,113	22,953	23,823
23	Indus	Guddu	53	Gev	23,092	28,229	33,170	36,019	39,584	42,851	44,403
24	Indus	Sukkur	92	Gev	22,574	26,490	29,948	31,814	34,025	35,939	36,811
25	Indus	Kotri	91	Gev	16,489	19,824	22,795	24,409	26,334	28,011	28,775

Source: Advisory Team



Source: Advisory Team

Figure 3.5.1 Location Map of Discharge Stations in the Indus River Basin



Source: Advisory Team

Figure 3.5.2 Discharge at Each Discharge Station in 50-Year Probability Flood

3.5.2 Rainfall by probability scale in the study area

Table 3.5.2 shows rainfall by probability scale for each rainfall station (1-day, 2-day, 3-day, 5-day, 7-day, 1-month rainfall). Figure 3.5.3 the location map of each rainfall station.

As an example, Figure 3.5.4 shows the 7-day rainfall at each rainfall station during the 50-year probability flood. In the study area, rainfall stations along the Indus River tend to have higher rainfall than other rainfall stations.

Table 3.5.2 (1) Rainfall by Probability Scale for Each Rainfall Station (1-day rainfall)

Basin	No	Observatory	Analysis		X-years Rainfall						
			Available Data	Probability Distribution	5-years	10-years	20-years	30-years	50-years	80-years	100-years
10.Sutlej	46	Bahawalpur	31	Gev	56.3	66.0	74.4	78.8	84.0	88.4	90.4
11.Indus River	59	Khanpur	31	Gev	74.6	103.7	136.1	157.1	185.9	215.2	230.0
	61	Rohri	31	Gev	62.0	89.2	121.5	143.3	174.6	207.6	224.9
	62	Sukkur	23	Gev	51.1	76.3	107.4	129.2	161.3	196.3	215.0
	63	Jacobabad	31	Gev	66.0	103.7	153.6	190.4	246.8	311.0	346.3
	64	Larkana	31	LogP3	71.5	107.3	145.4	168.4	197.9	225.4	238.5
	65	Mjo_Daro	30	Gev	57.4	80.5	106.3	122.9	145.9	169.1	180.9
	67	Padidan	31	Gev	79	125	186	230	298.9	376.8	419.6
	68	Nawabshah	31	Gev	69.9	94.7	120.9	137.1	158.4	179.3	189.6
	69	Chhor	31	Gev	108.8	139.9	171.4	190.3	214.8	238.0	249.4
	72	Badin	31	Gev	105.1	139.2	175.6	198.4	228.8	258.8	273.7
	73	Hyderabad	16	Gev	109.8	142.4	175.0	194.5	219.6	243.2	254.7
15.D.G. Khan Hill	78	Barkhan	31	Gev	63.5	77.6	91.7	100.1	110.7	120.7	125.6
16.Kacchi Basin Hill	79	Sibbi	31	LN3Q	58.7	71.3	82.8	89.3	97.2	104.3	107.7
17.Khithar Hill	80	Khuzdar	31	Gev	49.6	67.6	91.9	110.2	138.6	171.5	189.8
18.Kharan Closed Desert Hill	83	Kalat	31	SqrtEt	55.5	77.4	101.1	116.0	135.8	155.2	164.8
	84	Dalbandin	31	Gev	33.2	46.1	59.5	67.8	78.8	89.4	94.7
21.Karachi Area Hill	93	Karachi	31	Gev	88.6	111.5	132.6	144.4	158.7	171.5	177.4
	94	Lasbela	16	Gev	44.4	62.1	83.4	98.1	119.3	141.9	153.9

Source: Advisory Team

Table 3.5.2 (2) Rainfall by Probability Scale for Each Rainfall Station (2-day rainfall)

Basin	No	Observatory	Analysis		X-years Rainfall						
			Available Data	Probability Distribution	5-years	10-years	20-years	30-years	50-years	80-years	100-years
10.Sutlej	46	Bahawalpur	31	LogP3	67.1	78.1	86.6	90.8	95.3	98.9	100.5
11.Indus River	59	Khanpur	31	Gev	89.4	131.3	182.0	216.8	267.3	321.3	349.8
	61	Rohri	31	Gev	74.5	108.9	150.4	178.9	220.2	264.3	287.5
	62	Sukkur	23	Gev	64.1	97.4	139.4	169.1	213.4	262.0	288.3
	63	Jacobabad	31	Gev	78.4	126.3	192.2	242.1	320.5	412.0	463.4
	64	Larkana	31	LogP3	91.5	143.3	200.7	236.5	283.5	328.4	350.1
	65	Mjo_Daro	30	Gev	69.7	105.0	149.2	180.2	226.0	276.1	302.9
	67	Padidan	31	Gev	97	160	249	318	426.6	555.5	628.6
	68	Nawabshah	31	SqrtEt	90.5	129.6	172.5	199.5	235.6	271.0	288.5
	69	Chhor	31	Gev	146.6	193.5	243.6	274.9	316.8	358.0	378.6
	72	Badin	31	SqrtEt	136.9	187.1	241.5	275.5	320.7	364.7	386.5
	73	Hyderabad	16	SqrtEt	136.8	190.4	248.7	285.3	334.0	381.6	405.2
15.D.G. Khan Hill	78	Barkhan	31	SqrtEt	82.2	104.1	127.3	141.5	160.3	178.4	187.3
16.Kacchi Basin Hill	79	Sibbi	31	Gev	69.9	87.9	105.2	115.2	127.8	139.3	144.8
17.Khithar Hill	80	Khuzdar	31	Gev	63.9	87.8	118.6	140.8	174.2	211.5	231.7
18.Kharan Closed	83	Kalat	31	SqrtEt	68.7	95.9	125.6	144.2	169.0	193.3	205.3
21.Karachi Area Hill	93	Karachi	31	Gev	117.4	145.5	170.7	184.3	200.7	214.9	221.4
	94	Lasbela	16	Gev	56.9	84.5	121.6	149.3	192.3	241.7	269.2

Source: Advisory Team

Table 3.5.2 (3) Rainfall by Probability Scale for Each Rainfall Station (3-day rainfall)

Basin	No	Observatory	Analysis		X-years Rainfall						
			Available Data	Probability Distribution	5-years	10-years	20-years	30-years	50-years	80-years	100-years
10.Sutlej	46	Bahawalpur	31	Gev	72.5	87.5	101.3	109.1	118.5	127.0	130.9
11.Indus River	59	Khanpur	31	Gev	92.9	138.2	194.2	233.5	291.2	354.1	387.6
	61	Rohri	31	Gev	80.0	116.6	160.5	190.4	233.4	279.1	303.1
	62	Sukkur	23	LN2LM	79.9	136.1	211.2	265.6	346.5	434.8	481.9
	63	Jacobabad	31	Gev	86.1	137.2	206.1	257.5	337.4	429.4	480.5
	64	Larkana	31	Gev	93.5	141.1	199.1	239.1	297.2	359.7	392.8
	65	Mjo_Daro	30	Gev	77.9	121.8	179.5	221.7	286.0	358.9	398.9
	67	Padidan	31	Gev	102	171	268	344	464.7	609.0	691.2
	68	Nawabshah	31	SqrtEt	99.2	142.4	189.8	219.7	259.8	299.0	318.4
	69	Chhor	31	Gev	162.0	214.4	269.9	304.4	350.3	395.3	417.7
	72	Badin	31	SqrtEt	151.6	207.7	268.4	306.3	356.9	406.1	430.4
	73	Hyderabad	16	LN3Q	137.7	174.8	210.3	230.7	256.4	280.0	291.2
15.D.G. Khan Hill	78	Barkhan	31	Gev	87.2	106.5	125.6	136.7	150.9	164.1	170.4
16.Kacchi Basin Hill	79	Sibbi	31	Gev	74.7	95.5	116.4	128.9	145.0	160.3	167.6
17.Khithar Hill	80	Khuzdar	31	LN3Q	77.8	106.7	139.6	160.9	190.2	219.5	234.4
18.Kharan Closed	83	Kalat	31	SqrtEt	76.7	107.3	140.6	161.6	189.5	216.9	230.4
21.Karachi Area Hill	93	Karachi	31	Gev	124.8	157.1	187.0	203.7	224.1	242.3	250.8
	94	Lasbela	16	Gev	61.3	92.7	136.3	169.4	221.9	283.5	318.2

Source: Advisory Team

Table 3.5.2 (4) Rainfall by Probability Scale for Each Rainfall Station (5-day rainfall)

Basin	No	Observatory	Analysis		X-years Rainfall						
			Available Data	Probability Distribution	5-years	10-years	20-years	30-years	50-years	80-years	100-years
10.Sutlej	46	Bahawalpur	31	Gev	77.1	93.8	109.6	118.5	129.5	139.5	144.2
11.Indus River	59	Khanpur	31	Gev	104.5	155.7	219.0	263.1	328.0	398.4	435.9
	61	Rohri	31	Gev	87.9	129.6	180.2	215.1	265.7	319.9	348.6
	62	Sukkur	23	LN2LM	84.4	145.9	229.1	289.7	380.7	480.7	534.2
	63	Jacobabad	31	Gev	88.4	143.0	218.1	275.1	365.0	469.9	528.9
	64	Larkana	31	Gev	100.6	160.2	239.0	296.9	385.6	486.4	541.9
	65	Mjo_Daro	30	Gev	84.6	139.1	216.0	275.2	369.9	482.1	545.8
	67	Padidan	31	Gev	111	189	302	391	534.9	709.4	809.8
	68	Nawabshah	31	LN3Q	111.8	166.7	229.9	271.2	328.2	385.8	415.1
	69	Chhor	31	Gev	174.1	232.0	294.0	332.8	384.8	436.0	461.6
	72	Badin	31	Gev	165.1	215.5	266.9	297.8	337.9	376.2	394.8
	73	Hyderabad	16	LN3Q	152.9	194.0	233.3	255.8	283.9	309.7	322.0
15.D.G. Khan Hill	78	Barkhan	31	Gev	99.4	119.1	138.0	148.8	162.5	174.9	180.8
16.Kacchi Basin Hill	79	Sibbi	31	Gumbel	80.2	100.3	119.5	130.6	144.5	157.2	163.2
17.Khithar Hill	80	Khuzdar	31	Gev	87.2	120.9	161.8	190.0	231.0	275.1	298.5
18.Kharan Closed	83	Kalat	31	Gev	81.2	108.0	136.3	153.7	176.9	199.4	210.6
21.Karachi Area Hill	93	Karachi	31	Gev	136.3	169.2	198.4	214.2	233.1	249.5	256.9
	94	Lasbela	16	LogP3	82.6	128.3	188.8	232.9	299.6	373.8	413.9

Source: Advisory Team

Table 3.5.2 (5) Rainfall by Probability Scale for Each Rainfall Station (7-day rainfall)

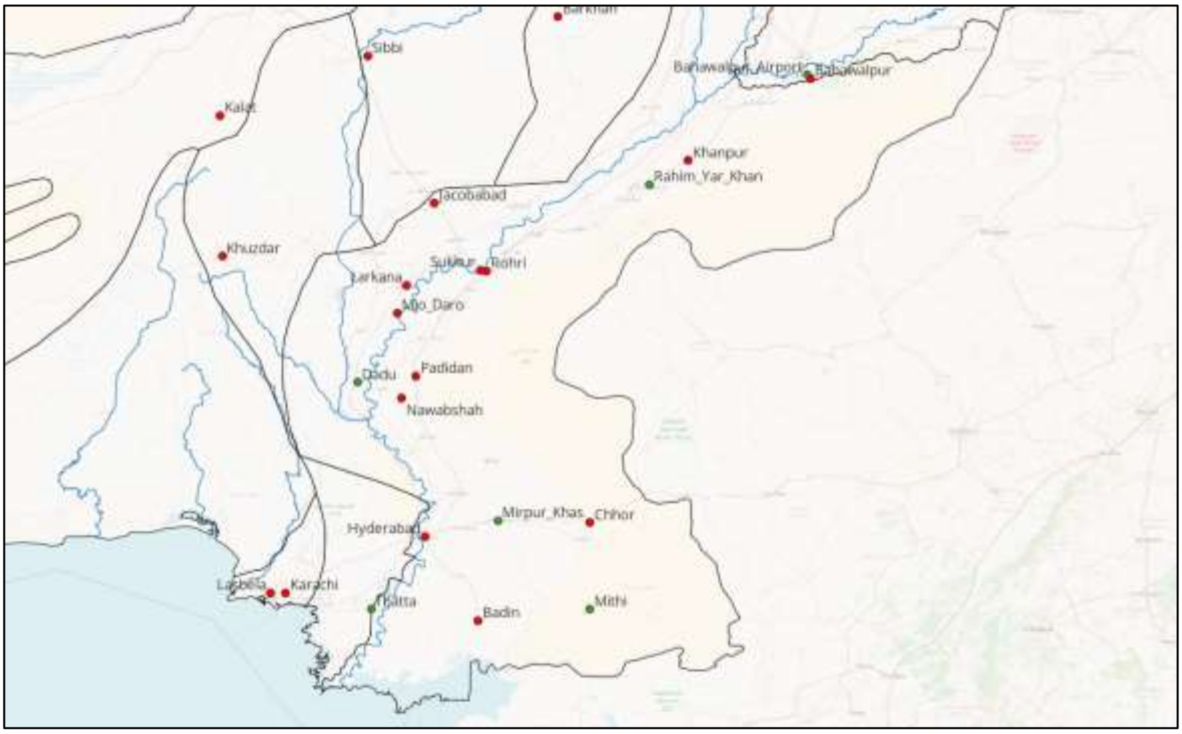
Basin	No	Observatory	Analysis		X-years Rainfall						
			Available Data	Probability Distribution	5-years	10-years	20-years	30-years	50-years	80-years	100-years
10.Sutlej	46	Bahawalpur	31	Gumbel	82.9	101.9	120.1	130.6	143.7	155.7	161.4
11.Indus River	59	Khanpur	31	LogP3	114.7	176.8	249.0	296.2	360.8	425.5	457.9
	61	Rohri	31	Gev	90.1	134.9	190.8	229.9	287.7	350.8	384.6
	62	Sukkur	23	Gev	80.4	126.8	187.8	232.5	300.8	378.1	420.6
	63	Jacobabad	31	Gev	98.3	159.1	242.5	305.6	404.6	520.0	584.7
	64	Larkana	31	LogP3	114.4	193.3	291.2	357.5	450.5	545.6	594.0
	65	Mjo_Daro	30	Gev	88.2	146.3	229.1	293.3	396.6	519.8	590.0
	67	Padidan	31	Gev	116	198	317	411	565.7	753.1	861.1
	68	Nawabshah	31	Gev	129.3	195.2	276.2	332.5	414.9	504.1	551.6
	69	Chhor	31	Gev	186.6	247.8	313.2	354.0	408.7	462.4	489.2
	72	Badin	31	Gev	175.5	228.8	282.7	315.1	356.8	396.5	415.7
	73	Hyderabad	16	LN3Q	158.3	201.2	242.1	265.6	294.9	321.9	334.7
15.D.G. Khan Hill	78	Barkhan	31	Gumbel	106.3	126.7	146.3	157.5	171.6	184.5	190.6
16.Kacchi Basin Hill	79	Sibbi	31	Gev	85.9	109.0	131.9	145.4	162.7	178.9	186.7
17.Khithar Hill	80	Khuzdar	31	Gev	95.2	133.8	181.6	215.2	264.5	318.3	347.0
18.Kharan Closed	83	Kalat	31	Gev	92.6	129.8	172.6	200.9	240.5	281.4	302.5
21.Karachi Area Hill	93	Karachi	31	Gev	143.1	177.9	208.8	225.5	245.5	262.8	270.7
	94	Lasbela	16	Gev	78.7	119.3	175.6	218.4	286.0	365.2	409.8

Source: Advisory Team

Table 3.5.2 (6) Rainfall by Probability Scale for Each Rainfall Station (1-month rainfall)

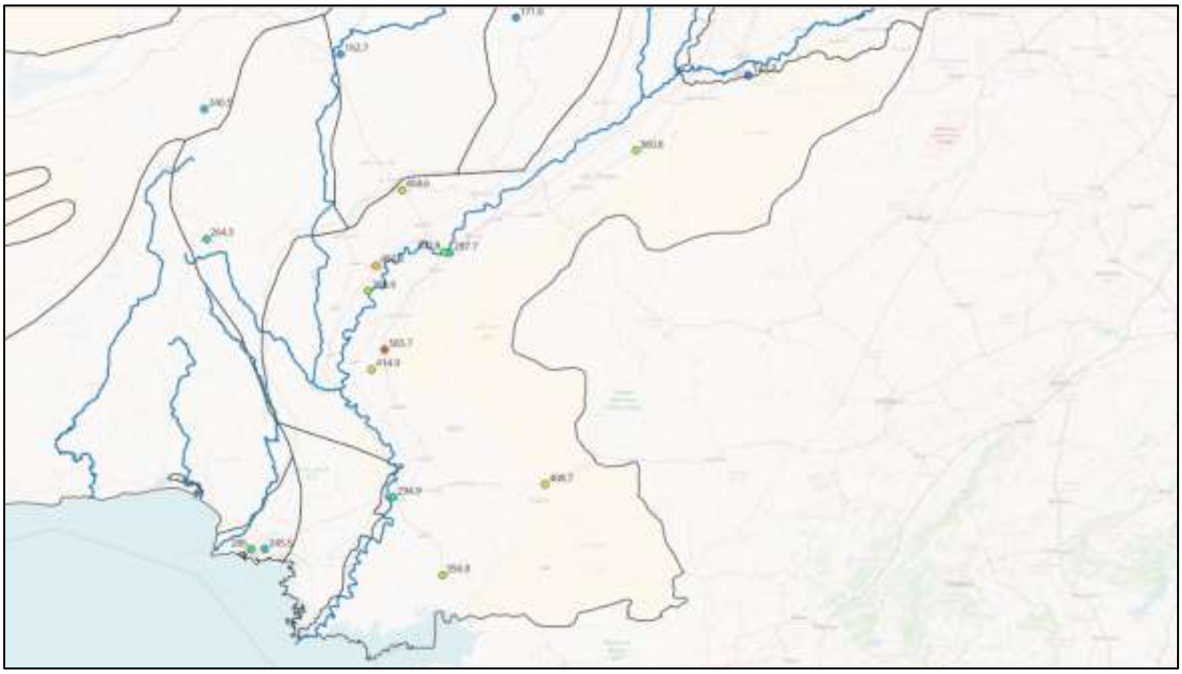
Basin	No	Observatory	Analysis		X-years Rainfall						
			Available Data	Probability Distribution	5-years	10-years	20-years	30-years	50-years	80-years	100-years
10.Sutlej	46	Bahawalpur	31	Gev	106.6	133.8	161.3	177.8	199.1	219.4	229.2
	47	Bahawalpur_Airport	13	Gumbel	140.4	173.4	205.0	223.2	245.9	266.7	276.6
11.Indus River	58	Dg_Khan	19	Gev	127.1	156.9	185.5	201.8	222.3	241.0	249.9
	59	Khanpur	31	LogP3	129.3	195.6	272.3	322.3	390.9	459.6	494.2
	60	Rahim_Yar_Khan	13	LN2LM	146.2	214.2	293.6	346.0	418.7	492.8	530.5
	61	Rohri	31	Gev	99.1	151.1	219.1	268.7	344.2	429.3	476.0
	62	Sukkur	23	Gev	98.0	150.0	216.5	264.1	335.7	415.2	458.4
	63	Jacobabad	31	LogP3	134.7	236.8	371.9	468.0	608.8	759.3	838.2
	64	Larkana	31	Gev	123.5	201.5	309.7	392.2	522.6	675.7	761.9
	65	Mjo_Daro	31	Gev	98.0	162.2	256.4	331.3	454.2	604.1	690.7
	66	Dadu	19	Gev	134.3	187.4	248.0	287.9	343.5	400.7	430.1
	67	Padidan	31	LogP3	154.6	276.7	437.1	550.0	713.4	885.7	975.1
	68	Nawabshah	31	Gev	154.9	231.8	324.4	387.8	479.4	577.3	628.9
	69	Chhor	31	Gev	238.5	320.7	408.9	464.3	538.7	612.2	648.9
	70	Mithi	19	SqrtEt	239.1	332.7	434.5	498.4	583.6	666.7	707.8
	71	Mirpur_Khas	19	Gev	181.3	279.5	406.3	497.8	635.9	790.3	874.4
	72	Badin	31	Gumbel	214.7	276.3	335.3	369.3	411.8	450.6	469.0
	73	Hyderabad	16	Gumbel	192.0	247.2	300.2	330.6	368.7	403.6	420.1
15.D.G. Khan Hill	78	Barkhan	31	Gumbel	171.2	202.2	232.0	249.1	270.5	290.1	299.3
16.Kacchi Basin Hill	79	Sibbi	31	LN3Q	118.5	148.5	177.1	193.4	213.9	232.6	241.5
17.Khithar Hill	80	Khuzdar	31	Gev	127.0	175.8	234.7	275.1	333.5	396.0	428.9
18.Kharan Closed Desert Hill	83	Kalat	31	Gev	114.0	153.3	198.3	227.8	269.1	311.6	333.5
20.Sehwan & Petaro Area Hill	92	Thatta	19	Gev	208.4	251.3	287.9	307.2	329.5	348.5	357.0
21.Karachi Area Hill	93	Karachi	31	Gumbel	199.3	260.9	320.0	354.0	396.5	435.4	453.8
	94	Lasbela	16	LogP3	104.8	167.4	258.5	330.0	445.4	583.4	662.1

Source: Advisory Team



Source: Advisory Team

Figure 3.5.3 Location Map of Rainfall Stations in the Study Area



Source: Advisory Team

Figure 3.5.4 7-day Rainfall for Each Rainfall Station in 50-Year Probability Flood

3.6 Proposed Bund Improvement

3.6.1 Candidate for Bund Strengthening Scheme (Takayama)

(1) Candidate Sites for Countermeasures

Based on the information in Table 3.2.3, it is considered that the Old Abad Bund and the Akil Link Bund have a high urgency to be rehabilitated and reinforced.

About the Old Abad Bund, according to Table 3.2.2 and the site inspection results, it is considered that the existing bund along the Indus River needs to be rehabilitated and reinforced at Location No.56: Moria Loop Bund Mile 0/0 to 1/0 and Location No.59: Old Abad Bund. In these two locations, the existing bund has suffered more damage at Location No.59: Old Abad Bund. Erosion is the main cause of the damage to the bund, and it is necessary to repair the bund in consideration of erosion and scouring protection measures at this location.

On the other hand, the occurrence of water leakage at the Akil Link Bund was observed during a joint site inspection conducted with engineers from the Sindh Irrigation Department. At this site inspection, it was announced Medium Flood, and most of the floodplain in front of the bund was inundated. Flood of the Indus River continues for a long time with a high water level. Hence countermeasures against seepage flow in the bund section would be one of the issues. Japan has accumulated a lot of experience and knowledge on the countermeasures for seepage control, and it is preferable to implement the countermeasure for seepage control from the aspect of technology transfer.

shows the two locations mentioned above. Both sites are in the vicinity of Larkana, which is a concentrated population area, and there is a risk that the urban area of Larkana will be affected if the existing bunds break.

Considering the above situation, the following two sites would be selected as candidate sites.

- [Seepage Control Works] Akil Link Bund
- [Scouring/Erosion Protection Work] Old Abad Bund

Source: Google Earth

Figure 3.6.1 Location Map of Bund Strengthening

(2) Study on Seepage Control Works(For Akil Link Bund)

1) Analysis of the Cause of the Damage and Necessary Countermeasures

During the site inspection, a water leakage was observed around the land side toe of Akil Link Bund. It can be inferred from the local situation at the site that the ground level on the land side is slightly lower than the ground level on the riverside across the bank, and therefore, it can be considered that the leakage is mainly caused by the fact that the foundation ground is sandy. Hence, the following measures are recommended.

- ✓ Lower the Water Level Inside the Bund During Floods
- ✓ Lower the Hydraulic Gradient Inside the Bund During Floods
- ✓ Reduce Seepage Flow in the Foundation Ground

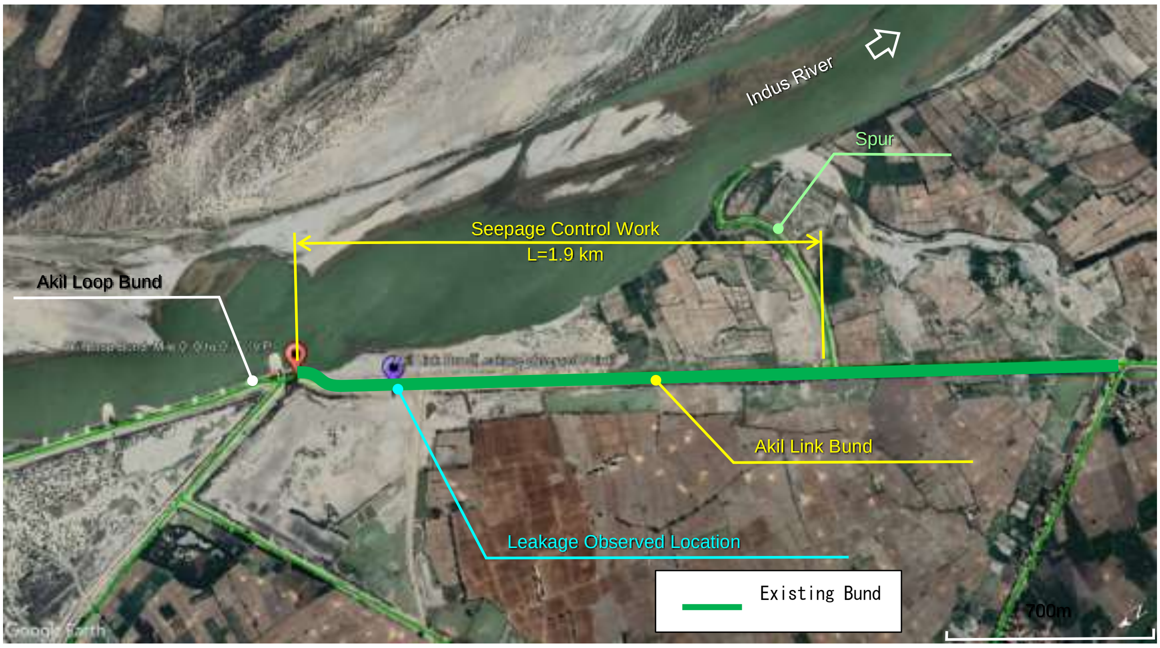
2) Area of the Countermeasure

The upstream end of the countermeasure shall be the intersection with the Akil Loop Bund, and the downstream end shall be the point connected to the existing stone pitching near the root of the existing spur (see Figure 3.6.2). The length of the countermeasure will be about 1.9 km. Figure 3.6.2 shows the area of the proposed countermeasure.

The area of the countermeasures needs to be finalized in the F/S stage or after it by confirming the local site condition in detail and the stability against seepage.

Source: Google Earth

Figure 3.6.2 River Bank Protection Near the Downstream End of Seepage Control Works



Source: Google Earth

Figure 3.6.3 Area of Seepage Control Works

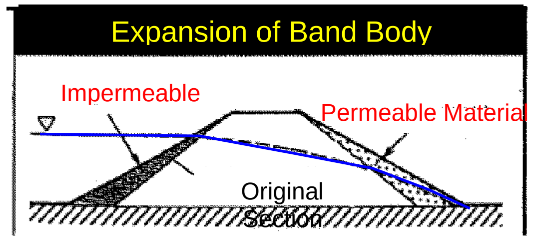
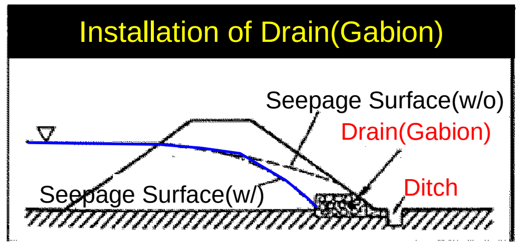
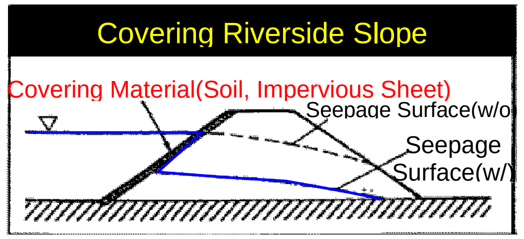
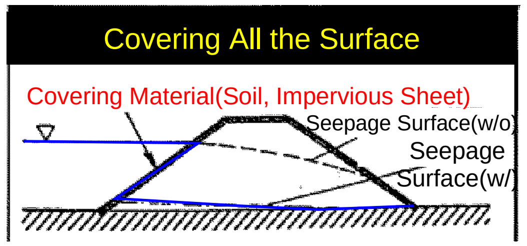
3) Selection of the Countermeasure

Table 3.6.1 and Table 3.6.2 shows the major reinforcement methods for seepage. There are reinforcement methods for the bund body and the foundation ground. These methods have been applied in bund reinforcement in Japan and all the methods are popular.

Considering the above-mentioned objectives, the following reinforcement methods from Table 3.6.1 and Table 3.6.2 are likely to be more applicable to this target site.

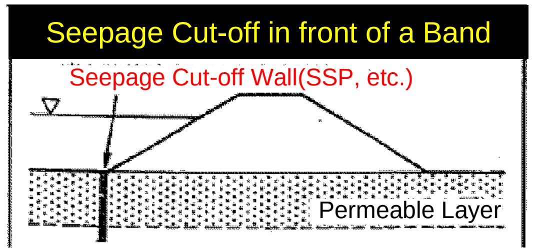
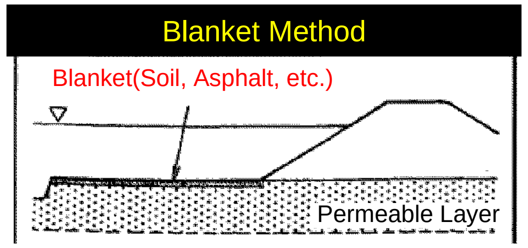
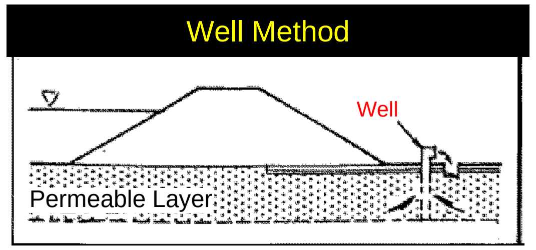
1. Expansion of Band Body
2. Installation of Drain
3. Seepage Cut-off

Table 3.6.1 Major Reinforcement Method for Seepage (Reinforcement of Bund Body)

	Major Reinforcement Method	Principle	Planning & Design	Construction	Maintenance	Others	Piping	Slope Stability	Applicability
Reinforcement of Bund Body		• By expanding the cross-section of the embankment to extend the length of the seepage path, reducing the mean hydraulic gradient to increase the safety of the bund body. • Safety against slip failure is increased with a milder slope. • It also functions as a counterweight to prevent piping of the foundation ground near the toe of the bund body. • Impact on both the riverside and landside is the most significant	• Requires area in the front and rear side of the bund. In this case, it should be noted that securing the flow area on the riverside and the land on the land side is needed. • The bund material used will be less permeable than the existing embankment for the riverside and will be more permeable than the existing embankment for the landside. • If the foundation ground is soft, consider the impact on the existing embankment (cracks at the top, etc.).	• Easy availability of bund materials is desirable. • To make it fit well with the existing bund body, step cuts have to be made.	• Since the bund body may settle on soft ground, continuous monitoring of the settlement at the crest to secure the crest height and management is needed.	• Easy to combine with other reinforcement methods. • Some liquefaction prevention effects can be expected due to the increase in effective overburden pressure, and stability against earthquakes will be improved with the milder slope.	○	◎	**High** • This method is effective in reducing the hydraulic gradient in the bund body.
		• Replacing the bund material around the toe with a permeable material and draining the water inside the bund body quickly. • Suppresses the rise of the water surface in the bund body and the decrease of the shear strength of the body. • Increased stability by replacing the toe with a draining material(gabion) with greater shear strength. • Impact on the land side is a little, but the reliability and effectiveness are better than the other options.	• This is especially effective when the permeability of the bund is on the order of 10^{-3} -10^{-4} cm/sec. Bund foot drainage is necessary (The area on the land side must be secured). • The thickness of the drain shall be 0.5m or more, and the width shall be set not to exceed the 0.3 of average hydraulic gradient. • Use manic or fine-grained crushed stone as the drain material and cover it with a filter material (usually an artificial material) such as geotextile.	• Attention not to create gaps between the bund and the joints of the filter material must be paid. • Damage to the filter material (artificial material) with heavy equipment must be avoided.	• To monitor the long-term stability of the effect, it is desirable to install water-level observation holes in the bund body and drains. • Observe the state of drainage during floods or heavy rains, and check for soil runoff after floods.	• When covering with soil for greening, attention to prevent the intrusion of soil into the drain is needed. • Some effect in preventing liquefaction is expected because it dissipates pore water pressure.	◎	◎	**High** • This method is the best way to drain the water in the bund body rapidly.
		• The river-side slope is covered with impervious material. Refrain rainfall and river water at high water levels from permeating to bund body. • Impact on both the riverside and landside is hardly expected.	• Effective for the bund body with highly permeable gravel or sandy soil. • It is necessary to examine the stability against sliding of the covering material (soil material or artificial material such as impervious sheet). • When an impervious sheet is used, cover it with concrete blocks or soil to prevent it from lifting and deteriorating due to residual water pressure. • In the case of less permeable ground, drainage measures are required.	• In the case of covering with soil, To make it fit well with the existing bund body, step cuts have to be made. • Installation of the joints and edges of the impermeable sheet needs to be careful. • Firmly compact the cover soil.	• When using soil, attention to the generation of cracks due to drying is needed. • When using impermeable sheets, attention to damage caused by piling or root growth of plants shall be needed. • It is important to note that groundwater in the bund body tends to stay around the toe of the riverside slope.	• If an impervious sheet is used, it is necessary to check the deformation or damage after earthquakes.	○	○	**Moderate** • This method is effective in preventing seepage flow in the bund body from the riverside slope.
		• All the surface of the bund is covered with impervious material. Refrain rainfall and river water at high water levels from permeating to bund body.	• It is necessary to examine the stability against sliding of the covering material (soil material or artificial material such as impervious sheet). • When an impervious sheet is used, cover it with concrete blocks or soil to prevent it from lifting and deteriorating due to residual water pressure. • It is necessary to consider drainage and ventilation measures to prevent wetting of the bund body and increase of air pressure.	• In the case of soil material, To make it fit well with the existing bund body, step cuts have to be made. • Installation of the joints and edges of the impermeable sheet needs to be careful. • Firmly compact the cover soil.	• When using soil, attention to the generation of cracks due to drying is needed. • When using impermeable sheets, attention to the damage caused by piling or root growth of plants shall be needed. • Groundwater in the bund body tends to stay around the toe of the riverside slope, attention to the deformation around it is needed.	• The effect of suppressing rainfall infiltration can be expected just by covering the top and berms. • If an impervious sheet is used, it is necessary to check the deformation or damage after earthquakes.	○	○	**Moderate** • Ventilation of the bund body is needed.

Legend:◎. More Effective; ○. Effective; △. Less Effective.
Source: Translated and Added by the Adviser Team on Guideline for Structural Study of River Dike, Japan, 2012.2

Table 3.6.2 Major Reinforcement Method for Seepage (Reinforcement of Foundation Ground)

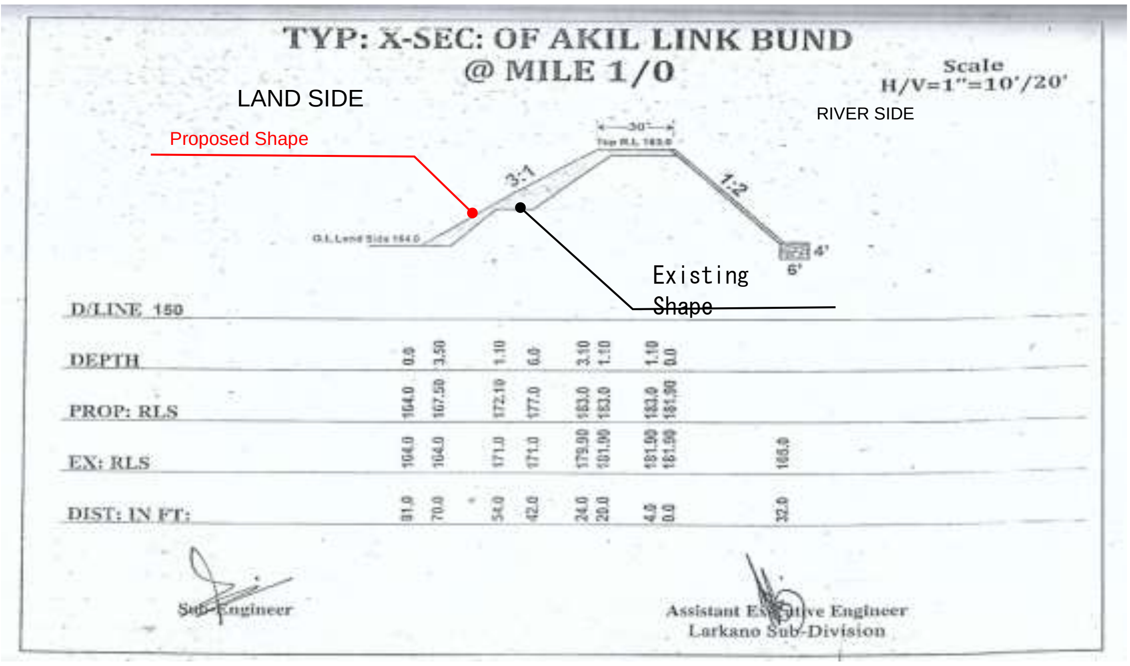
	Major Reinforcement Method	Principle	Planning & Design	Construction	Maintenance	Others	Piping	Slope Stability	Applicability
Reinforcement of Foundation Ground		• By installing the seepage cut-off wall such as steel sheet piles at the edge of the riverside slope, the seepage water into the foundation ground is reduced.	• Followings are used as materials for cutoff walls. ✓ [Sheet Piling] Steel Sheet Pile, Concrete Sheet Pile, ✓ [Consecutive Underground Wall] Slurry Trench, Concrete Wall ✓ [Grouting] Cement Grouting • To halve the seepage water, it is necessary to penetrate 80 to 90% of the thickness of the permeable layer.	• The pilling method of the cutoff wall shall be selected considering the surrounding environment. • Attention to the construction of the joints of cutoff walls. • Attention to the treatment of the joint between the existing bund body and the cutoff wall head.	• Since the cutoff wall is installed in the ground, basically no maintenance is required.	• It will block groundwater flow, so it is necessary to consider the impact on the surrounding area. • Since it constrains the side directions, it can be expected to have some effect against deformation due to liquefaction in the riverside.	○	△	**High** • This method is effective in preventing seepage flow in the foundation ground.
		• With covering flood plain in front of a bund covered with an impervious material (mainly soil material), the seepage path is extended to reduce the seepage pressure around the toe.	• Effective when the flood plain consists of gravel soil or sandy soil. • Blanket length of 30m or more can bring effect. • When soil material (good quality soil) is used, the thickness must be 50 cm or more to prevent scouring and must be covered with sodding.	• When soil material is used, it should be firmly compacted to improve impermeability. • Attention to the treatment of the joint between the existing cut-off wall and the blanket.	• When using soil material, pay attention to the generation of cracks due to drying is needed. • It is important to note that groundwater in the bund body tends to stay around the toe of the river-side slope.	• It does not lead to the improvement of seismic resistance. However, if a flood plain is newly installed, the overburden pressure on the riverside will increase, and some effect against liquefaction can be expected.	○	△	**Low** • The existing floodplain is very spacious, and it will be costly and ineffective.
		• Seepage pressure around the toe is reduced by draining the seepage water from the foundation ground by a pressure-reducing well-installed rear of the toe.	• It is necessary to install a well and bund foot drainage and an area on the land side is required. • As a short-term, emergency response, it is recommended to consider applying it to rivers with beds above ground and rivers in alluvial fans.	• Wells, etc. shall have a structure that does not cause clogging.	• Attention to soil runoff and clogging of filter materials is needed. • A facility to control the operation of the pump is required.	• It is desirable that there is a drainage in the surrounding area and that the water can be drained appropriately.	○	△	**Low** • This method is for short-term emergency response.

Legend:◎. More Effective; ○. Effective; △. Less Effective.
Source: Translated and Added by the Adviser Team on Guideline for Structural Study of River Dike, Japan, 2012.2

4) Countermeasures to be Applied

(a) Basic Dimensions

As of 2023/8, no survey cross-section of the Akil Link Bund is available. On the other hand, since the Sindh Irrigation Department has provided the materials related to the Typical Section, the existing ground height and the bund height of the plan are set concerning it (see Figure 3.6.1).



Source: Sindh PID

Figure 3.6.4 Typical section of Akil Link Bund

Table 3.6.3 Basic Dimensions

Item	Dimensions	Verification
Top Height of Existing Bund	RD.181.9ft (55.44m)	Reference to the typical cross-section of Akil Link Bund (Figure 3.6.4)
Top Height of the Proposed Bund	RD.183.0ft (55.79m)	Same as above
Top Width	30 ft (9.15m)	Same as above
Slope	Riverside: 2.0:1 Landside: 3.0:1	Same as above

Source: Prepared based on the information from Sindh-PID

Since the stability of the slope has not been an issue at this location so far, it is decided not to expand the section beyond the current proposed section in this study.

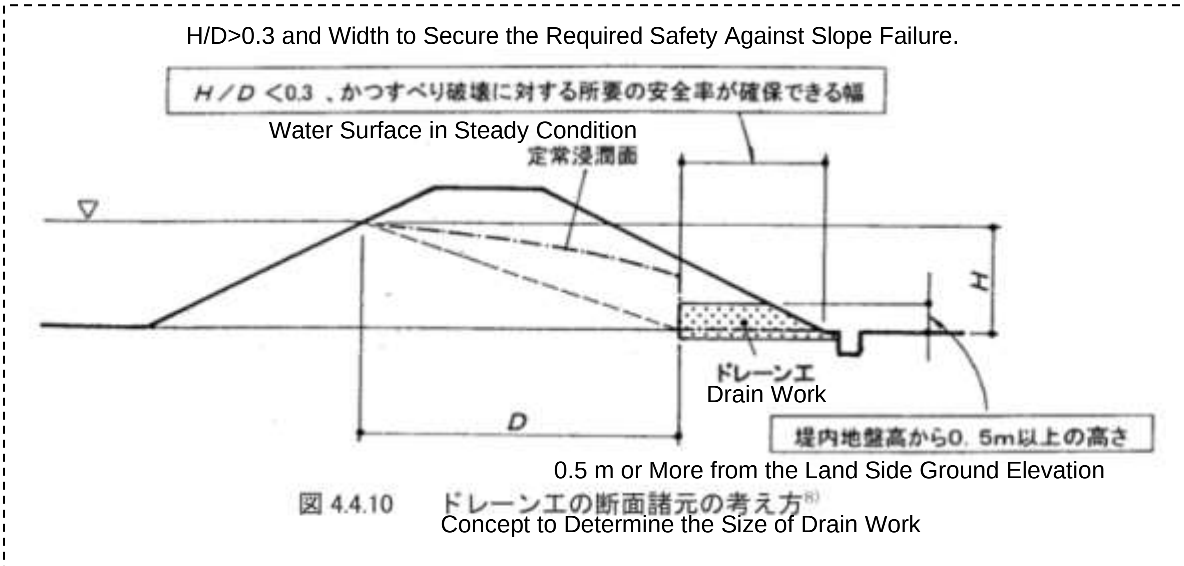
(b) Drain Work

Providing a drain at the toe of the landside slope, the water level of the bund body can be lowered efficiently during floods. In Japan, gabion is often used for drain work. Here, single-grain crushed stone and gabion are used for the drain work. Gabion is also commonly used in Pakistan and is easy to obtain.

The recommended size for the drain work is 0.5 m or more in height, 1/10 in bund width and an average hydraulic gradient not exceeding 0.3. Figure 3.6.5 shows the concept for determining the drain dimensions. Here, the size of the drain is set to B x H = 0.5 m x 1.0 m considering the sample cases in Japan.

To drain the surface water and the collected water in the drain work, a U-ditch(bund foot drainage) is installed at the toe of the landside slope.

The cross-sectional shape of the drain shall be finalized at the F/S or subsequent stages, considering the results of seepage flow analysis with the external force conditions such as design water level and design rainfall.



Source: Translated and Added by the Adviser Team on Guideline for Structural Study of River Dike, Japan, 2012.2

Figure 3.6.5 Concept to Determine the Size of Drain Work

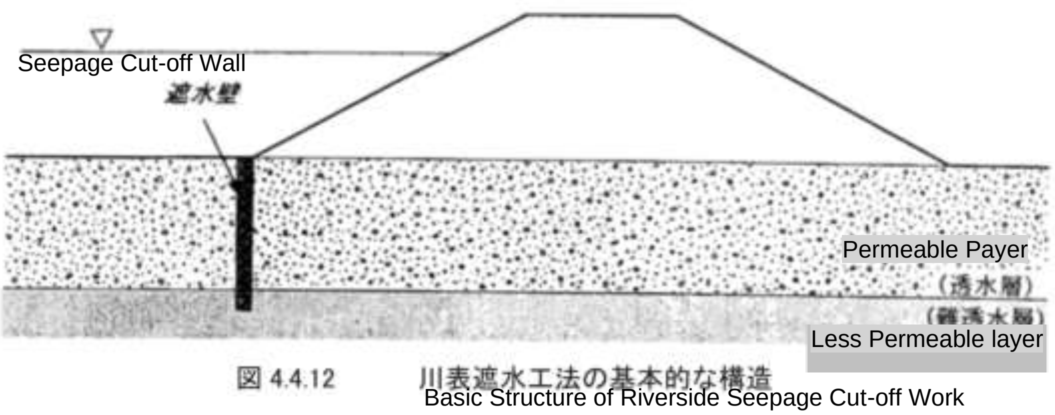
(c) Seepage Cut-off Wall

Seepage cut-off work is a method to prevent piping failure by installing a seepage cut-off wall in the foundation ground near the riverside toe of the bund to reduce the amount of water and water pressure that seeps into the foundation ground from the river. This method is applied when the permeability of the foundation ground is high. However, when the permeable layer is thick and deposited, the penetration length of the seepage cut-off wall becomes long, which may cause issues in terms of economy and workability.

In Pakistan, some measures are taken to install seepage cut-off walls such as sheet piles on bund bodies. However, in consideration of the fact that installing other material with the soil material inside the bund body may cause a water path near the boundary between these different materials and that repairing the bund when damaged will not be easy compared with the case of soil material alone, To install a seepage cut-off wall near the riverside toe following the Japanese standard would be proposed as shown in.

summarizes the types and characteristics of Seepage cut-off work. From the methods listed, the steel sheet pile method which is the most commonly used is selected, considering the marketability of materials, workability, a lot of actual samples, and the fact that the thickness of the permeable layer is not yet grasped at present.

The final vertical length of the seepage cut-off wall shall be determined at the F/S or the subsequent stages, after conducting a geotechnical investigation of the project site and considering the results of seepage flow analysis with external force conditions such as design water level and design rainfall.



Source: Guideline for Structural Study of River Dike, 2012.2

Figure 3.6.6 Basic Structure of Riverside Seepage Cut-off Work

Table 3.6.4 Types and Characteristics of River Side Seepage Cut-off Work

Type	Method	Characteristics
Sheet Pile	Steel Sheet Pile Method	・ Due to the good workability and frequently used. ・ There is water leakage from the joints, especially when the ground is gravel soil, the joints may open and the effect may be reduced.
	Concrete Sheet Pile Method	・ There is an RC sheet pile and a PC sheet pile. The length is limited to within 5 m, and the actual samples are limited.
	Sheet Wall Method	・ A wide thin steel sheet is penetrated with a vibro hammer and a water jet, and the joint is filled with grout material to ensure seepage cut-off. ・ Compared with the steel sheet pile, the sheet wall is better at seepage cut-off effect and more economical. However, since it is thin, it cannot be penetrated with a large force, and workability would be an issue depending on the ground.
Continuous Underground Wall	Slurry Trench Method	・ A trench is excavated in the ground, and the excavated soil is refilled with a mixture of bentonite and cement to create a seepage cut-off wall. ・ A method has been developed in which a soft vinyl chloride sheet is inserted into the slurry trench as a barrier to enhance the seepage cut-off effect. ・ In overseas countries, there are samples such as seepage cut-off walls of fill dams and bunds. Although there are few samples in Japan, it has advantages in that it is economical, has good workability, and can be applied to various grounds.
	Concrete Wall Method	・ This method uses trenches to construct concrete walls. However, it has few samples in rivers due to its low economic efficiency and workability.
Grouting	Cement-Based Grouting Method Chemical Injection Method	・ Cement milk or a water-blocking chemical solution is pressed into the foundation ground. Although construction is easy, there is uncertainty about the seepage cut-off effect and its durability.

Source: Guideline for Structural Study of River Dike, 2012.2

(d) Other Countermeasures

(i) Protection of Riverside Slope (Revetment)

Stone Pitching is commonly used for the protection of the riverside slope of existing bunds. When the existing bund was observed during the site inspection, the following issues were observed in several locations. Photos from the site inspection are shown in Photo 3.6.1 to Photo 3.6.4.

- The size and quality of stones used in stone pitching vary depending on the sites and include small particle sizes that are easily washed away by running water.
- It can be considered that the filter material between the stone pitching and the slope does not function well or is not installed because the slope behind the stone pitching has been sucked out and the cavities are observed.
- At the locations where stone pitching stops up to the slope shoulder, there is damage on the slope shoulder.

Source: Advisory Team

Photo 3.6.1 Stone Pitching around Top (1)

Source: Advisory Team

Photo 3.6.2 Stone Pitching around Top (2)

Source: Advisory Team

Photo 3.6.3 Stone Pitching around Top (3)

Source: Advisory Team

Photo 3.6.4 Stone Pitching around Top (4)

In addition to the above situation, the area covered by this study is the immediate downstream side of the Akil Loop Bund, which has been frequently damaged by erosion and is only about 50 to 100 m from the main water channel of the Indus River. Since it is highly likely to be affected by running water and turbulence during floods, A slope protection material instead of stone pitching which is commonly used on existing bund slopes.

In this study, covering with concrete facing considering the following matters would be proposed.

- Due to the high-temperature climate, in the case of wet stone masonry, cracks are likely to occur due to the difference in the thermal expansion rate between stone and concrete, and there is a concern that the soil of the bund may be washed out from the cracks.

- In Pakistan, thin gabion baskets are not popular, and it is not common to use the spread type of gabion used in Japan. Therefore, gabion baskets may be custom-made and the cost may be high.
- In Pakistan, the spread type of concrete block used in Japan is not common.

The type of revetment shall be finalized at the F/S and the subsequent stages after investigation of other applicable types of materials, considering the design velocity of the project site and the flow conditions during the flood.

Protection of the Land Side Slope (Slope Protection)

At most of the sites, no protection work is installed on the land side slope of the existing bund. When the existing bund was inspected, it was found that erosion of the slope by rainwater occurred in most places and that damage was observed due to the lack of protection work on the shoulder (See Photo 3.6.5, Photo 3.6.6).

The main reason for this situation is that the slope on the land side is left unprotected. However, it is also a fact that in Pakistan, it is difficult to cover the slope with vegetation like in Japan due to the dry climate.

Although the erosion of the slope caused by rainwater is not serious damage that can lead to the breach of the bund immediately, there are some problems such as the fact that the section of the bund becomes short of the required section of the bund due to the reduction of the section, and that the slope repair work must be carried out periodically to prevent this. The extension of the bund of the Indus River is more than 4,500 km, and it is guessed that the urban area is not adjacent to the vicinity of all the bunds and that there are some places where the inspection of the bund is not often carried out. There are also limits to the number of people and budget for PID in charge of maintenance.

Source: Advisory Team

Photo 3.6.5 Situation of Land Side Slope (1)

Source: Advisory Team

Photo 3.6.6 Situation of Land Side Slope (2)

Given the above situation, it is recommended to install an inexpensive slope protection work instead of covering with vegetation such as grass sodding.

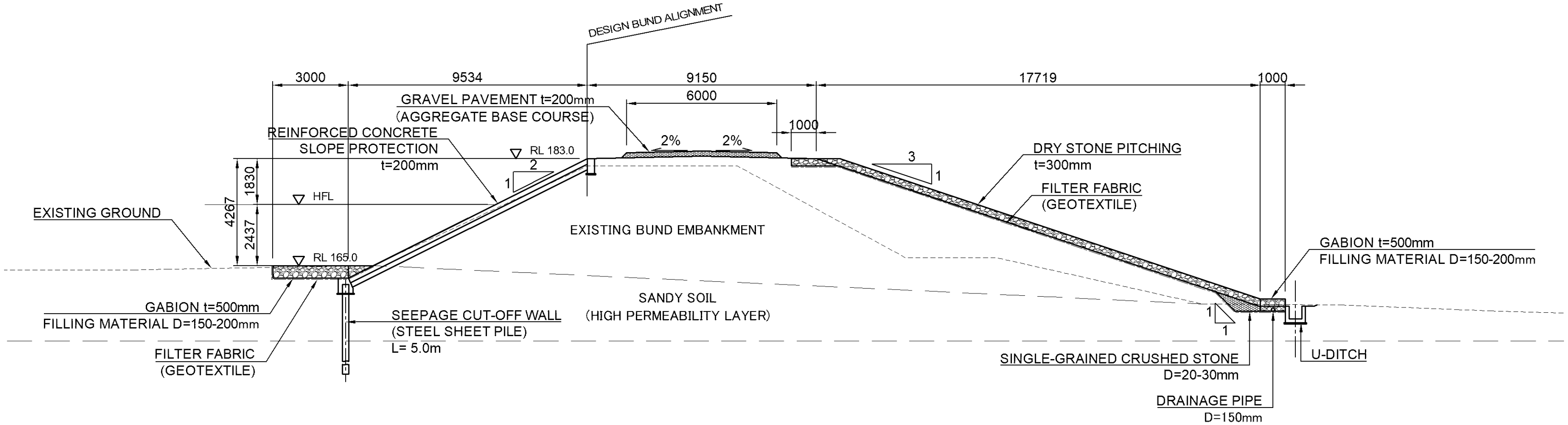
In this study, it is proposed to install stone pitching outside the required section so that the required section of the bund can be secured even if it is slightly eroded by rainwater. To protect the shoulder, the stone pitching is extended 1 m from the shoulder to the center of the bund. In addition, a filter fabric is installed between the stone pitching and the bund body as a part of the seepage control work. The seepage flow analysis is carried out in the F/S stage or the subsequent states, and if the infiltration line in the bund does not reach the landside slope, the filter fabric can be removed.

Stone pitching is a widely used method in the field and materials are relatively easy to obtain. In the case of vegetation cover, it is necessary to sprinkle water after installation, but such labor is unnecessary. Here, considering the erosion caused by rainwater, making the section on the land side thicker than the required section required is an option. However, it is not recommended to adopt such a method because it will need labor and costs for regular slope maintenance.

It should be noted that the type of protective work for the landside slope is to be determined at the F/S or the subsequent stage after the investigation of other applicable types and materials. In this study, stone pitchings with geotextile would be proposed.

5) Typical Section

The next page shows a typical section of the target location for seepage control works.



Source: Advisory Team

Figure 3.6.7 Typical Section for Seepage Control Works

6) Studied Needed in Subsequent Stages

(a) Topographic Survey and Geotechnical investigation

To grasp the existing bund cross-section shape, it is necessary to conduct a topographic survey in the project area. In the topographic survey, it is recommended to include in the survey area the main river channel flowing in front of the bund to a range of about 20~30 m from the existing riverbank, together with the cross-sectional survey of the existing bund. The purpose of this survey is to confirm whether deep excavation has occurred near the existing riverbank.

The geotechnical investigation shall be carried out to grasp the soil characteristics of the bund body and foundation ground. In the case of soil where the undisturbed sample can be obtained, a physical test and mechanical test need to be carried out. In addition, it is recommended that to evaluate seepage stability, an insite permeability test and particle size distribution of bund soil and foundation soil be carried out.

(b) Review and Reflect on the Latest Version of the Bund Manual

It was not possible to obtain the latest version of the Sindh Band Manual during this study. Therefore, it is necessary to obtain the latest version of the Sindh Band Manual from the Sindh State Government, check whether the bund top width and side slope conform to the standards, and revise the plan section if necessary.

(c) Conduct of Seepage Flow Analysis

After obtaining information on the river water level and the amount of rainfall at the surrounding stations and setting the external force, the seepage flow analysis shall be conducted considering the conditions obtained from the topographic survey and geotechnical investigation results. It is necessary to confirm the movement of groundwater level and groundwater in the bund body by the seepage flow analysis and to check the safety of the existing bund and the required bund cross section by calculation of slip calculation and piping.

(d) Determination of Specifications of Countermeasures

The countermeasures proposed in this study were established in situations where the basic information such as survey drawings and ground conditions were not obtained. Therefore, it is necessary to determine the specifications of necessary countermeasures based on the results of the topographic survey geotechnical investigation and the seepage flow analysis.

(e) Investigation and Study of Revetment and Slope Protection Materials

As mentioned above, in the existing bunds, stone pitching is mainly used as the revetment on the riverside, but there are issues such as the occurrence of washout of the soil from the bund body. In addition, the slope on the land side is difficult to protect by vegetation due to the severe climate, and it is left uncovered, causing erosion by rainwater.

About revetment, it is necessary to determine the optimum revetment type after comparing the applicable types of revetment with concrete facing. For example, the following types of revetment types can be extracted as candidates.

- <u>Stone Masonry (Dry, Wet)</u>
  →Can be used if the size of the stones used is strictly controlled and filter fabric is installed.
- <u>Spread Type of Gabion</u>
  →Gabion baskets 30 cm to 50 cm thick can be used if they are cheap and available.
- <u>Spread type of Concrete Blocks, Articulated Concrete Blocks</u>
  →This method is common in Japan. Since concrete blocks are not widely used in Pakistan, it is difficult to adopt them. However, if it is cheaper than concrete facing, it may be applicable.

- Covering Material Using Geotextile
  → A material called Sand Filled Mattress, which is a sheeted bag made of geotextile that is filled with sand and used as a revetment (see Photo 3.6.7). Although the material is imported from a third country, it can be used under some flow velocity, and the color of the surface can be similar to that of vegetation, so the lightness can be reduced compared with concrete facing. However, it requires sand to be filled inside.

Source: Manufacturer's materials

Photo 3.6.7 Sand Filled Mattress

In addition to the use of stone pitching proposed in this study, the following materials need to be investigated and studied for their applicability in covering the land side slope.

- Seed Spraying Using Dry-Resistant Plants as an Alternative to Grass Sodding

  →In an arid region such as Pakistan, viable and shallow-rooted plants shall be investigated to verify their applicability as a covering material for bund slopes. After verification, it is possible to apply the method to fill or cut slopes by seed spraying if applicable.

- Erosion Control Mat

  →A method of laying an erosion control mat on a slope without expecting vegetation. It seems to have been constructed in Pakistan in the past, but it seems to have been stolen. Also, it is highly likely that it will be imported from a third country and will not be a cheap material.

(3) Study on Erosion and Scouring Protection Work(For Old Abad Bund)

1) Analysis of the Cause of the Damage and Necessary Countermeasures

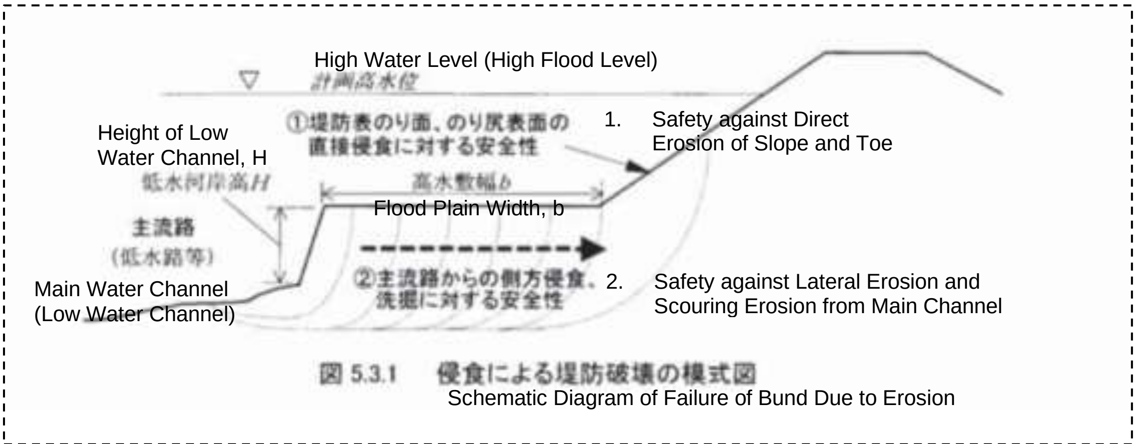
Figure 3.6.8 shows a schematic diagram of bund failure due to erosion. Two types of erosion affect the stability of bunds.

1. Direct Erosion of Bund Slope and Toe
2. Lateral Erosion from the Main Water Channel

According to previous satellite images, it can be seen that although there was a sufficient floodplain in front of the bund around 2003, the floodplain in front of the bund was scoured due to lateral erosion from the main channel from around 2013, leading to the situation where the main channel is located in front of the bund as of 2023 (see p3-7).

In addition, it can be considered that there is no protection for the slope and the riverbank at this site at present, and when the water level of the Indus River rises, the slope and tor are directly eroded. In addition, the existing bund height is about 1 to 1.5 m from the existing landside ground, and it is extremely low compared with the existing bund connected in the upper and downstream sides. Therefore, it is considered that overflow occurs when the water level of the Indus River is high, and flow falling in the direction of the Indus River occurs when the water level subsides.

Based on the above, the necessary measures at this location are to restore the bund height to the same level as the upstream and downstream side and to cope with the direct erosion to the riverside slope and toe and the lateral erosion by the main water channel.



Source: Guide to the Study of River Bund Structure, 2012.2

Figure 3.6.8 Schematic Diagram of Failure of Bund Due to Erosion

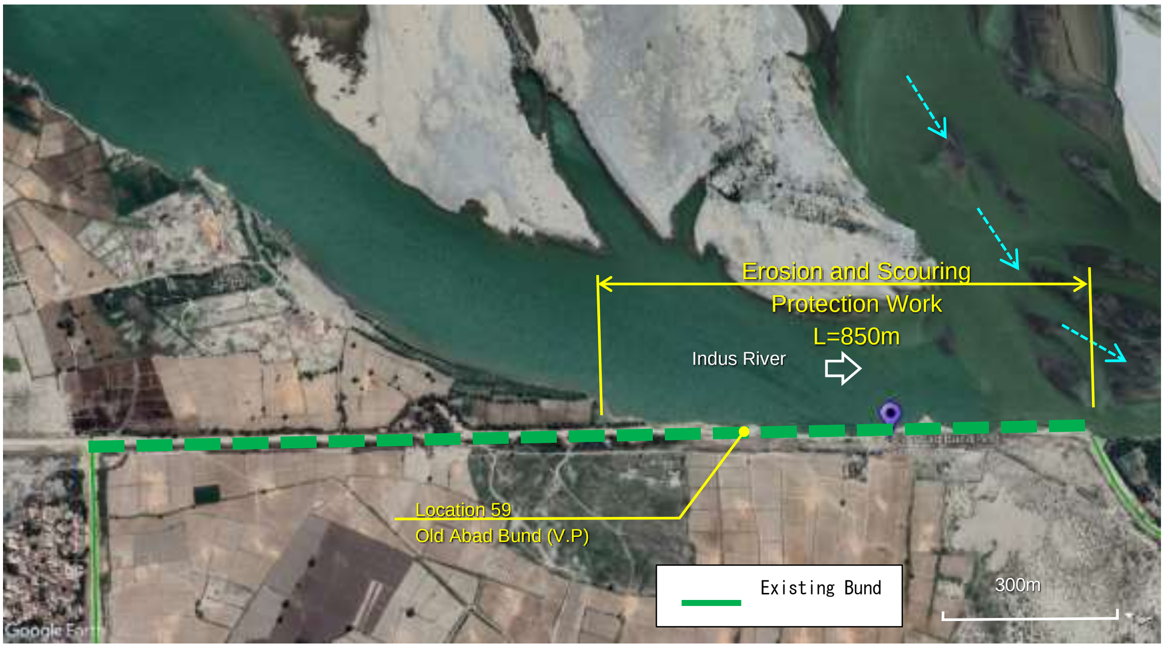
2) Area of the Countermeasure

The upstream end of the countermeasure is the point where the erosion has not been in progress since 2020 (Figure 3.6.9), referring to the past satellite image, and the downstream end is the connection point with the existing bund. The extension of the countermeasure is about 850 m. Figure 3.6.10 shows the area of the erosion and scouring protection works.

The area of countermeasures needs to be finalized after detailed confirmation of the local situation in the F/S or the subsequent stages.

Source: Google Earth

Figure 3.6.9 River Bank Erosion near the Upstream End of the Erosion and Scouring Protection Works



Source: Google Earth

Figure 3.6.10 Area of Erosion and Scouring Protection Work

3) Selection of the Countermeasures

The safety of bunds against erosion is related to the shape of the river channel (planar and transversal), the condition of the riverbank in front of the bund, the flow condition during floods near the bund, the soil condition of the bund, and the condition of the structures protecting the bund and the riverbank. In this study, the focus is on the reinforcement of existing bunds affected by erosion, but originally, it is necessary to consider a wide range of measures, including the measures to be taken by the excavation of river channels and the installation of spurs, considering the above-mentioned local conditions at the site.

Therefore, although the countermeasure proposed here can be deployed in sites with similar characteristics, the use of this method in other sites should be determined after the verification of the characteristics.

Table 3.6.5 shows examples of bund strengthening methods against erosion. Since there is no revetment at the present site, the installation of a revetment to strengthen the capacity, and the installation of spurs to reduce the erosion external force, which is expected to reduce the flow velocity are proposed. To cope with the influence of lateral erosion, steel sheet piles are installed at the revetment foundation work, and foot protection works are installed in the front of the revetment.

Regarding strengthening the capacity, it is difficult at present to protect, build, and expand the flood plain because the main water channel is already close to the front of the bund, and it is difficult to sufficiently withstand the flow velocity with the erosion control mat.

Table 3.6.5 Examples of Bund Strengthening Methods Against Erosion

Result of Safety Analysis		Bund Strengthening Method	
		1. Strengthening Capacity	2. Reduction of External Force
With Revetment	Direct Erosion on Slope and Toe	・ Installation of High Water Revetment ・ Installation of Erosion Control Mat ・ Control of Vegetation of Bund	・ Installation of Spurs to Expect the Reduction of Flow Velocity ・ Fill with Replacement Method ・ Modification of Alignment ・ Installation of Spurs to Expect. ・ Change of Flow Direction ・ Vane Method

Result of Safety Analysis			Bund Strengthening Method	
			1. Strengthening Capacity	2. Reduction of External Force
	Lateral Erosion and Scouring from the Main River Channel		· Installation of Low Water Revetment · Installation of Spurs · Installation/expansion of Flood Plain which does not affect the upstream and downstream. · Installation of Spurs in Longitudinal Direction	· Fill with Replacement Method · Modification of Alignment · Installation of Spurs to Expect. Change of Flow Direction · Vane Method
Without Revetment	Lack of Thickness of Slope Protection Work		· Rehabilitation of Revetment · Expansion of Slope Protection Work · Change Dry Masonry to Wet Masonry	· Installation of Spurs to Expect the Reduction of Flow Velocity · Fill with Replacement Method · Modification of Alignment · Installation of Spurs to Expect. Change of Flow Direction · Vane Method
	Lack of Embedment of the Foundation Work		· Rehabilitation of Revetment · Extension of Embedment of the Foundation · Installation of Foot Protection Work	· Installation of Foot Protection Work · Fill with Replacement Method · Modification of Alignment · Installation of Spurs to Expect. Change of Flow Direction · Vane Method
	Foot Protection Work	Lack of Weight	· Installation of Foot Protection Work · Unifying the Foot Protection Work(Connection, Layered Stacking) · Adding Concrete Blocks	· Installation of Spurs to Expect the Reduction of Flow Velocity · Fill with Replacement Method · Modification of Alignment · Installation of Spurs to Expect. Change of Flow Direction · Vane Method
		Lack of Width	· Installation of Foot Protection Work · Adding Concrete Blocks	· Installation of Spurs to Expect the Reduction of Flow Velocity · Fill with Replacement Method · Modification of Alignment · Installation of Spurs to Expect. Change of Flow Direction · Vane Method

Note: [dashed box] shall be adopted with River Planning
Source: Guideline for Structural Study of River Dike, 2012.2

4) Countermeasure to be Applied

(a) Basic Dimensions

Basic dimensions at this site are assumed as described below because the information on the bund such as the existing survey drawings and the typical section is not available in this study.

Table 3.6.6 Basic Dimensions

Item	Dimensions	Verification
Height of Existing Bund	About 4 m	Based on the adjacent bunds and Google Earth
Top width	30 ft (9.15m)	Reference to the typical cross-section of Akil Link Bund (Figure 3.6.4)
Slope	River Side: 2.0:1 Land Side: 3.0:1	Same as Above

Source: Prepared based on the information from Sindh-PID

(b) Revetment

As described in the "Study on Seepage Control Works," stone pitching in protecting the slope of the riverside, which is commonly used, has issues. In addition, the target site of the erosion and scouring protection works in this study is located directly behind the main water channel and river flow directly hitting (the direction of the main channel is almost perpendicular), expecting that complex flows occur during floods. Therefore, it is necessary to have a strong structure to cover the slope. Hence, covering it with concrete facing is proposed.

Source: Advisory Team

Photo 3.6.8 Sample of Sheet Pile Revetment in Front of a Bund (Philippines)

In addition, a steel sheet pile revetment would be installed in front of the bund slope to resist lateral erosion by the main channel. Currently, the main channel is located in front of the existing bund even in ordinary time, so a coffer dam is required for the work for the low-channel, but in the case of a steel sheet pile revetment, it is possible to install without a coffer dam. Photo 3.6.8 shows a case of sheet pile revetment in front of the Bund.

(c) Foot Protection Work

Foot protection work would be installed in front of the revetment. As mentioned above, since the front of the existing bund is a mainstream of the river even in ordinary times, the Foot protection work is installed by Riprap, which can be installed without using a coffer dam. About the size of the riprap, it is necessary to set the design flow velocity at the relevant location in the F/S or the subsequent stages and determine it based on the flow conditions. Here, it is assumed that a certain amount of heavy riprap is required because of the expected occurrence of complicated flows, and the equivalent of Class C(80 kg/piece) is considered.

(d) Spurs

Based on the transition of the river channel after 2013, it can be considered that the position of the main channel tends to be fixed at the current position in front of the bund. If the scouring in front of the bund develops more due to the channel fixing, the flow velocity during flood in front of the bund will increase further. In addition, since the method of lining with concrete material is proposed as described above, the roughness near the revetment will be low, and the flow velocity near the bund will be increased.

From the above situation, it is proposed to install a spur in front of the bund to reduce the flow velocity near the bund and the revetment.

Riprap is commonly used in existing spurs. Although existing spurs are being maintained with repeated damage and repair, the following can be issued.

- The size of riprap, which is used as a covering material for spurs, is inadequately controlled, and there are many cases where small stones are mixed with insufficient flow resistance.
- In the vicinity of the spurs, there are many places where complex swirling flows occur due to the direction of the main channel and the very loose longitudinal river gradient, and the flow velocity is locally accelerated in such places.

Given the above situation, it can be said that it is <u>desirable to use a material that ensures a certain weight or more.</u> Therefore, the use of concrete blocks would be proposed in this study. The installation would be in random piled-up that can be performed without a coffer dam. It is necessary to determine the required weight of the concrete block in consideration of the design flow velocity and flow condition at the F/S or the subsequent stage. In this study, a 1-ton type block is used. Photo 3.6.9 shows short spurs with concrete block.

Source: Advisory Team

Photo 3.6.9 Spurs with Concrete Blocks (Philippines)

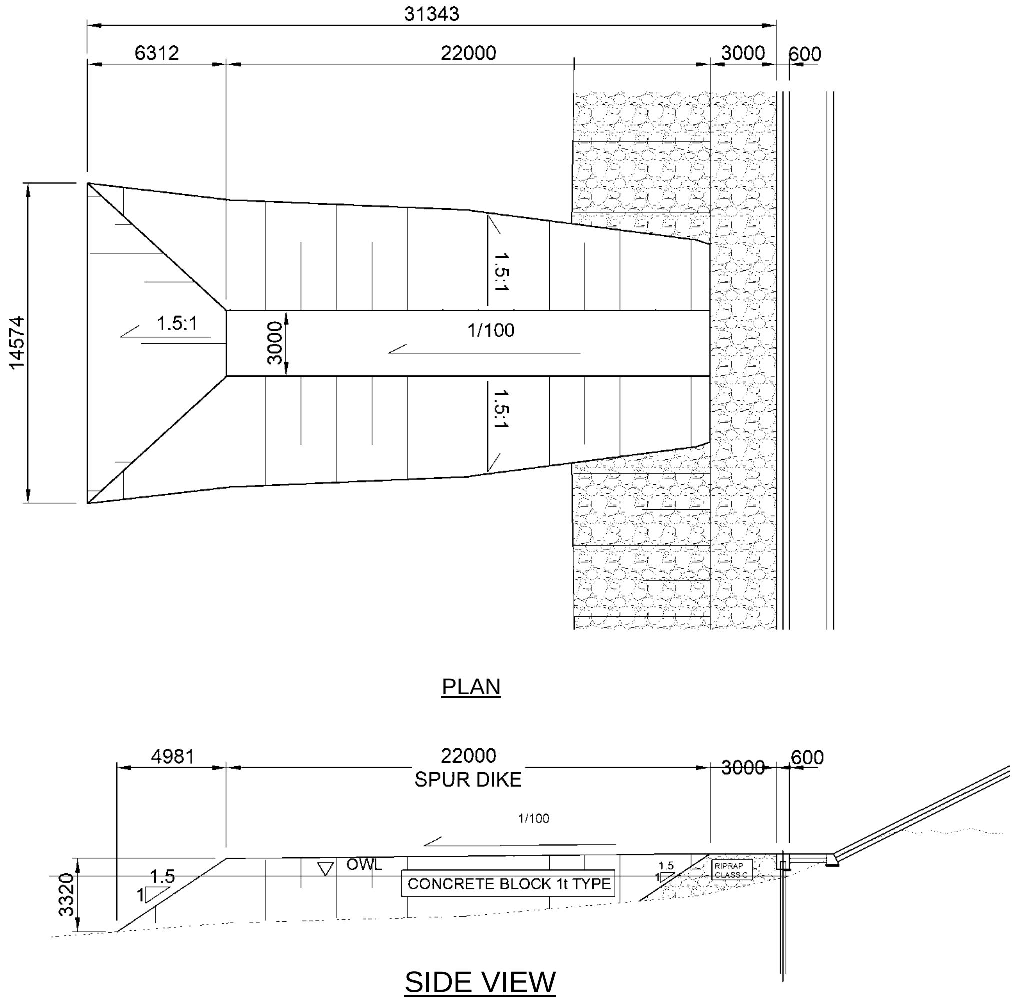
The specifications of the spurs shall be set as shown in Table 3.6.7 by the description of "Technical Criteria for River Works: Practical Guide for Planning [I]" of Japan. In addition, if the length is about 25 m, it is not necessary to construct the work on the water because it is within the range that can be reached with a crane from the bund.

Figure 3.6.11 shows a general diagram of a spur.

Table 3.6.7 Specifications of Spur

Item	Dimensions/Size	Verification
Material	Concrete Block 1t Type	
Length	25 m	About 10% of the Width of the Main Channel
Top width	3.0 m	Arrange about 3 concrete blocks [2)]
Top Height	Same Height as Top of Sheet Pile Revetment longitudinal Slope 1/100	Approximately OWL +1.0 m [1)]
Installation Interval	50 m	Twice the length[1)]

Source: 1) Technical Criteria for River Works: Practical Guide for Planning [I]
2)Manufacturer's Brochure



Source: Advisory Team

Figure 3.6.11 General of a Spur

(e) Other Countermeasures

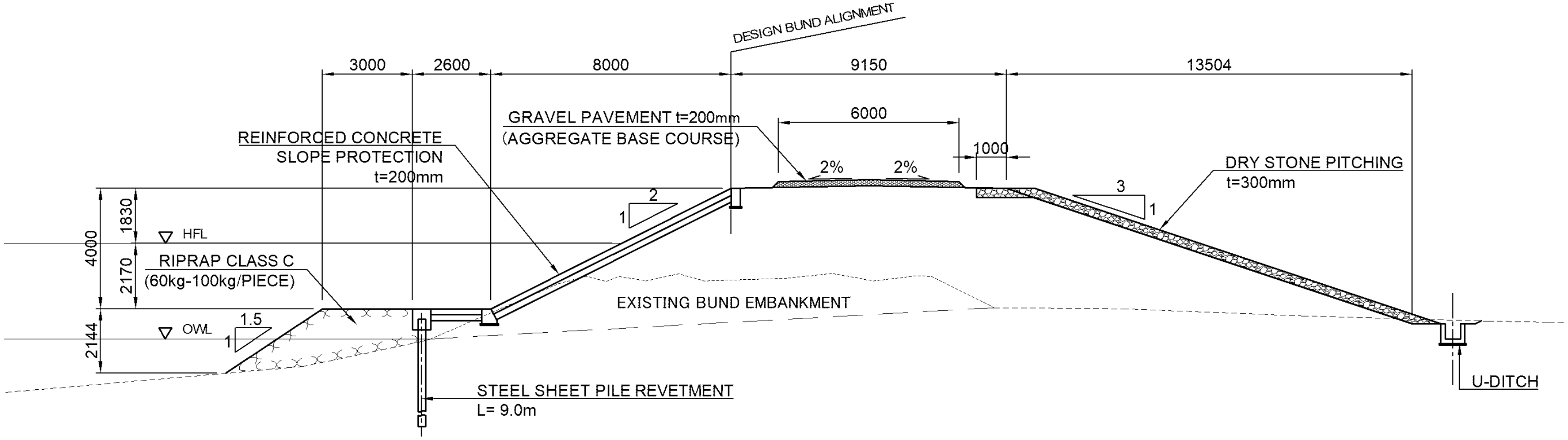
(i) Land Side Slope Protection (Slope Protection)

As described above in the study of seepage control works, the landside slope of the existing bund is not covered and has been eroded by rainwater, and there are problems in securing and maintaining the required section of the bund.

Since the situation is the same in the Old Abad Bund, which is the target site for the erosion and scouring protection, the protection of the slope with stone pitching would be proposed as same as the case of seepage control work.

5) Typical Section

The next page shows a typical section of the target location for erosion and scouring protection works.



Source: Advisory Team

Figure 3.6.12 Typical Section of Erosion and Scouring Protection Works

6) Studied Needed in Subsequent Stages

Topographic Survey and Geotechnical Investigation

It is necessary to conduct a topographic survey of the site to grasp the existing bund's cross-sectional shape. In the topographic survey, the main channel flowing in front of the bund shall be included in the scope of the cross survey along with the cross survey of the existing bund. This is to grasp the depth of the existing river channel and to provide basic data for calculating the design velocity of the revetment. In addition, the purpose of this study is to check whether deep excavation has occurred.

Geotechnical investigation is carried out to grasp the soil characteristics of the bund body and foundation ground. In the case of soil in which undisturbed samples can be obtained, physical tests and mechanical tests shall be carried out.

(a) Review and Reflect on the Latest Version of the Bund Manual

It was not possible to obtain the latest version of the Sindh Band Manual during this study. Therefore, it is necessary to obtain the latest version of the Sindh Band Manual from the Sindh State Government, check whether the bund top width and side slope conform to the standards, and revise the plan section if necessary.

(b) Calculation of Design Flow Velocity

The design water depth is set from the result of the aforementioned cross-sectional survey of the main channel, the average flow velocity is calculated from Manning's formula, and the design flow velocity is calculated by considering the curvature correction, etc.

If possible, the flow rate is observed in the vicinity of the target area during a flood. It is desirable to compare the measured flow velocity with the design flow velocity calculated by the calculation formula and confirm the validity of the design flow velocity calculated by the calculation formula.

(c) Study of Revetment Type

About revetment, it is necessary to determine the optimum revetment type after comparing the applicable types of revetment with concrete facing. For example, the following types of revetment types can be extracted as candidates. However, it is necessary to extract applicable types of revetment types while paying attention to the fact that the target site in this study is located where the flow-hitting point is.

- <u>Stone Masonry (Dry and Wet)</u>
  →Can be used if the size of the stone used is strictly controlled and filter fabric is laid.
- <u>Spread Type of Gabion</u>
  →Gabion baskets 30 cm to 50 cm thick can be used if they are cheap and available.
- <u>Spread type of Concrete Blocks, Articulated Concrete Blocks</u>
  →This method is common in Japan. Since concrete blocks are not widely used in Pakistan, it is difficult to adopt them. However, if it is cheaper than concrete facing, it may be applicable.

(d) Consideration of Protection of Land Side Slope

In addition to the use of stone pitching proposed in this study, it is necessary to investigate the following materials and study their applicability.

- <u>Seed Spraying Using Dry-Resistant Plants as an Alternative to Grass Sodding</u>

  →In an arid region such as Pakistan, viable and shallow-rooted plants shall be investigated to verify their applicability as a covering material for bund slopes. After verification, it is possible to apply the method to fill or cut slopes by seed spraying if applicable.

- <u>Erosion Control Mat</u>

→A method of laying an erosion control mat on a slope without expecting vegetation. It seems to have been constructed in Pakistan in the past, but it seems to have been stolen. Also, it is highly likely that it will be imported from a third country and will not be a cheap material.

(e) Consideration of Possibilities Other Than Protection Measures such as Revetment

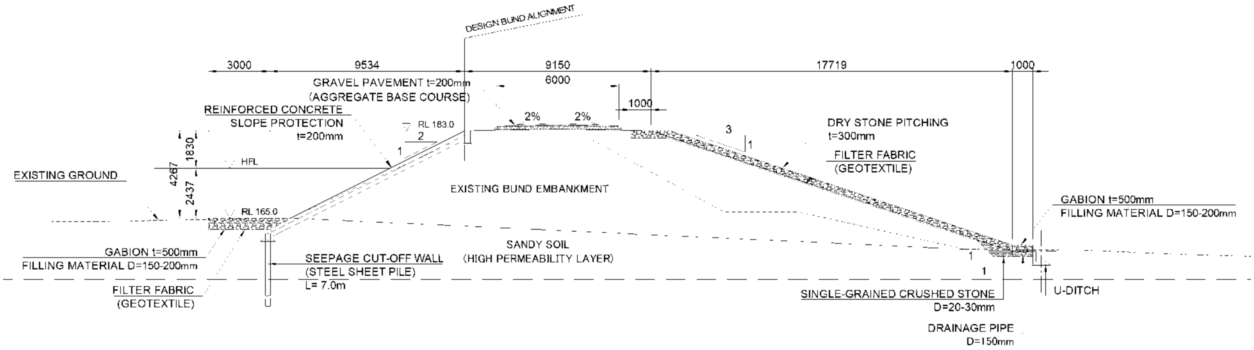
Since 2013, the main river channel has been located in front of the right bank bund at the target site, and there is a tendency for the channel to be fixed. Therefore, it is recommended that the possibility of excavation of the sand bar on the opposite bank side of the main channel be also studied to reduce the flow velocity in front of the bund and prevent the development of deep scouring. However, due to the large scale of the Indus River, it is necessary to be careful because the area of the river channel excavation will be extremely wide and the cost may be high.

3.6.2 Construction Schedule

(1) Seepage Control Works

Set up the construction process using the construction method for seepage control works considered in 3.6.1.

A standard cross-section of the construction outline is shown in Figure 3.6.13.



Source: Advisory Team

Figure 3.6.13 Standard Cross-Section of the Seepage Control Works

The main seepage measures that have been set up are shown below

1. Measures to block water from the seepage layer of the foundation; Installation of water-blocking sheet piles
2. Slope protection work against front slope seepage; Concrete covering + Backfilling crushed stone
3. Slope protection work against back slope seepage; Split stone covering + Suction prevention material + Drain + U-shaped gutter

1) Setting up the Construction Process

It sets construction conditions and construction Process.

(a) Construction conditions

Construction will be carried out in dry conditions from October to June, when the water level of the Indus River is low. The basic conditions for construction are shown below.

✓ As a general rule, No cofferdam will be constructed.

- ✓ Enter the construction site from the northwest. A stockyard (materials and equipment storage area) will be established on the flat ground inside the bund near the entrance.
- ✓ The construction road will use the existing bund.
- ✓ Materials and equipment will be procured at Larkana (L=10km).

Figure 3.6.14 shows the transportation route set under the above conditions, and Figure 3.6.15 shows the stockyard. The stockyard will be approximately 150m x 150m.

Source: Google Earth

Figure 3.6.14 Transportation Route to Seepage Measures Area

Source: Google Earth

Figure 3.6.15 Stockyard for Seepage Measures

(b) Construction Procedure

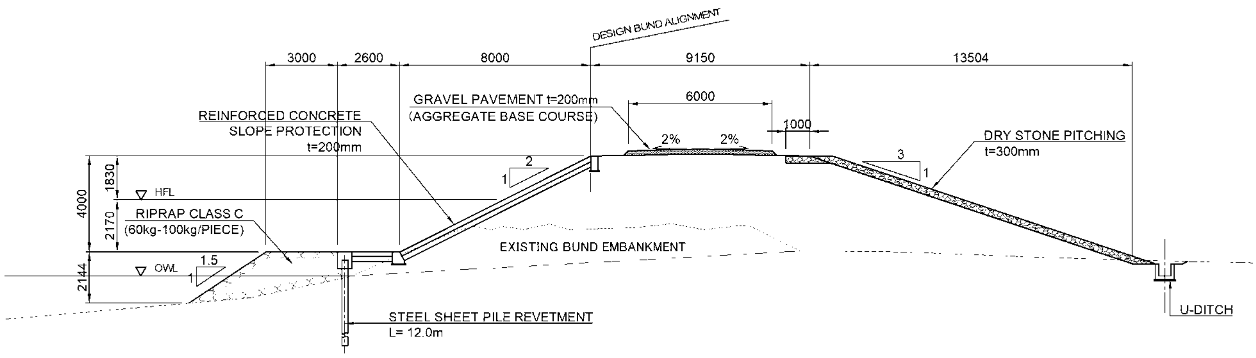
Consider the construction process based on construction conditions. Construction will begin with earthworks and embankments to stabilize the embankment, and then seepage measures will be carried out. The steel sheet piles will be driven using large heavy machinery in advance, and slope protection works on the river front and back will be constructed as needed. Along with the slope protection construction, it will also be carried out seepage measures on the back side of the river. The overall construction process is as follows.

1. Preparatory work: office installation, stockyard leveling, etc.
2. Removal work: Removal of existing bank protection and structures
3. Embankment work: Compaction embankment at the set height
4. Excavation work: Foundation work, excavation for U-shaped side ditches, etc.
5. Impermeable sheet pile driving work: Dry impermeable sheet pile driving by bringing in large heavy machinery
6. Foundation work; foundation of slope protection work
7. Concrete cladding; River slope protection work
8. Crown work: Crown work of concrete cladding
9. Split stone cladding (empty cladding); Slope protection work behind the river
10. U-shaped gutter construction; drainage channel behind the river
11. Permeability work (permeable pipe + gabion); water collection at the bottom of the river
12. Root protection work (gabion): Measures against scouring of foundations on the river front side
13. Top paving work (crushed stone pavement); Top paving of management passage

A detailed study of the construction process will be conducted after the detailed construction scope and type of construction have been determined.

(2) Erosion and Scouring Protection Works

Set up the construction process based on the using construction methods for to prevent embankment erosion measures based on the results of the study in 3.6.1. A standard cross-section of measures for embankment erosion is shown in Figure 3.6.16 .



Source: Advisory Team

Figure 3.6.16 Standard Cross-Section of the Erosion and Scouring Protection Works

The erosion and scouring protection measures based on the study results are shown below.

1. Embankment work; Embankment
2. Scouring measures; Rip rap + Steel sheet pile driving + Concrete covering
3. Surface slope protection work; Concrete covering + Crushed stone backfill

4. Back slope protection work; Split stone covering + U-shaped gutter

1) Setting up the Construction Process

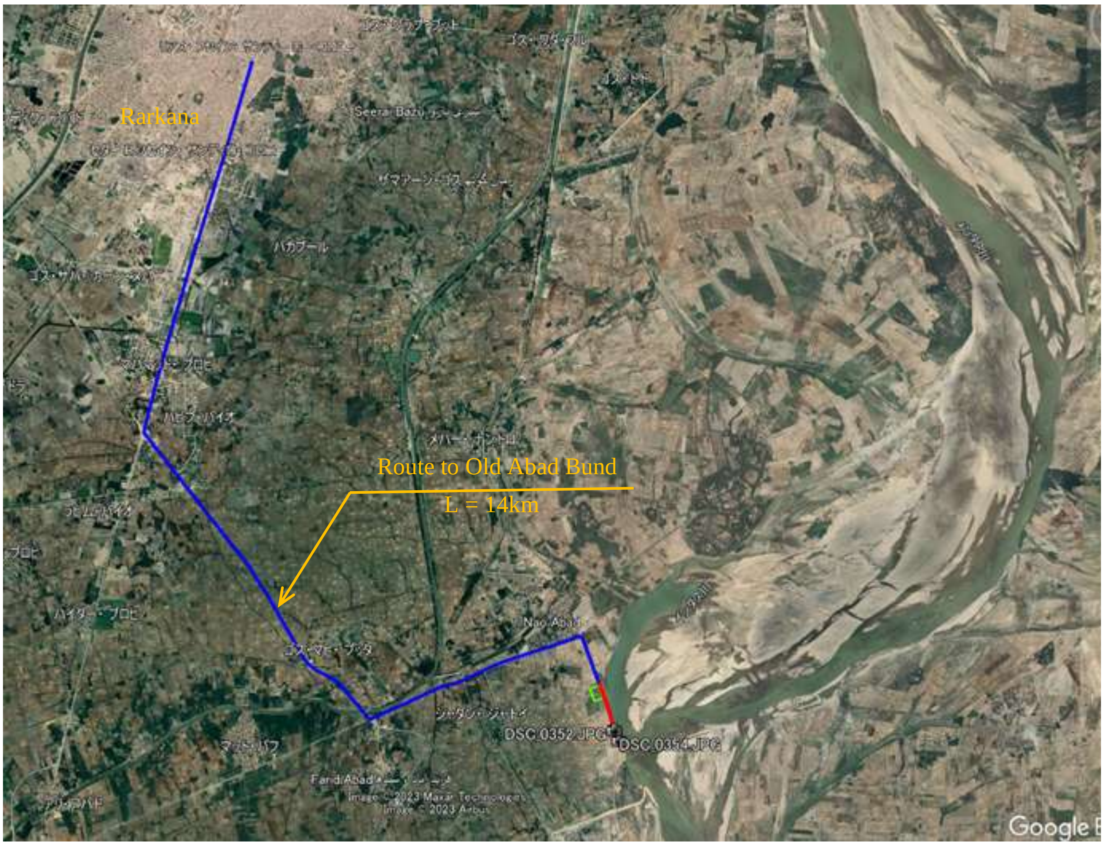
It sets construction conditions and construction Process.

(a) Construction Schedule

Construction will be carried out in dry conditions from October to June, when the water level of the Indus River is low. The basic conditions for construction are shown below.

- ✓ As a general rule, no cofferdam will be constructed.
- ✓ Enter the construction site from the north. A stockyard (materials and equipment storage area) will be established on the flat ground inside the bund near the entrance.
- ✓ The construction road will use the existing bund.
- ✓ Materials and equipment will basically be procured at Larkana (L=15km).

Figure 3.6.17 shows the transportation route set under the above conditions, and Figure 3.6.18 shows the stockyard. The stockyard will be approximately 150m x 150m.



Source: Google Earth

Figure 3.6.17 Transportation Route to Erosion Measures Area

Source: Google Earth

Figure 3.6.18 Stockyard for Erosion Measures

(b) Construction process

Consider the construction process based on construction conditions. As with infiltration countermeasures, construction will be carried out in advance by earthworks and embankments to stabilize the embankment, and then erosion countermeasures will be taken. The steel sheet piles will be driven using large heavy machinery first, followed by the construction of rubble and foundation work on the river surface. After that, slope protection works will be constructed on the front and back sides of the river. After the slope protection work is completed, a U-shaped gutter will be constructed on the back side of the river. The overall construction process is as follows.

1. Preparation work ; River front side, foundation for slope protection work
2. Embankment work ; Compact embankment up to the ruler cross section
3. Exeavation work ; Excavation for foundation work and U-shaped side ditch construction
4. Steel sheet pile driving; Impermeable sheet pile driving by bringing in large heavy machinery, dry work
5. Foundation work ; River front side, foundation for slope protection work
6. Law bottom concrete covering ; Concrete flat cladding between water-shielding sheet pile and slope protection foundation
7. Rip rap stone work ; Foundation protection work in front of water-shielding sheet piles, construction of water embankments

8. Concrete covering；River slope protection work
9. Crown work；Crown concrete of riverside slope protection work
10. Split stone masonry (empty)；Slope protection work behind the river
11. U-shaped waterway construction；Drainage channel at the bottom of the slope
12. Crest pavement work (crushed stone pavement)；Top paving of management passage

A detailed study of the construction process will be conducted after the detailed construction scope and type of construction have been determined.

3.6.3 Unit Cost for Bund Improvement

The construction unit price for each type of work will be determined by researching the published comprehensive construction unit price list and market prices in Sindh province, which is the target province for bund reinforcement.

- ✓ 「Composite Schedule of Rates 2022 (7th July 2022);Larkana」Standing Rates Committee Sindh, Karachi
- ✓ 「Composite Schedule of Rates 2022 (Sindh May 2022)」

  National Highway Authority/Ministry of Communications Government of Pakistan
- ✓ 「Schedule of Rates for Public Health Engineering Works Finished Items(7th July 2022)」Volume-III Part-II, Government of Sindh

(1) Construction Unit Price

1) Construction Unit Price set from the Comprehensive Construction Unit Price List of Larkana District, Sindh Province

The comprehensive construction unit price list summarizes the total construction unit cost for each type of work, including labor costs, machine usage costs, material costs, and loss charges. Use the latest 2022 construction unit price list. The target work types are extracted and shown in Table 3.6.8.

Table 3.6.8 Composite Schedule of Rates in Larkana District, Sindh Province

Item No.	Description	Unit	Manpower	Equipment	Material	OH-Profit	Rate (Rs)
101	CLEARING AND GRUBBING	Sq.m	1.73	19.64	-	5.34	26.71
107a	STRUCTURAL EXCAVATION IN COMMON MATERIAL	Cu.m	28.08	277.11	-	76.3	381.49
107e	COMMON BACK FILL	Cu.m	88.46	125.55	11.7	56.43	282.14
202ii	AGGREGATE BASE COURSE (WITH GRADER)	Cu.m	55.94	405.24	1,285.00	436.55	2,182.73
401a3ii	CONCRETE CLASS "A3" (ON GROUND)	Cu.m	1,097.72	2,666.66	9,684.27	3,362.16	16,810.81
401f	LEAN CONCRETE	Cu.m	919.2	999.71	4,568.29	1,621.80	8,109.00
404 b	REINFORCEMENT AS per AASHTO M-31 GRADE 60	Ton	5,030.68	815.77	187,073.25	48,229.93	241,149.63
507a	STEEL WIRE MESH (9 SWG) FOR GABIONS	Kg	16.19	-	243.26	64.86	324.3
507b	ROCK FILL IN GABIONS	Cu.m	307.68	-	733.23	260.23	1,301.14
509c	RIP RAP CLASS "C"	Cu.m	1,067.27	50.32	838.6	489.05	2,445.24
509h	FILTER LAYER OF GRANULAR MATERIAL	Cu.m	162.58	278.85	1,232.78	418.55	2,092.76
509h'	FILTER LAYER OF GEITEXTAL MATERIAL	sq.m	32.52	55.77	1,000.00	83.71	1172.00
511a2	DRY STONE PITCHING (20-25 cm THICK)	Sq.m	294.5	81.88	180.76	139.28	696.41

Source: Composite Schedule of Rates 2022 (7th July 2022); Larkana

2) Steel sheet pile driving unit cost

The unit price for driving steel sheet piles is based on the driving cost of the National Highway Authority (NHA) and the market unit price of steel sheet piles. The driving cost and unit price of steel materials are shown in Table 3.6.9 and Table 3.6.10 respectively. Table 3.6.11 and Table 3.6.12

respectively show the steel price and unit weight of steel.

Table3.6.9 Driving Cost

	Description	Unit	Rate (Rs)		Unit	Rate (Rs)		Specification	Remarks.
			Labour	Composite		Labour	Composite		
3	Driving steel piles 25' to 30' (7.5 to 9M)	P.Sft.	80.44	-	P.Sqm.	865.88	-	Do	Rate includes laying and removing of track and also carriage of piles machine, to average distance of 3.0 chains.
4	Driving steel piles more than 15' (4.5M) and less than 25' (7.5M).	P.Sft.	77.22	-	P.Sqm.	831.22	-	Do	These rates are for trackle gang only supplied by contractors mechanical stafffon machine will be supplied by Government T-Piles and adjustable junction piles will be counted as 2 piles.

Source: Composite Schedule of Rates 2022 (Sindh May 2022); NHA

Table 3.6.10 Steel Unit Price

Item	cost	
Composite Rate MRS 2022 Bi-Annual	303,740.0	Rs per ton
SP- II	36,448.8	Rs per sqm
SP- III	45,561.0	Rs per sqm

Source : Advisory Team

Table 3.6.11 Steel Price

Item	Composite Rate MRS 2022 Bi-Annual
Steel Grade 60	303,740/- per Ton
Steel Grade 40	291,590/- per Ton

Source : No. MRS/FD/4-2/NOTIFICATION/2021-22 ;
Government of Khyber Pakhtunkhwa Finance Department

Table 3.6.12 Steel Unit Weight

Item	number	Unit	Note
SP- II	48	kg/m	400 mm
	120	kg/sqm	2.5 n
SP- III	60	kg/m	400 mm
	150	kg/sqm	2.5 n

Source : Product catalog

3) *Advisory Team*Drain Pipe Laying Unit Price

Drain pipe laying unit price is set from the pipe laying unit price list of Public Health Engineering Works. Table 3.6.13 shows the unit cost for laying the 150mm diameter cable that is planned to be installed this time. The installation unit price includes the cost of materials and labor.

Table 3.6.13 Transportation Cost

S.#	Description	S.I Units	
		Units	Rate in Rs.
(f) 150 mm 6" dia.			
	1st mile (0. to 1.6 km)	% RM	125.7
	2nd mile (1.61 to 3.2 km)	% RM	31.37
	3rd mile (3.21 to 4.8 km)	% RM	25.69
	4th mile (4.81 to 6.4 km)	% RM	23.72
	5th mile (6.41 to 8.0 km)	% RM	21.92
	6th mile (8.01 to 9.6 km)	% RM	20.44
	7th & subsequent mile 9th & subsequent Km	% RM	19.23

Source：「Schedule of Rates for Public Health Engineering Works Finished Items(7th July 2022)」Volume-III Part-II, Government of Sindh

Table 3.6.14 Pipe Laying Cost

S #	Description.	Unit	S.I Unit. Rates in Rs.	
			Labour	Composite
a)	80 mm (3" dia)	R.M	---	780.88
b)	100 mm (4" dia)	R.M	---	1158.19
c)	125 mm (5" dia)	R.M	---	1814.39
d)	150 mm (6" dia)	R.M	---	2224.52
e)	200 mm (8" dia)	R.M	---	3389.27
f)	250 mm (10" dia)	R.M	---	5206.95
g)	300 mm (12" dia)	R.M	---	7260.85

Source：「Schedule of Rates for Public Health Engineering Works Finished Items(7th July 2022)」Volume-III Part-II, Government of Sindh

4) Formwork Assembly Unit Price

The unit price for assembling concrete formwork will be determined by conducting a market price survey. The results of the market price survey are shown in Table 3.6.15.

Table 3.6.15 Formwork Cost (including Assembly)

cost	Unit	Note
100	sqft	
1,076.43	sqm	0.0929

Source：Advisory Team

5) Wave-Dissipating Blocks Installation Unit Price

The unit price for installing a wave-dissipating block will be set separately for production costs and installation costs in accordance with domestic cost estimation standards. The production cost is determined based on the unit price of materials and labor. Installation costs will be determined based on domestic cost estimation standards. The results are shown in Table 3.6.16 and Table 3.6.17.

Table 3.6.16 Wave Dissipating Block Production Cost

ConcreteBlock Hexapod 1t Type			Unit	cost per piece	unit cost	Note
Concrete :	V=	0.44	cum/piece	7,397	16,810.81	401a3ii
FormWork :	A=	3.86	sqm/piece	4,155	1,076.43	market priece
Reinforce	W=	8.4	kg/piece	1,997	237.78	404a
Production fee		100%		13,549		
	Total			27,098		

Source : Composite Schedule of Rates 2022 (7th July 2022); Larkana

Table 3.6.17 Transportation & Installation Cost

Iteam	Unit	unit cost
Transportation & installation	piece	10,000

Source : Japanese construction results

3.6.4 Construction Cost for the Proposed Bund Scheme

Calculate the construction cost for each measure based on the set construction unit price. Compensation costs for land acquisition, house relocation, etc. are not included. The overall results are shown in Table 3.6.18, and Table 3.6.19 and Table 3.6.20 show the results for each bund reinforcement section, respectively.. Detailed results are summarized in the appendix.

Table 3.6.18 Bund Improvement Cost

Part Name	Construction Length (m)	Construction Cost (million Rs.)	Note
Akil Link Bunk	1,900	1,761	Seepage Control Works
Old Abad Bund	850	1,963	Erosion and Souring Protection Works

Source: Advisory Team

Table 3.6.19 Cost of Bund Improvement for Seepage Control

Item	Project Cost (million Rs)
Clearing and Grubbing	2.0
Earth Work	31.8
Sloop Protection ; Concrete	243.1
Protection Work ; Gabion, Dry Stone Piching	67.2
Piling Work	1,325.1
Drain Work	84.5
Pavement Work	7.5
Total	1,761.2

Source: Advisory Team

Table 3.6.20 Cost of Bund Improvement for Erosion and Scoring Protection

Item	Project Cost (million Rs)
Clearing and Grubbing	0.9
Earth Work	21.2
Sloop Protection ; Concrete	140.3
Protection Work ; Riprap, Dry Stone Pitching	25.8
Piling Work	1,329.8
Pavement Work	3.3
Spur Length : 25m, 50 m interval	441.7
Total	1,963.0

Source: Advisory Team

3.7 Evaluation of the Project

3.7.1 Evaluation of the Recommended Project

Table 3.7.1 summarizes the evaluation and validity of various features of the project, including strengthening two bunds recommended in this study. From the summary in Table 3.7.1, it can be said that the implementation of the project recommended in this study is fully valid.

Table 3.7.1 Evaluation of Bund Improvement Project

Item	Seepage Control Works Akill Link Bund	Scouring Protection Work Old Abad Bund	Remarks
Length	L=1.9 km	L=0.85 km	
Effect To Reduce Damages	High urgency to strengthen the existing bund, and there is a densely populated area (Larkana) behind the bunds. Hence, the effect of reducing the damage is sufficient.	High urgency to rehabilitate and strengthen the existing bund, and there is a densely populated area (Larkana) behind the bunds. Hence, the effect of reducing the damage is sufficient.	Considering the characteristics of the hinterland, the amount of damage will be greater if an inundation occurs in the upstream area. However, consider a risk by vulnerability x damage.
	○	○	
Socio-Environment	There are no densely populated residential areas, farmland, or areas subject to nature conservation within the project's affected area, so there will be little impact.	Same as the Left	
	○	○	
Construction/ Difficulty	The work can be implemented using locally available materials and common construction methods.	Same as the Left	Although steel sheet piles will be imported from third countries, it is available in Pakistan's domestic market.
	○	○	
Cost	Suitable scale for a grant project 1.76 Billion PKR	Suitable scale for a grant project 1.96 Billion PKR	
Validity	Valid		

Legend: ◎. preferable; ○. No Problem; △.With Issues
Source: Advisory Team

3.7.2 Assumption of Flood Damage by Bund Breach

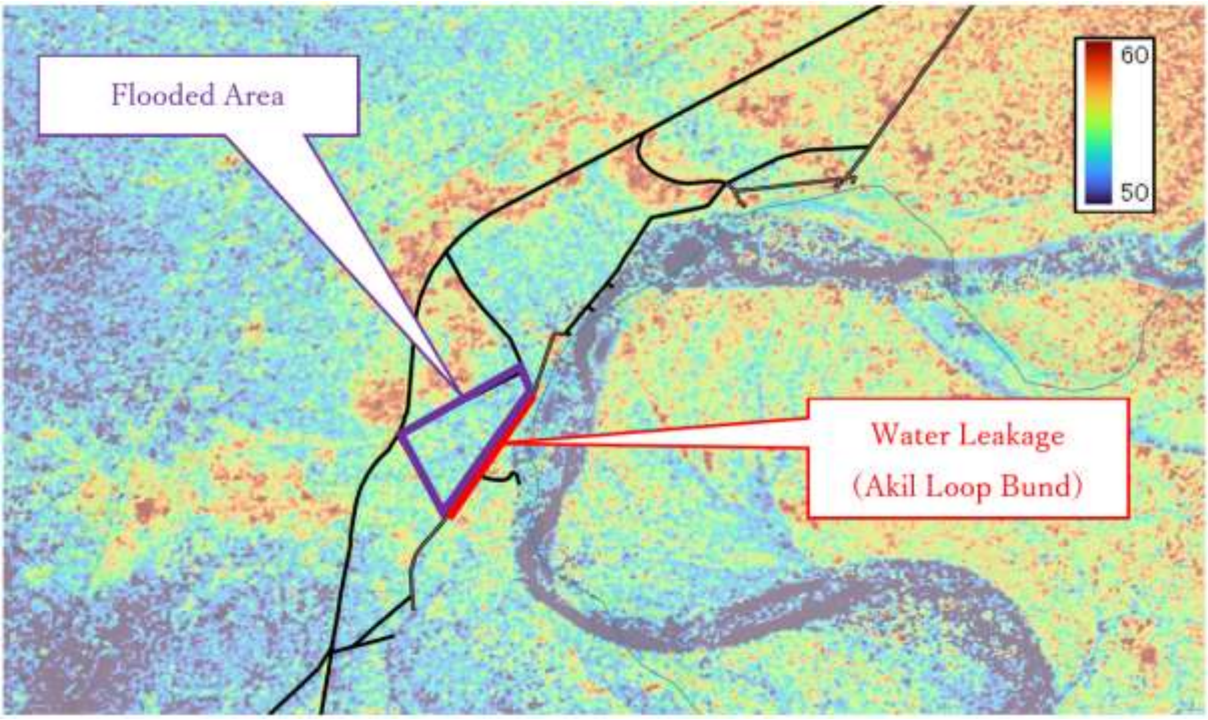
3.7.2.1 Akil Loop Bund

(1) Situation Around Vulnerable Point and Flooded Area

Figure 3.7.1 shows the ground elevation and bund conditions around Akil Loop Bund (the extracted vulnerable point), and Figure 3.7.2 shows the map around Akil Loop Bund by Google Earth. If a water leak occurs in Akil Loop Bund, the immediate risk of flooding is only in the surrounding area by bunds (enclosed in purple line). So, the flood damage is limited because there are only fields and no residential areas.

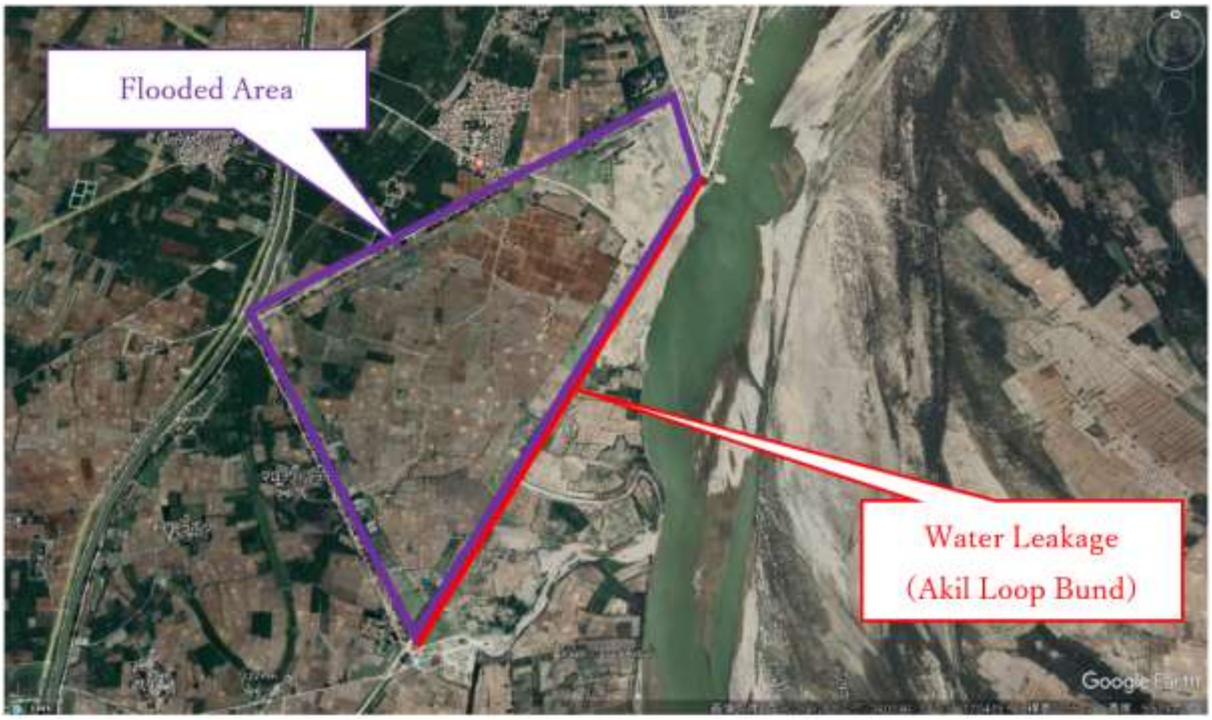
However, if the rear bunds fail to prevent flooding, the flooding area may extend to areas where the ground elevation is lower than that near the bunds (55 m = 180.45 ft). Figure 3.7.3 and Figure 3.7.4 show the assumption of flood expansion near Akil Loop Bund with a ground elevation map and surrounding map.

In the study area, there are many areas where the ground elevation is lower than that near the bunds (55 m = 180.45 ft), and assuming that all such areas will be flooded, the maximum extension area of the Akil Loop Bund Breaches can be set as shown in Figure 3.7.5.



Source: Advisory Team

Figure 3.7.1 Ground Elevation and Bund Conditions Around Akil Loop Bund



Source: Created by Advisory Team from Google Earth

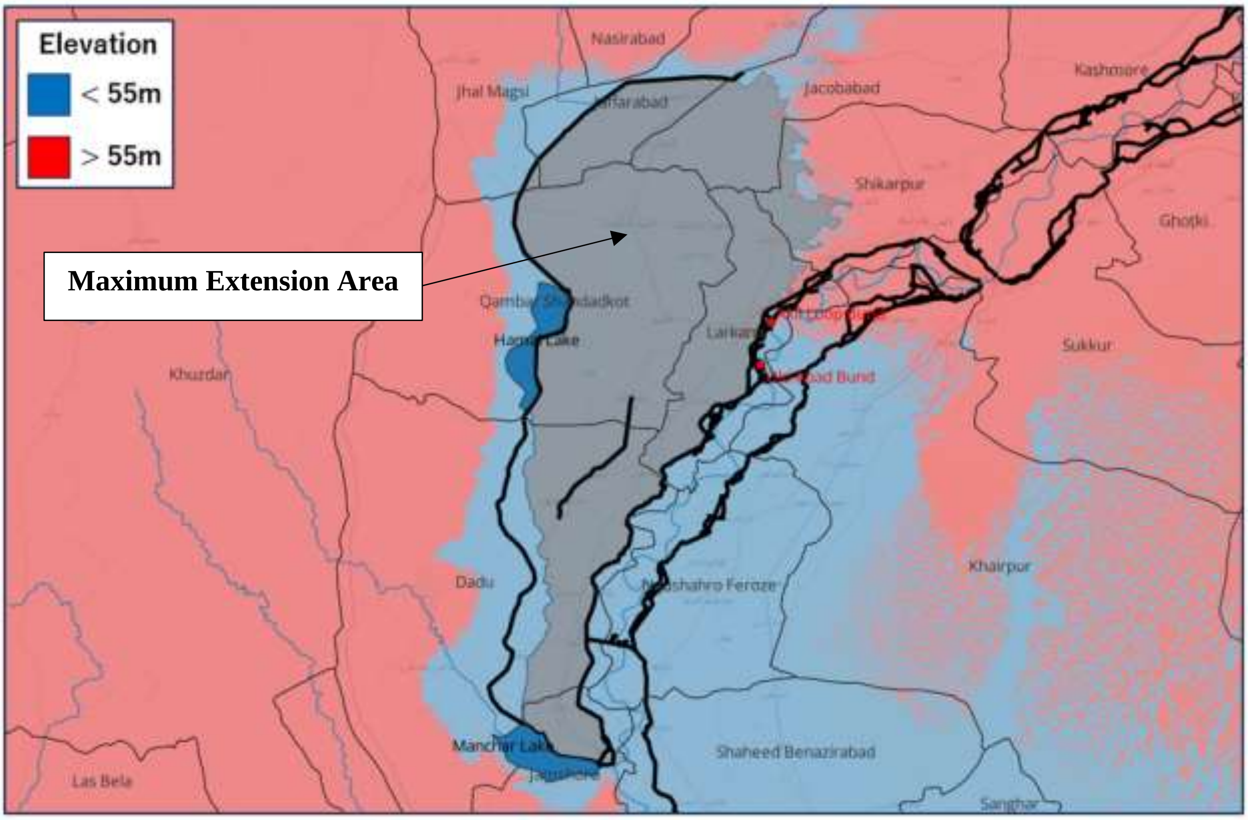
Figure 3.7.2 Map Around Akil Loop Bund

Source: Advisory Team

Figure 3.7.3 Assumption of Flood Expansion near Akil Loop Bund with Ground Elevation Map

Source: Created by Advisory Team from Google Earth

Figure 3.7.4 Assumption of Flood Expansion near Akil Loop Bund with Surrounding Map



Source: Advisory Team

Figure 3.7.5 Maximum Extension Area if the Akil Loop Bund Breaches

(2) Estimated Amount of Damage to Houses

Using the same method as that used in Section 3.1.3, the estimated amount of damage to houses in the study area is about 2.8 tri. PKR is shown in Table 3.7.2. The number of affected households was estimated for each tehsil as shown in Table 3.7.3.

Table 3.7.2 Estimated Damage to Houses (Akil Loop Bund)

Contents	Price	Unit
House asset	8,000,000	PKR
No of affected household	597,959	-
Total price of affected house	4,783,672,000,000	PKR
Damage Rate	0.592	-
Amount of Damage	2,831,933,824,000	PKR

Source: Advisory Team

Table 3.7.3 Estimation Result of the Number of Flood-Affected Households (Akil Loop Bund)

Province	District	Tehsil	Total Area (km2)	Total Area (mi2)	Flooded Area (km2)	Total Area (mi2)	Inundation Rate (%)	Population	People per Household	Household	Affected People	Affected Household
Sindh	Qambar Shahdadkot	Qubo Saeed Khan	623	241	483	187	77.54	85,970	5.55	15,490	66,664	12,012
		Shahdadkot	398	154	398	154	100.00	202,745	5.55	36,531	202,745	36,531
		Miro Khan	772	298	772	298	100.00	427,150	5.55	76,964	427,150	76,964
		Kambar Ali Khan	2,755	1,064	707	273	25.67	395,206	5.55	71,208	101,430	18,276
		Warah	1,059	409	828	320	78.19	229,971	5.55	41,436	179,810	32,398
	Jacobabad	Garhi Khairo	744	287	744	287	100.00	158,360	5.55	28,533	158,360	28,533
		Jacobabad	686	265	132	51	19.27	382,513	5.55	68,921	73,719	13,283
		Thul	1,341	518	0	0	0.00	465,424	5.55	–	–	–
	Shikarpur	Garhi Yasin	943	364	284	110	30.15	315,883	5.55	56,916	95,254	17,163
		Shikarpur	568	219	37	14	6.52	391,172	5.55	70,481	25,500	4,595
		Lakhi	685	264	0	0	0.00	248,143	5.55	–	–	–
		Khanpur	381	147	0	0	0.00	276,283	5.55	–	–	–
	Sukkur	Sukkur	312	121	0	0	0.00	551,357	5.55	–	–	–
		Pano Aqil	900	347	0	0	0.00	435,823	5.55	–	–	–
		Rohri	1,049	405	0	0	0.00	371,104	5.55	–	–	–
		Salehpat	2,943	1,136	0	0	0.00	129,619	5.55	–	–	–
	Larkana	Ratodero	591	228	419	162	70.96	331,584	5.55	59,745	235,285	42,394
		Larkana	568	219	450	174	79.25	738,069	5.55	132,985	584,917	105,390
		Bakrani	332	128	180	70	54.36	229,444	5.55	41,341	124,722	22,472
		Dokri	419	162	249	96	59.34	225,294	5.55	40,594	133,685	24,087
	Dadu	Mehar	993	384	681	263	68.52	460,679	5.55	83,005	315,670	56,878
		Khairpur Nathan Shah	2,605	1,006	392	151	15.03	334,258	5.55	60,227	50,241	9,052
		Dadu	818	316	593	229	72.45	460,481	5.55	82,970	333,625	60,113
		Johi	3,577	1,381	41	16	0.00	294,848	5.55	–	–	–
	Naushahro Feroze	Kandiaro	666	257	0	0	0.00	446,079	5.55	–	–	–
		Moro	755	292	0	0	0.00	368,789	5.55	–	–	–
		Mehrabpur	484	187	0	0	0.00	–	5.55	–	–	–
		Bhiria	398	154	0	0	0.00	424,684	5.55	–	–	–
		Naushahro Feroze	733	283	0	0	0.00	372,821	5.55	–	–	–
	Jamshoro	Sehwan	2,342	904	305	118	13.00	269,291	5.55	48,521	35,021	6,310
		Thano Bula Khan	5,275	2,037	0	0	0.00	145,450	5.55	–	–	–
		Manjhand	2,429	938	0	0	0.00	140,840	5.55	–	–	–
		Kotri	1,218	470	0	0	0.00	437,561	5.55	–	–	–
Balochistan	Jhal Magsi	Jhal Magsi	1,806	697	21	8	1.19	88,575	6.87	12,893	1,053	153
		Gandawa	2,035	786	0	0	0.00	60,650	6.87	–	–	–
	Jaffarabad	Gandakha	572	221	328	126	57.30	74,976	6.87	10,914	42,958	6,253
		Usta Muhammad	402	155	372	144	92.60	186,226	6.87	27,107	172,454	25,102
		Jhat Pat	822	318	3	1	0.00	252,611	6.87	–	–	–
Total			46,001	17,761	8,419	3,251	18.30	11,409,933	–	1,066,782	3,360,262	597,959

Source: Advisory Team

(3) Estimated Crop Damage

Using the same method as that used in Section 3.1.3, the estimated crop damage in the study area is approximately 68 bil. PKR is shown in Table 3.7.4.

Table 3.7.4 Estimated Amount of Crop Damage (Akil Loop Bund)

Province	District	Inundation Rate(%)	Cotton	Rice	Wheat	Total
Sindh	N. Feroze	0	0	0	0	0
	Jacobabad	31.63	0	4,785,036,723	1,851,566,057	6,636,602,780
	Shikarpur	12.47	391,456	2,768,777,080	884,362,485	3,653,531,020
	Larkana	67.99	70,453,330	13,805,598,973	6,174,024,076	20,050,076,380
	Qamber	56.86	0	9,533,563,947	5,505,217,069	15,038,781,016
	Dadu	21.34	180,296,689	1,977,640,179	2,949,895,604	5,107,832,472
	Jamshoro	2.7	31,793,148	2,466,872	188,556,358	222,816,377
Balochistan	Jafferabad	39.11	76,733	8,953,531,143	8,217,594,084	17,171,201,960
	Jhal Magsi	0.56	9,212	68,452	85,921,023	85,998,687
Total		-	283,020,568	41,826,683,369	25,857,136,756	67,966,840,692

Source: Advisory Team

(4) Total Estimated Flood Damage

The estimated flood damage in case of flooding by the Akil Loop Bund breach is shown in Table 3.7.5 by summing the estimated amount of damage to houses and crops outlined in the preceding section.

Table 3.7.5 Total Estimated Flood Damage (Akil Loop Bund)

Contents	Damage	Unit
Amount of House Damage	2,831,933,824,000	PKR
Amount of Crop Damage	67,966,840,692	PKR
Total Amount of Damage	2,899,900,664,692	PKR

Source: Advisory Team

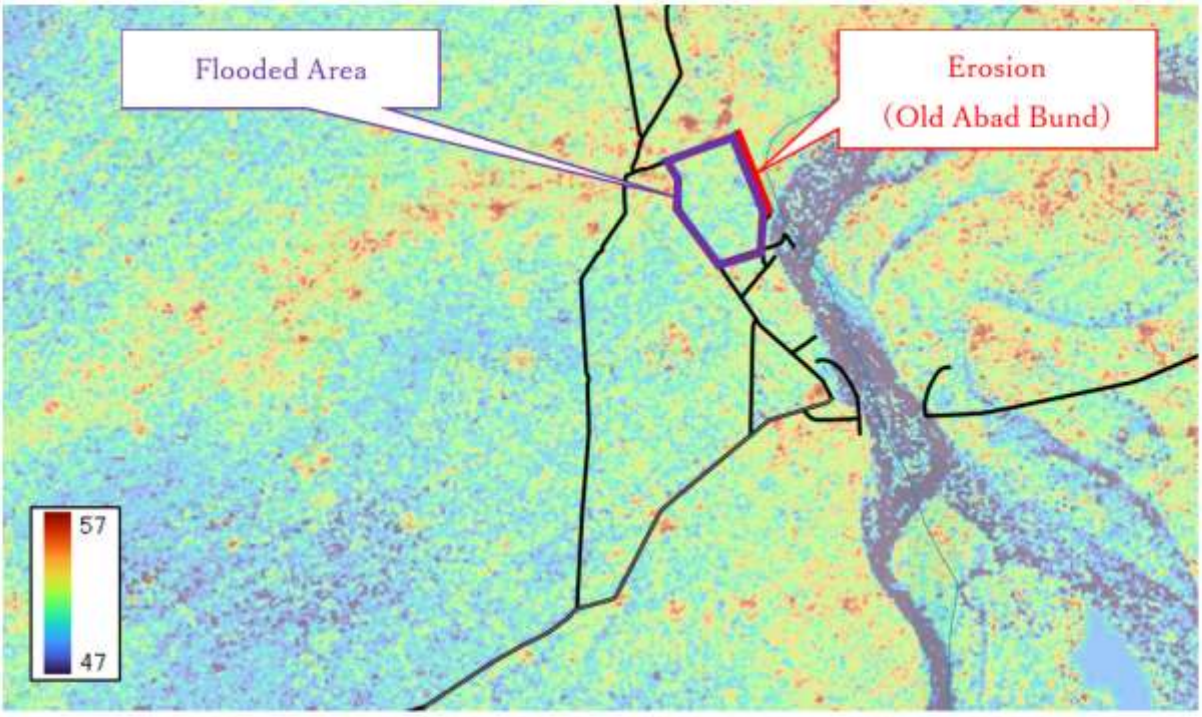
3.7.2.2 Old Abad Bund

(1) Situation Around Vulnerable Point and Flooded Area

Figure 3.7.6 shows the ground elevation and bund conditions around Old Abad Bund (the extracted vulnerable point), and Figure 3.7.7 shows the map around Old Abad Bund by Google Earth. If erosion occurs in Old Abad Bund, the immediate risk of flooding is only in the surrounding area by bunds (enclosed in purple line). So, the flood damage is limited because there are only fields and no residential areas.

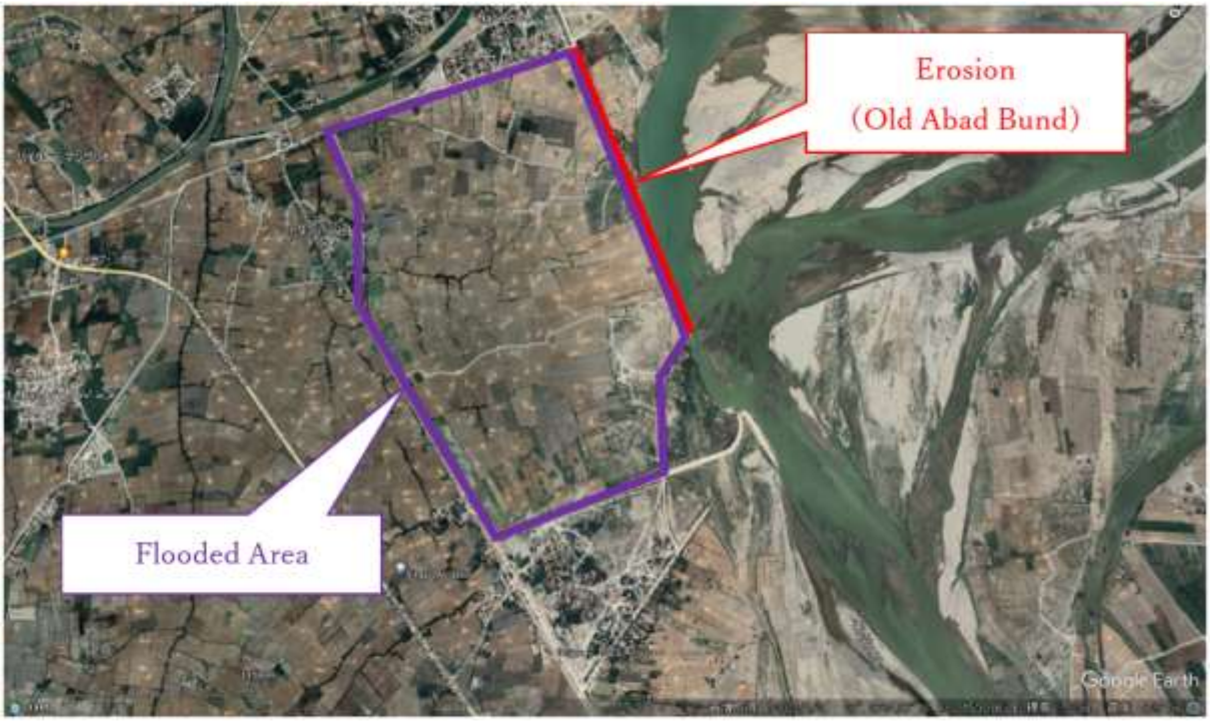
However, if the rear bunds fail to prevent flooding, the flooding area may extend to areas where the ground elevation is lower than that near the bunds (52 m = 170.60 ft). Figure 3.7.8 and Figure 3.7.9 show the assumption of flood expansion near Old Abad Bund with a ground elevation map and surrounding map.

In the study area, there are many areas where the ground elevation is lower than that near the bunds (52 m = 170.60 ft), and assuming that all such areas will be flooded, maximum extension area if the Old Abad Bund breaches can be set as shown in Figure 3.7.10.



Source: Advisory Team

Figure 3.7.6 Ground Elevation and Bund Conditions Around Old Abad Bund

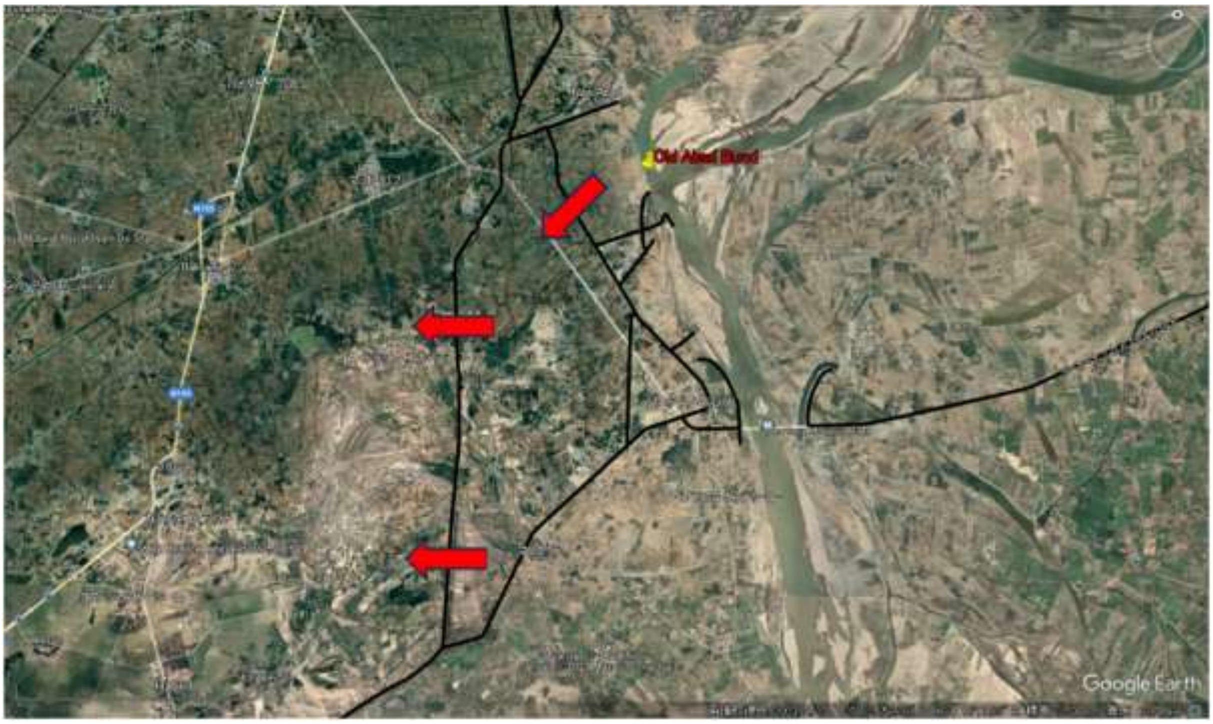


Source: Created by Advisory Team from Google Earth

Figure 3.7.7 Map Around Old Abad Bund

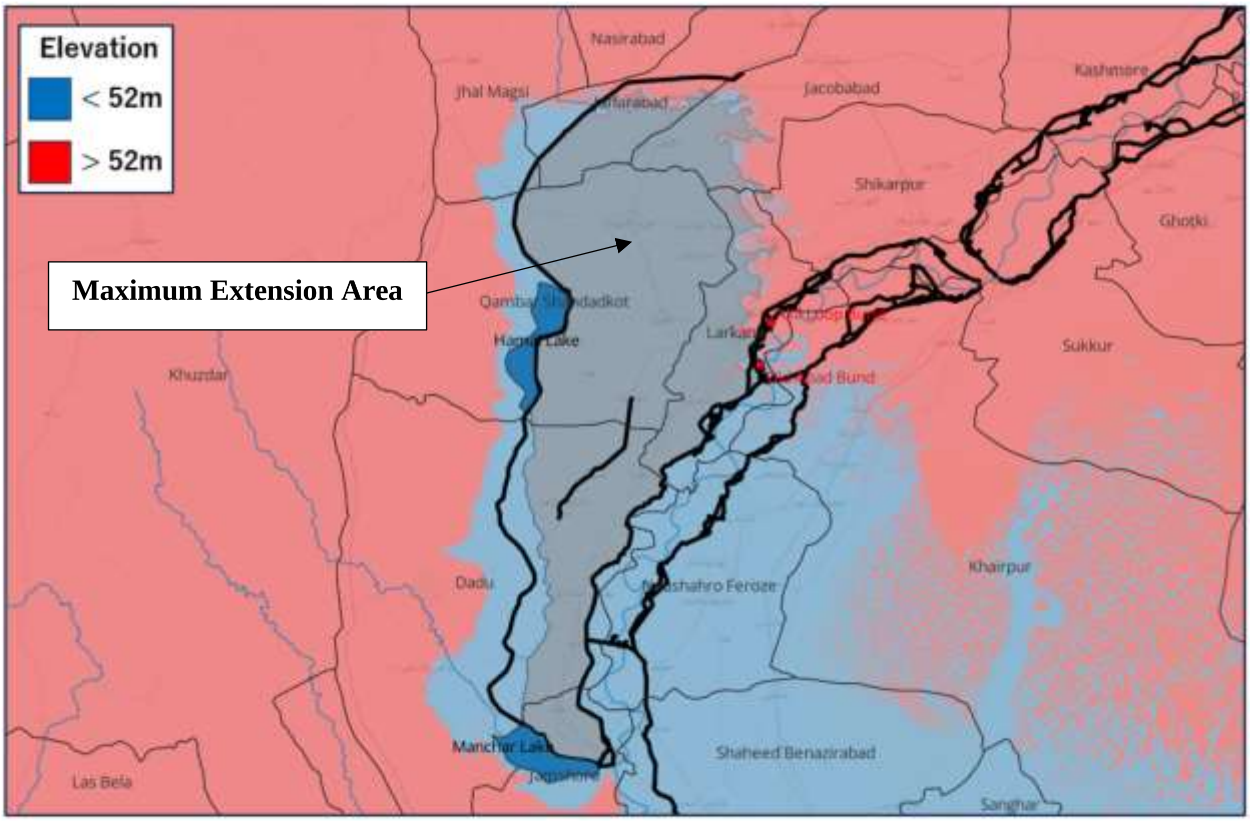
Source: Advisory Team

Figure 3.7.8 Assumption of Flood Expansion near Old Abad Bund with Ground Elevation Map



Source: Created by Advisory Team from Google Earth

Figure 3.7.9 Assumption of Flood Expansion near Old Abad Bund with Surrounding Map



Source: Advisory Team

Figure 3.7.10 Maximum Extension Area if the Old Abad Bund Breaches

(2) Estimated Amount of Damage to Houses

Using the same method as that used in Section 3.1.3, the estimated amount of damage to houses in the study area is about 2.4 tri. PKR is shown in Table 3.7.6. The number of affected households was estimated for each tehsil as shown in Table 3.7.7.

Table 3.7.6 Estimated Damage to Houses (Old Abad Bund)

Contents	Price	Unit
House asset	8,000,000	Rs
No of affected household	497,133	-
Total price of affected house	3,977,064,000,000	Rs
Damage Rate	0.592	-
Amount of Damage	2,354,421,888,000	Rs

Source: Advisory Team

Table 3.7.7 Estimation Result of the Number of Flood-Affected Households (Old Abad Bund)

Province	District	Tehsil	Total Area (km2)	Total Area (mi2)	Flooded Area (km2)	Total Area (mi2)	Inundation Rate (%)	Population	People per Household	Household	Affected People	Affected Household
Sindh	Qambar Shahdadkot	Qubo Saeed Khan	623	241	483	186	77.46	85,970	5.55	15,490	66,593	11,999
		Shahdadkot	398	154	398	154	100.00	202,745	5.55	36,531	202,745	36,531
		Miro Khan	772	298	772	298	100.00	427,150	5.55	76,964	427,150	76,964
		Kambar Ali Khan	2,755	1,064	707	273	25.66	395,206	5.55	71,208	101,408	18,272
		Warah	1,059	409	828	320	78.19	229,971	5.55	41,436	179,818	32,400
	Jacobabad	Garhi Khairo	744	287	484	187	64.98	158,360	5.55	28,533	102,909	18,542
		Jacobabad	686	265	12	5	1.82	382,513	5.55	68,921	6,958	1,254
		Thul	1,341	518	0	0	0.00	465,424	5.55	—	—	—
	Shikarpur	Garhi Yasin	943	364	5	2	0.51	315,883	5.55	56,916	1,613	291
		Shikarpur	568	219	0	0	0.00	391,172	5.55	—	—	—
		Lakhi	685	264	0	0	0.00	248,143	5.55	—	—	—
		Khanpur	381	147	0	0	0.00	276,283	5.55	—	—	—
	Sukkur	Sukkur	312	121	0	0	0.00	551,357	5.55	—	—	—
		Pano Aqil	900	347	0	0	0.00	435,823	5.55	—	—	—
		Rohri	1,049	405	0	0	0.00	371,104	5.55	—	—	—
		Salehpat	2,943	1,136	0	0	0.00	129,619	5.55	—	—	—
	Larkana	Ratodero	591	228	143	55	24.26	331,584	5.55	59,745	80,447	14,495
		Larkana	568	219	367	142	64.59	738,069	5.55	132,985	476,693	85,891
		Bakrani	332	128	194	75	58.37	229,444	5.55	41,341	133,928	24,131
		Dokri	419	162	248	96	59.25	225,294	5.55	40,594	133,486	24,052
	Dadu	Mehar	993	384	681	263	68.54	460,679	5.55	83,005	315,768	56,895
		Khairpur Nathan Shah	2,605	1,006	392	151	15.04	334,258	5.55	60,227	50,259	9,056
		Dadu	818	316	593	229	72.51	460,481	5.55	82,970	333,886	60,160
		Johi	3,577	1,381	41	16	0.00	294,848	5.55	—	—	—
	Naushahro Feroze	Kandiaro	666	257	0	0	0.00	446,079	5.55	—	—	—
		Moro	755	292	0	0	0.00	368,789	5.55	—	—	—
		Mehrabpur	484	187	0	0	0.00	—	5.55	—	—	—
		Bhiria	398	154	0	0	0.00	424,684	5.55	—	—	—
		Naushahro Feroze	733	283	0	0	0.00	372,821	5.55	—	—	—
	Jamshoro	Sehwan	2,342	904	304	118	13.00	269,291	5.55	48,521	35,001	6,306
		Thano Bula Khan	5,275	2,037	0	0	0.00	145,450	5.55	—	—	—
		Manjhand	2,429	938	0	0	0.00	140,840	5.55	—	—	—
		Kotri	1,218	470	0	0	0.00	437,561	5.55	—	—	—
Balochistan	Jhal Magsi	Jhal Magsi	1,806	697	22	8	1.21	88,575	6.87	12,893	1,070	156
		Gandawa	2,035	786	0	0	0.00	60,650	6.87	—	—	—
	Jaffarabad	Gandakha	572	221	314	121	54.99	74,976	6.87	10,914	41,233	6,002
		Usta Muhammad	402	155	204	79	50.68	186,226	6.87	27,107	94,386	13,739
		Jhat Pat	822	318	0	0	0.00	252,611	6.87	—	—	—
Total			46,001	17,761	7,193	2,777	15.64	11,409,933	—	996,301	2,785,352	497,133

Source: Advisory Team

(3) Estimated Crop Damage

Using the same method as that used in Section 3.1.3, the estimated crop damage in the study area is approximately 52 bil. PKR is shown in Table 3.7.8.

Table 3.7.8 Estimated Amount of Crop Damage (Old Abad Bund)

Province	District	Inundation Rate(%)	Cotton	Rice	Wheat	Total
Sindh	N. Feroze	0	0	0	0	0
	Jacobabad	17.9	0	2,707,940,478	1,047,835,360	3,755,775,838
	Shikarpur	0.19	5,964	42,186,660	13,474,649	55,667,273
	Larkana	49.86	51,666,466	10,124,241,283	4,527,678,195	14,703,585,943
	Qamber	56.85	0	9,531,887,274	5,504,248,863	15,036,136,138
	Dadu	21.36	180,465,664	1,979,493,638	2,952,660,267	5,112,619,569
	Jamshoro	2.7	31,793,148	2,466,872	188,556,358	222,816,377
Balochistan	Jafferabad	28.85	56,603	6,604,688,660	6,061,815,119	12,666,560,382
	Jhal Magsi	0.57	9,377	69,674	87,455,327	87,534,378
Total		-	263,997,223	30,992,974,538	20,383,724,137	51,640,695,898

Source: Advisory Team

(4) Estimated Total Damage

The estimated flood damage in case of flooding by the Old Abad Bund breach is shown in Table 3.7.9 by summing the estimated amount of damage to houses and crops outlined in the preceding section.

Table 3.7.9 Total Estimated Flood Damage (Old Abad Bund)

Contents	Damage	Unit
Amount of House Damage	2,354,421,888,000	Rs
Amount of Crop Damage	51,640,695,898	Rs
Total Amount of Damage	2,406,062,583,898	Rs

Source: Advisory Team

CHAPTER 4 PROJECT ON ENHANCEMENT OF DRAINAGE SYSTEM OF THE MANCHAR LAKE BASIN

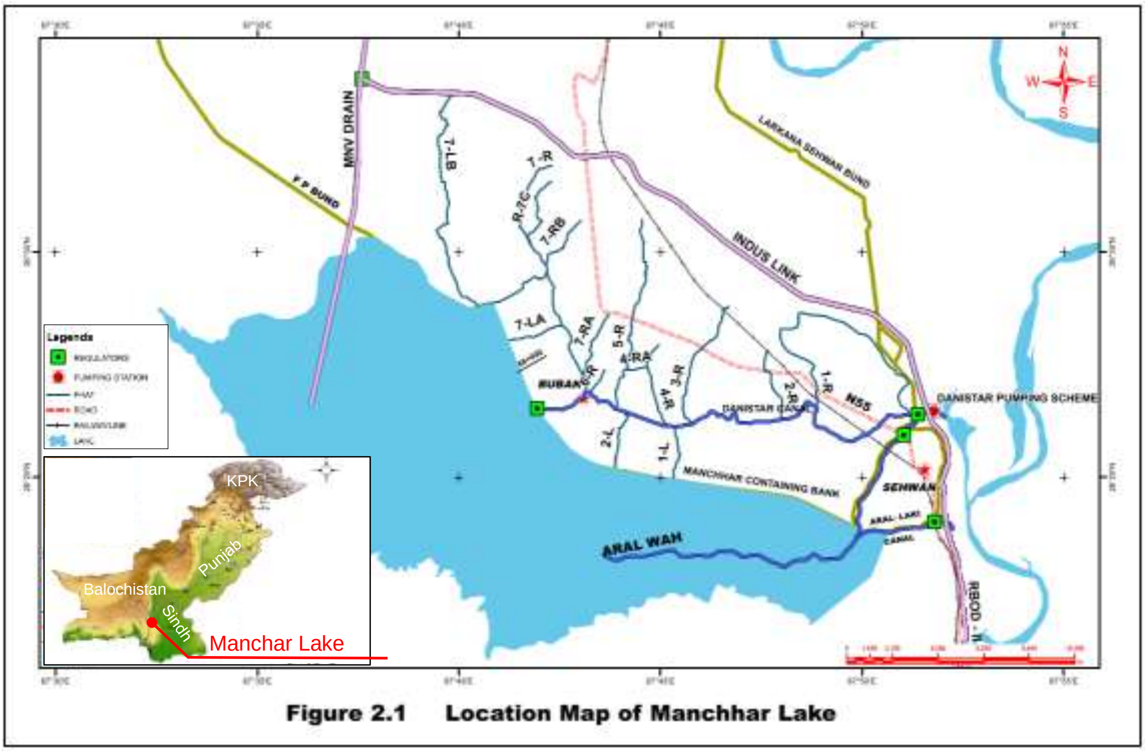
4.1 River/Cannel system in/around RBOD intake/drainage area

4.1.1 General

Manchar Lake is the biggest shallow water natural lake of Pakistan, situated at a distance of 18 km in the west of Sehwan City in district Jamshoro of Sindh. It is flanked by the Kirthar Hills in the west, Laki Hills in the south, and River Indus in the east. Manchar Lake is a shallow saucer shaped basin and the area of the lake varies from 50 to 270 km^2 depending on the influx of water. The water supply is dependent upon two major fresh water sources i.e., Indus River and Hill Torrents from Kirthar hills. Figure 4.1.1 shows the location maps of Manchar Lake.

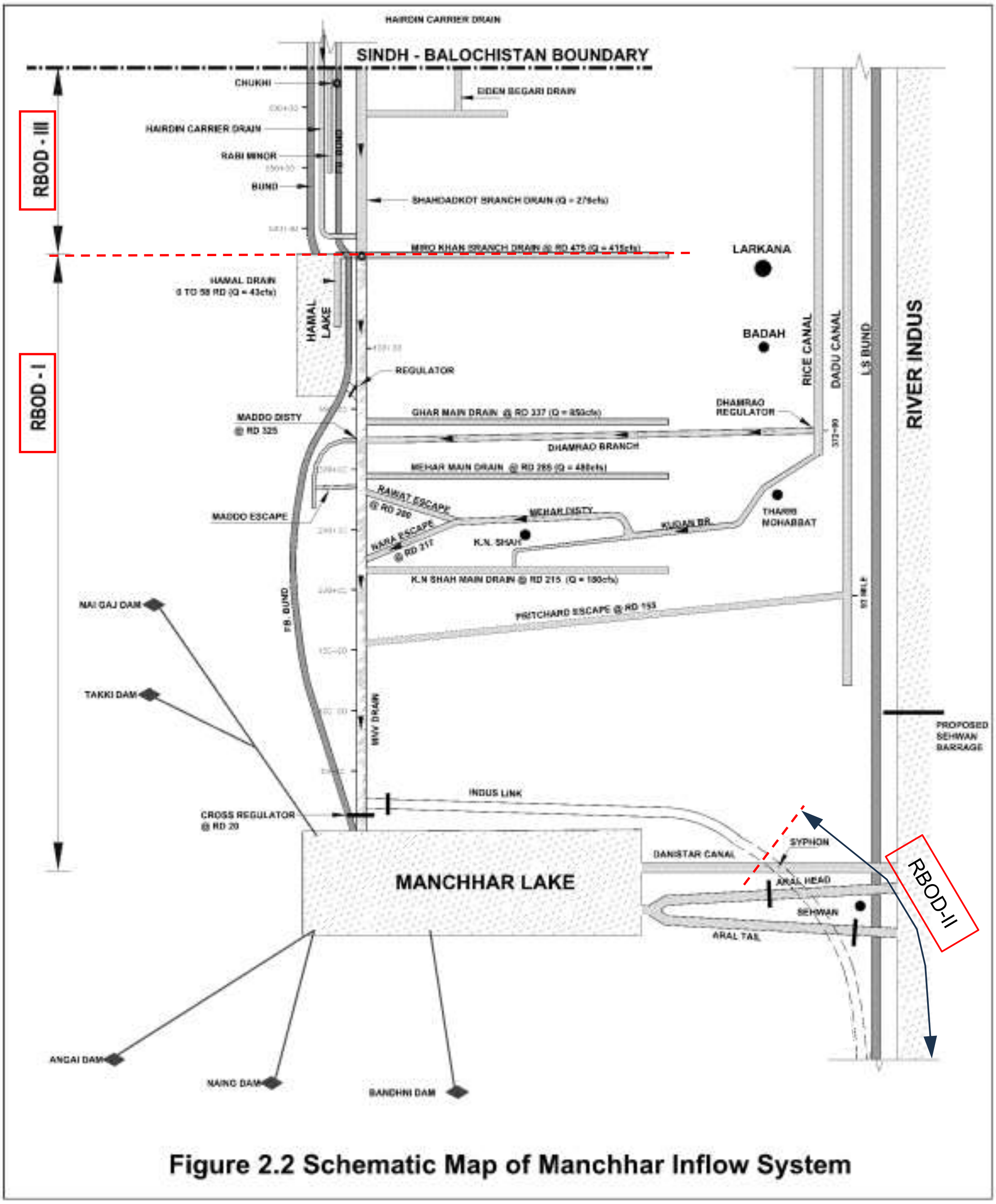
Basically, the lake was filled by the hill torrents and flood spills of the Indus River. Besides, Main Nara Valley Drain (MNVD) was also the main source of water. The purpose of the MNV Drain was principally to carry flood flows from the hill torrents and escape flows from the irrigation canals and disposed of into Manchar Lake. Later it was remodeled to carry agricultural wastewater and saline effluent(The source seems the ground water including salt content from the hill torrent area.) of RBOD-I and RBOD-III, since RBOD-II is not yet completed. MNVD directly outfalls into Manchar Lake which has greatly polluted the Lake and seriously disturb the natural wet land ecosystem and resident on the lake.

RBOD-III is proposed in the upstream of RBOD-III and the target area is from the upstream of Hamal Lake to the provincial boundary. Figure 4.1.2 shows the locations of RBOD-I, II and III.



Source: Draft Feasibility Report on Feasibility Study/ Planning for Supplying Economical Flows in Manchar Lake, September 2017.

Figure 4.1.1 Location Map of Manchar Lake



Source: *Added on Draft Feasibility Report on Feasibility Study/ Planning for Supplying Economical Flows in Manchar Lake, September 2017.*

Figure 4.1.2 Locations of RBOD-I, II, III

4.1.2 Existing Drainage (Takayama)

(1) RBOD Projects

1) RBOD-I Project

The RBOD-I Project has been constructed mainly as a means of disposing of effluent from the Right Bank of Sukkur and Guddu Barrage Commands in Sindh Province. The area benefited under the project is 5,186km^2(1.28 Million) Acres and a major part of the project area lies within the districts of Larkana, Kamber-Shahdadkot, Dadu & Jamshoro Districts of Sindh Province.

2) RBOD-II Project

The RBOD-II (Extension from Sehwan to sea) is envisaged to provide an Outfall for surface drainage from the Right Bank Command of Sukkur and Guddu Barrages without causing adverse effects on users of the Indus River. The RBOD-II runs along the Right Bank of the River Indus. The drain will be connected to RBOD-I at Sehwan and will carry the effluent directly to the sea at Gharo. The drain will carry a discharge of 2,271 cfs(=64.3 m^3/s) up to Khui (RD-754) where KG Drain will merge with RBOD extension and 2,721 cfs(=77.1 m^3/s) downstream of Khui upto outfall structure. It will be subsequently enlarged to carry a future estimated discharge of 3,525 cfs(=99.8 m^3/s) up to Khui and 3,975(=112.6 m^3/s) cfs downstream of Khui up to the proposed outfall structure (Table 2.2). The capacity of the outfall structure is 4200 cfs(=118.9 m^3/s).

3) RBOD-III Project

(2) The RBOD-III Project is located on the right bank of the Indus River spread over Districts Nasirabad and Jafarabad of Balochistan and Districts Jacobabad and Kambar Shahdadkot of Sindh Province. The Project is to collect the water from several drainage systems and to discharge it. Main Nara Valley Drain

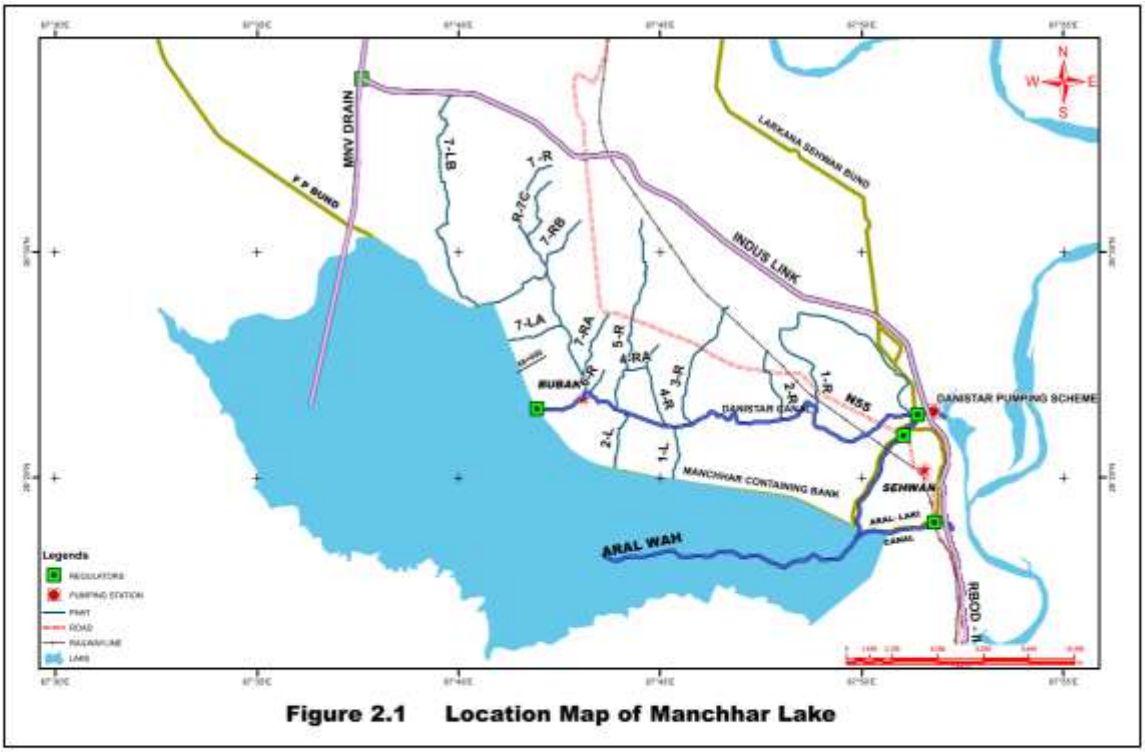
The Main Nara Valley Drain (MNVD) offtakes from F.P(Flood Protection) Bund RD 364 where its head regulator is located. The head regulator was constructed in 1972. On the western side of F.P Bund there exists Hamal Lake. The effluent water of Hamal Lake finds its way into MNVD.

4.1.3 Existing Canal Connecting to the Indus River

Figure 4.1.3 shows the existing canal connecting to the Indus River. As of June 2023, 4 canals are flowing into the Indus River around Sehwan.

- ✓ Indus Link
- ✓ Danister Canal
- ✓ Aral Wah(Head)
- ✓ Aral Laki(Tail)

Indus Link is not connected with Manchar Lake, and there is a plan to extend Indus Link downstream, which is called RBOD-II. As of June 2023, the Indus link is connecting with the Indus River at the confluence of Aral Laki and Indus River.



Source: Draft Feasibility Report on Feasibility Study/ Planning for Supplying Economical Flows in Manchar Lake, September 2017.

Figure 4.1.3 Locations of the Existing Canals Connecting to the Indus River

Source: Google Earth (The Image is as of 2022.4.)

Figure 4.1.4 Situation around Confluence of Aral Laki and Indus River

(1) Aral Wah (Head)

This canal provides fresh water from the River Indus into Manchhar Lake when river levels are higher.. The head regulator of Aral Wah is located at 16.4 km(=102 Mile) of Larkana Sehwan Bund

(L.S Bund). This regulator, which is designed to carry 4,370 cusecs(=123.7 m^3/s) discharge, is also used as double acting for draining and filling water for Manchhar Lake as per water demands. The crest level of the Aral Head Regulator is at R.L 30.57 m(=100.35 ft) and whenever the River Indus level rises to about R.L 31.75 m(=105 ft) and the corresponding level of water in Manchhar Lake is low, the flow from River Indus is allowed to enter in Manchhar Lake.

(2) Danister Wah(Canal)

The Danister Wah is also an inundation canal. This canal was closed due to the construction of Larkana Sehwan Bund (L.S Bund) during the early thirties. On the pressing demand of growers of Taluka Sehwan Sharif, this Canal was re-commissioned by constructing a head regulator at 16.25 km(=Mile 101) of Larkana Sehwan Bund with the designed discharge of 500 cusecs(=14.2 m^3/s) during the year 1972. The head regulator of Danister Wah was damaged during the super flood of 2010 and it was reconstructed/remodeled during the years 2012 - 2013 to carry a discharge of about 3,500 cusecs(=99.1 m^3/s). The Tail Regulator of this canal is located at RD 62 of Manchhar Containing Bank (MCB). The discharge of this regulator is 500 cusecs(=14.2 m^3/s).

(3) Aral–Laki(Tail) Canal

The Aral-Laki Canal is situated near Lal Bagh downstream of Sehwan Sharif. This canal is controlled through a regulator known as the Aral Tail Regulator. As this Regulator is constructed on low-level land, therefore it is the best and most favorable source of feeding as well as draining of the lake water. This regulator was damaged during super flood of 1995 and after flood it was remodeled by adding one span on either side to carry 25,000 cusecs(=707.9 m^3/s) discharge.

The above-mentioned regulators are double acting and are used for filling as well as depletion of Manchhar Lake.

4.1.4 Current River System Around Manchar Lake

According to "Feasibility Study / Planning for Supplying Ecological Flows in Manchar Lake" (2017 F/S Report), the current and future water balances around Manchar Lake can be summarized in Table 4.1.1, Figure 4.1.5 and Figure 4.1.6. Proposed measures to improve the water quality of Lake Manchar is listed in Table 4.1.2, and the location map of these measures is shown in Figure 4.1.7.

Table 4.1.1 Current and Future Water Balances Around Manchar Lake

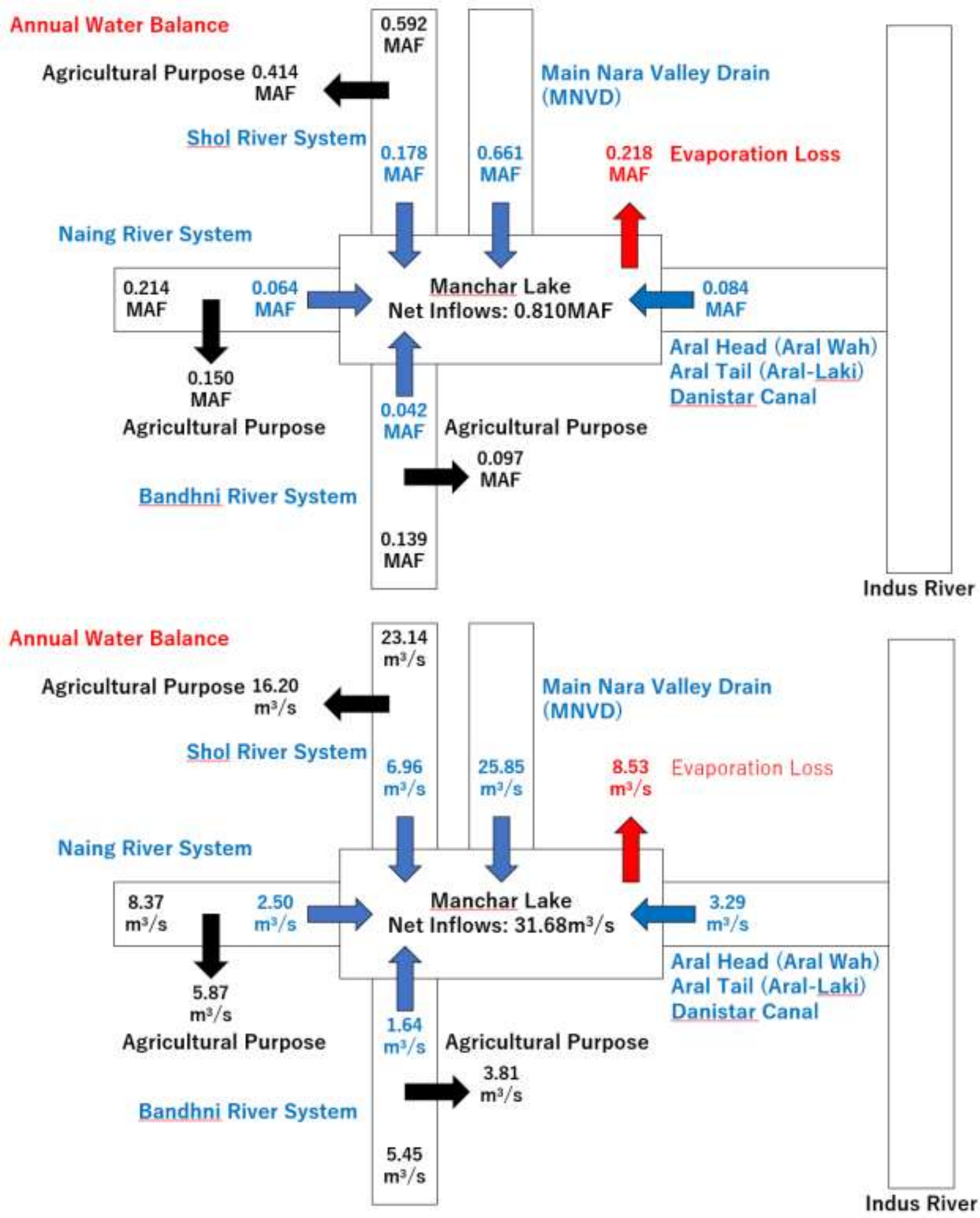
Inflow Source	Existing Inflows		Future Inflows	
	MAF	m3/s	MAF	m3/s
Shol River System	0.178	6.96	0.036	1.41
Naing River System	0.064	2.50	0.064	2.50
Bandhni River System	0.042	1.64	0.042	1.64
Indus River	0.084	3.29	0.168	6.57
Main Nara Valley Drain (MNVD)	0.661	25.85	—	—
Dhamrao Link (Proposed)	—	—	0.124	4.85
Sapna Lake (Proposed)	—	—	0.054	2.11
Total	1.029	40.25	0.488	19.09
Evaporation Loss	0.218	8.53	0.189	7.39
New Inflows	0.810	31.68	0.299	11.69

Source: 2017 F/S Report

Table 4.1.2 Proposed Measures to Improve the Water Quality of Lake Manchar (2017 F/S Report)

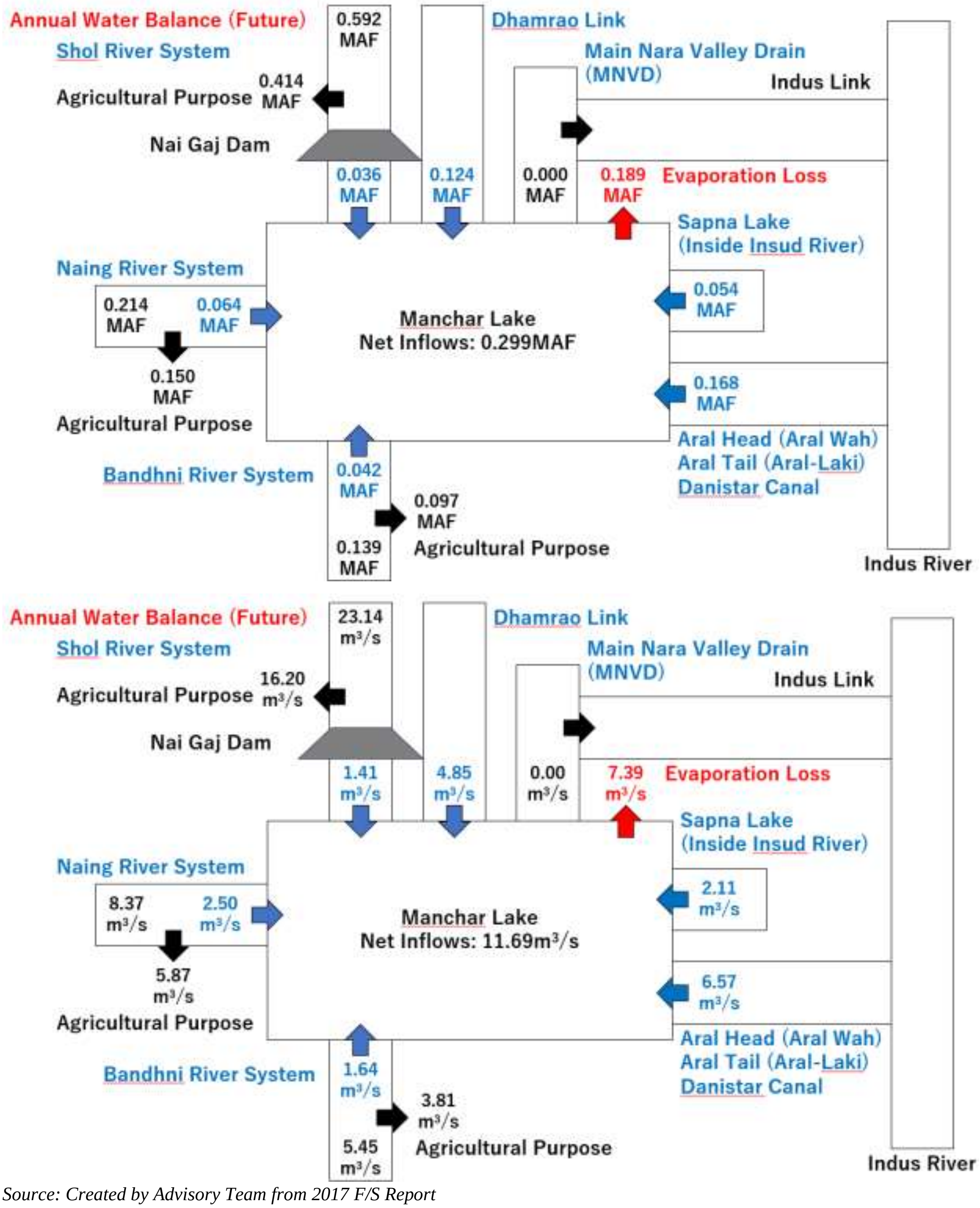
No	Options
1	Construction of Dhamrao Link
2	Construction of Pipeline from Nai Gaj Dam to Manchar Lake
3	Construction of Pumping Station near Sapna Lake
4	Remodeling of Aral Wah and Aral-Laki Canal
5	Diversion of Saline Water of MNV Drain into Indus River through Indus Link
6	Eliminating the Urban Sewage entering into MNV Drain
7	Expediting the Construction of RBOD-II Project

Source: 2017 F/S Report



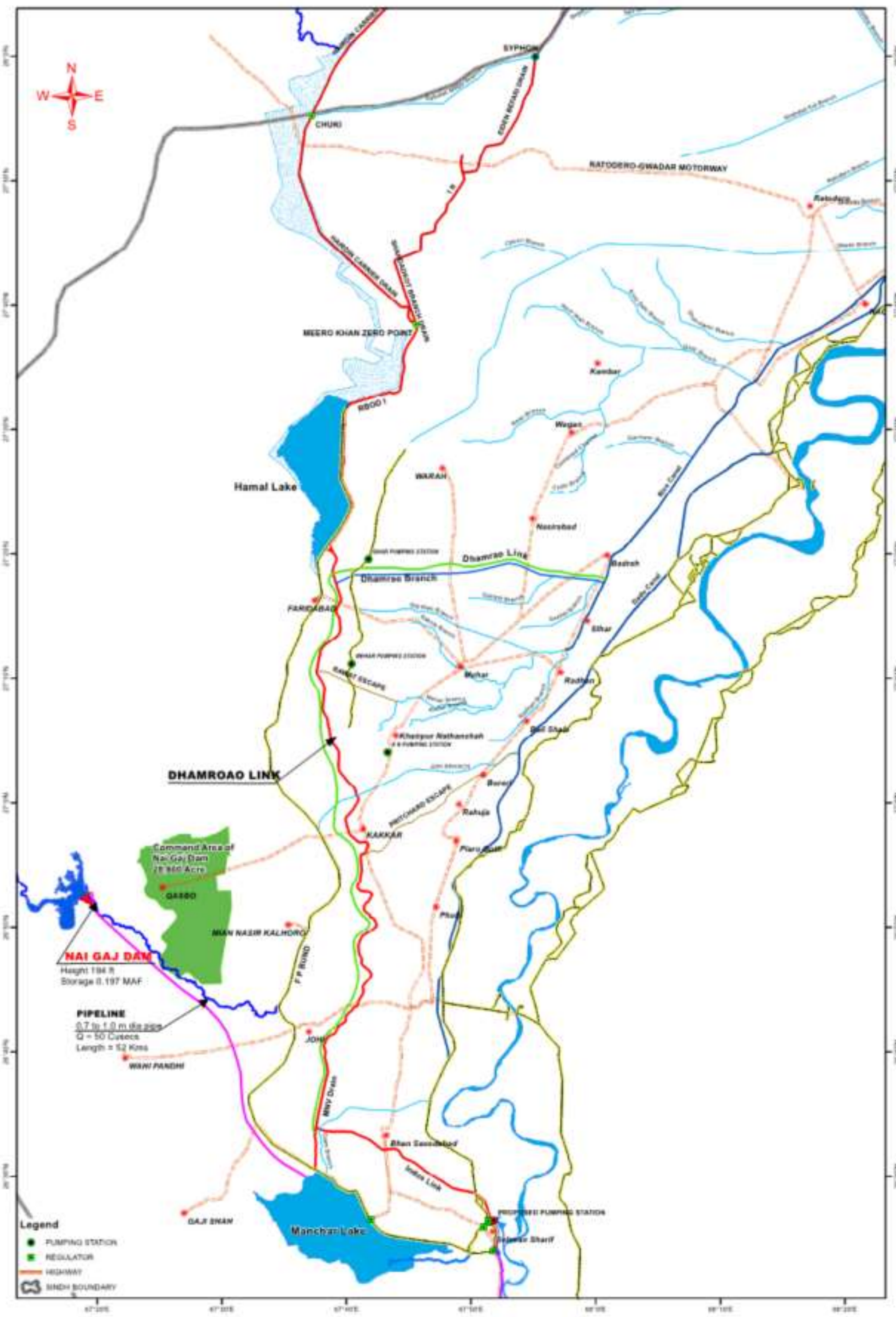
Source: Created by Advisory Team from 2017 F/S Report

Figure 4.1.5 Current Water Balance Around Lake Manchar



Source: Created by Advisory Team from 2017 F/S Report

Figure 4.1.6 Future Water Balance Around Lake Manchar



Source: 2017 F/S Report

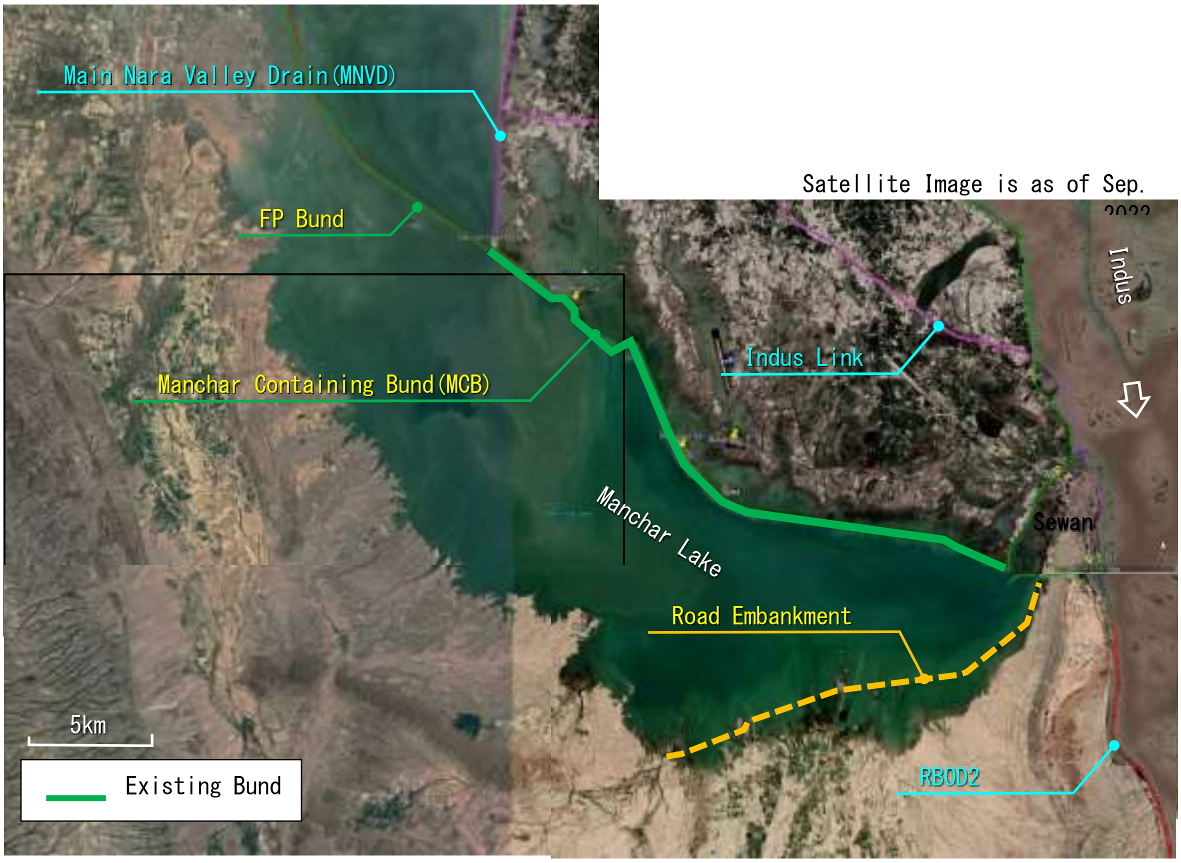
Figure 4.1.7 Location Map of Proposed Measures to Improve the Water Quality of Lake Manchar (2017 F/S Report)

4.2 Situation of the Bund of Manchar Lake and Water Gates

(1) Situation of Manchar Containing Bank (MCB)

A lake bank called Manchar Containing Bund (MCB) is located on the north side of Manchar Lake. The FP Bund functions as a lakeshore bank on the northwest side of the Main Nara Valley Drain (MNVD) inflow point. On the other hand, there are no bunds on the east, west and south sides of the lake. Because there are mountains on the south side of the lake and there is no large urban area. There is a road embankment on the southeast side of the lake, which is higher than the ground level of the surrounding area, and some of the embankments function as bunds.

Figure 4.2.1 shows the condition of embankments around Manchar Lake. The satellite image in Figure 4.2.1 was taken in 2022.9, and according to an interview with an engineer from Sindh Province, during the flood in 2022, along the FP Bund and MCB artificial breach was carried out, so that the inundation area respread behind the bund. On the other hand, the situation shown in Figure 4.2.1 indicates that the inundation area extended behind the road embankment on south side. As of August 2023[1], no information about the top height of the road embankment was obtained, but since there is no information that the existing embankment was artificially cut in this side, it can be assumed that the original top height of the embankment is lower than that of MCB.

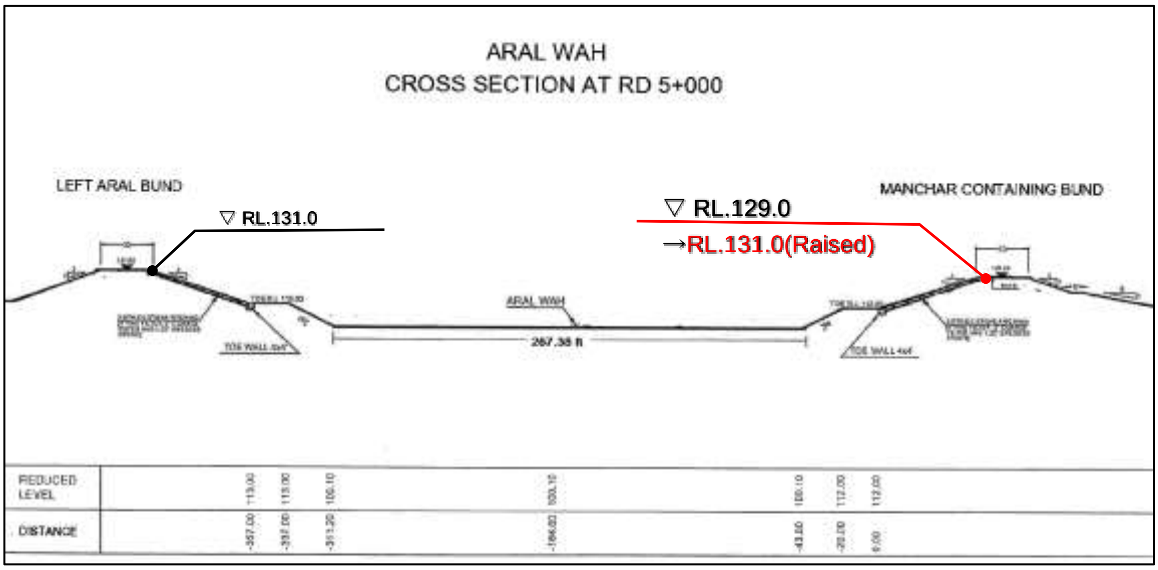


Source: Google Earth

Figure 4.2.1 Bunds Located around Manchar Lake

The MCB has been raised several times, and according to the engineer from Sindh Province, the bund height as of August 2023 is RL. 131.0. This is equivalent to the bund height of Aral Tail (see Figure 4.2.2).

1 Source: Google Earth



Source: Added to Aral Wah Cross Section at RD5 +000

Figure 4.2.2 Bund Height of Aral Bund and MCB Current Bund

Also, as of July 2023, at some parts of the existing MCB rehabilitation of stone pitching was ongoing. The site inspection was carried out immediately after several days of rain, but at that time, the top of the bund was not paved, which hindered the running of vehicles (see Photo 4.2.1). In addition, the area immediately behind the MCB was a low-lying area, and at the site inspection in July 2023, it was widely flooded (see Photo 4.2.2).

Photo 4.2.1 Situation of the top and lake side of the MCB

Photo 4.2.2 Situation of the landside of the MCB

(2) Situation of Weirs and Watergates around Manchar Lake

1) Danister Head Regulator

The Danister Head Regulator is located near the confluence with Aral Head on the Indus River side of the Danister Canal. Table 4.2.1 shows the Danister Head Regulator specifications and Figure 4.2.3 shows the general drawing. Photo 4.2.3 and Photo 4.2.4 show the situation at the site inspection in July 2023.

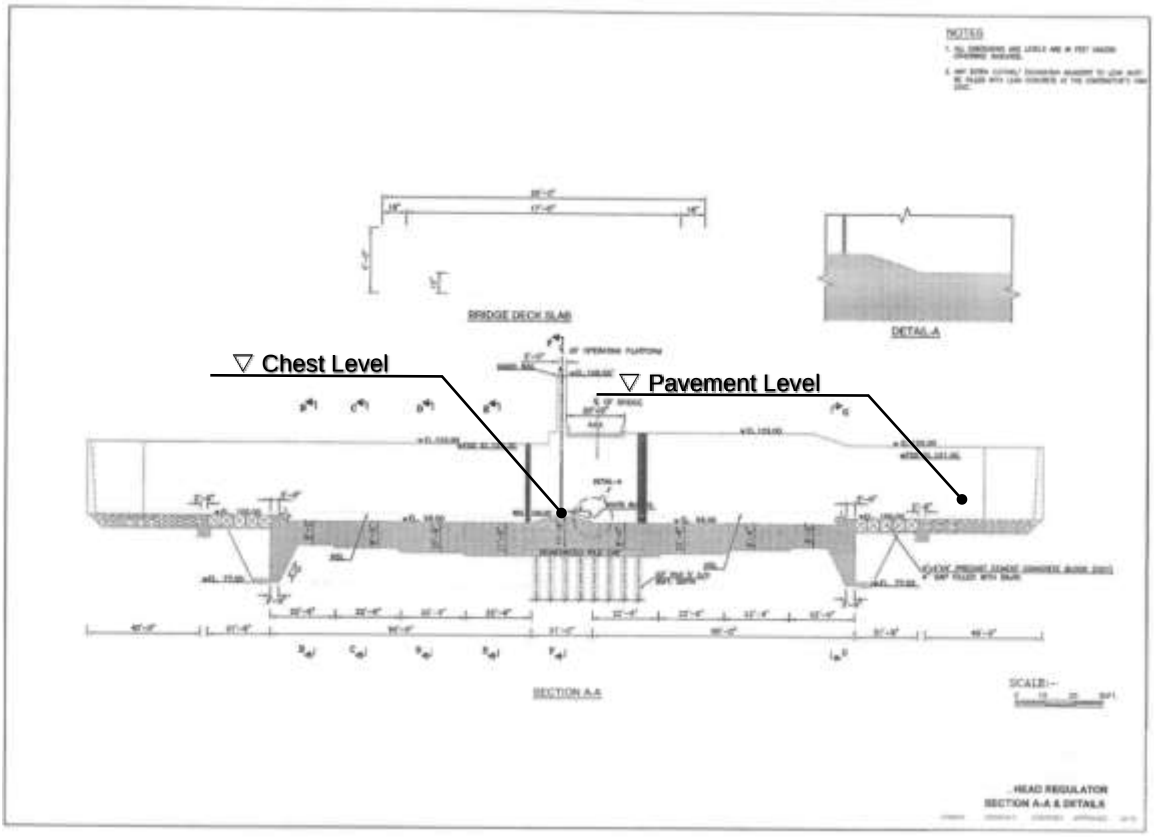
When the site inspection was conducted in July 2023, it appeared that no fatal damage had occurred to the equipment. There had been intermittent rainfall for several days just before the inspection, but water had not been drained during the site inspection.

Danister Canal is a channel with a river width of about 40 m to 50 m, but the Regulator section has a water width of about 10 m.

Table 4.2.1 Canister Head Regulator Specifications

	Item	Description
1	No. of Gate	5 Nos.
2	Diamantine of Gate	8 x 20ft (2.44 x 6.10 m)
3	Type of Gate	Vertical Type Screw Operated
4	Discharge Capacity	3,500 cusec (99.11 m^{3}/s)
5	Pavement RL	RL 100 ft (RL.30.48 m)
6	Crest RL	RL 100 ft (RL.30.48 m)
7	FSD	RL 100 ft (RL.30.48 m)

Source: Silent Features of Danister Head Regulator, Sindh Irrigation Department



Source: Silent Features of Danister Head Regulator, Sindh Irrigation Department

Figure 4.2.3 General Draiwngs of Danister Head Regulator

Photo 4.2.3 Situation of Danister Head Regulator(1)

Photo 4.2.4 Situation of Danister Head Regulator (2)

2) Danister Tail Regulator

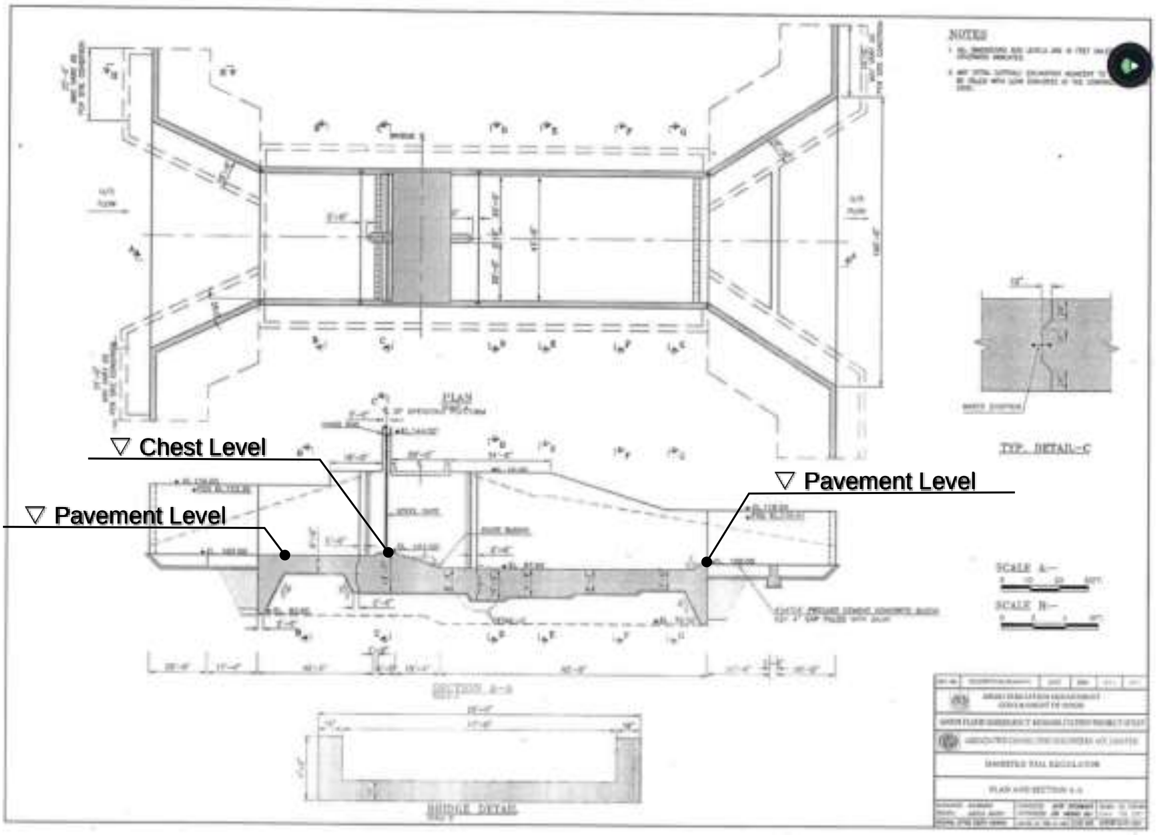
The Danister Tail Regulator is located on the Manchar Lake side of the Danister Canal near its intersection with the MCB. Table 4.2.2 shows the Danister Tail Regulator specifications and Figure 4.2.4 shows the general drawing. Photo 4.2.5 and Photo 4.2.6 show the situation at the site inspection in July 2023.

When the site inspection was conducted in July 2023, the existing regulator had been removed and a new regulator was being installed. The construction of the new regulator was being carried out with a coffer dam in the Manchar Lake side.

Table 4.2.2 Danister Tail Regulator Specifications

	Item	Description	
1	No. of Gate	2 Nos.	
2	Diamantine of Gate	20 x 24ft	(6.10 x 7.32 m)
3	Type of Gate	Vertical Type Counter Balanced	
4	Discharge Capacity	9,000 cusec	(254.85 $m^{3/}s$)
5	Pavement RL	Manchar Side RL 102 ft Land Side RL 97.90 ft	(RL.31.09 m) (RL.29.84 m)
6	Crest RL	RL 103 ft	(RL.31.39 m)
7	FSD	RL 123.3 ft	(RL.37.58 m)

Source: Silent Features of Danister Tail Regulator(62) New Under Construction, Sindh Irrigation Department



Source: Silent Features of Danister Tail Regulator(62) New Under Construction, Sindh Irrigation Department

Figure 4.2.4 General Drawing of Danister Tail Regulator

Photo 4.2.5 Situation of Danister Tail Regulator (1)

Photo 4.2.6 Situation of Danister Tail Regulator (2)

3) Aral Head Regulator

The Aral Head Regulator is located on the Indus River side of Aral Head near the intersection with Indus Highway.

(a) Existing Regulator

Table 4.2.3 shows the existing Regulator specifications, and Figure 4.2.5 shows the general drawing. Photo 4.2.7 and Photo 4.2.8 show the situation at the site inspection in July 2023.

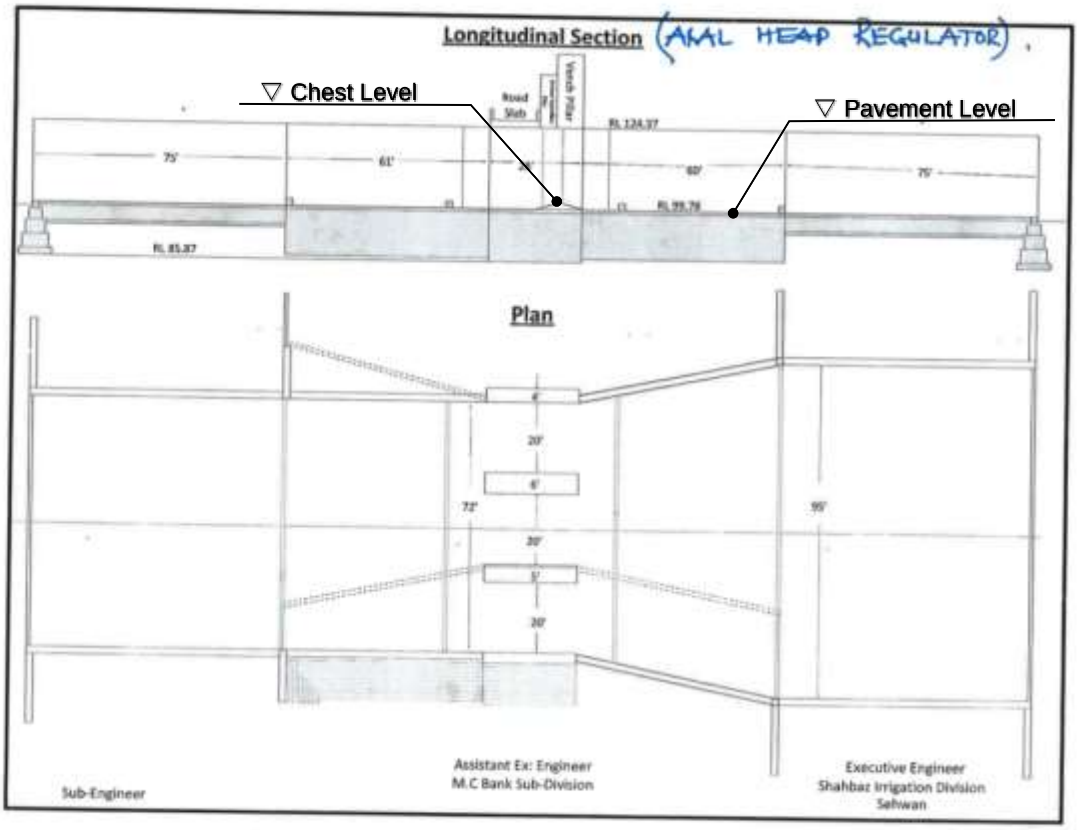
When the site inspection was conducted in July 2023, there was not any serious damage. On the other hand, the installation work of the new regulator was being carried out on the upstream side of the existing regulator, and the drain was not carried out.

The Aral Head is a channel with a river width of about 110 m to 130 m, but the existing regulator section has a water flow width of about 20 m, and this is the bottleneck.

Table 4.2.3 Specifications of the existing Aral Head Regulator

	Item	Description	
1	No. of Gate	3 Nos.	
2	Diamantine of Gate	20 x 22 ft	(6.10 x 6.71 m)
3	Type of Gate	Vertical Type Counter Balanced	
4	Discharge Capacity	10,000 cusec	(283.7 m^3/s)
5	Pavement RL	RL 99.78 ft	(RL.30.41 m)
6	Crest RL	RL 101.37 ft	(RL.30.90 m)
7	FSD	RL 121.5 ft	(RL.37.03 m)

Source: Silent Features of Aral Head Regulator OLD, Sindh Irrigation Department



Source: Silent Features of Aral Head Regulator New Designed/Under Construction, Sindh Irrigation Department

Figure 4.2.5 General Drawing of Existing Aral Head Regulator

Photo 4.2.7 Existing Aral Head Regulator (1)

Photo 4.2.8 Existing Aral Head Regulator (2)

(b) New Regulator

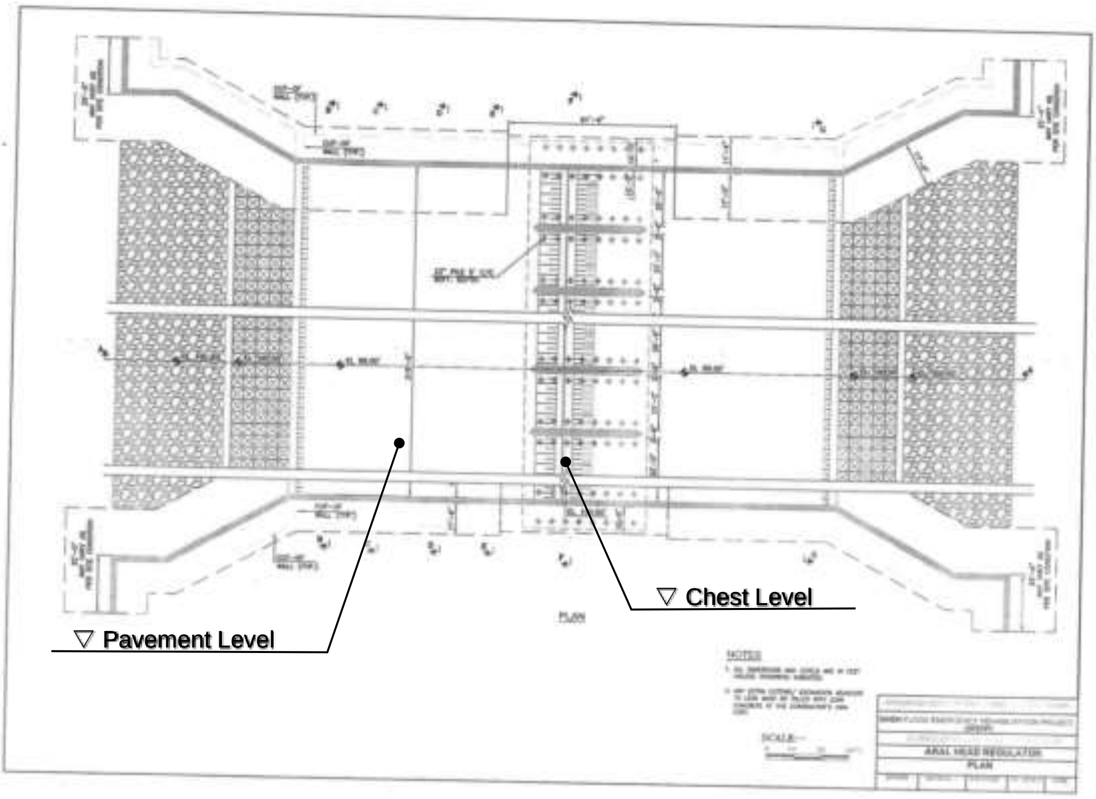
Table 4.2.4 shows the new regulator specifications and Figure 4.2.6 shows the general drawing. Photo 4.2.9 and Photo 4.2.10 show the situation at the site inspection in July 2023.

At the site inspection in July 2023, the installation work of the new regulator was being carried out, and water was not being drained. The location of the new regulator is near the intersection with the existing railway bridge.

Table 4.2.4 New Aral Head Regulator Specifications

	Item	Description	
1	No. of Gate	14 Nos.	
2	Diamantine of Gate	20 x 24 ft	(6.10 x 7.32 m)
3	Type of Gate	Vertical Type Counter Balanced	
4	Discharge Capacity	90,000 cusec	(2548.52 m^3/s)
5	Pavement RL	RL 98 ft	(RL.29.87 m)
6	Crest RL	RL 100 ft	(RL.30.48 m)
7	FSD	RL 123.5 ft	(RL.37.64 m)

Source: Silent Features of Aral Head Regulator New Designed/Under Construction,Sindh Irrigation Department



Source: Silent Features of Aral Head Regulator New Designed/Under Construction, Sindh Irrigation Department

Figure 4.2.6 General Drawing of the New Aral Head Regulator

Photo 4.2.9 New Aral Head Regulator (1)

Photo 4.2.10 New Aral Head Regulator (2)

4) Aral Tail Regulator

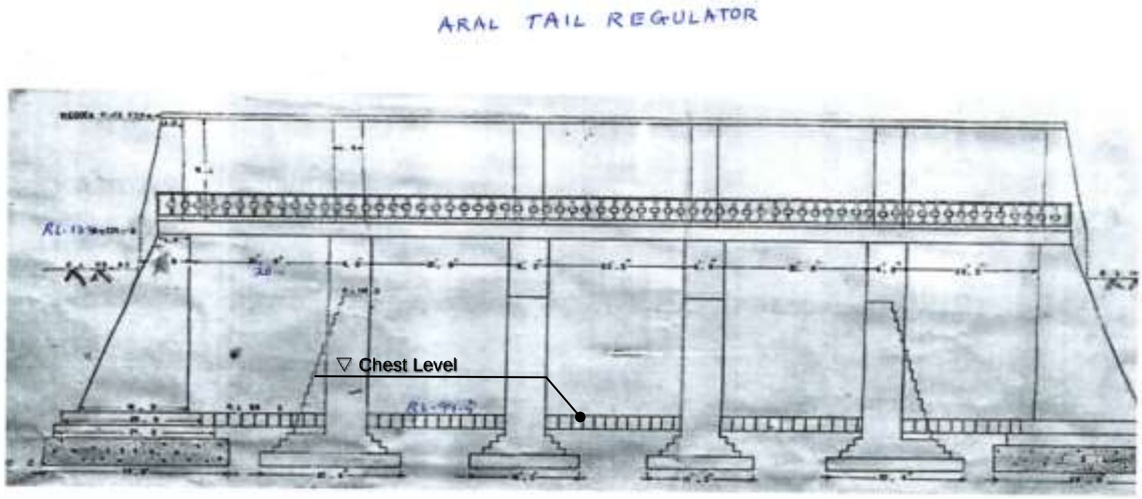
The Aral Tail Regulator is located on the Indus River side of Aral Tail near the intersection with Indus Highway. Table 4.2.5 shows the Aral Tail Regulator specifications and Figure 4.2.7 shows the general drawing. Photo 4.2.11 and Photo 4.2.6 show the situation at the site inspection in July 2023.

When the site inspection was conducted in July 2023, no serious damage was found. The Aral Tail is a waterway with a river width of about 70 m to 80 m, but the Regulator section has a water passage width of about 30 m, and this area is a bottleneck.

Table 4.2.5 Aral Tail Regulator Specifications

	Item	Description	
1	No. of Gate	5 Nos.	
2	Diamantine of Gate	20 x 24 ft	(6.10 x 7.32 m)
3	Type of Gate	Vertical Type Counter Balanced	
4	Discharge Capacity	25,000 cusec	(707.92 $m^{3/}s$)
5	Pavement RL	RL 98.5 ft	(RL.30.02 m)
6	Crest RL	RL 99.5 ft	(RL.30.33 m)
7	FSD	RL 121.5 ft	(RL.37.03 m)

Source: Silent Features of Aral Tail Regulator, Sindh Irrigation Department



Source: Silent Features of Aral Tail Regulator, Sindh Irrigation Department

Figure 4.2.7 General Drawing of Aral Tail Regulator

Photo 4.2.11 Aral Tail Regulator (1)

Photo 4.2.12 Aral Tail Regulator (2)

4.3 O&M of the Lake Bund, Water Gates and Channels

Many channels, water gates, and lake bunds have been constructed in Manchar Lake to improve water quality and prevent floods. The main facilities are shown in the table below.

Table 4.3.1 Main Channels, Water Gates, and Lake Bund of Manchar Lake

Canel Name	Discharge Capacity (cusec;m3/s)	Connection Water gate
Aral Wah(Head)	2670 cusec (75.6m3/s)	Aral Head Regulator
Danister Wah(Canel)	3,500cusec (99.1m3/s)	Danister Head Regulator- Danister Tail Regulater
Aral Laki(Tail)	2500cusec (70.8m3/s)	Aral Tail Regulator
Water Gate/Weir Name	Diamantine of Gate	Installation Canel
Danister Head Regulator	8 x 20ftx 5 Nos. (2.44 x 6.10 m)	Danister Wah(Canel) ;Indus river side
Danister Tail Regulator	20 x 24ft x 2 Nos. (6.10 x 7.32 m)	Danister Wah(Canel) ;Indus river side
Aral Head Regulator	20 x 24 ft x 14 Nos. (6.10 x 7.32 m)	Aral Wah(Head) ;Indus river side
Aral Tail Regulator	20 x 24 ft x 5 Nos. (6.10 x 7.32 m)	Aral Laki(Tail) ;Indus river side
Lakeshore Embankment Name		Location
Manchar Containing Bund（MCB）		North side of Machar Lake
FP Bund		Connected to MCB
Road Embankment		South side of Machar Lake

Source; Advisory Team

4.3.1 Operation and Maintenance of Channels

The water quality of Manchar Lake has deteriorated due to the inflow of wastewater from the Main Nara Valley Drain (MNVD), which is having a major impact on agriculture, fishing, and domestic water supply. Furthermore, during floods, the lake water level rose to nearly the height of the lakeshore bund, resulting in an artificial breach of the lakeshore bund. Due to such situation, PID operate and maintains three channels connected to the Indus River to improve water quality and prevent flooding. The operational status of each channel is shown.

(1) Aral Wah(Head)

It is a channel whose main purpose is to channel fresh water from the Indus River into Manchar Lake. By opening and closing the Aral Head Regulator on the Indus River bund, it functions as a drainage channel to the lake and controls the flow rate of the channel. The channel is also used as an irrigation channel to irrigate farmland within the basin. During floods, Manchar Lake acts as a drainage channel to the Indus River due to its lower water level. The irrigated area by this canal is about 10,100 ha (= 25,000 acres).

(2) Danister Wah(Canal)

It was originally constructed as a flood drainage channel. Currently, it is used as a drainage channel for Manchar Lake and as an irrigation channel for farmland around the channel. Its operation as a drainage channel and irrigation channel is carried out by opening and closing the Danister Head Regulator on the Indus River and the Danister Tail Regulator on the Manchar Lake. The irrigated area by this canal is about 14,200 ha(=35,000 acres).

(3) Aral leki(Tail)

It was built as a drainage channel to connect Manchar Lake and Indus River. It is still used as a drainage channel for Manchar Lake. Its operation as a drainage channel is carried out by opening and closing the Danister Tail Regulator on the Indus River. The problem with the channel is that the cross-section of the channel has decreased due to sedimentation of the Indus River.

The current maintenance status and issues of the channels are shown below.

- Many channels are under repair due to flood damage in 2022.
- Regarding irrigation channels, the irrigation water level is higher than the field level, and the channel bottom is lower than the field level to facilitate drainage.
- Conduct periodic inspections of waterways and embankments, as well as damage inspections before and after disasters.
- Ensure the cross section as planned.
- Take measures such as scouring of channels and erosion of slopes.
- Prevent the inflow of surrounding earth and sand.
- Conduct quality control of embankment materials, degree of compaction, etc., and construction management for embankment restoration.
- Take measures against cattle intrusion.

4.3.2 Operation and Maintenance of Water Gates and Weirs

Each of the three channels connecting Manchar Lake and the Indus River has water gates for irrigation and flood control. In addition, there are drainage water gates on the inlet channel MNVD and FP bund. The operation and maintenance of the water gates is shown below.

No major problems have occurred with the operation of each water gate. However, due to the 2022 flood that caused a lot of damage at Danister Wah (canal), it became necessary to improve the drainage capacity of the existing water gates. Currently, Danister Tail Regulator and Danister Head Regulator are being renovated.

PID staff are stationed at the water gates and weirs and operate and maintain them 24 hours a day. However, there is no manual for regular inspections, etc. for unified operation and maintenance. The following issues will be identified for proper operation and maintenance in the future.

- Perform regular inspections and damage status inspections before and after disasters.
- Prepare inspection manuals for safety evaluation, deterioration diagnosis, etc.
- Create an emergency response manual for opening/closing malfunctions, etc.

It is necessary to clarify the current problems and prepare and create a manual for practical use.

4.3.3 Operation and Maintenance of Lake Bund

Manchar Lake has a lake bund installed for irrigation and flood control purposes. Manchar Containing Bund (MCB), located in north of Manchar Lake, is an important bund for maintaining the water level of Manchar Lake and for internal protection. Manchar Lake also has FB Bund connected to MCB and Road Bund on the south side. In addition, there are Indus Link Bund, RBOD-II Bund, etc. for flood protection of the Indus River. The lake bund is designed with a 50-year return strength.

Regarding the maintenance and management of lake bunds, the Hydraulic Structures Safety Evaluation Unit (HSSEU) has been established in Punjab and has begun evaluating the safety of bunds. Inspections are conducted from time to time, such as during disasters. The following issues will be identified for proper operation and maintenance in the future.

- Ensure the shape and structure based on the standard cross-sectional drawing.
- Conduct quality control of embankment materials, degree of compaction, etc., and construction management for embankment restoration.
- Take measures against seepage leakage.
- The main bund (MCB) will have a structure that allows passage even in the event of a disaster.
- As a bund defense measure, materials and equipment used for repairs and flood prevention activities will be stored nearby.
- Prepare a bund inspection and diagnosis manual.

4.4 Overview of Flood Management in Manchhar Lake

Regarding the operation method for flood management in Manchhar Lake, according to the engineer in Sindh Province the gate operation is carried out depending on the water level relationship between Manchhar Lake and the Indus River, but as of August 2023, no standard operation procedures or other materials were available.

On the other hand, data on the gate operation status of each facility during the flood in 2022 was obtained from Sindh Province. According to the data, the operation of gates at each facility between August and November 2022 was as shown in Table 4.4.1. Figure 4.4.1 shows the daily water level of Manchar Lake during the same period.

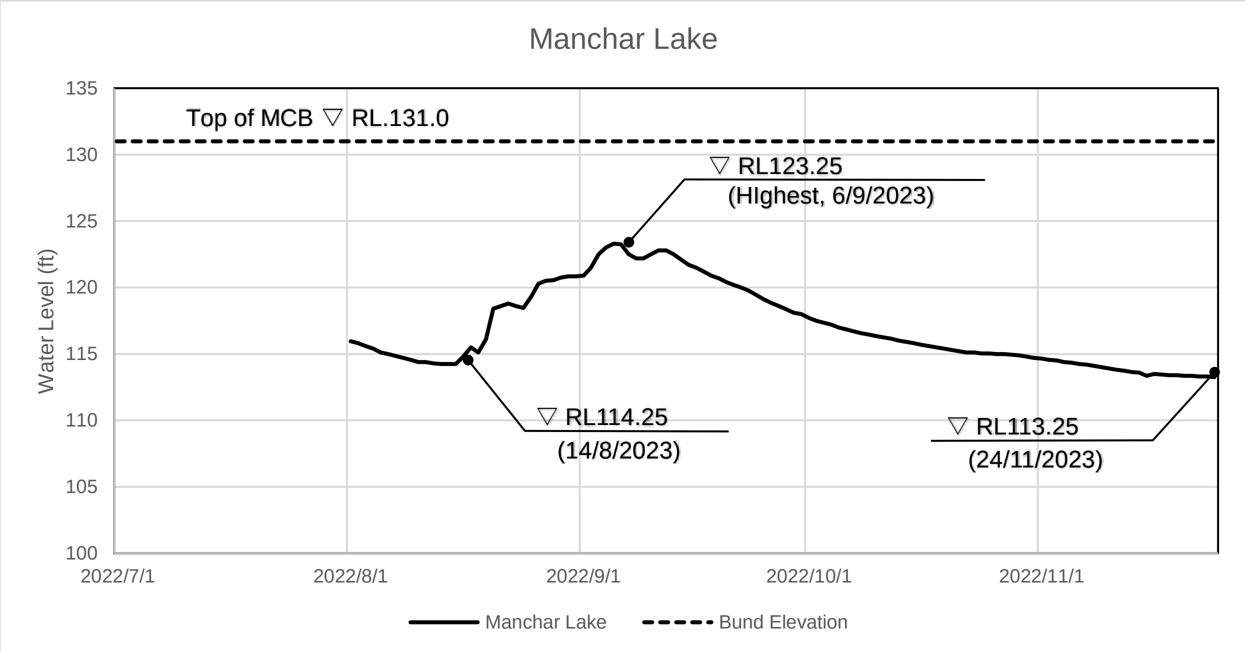
Table 4.4.1 shows that the Aral Head Regulator and the Aral Tail Regulator were operating at full open at least during the 2022 flood period, although it is not clear when the gates were opened. The water level during this period was RL. 113.25 ft(=34.52 m) or more, and the water level of Manchar Lake continued higher than that of the Indus River during this period based on the water level at the regulator location shown in Figure 4.6.8. The water level of RL113 is almost the same as that of the MCB's lake-side berm height (see Figure 4.2.2).

From this situation, it can be inferred that the Aral Head Regulator and the Aral Tail Regulator are fully opened when the water level of Manchar Lake is high and it is judged to bedangerous.

Table 4.4.1 Gate Operation Records for Each Facility (1/8/2022 to 24/11/2022)

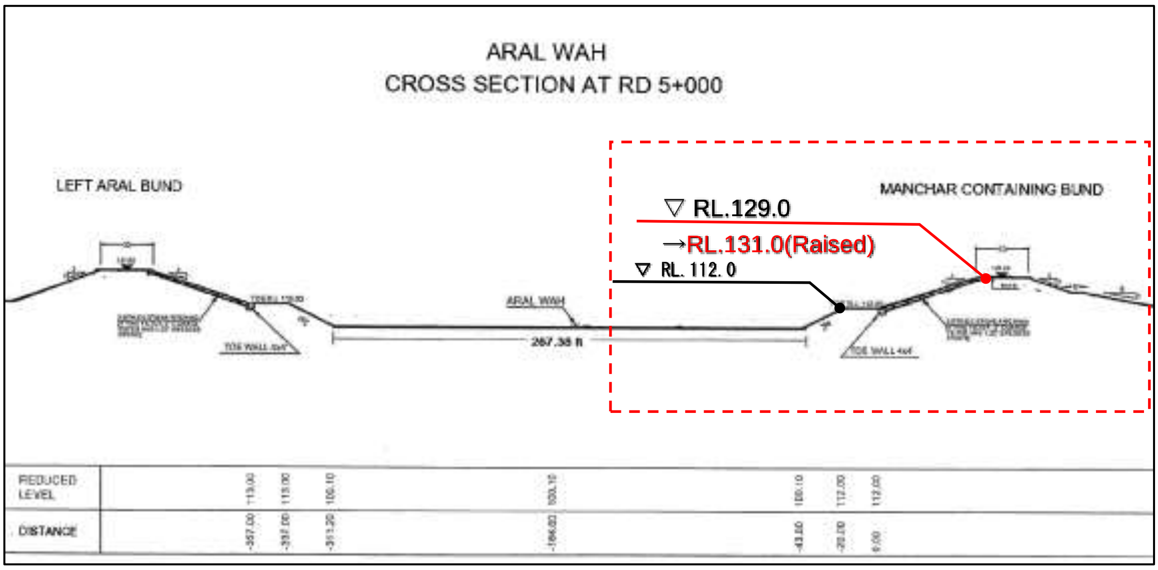
Duration	Aral Head Regulator	Aral Tail Regulator	Danister Head Regulator (Indus River Side)	Danister Tail Regulator (Manchar Lake Side)
1/8/2023 - 9/8/2023	Full Open	Full Open	Close	Close
9/9/2023 - 9/13/2023	Full Open	Full Open	Full Open	Close
9/14/2023-11/24/2023	Full Open	Full Open	Close	Close

Source: Sindh Irrigation Department



Source: Sindh Irrigation Department

Figure 4.4.1 Daily Water Level of Manchhar Lake (2022/8/1 to 2022/11/24)



Source: Aral Wah Cross Section at RD5 +000

Figure 4.4.2 Current cross-sectional view of MCB

In the F/S or the subsequent stage, it is necessary to confirm the more detailed rules on gate operation, obtain the water level of Manchar Lake for a longer period and the discharge amount from the gate and the gate operation record, and set the water level for the timing of discharge start and discharge end.

Regarding the minimum water level, there is a description of Maintaining the Conservation Level[2] above RL. 110, and RL. 110 is considered to be the minimum water level set from the aspect of water utilization and water quality maintenance of the lake.

2 Feasibility Report Feasibility Study/Planning for Supplying Ecological Flows in Manchhar Lake Irrigation, Department Government of Sindh

4.5 On-going/Related projects regarding the Manchar Lake

The main recent construction work at Manchar Lake is emergency flood rehabilitation work to prevent damage in 2022. The rehabilitation work will be carried out under Sindh Flood Emergency Rehabilitation Project (SFERP) with the Financial Assistance of World Bank (WB) (212 mil. USD) after the flood in 2022.

Table 4.5.1 shows the number of packages for these emergency flood rehabilitation works, and Table 4.5.2 shows the construction length.

Table 4.5.1 Number of emergency flood rehabilitation works packages

S. No	DESCRIPTION OF EMERGENT REHABILITATION PACKAGES UNDER SFERP	No. of Packages
1	Rehabilitation of Manchar Containing Bund (100RD) 30 kms	4
2	Rehabilitation of FP Bund (596RD) 180 kms	9
3	Rehabilitation of Left Aral Bund (RD0+000TORD19+000) 6 kms	1
4	Remodeling & Rehabilitation of Aral Head Regulator (MCRD0+000)	1
5	Remodeling and Rehabilitation of Aral Wah (14RD) 4 km	1
6	Rehabilitation of Danister Channel (RD0+000toRD56+434) 17 kms	2
7	Remodeling and Rehabilitation of Danister Tail Regulator and Regulator for 10 Phats (Minors) Danister Canal (Civil Works)	1
8	Rehabilitation of Gates in Aral Head Regulator, Danister Tail Regulator and 10Phats (Minors) Regulators	1
10	Rehabilitation of Retaining Wall along Danister Canal (Bubak/MinaiTown) (3RD) 1 km	1

Source：SFERP progress report June 2023

Table 4.5.2 Extension of emergency flood rehabilitation works in Machar Lake

S.No	Name of work	Total Nos. of Breaches	Length of Breach Feet	Remarks
1	Plugging and Strengthening of Relief Cut along Manchar Containing Bund at RD 14	1	750	Breach Closed
2	Plugging and Strengthening of Relief Cut along Manchar Containing Bund at RD 52	1	900	Breach Closed
3	Plugging and Strengthening of Breach along FP Bund along RD 169	1	400	Breach Closed
4	Plugging and Strengthening of Breach along FP Bund along RD 215	1	600	Breach Closed
5	Plugging and Strengthening of Breach along FP Bund along RD 340	1	1,100	Breach Closed
6	Plugging and Strengthening of Breach along FP Bund along RD 432	1	880	Breach Closed, add scope will be completed soon
7	Plugging and Strengthening of Breach along FP Bund along RD 476	1	500	Breach Closed
8	Plugging, Strengthening & Stone Pitching of Relief Cut Larkana Sehwan Bund along Mile 95/6	1	195	Breach Closed
9	Plugging, Strengthening & Stone Pitching of Relief Cut Larkana Sehwan Bund along Mile 97/2	1	895	Breach Closed
10	Plugging, Strengthening & Stone Pitching of Relief Cut Larkana Sehwan Bund along Mile 99/3	1	1,980	Breach Closed
11	Plugging and Strengthening of Breaches along Indus Link Drain	10	5,070	
12	Plugging and Strengthening of Breach along Main Nara Valley (MNV) Drain at RD 2+318	1	780	Breach Closed
13	Plugging and Strengthening of Breach along Main Nara Valley (MNV) Drain at RD 8+068	1	700	Breach Closed
14	Plugging and Strengthening of Breach along Main Nara Valley (MNV) Drain at RD 210	2	550	Breach Closed
15	Plugging and Strengthening of Breach along Main Nara Valley (MNV) Drain at RD 280	1	700	Breach Closed
16	Plugging and Strengthening of Breach along Main Nara Valley (MNV) Drain at RD 330	1	250	Breach Closed
17	Plugging and Strengthening of Breaches along Indus Link Drain	10	5,070	Work in progress
18	Rehabilitation of Manchar Containing Bund (100 RD) 30 kms	4	Not available	Work in progress
19	Rehabilitation of FP Bund (596 RD) 180 kms	9	Not available	Work in progress
20	Rehabilitation of Left Aral Bund (RD 0+000 TO RD 19+000) 6 kms	1	Not available	Work in progress
21	Remodeling & Rehabilitation of Aral Head Regulator (MC RD 0+000)	1	Not available	Work in progress
22	Remodeling and Rehabilitation of Aral Wah (14 RD) 4 km	1	Not available	Work in progress
23	Rehabilitation of Danister Channel (RD 0+000 to RD 56+434) 17 kms	2	Not available	Work in progress
24	Remodeling and Rehabilitation of Danister Tail Regulator and Regulator for 10 Phats (Minors) Danister Canal (Civil Works)	1	Not available	Work in progress
25	Rehabilitation of Gates in Aral Head Regulator, Danister Tail Regulator and 10 Phats (Minors) Regulators	1	Not available	Work in progress
26	Rehabilitation of Retaining Wall along Danister Canal (Bubak/ Minai Town) (3 RD) 1km	1	Not available	Breach Closed

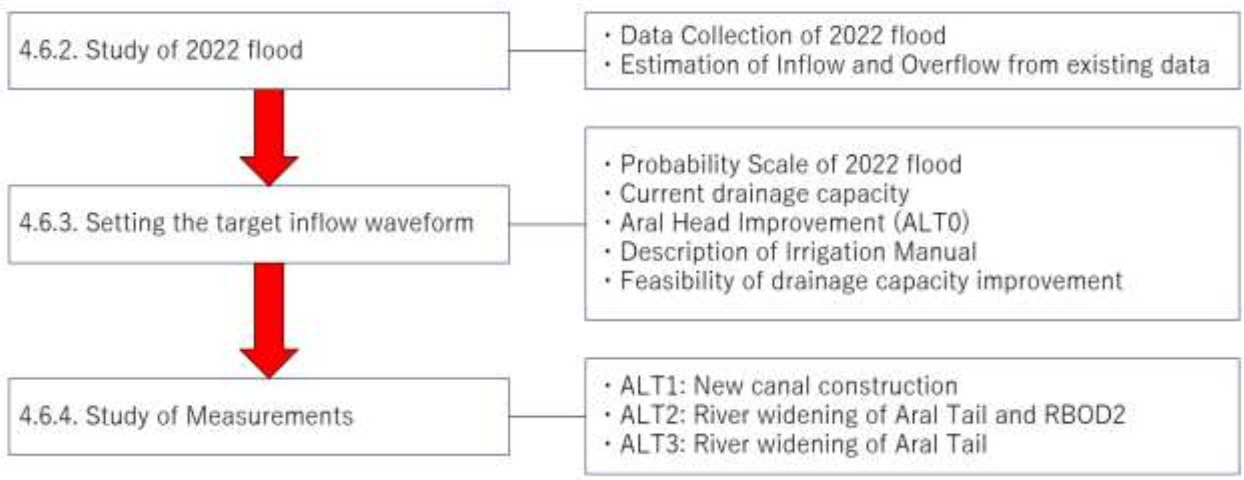
Source： SFERP progress report June 2023

4.6 Hydrological analysis of Lake Manchar

4.6.1 Study Policy of Hydrological Analysis

Figure 4.6.1 shows the study policy of hydrological analysis of Lake Manchar.

- In Section 4.6.2, data collection of the 2022 flood was conducted, and inflow and overflow volumes were calculated from actual data such as water level of Lake Manchar and discharge from each regulator.
- In Section 4.6.3, the target inflow waveform was determined based on the probability scale of the 2022 flood, the current drainage capacity, the drainage capacity after Aral Head renovation (ALT0), the description in the Irrigation Manual, and the possibility of improving the drainage capacity.
- In Section 4.6.4, the channel width required for each drainage capacity improvement measurement was examined using non-uniform flow calculation.



Source: Advisory Team

Figure 4.6.1 Study Policy of Hydrological Analysis of Lake Manchar

4.6.2 Situation of the 2022 Flood

4.6.2.1 Observation Data of the 2022 Flood

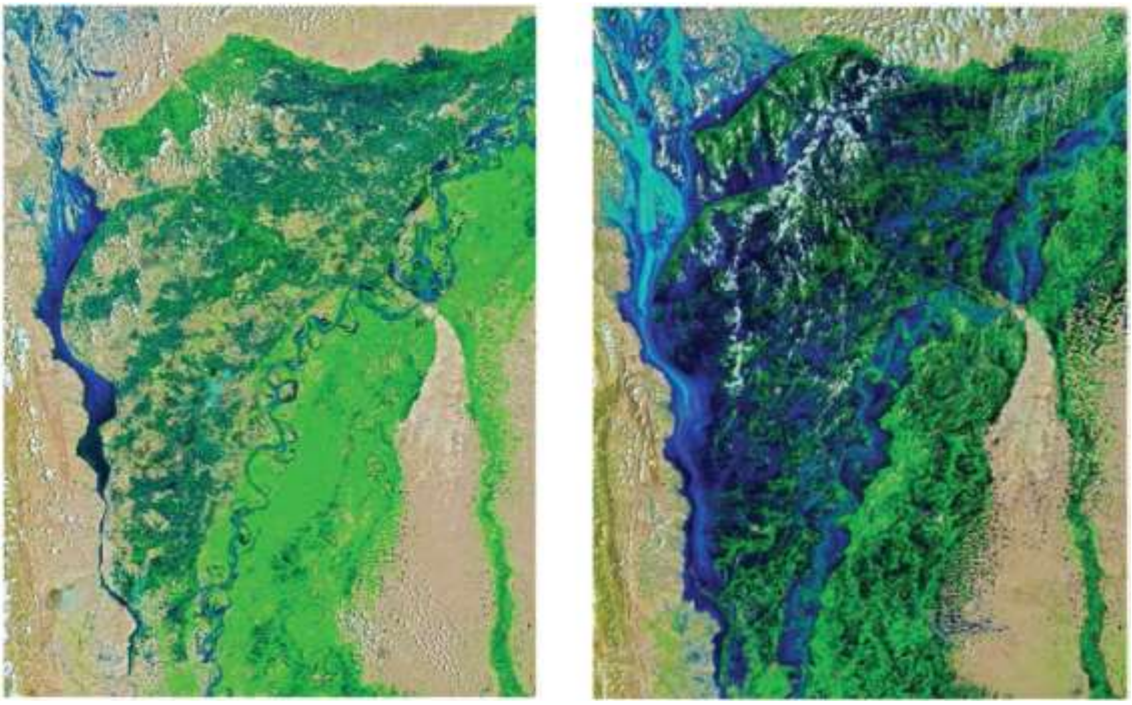
(1) Rainfall Observatory

There are 3 inflow sources in the Lake Manchar basin: the hill torrent basin (Shol River System, Naing River System, Bandhni River System), the northern irrigation canal MNVD (Main Nara Valley Drain) and the Indus River. For the inflow source of the Indus River, the direction of the flow during the flood is from Lake Manchar to the Indus River (i.e., it does not work as a source during flood). In fact, according to the data of regulators in the 2022 flood, the flow direction is from Lake Manchar to the Indus River.

In addition, important data regarding the MNVD, such as the basin map, the network of related waterways, and the amount of inflow during the 2022 flood, could not be obtained. As shown in Figure 4.6.2, during the 2022 flood, inundation occurred in whole of the upstream area. Furthermore, as shown in Figure 4.6.3, the maximum inflow is about 2,400 ft3/s (=68 m3/s) and in several years of observation in MNVD, it is much lower than the maximum inflow of the 2022 flood (about 2,000 m3/s). It was determined that the impact of MNVD during the 2022 flood would be limited. Therefore, in this study, only the inflow from the hill torrent basin will be considered.

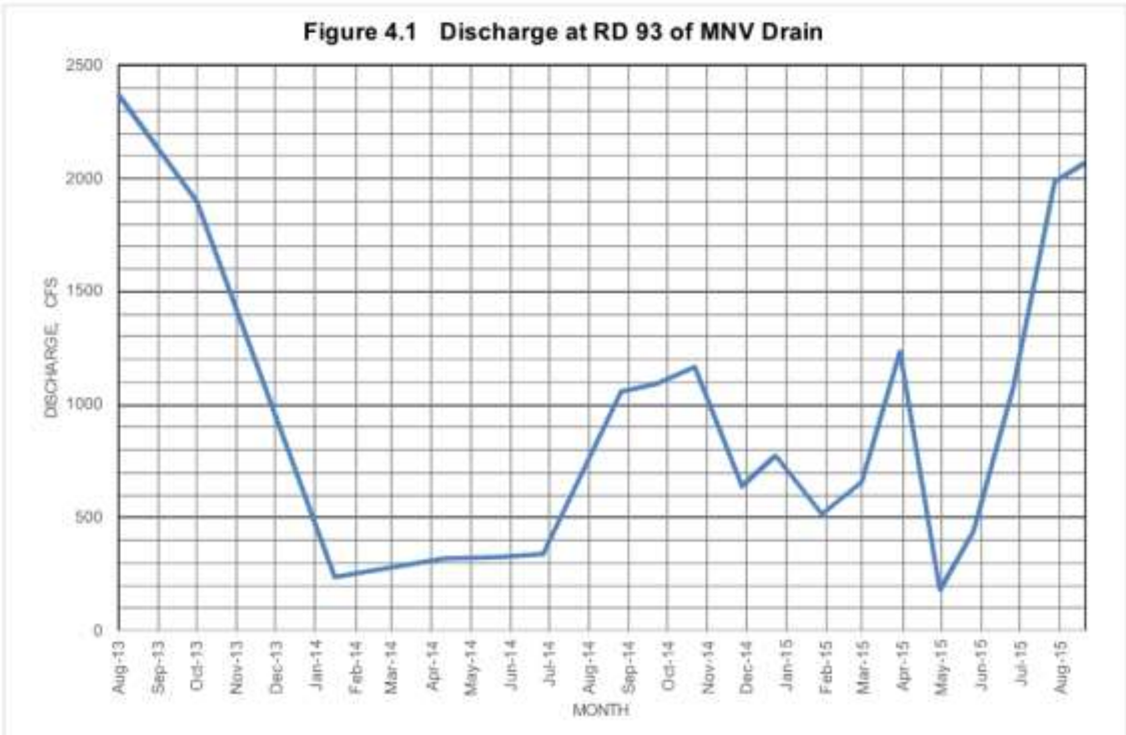
Figure 4.6.4 shows the location map of rainfall stations around Lake Manchar, and each rainfall station is divided into Thiessen. Table 4.6.1 shows the overview of each rainfall station around Lake Manchar. Inflow estimation is based on the Thiessen division, however, the data from the Hyderabad rainfall station are not used because of the different rainfall characteristics (the data from the Nawabshah rainfall observatory were used). In addition, if there was missing data from the Nawabshah rainfall station, it was supplemented with data from the nearby Padidan rainfall station.

Figure 4.6.5 shows rainfall data from August 2022 to September 2022 for each rainfall station. Figure 4.6.6 shows the average rainfall in the basin weighted by the area of the Thiessen division area.



Source: Pakistan Floods 2022, Post Disaster Needs Assessment, Main Report

Figure 4.6.2 Inundation Area Comparison of 4th August 2022(left) and 28th (right)



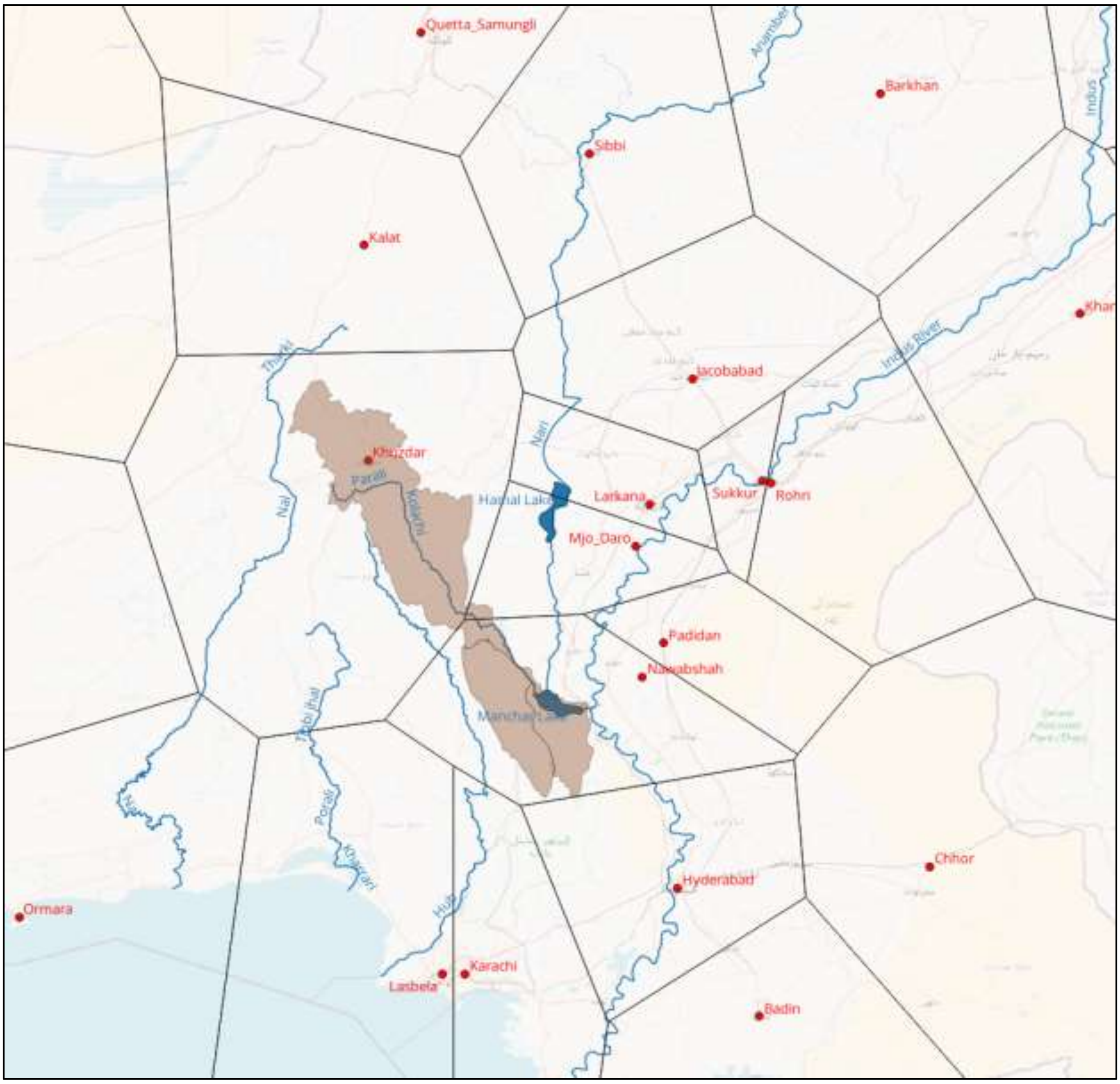
Source: 2017 F/S Report

Figure 4.6.3 Inflow Discharge of MNVD (Main Nara Valley Drain)

Table 4.6.1 Overview of Each Rainfall Station Around Lake Manchar

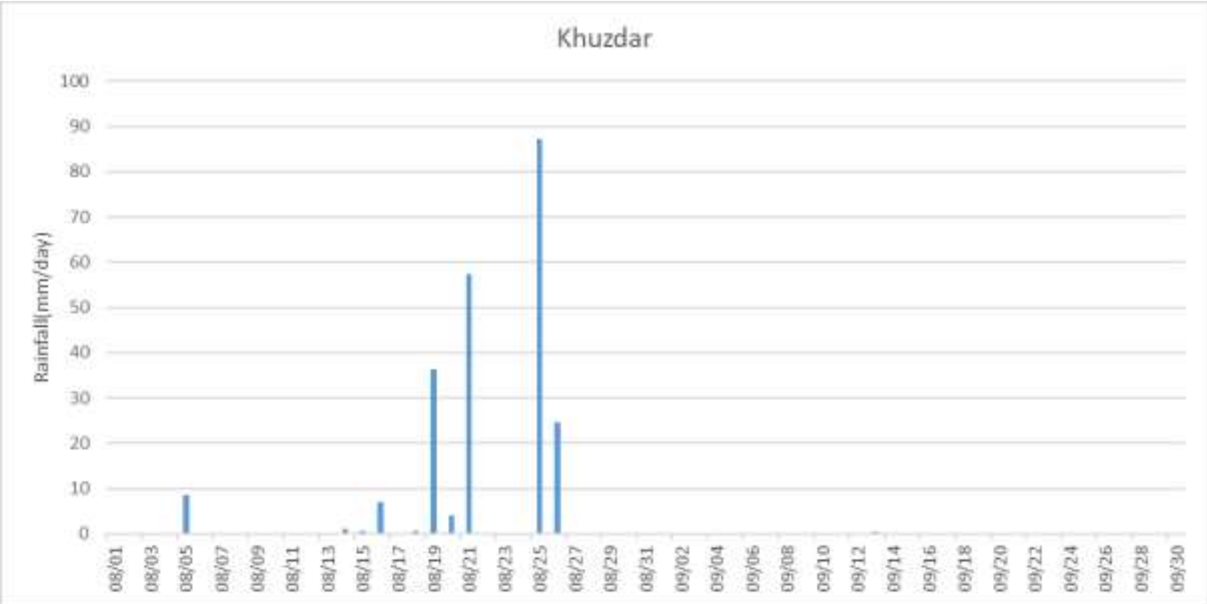
Observatory	Basin Area(km2)	Basin Area(mi2)	Purpose	備考
Khuzdar	6,753	2,607	Estimation of Inflow	—
Nawabshah	4,149	1,602	Estimation of Inflow	—
Mjo_Daro	126	49	Estimation of Inflow	—
Padidan	—	—	Data completion	Used when Nawabshah observatory has missing data.
Hyderabad	1	0	—	Not used due to different rainfall characteristics.

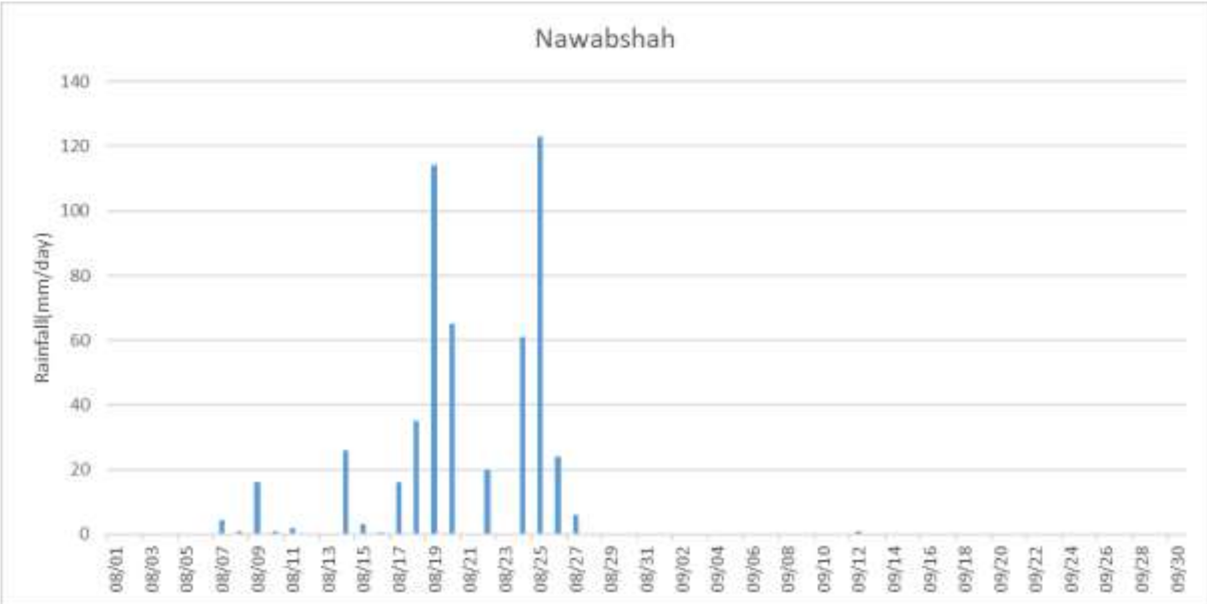
Source: Advisory Team



Source: Advisory Team

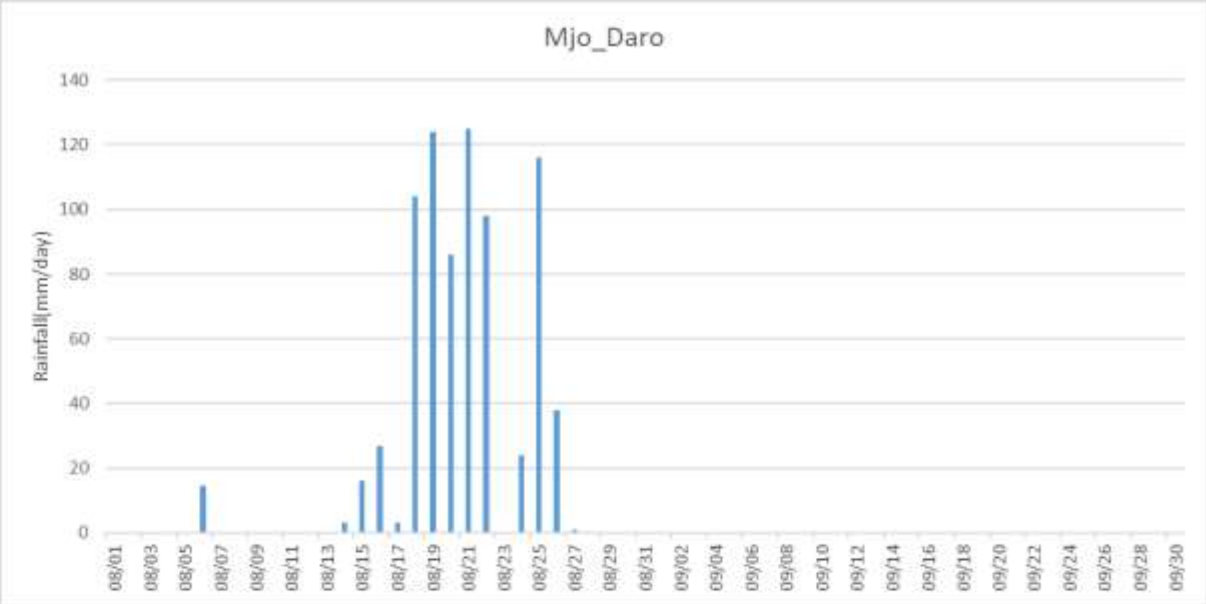
Figure 4.6.4 Location Map of Rainfall Stations Around Lake Manchar

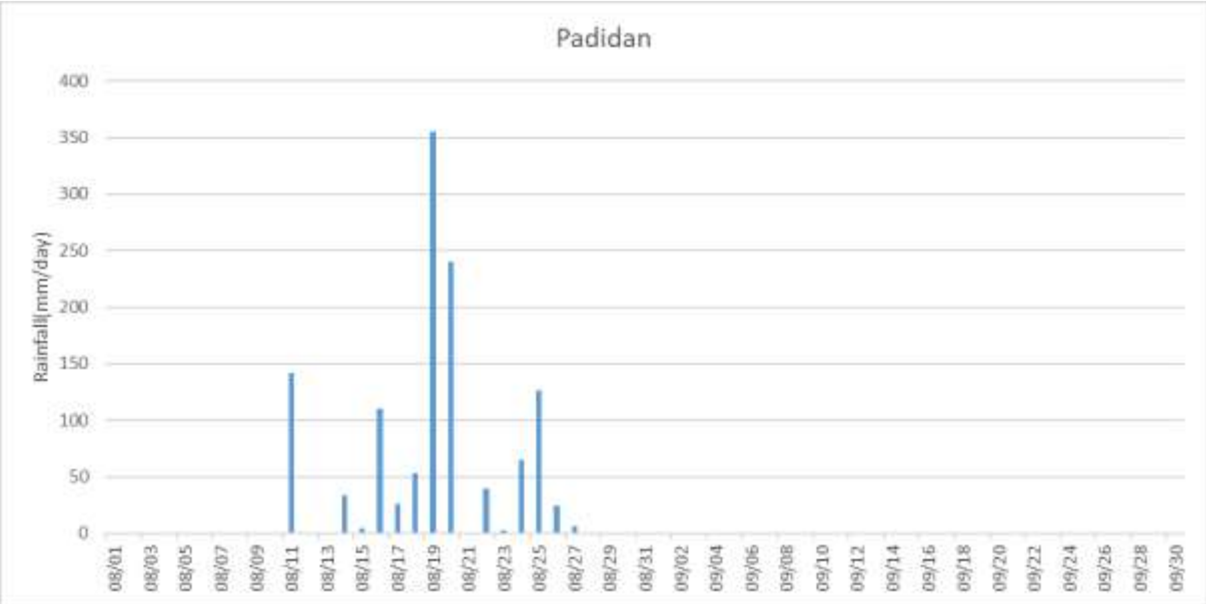




**The rainfall data of 8/26, 8/27 and 8/29 were complemented by the Padidan rainfall station.*
Source: Created by the advisory team based on PID data

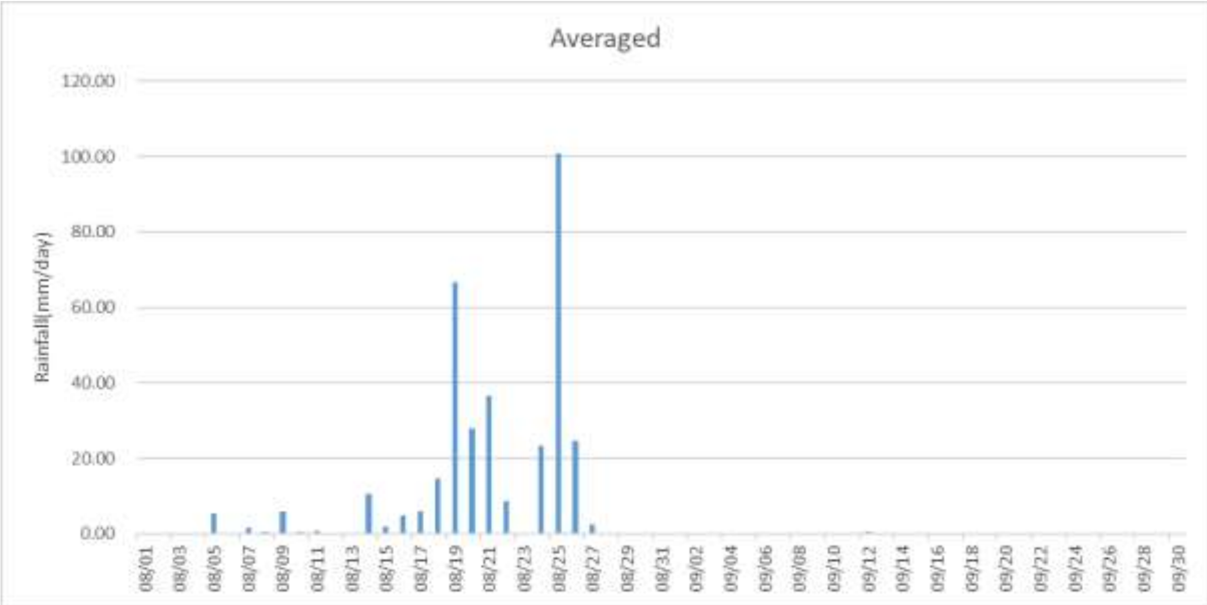
Figure 4.6.5 (1) Time Series Data of Rainfall Stations Around Lake Manchar





Source: Created by Advisory Team based on PID data

Figure 4.6.5 (2) Time Series Data of Rainfall Stations Around Lake Manchar



Source: Created by advisory team based on PID data

Figure 4.6.6 Time Series Data of Average Rainfall in the Basin

(2) Water Level and Discharge of Lake Manchar and Each Regulator

Table 4.6.2 shows the specifications of each Regulator around Lake Manchar. Figure 4.6.7 shows the location map of each regulator around Lake Manchar. Figure 4.6.8 shows the time series of the water level and discharge of each regulator and the water level of Lake Manchar from August 2022 to November 2022. During this period, the Aral Head Regulator and the Aral Tail Regulator were mainly discharged from Lake Manchar to the Indus River. In addition, the Danister Head Regulator and the Danister Tail Regulator were closed for most of the period and should not be considered in the 2022 flood study.

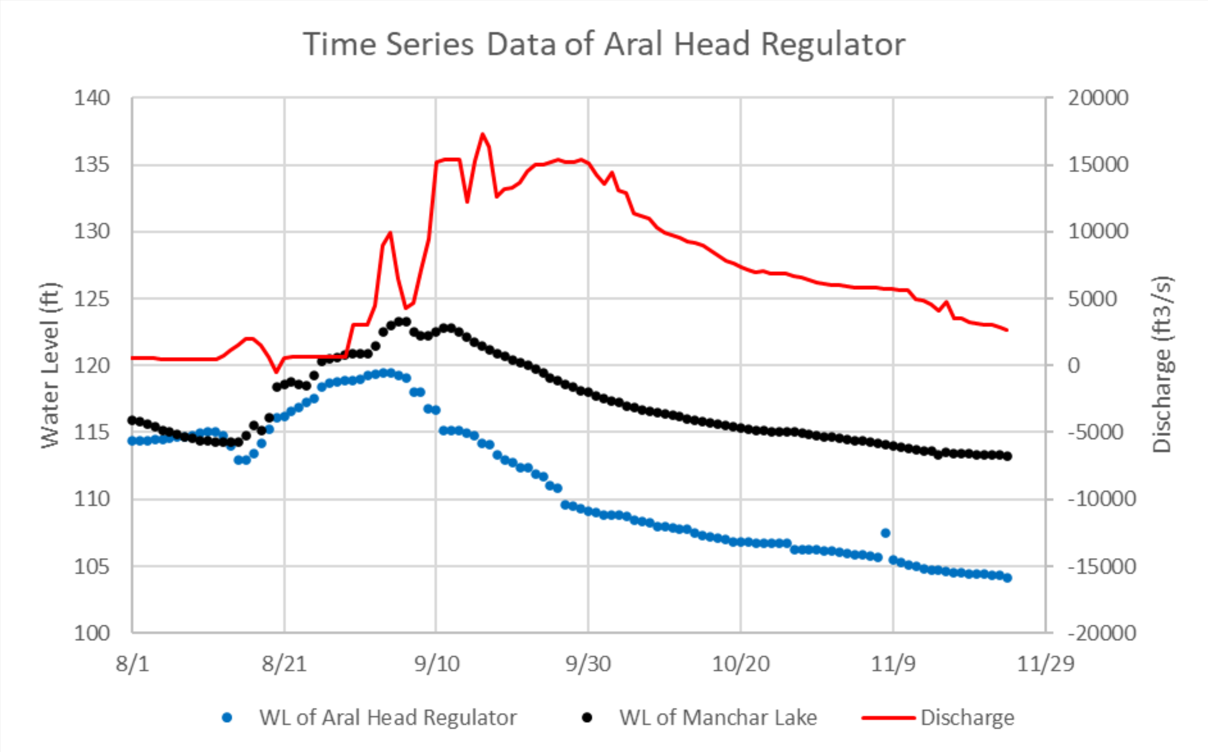
Table 4.6.2 Specifications of Each Regulator Around Lake Manchar

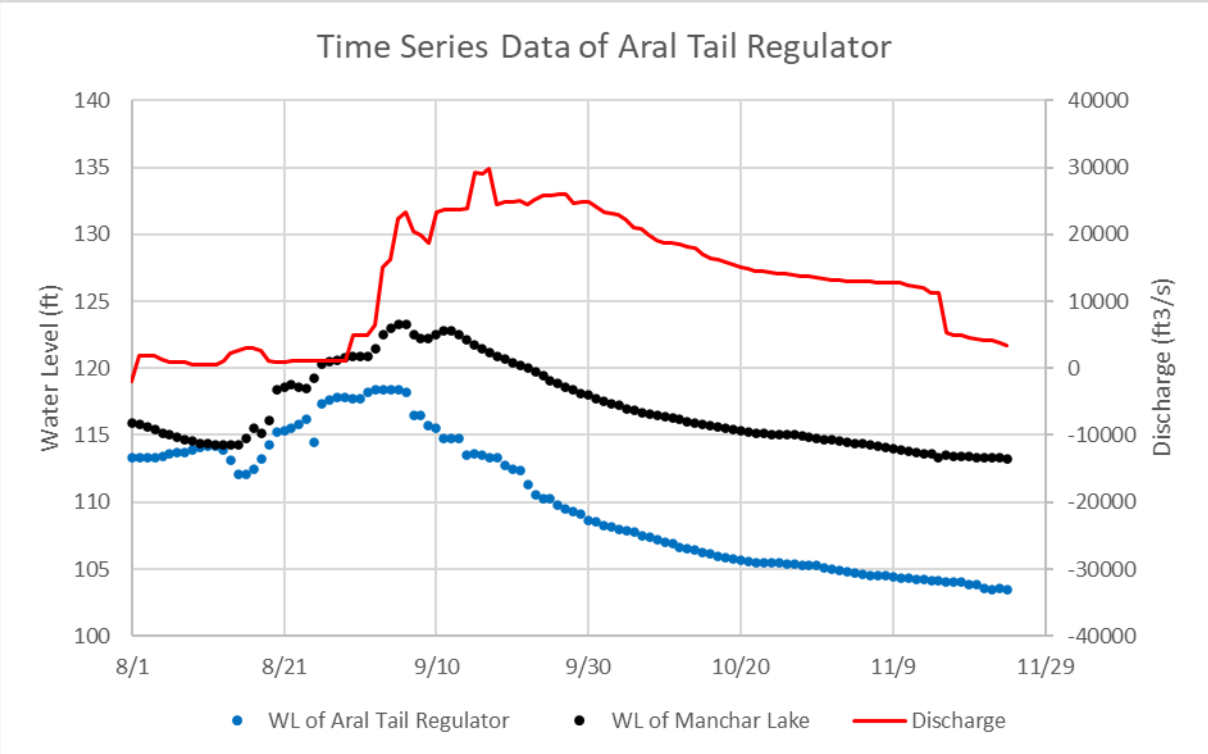
No	Data	Aral Head Regulator	Aral Tail Regulator	Danister Head Regulator	Danister Tail Regulator	Unit
1	No of Gates	3	5	5	2	Nos
2	Diamantine of Gates	20 x 22	20 x 24	8 x 10	20 x 24	ft x ft
3	Type of Gates	Vertical Type Counter Balanced	Vertical Type Counter Balanced	Vertical Type Counter Balanced	Vertical Type Counter Balanced	—
4	Discharge Capacity	10,000	25,000	3,500	9,000	ft^3/sec
5	Pavement RL	99.78	98.5	100	Manchar Side: 102 Indus River Side: 97.9	ft
6	Crest Level	101.37	99.5	100	103	ft
7	FSD	121.5	121.5	110	123.3	ft

Source: Sindh-PID

Source: Google Earth

Figure 4.6.7 Location Map of Each Regulator Around Lake Manchar





Source: Sindh-PID

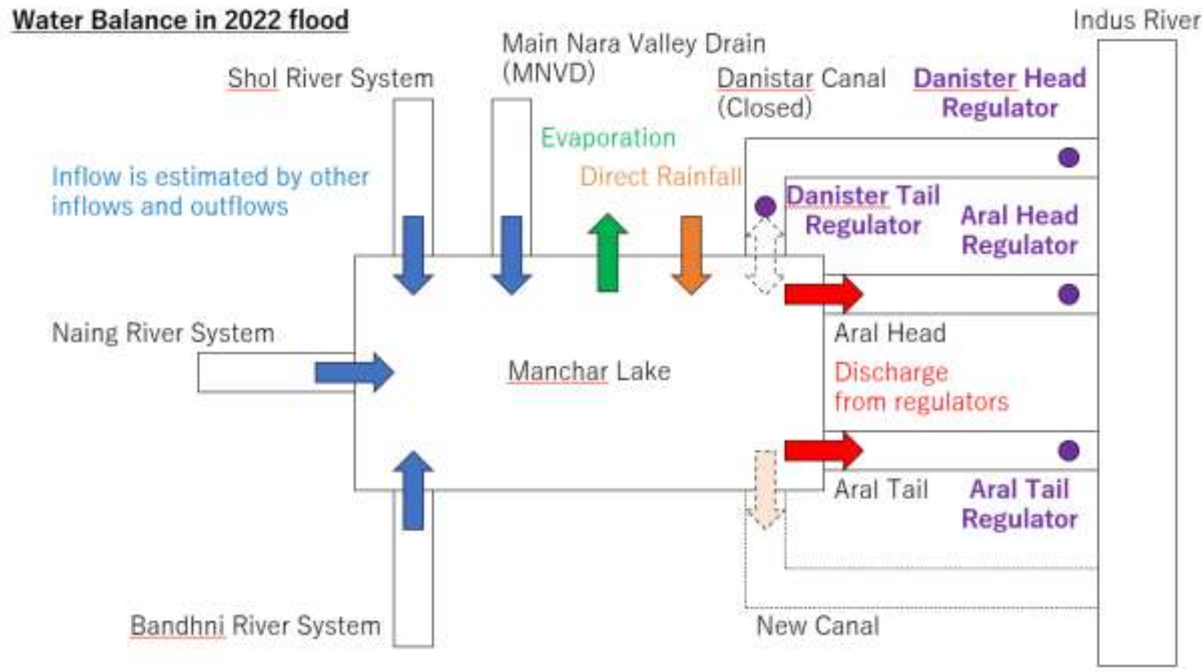
Figure 4.6.8 Time Series of Water Level and Discharge of Aral Head Regulator and Aral Tail Regulator

4.6.2.2 Estimation of Inflow and Overflow During the 2022 Flood

(1) Estimation Policy of Inflow and Overflow During the 2022 Flood

Based on the water balance during the 2022 flood shown in Figure 4.6.9, the inflow during the 2022 flood was estimated. The total inflow to Lake Manchar was back-calculated from various time series data of discharge of each regulator during the 2022 flood, direct rainfall to Lake Manchar (using data from nearby rain stations), evaporation (assuming 0.8 times PAN evaporation), and water level of Lake Manchar. The waveform of the estimated inflow was also scrutinized.

In addition, in Lake Manchar, the artificial breach was carried out in early September. The amount of flood caused by artificial breaches was also considered in this study.

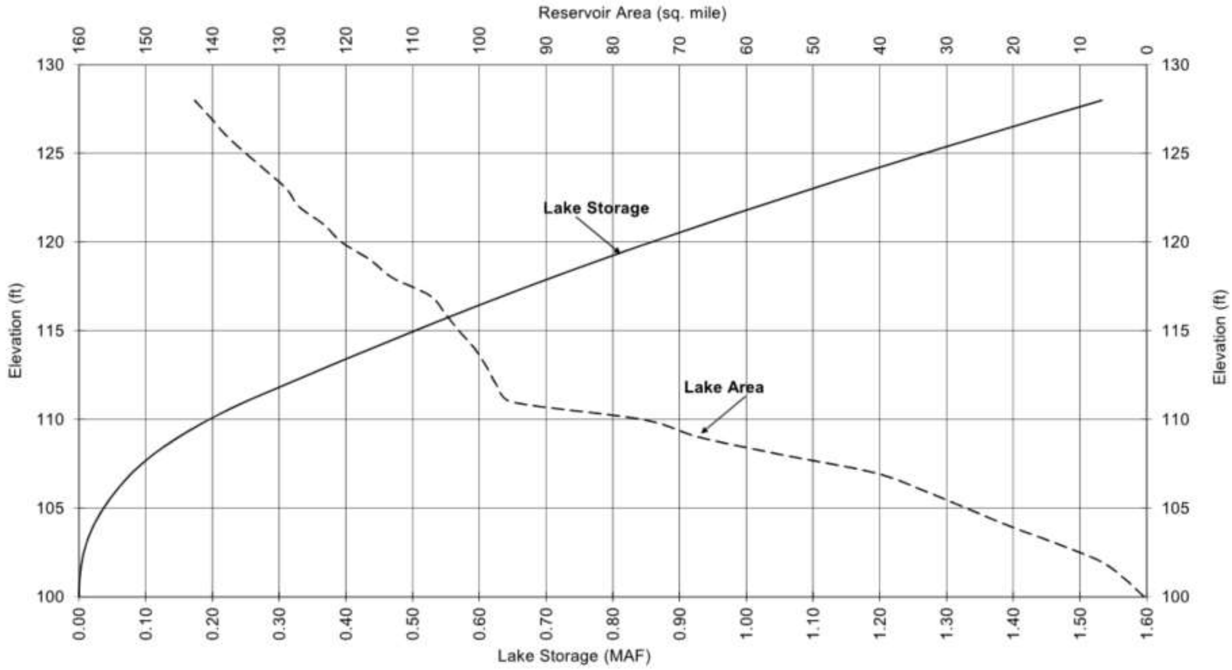


Source: Created by an advisory team based on 2017 F/S Report

Figure 4.6.9 Water Balance During the 2022 Flood

(2) Relationship Between Water Level, Surface Area and Capacity of Lake Manchar

The relationship between the HAV (water level, surface area, and capacity) of Lake Manchar is shown in Figure 4.6.10, and the diagram published in the 2017 F/S Report is quoted.



Source: 2017 F/S Report

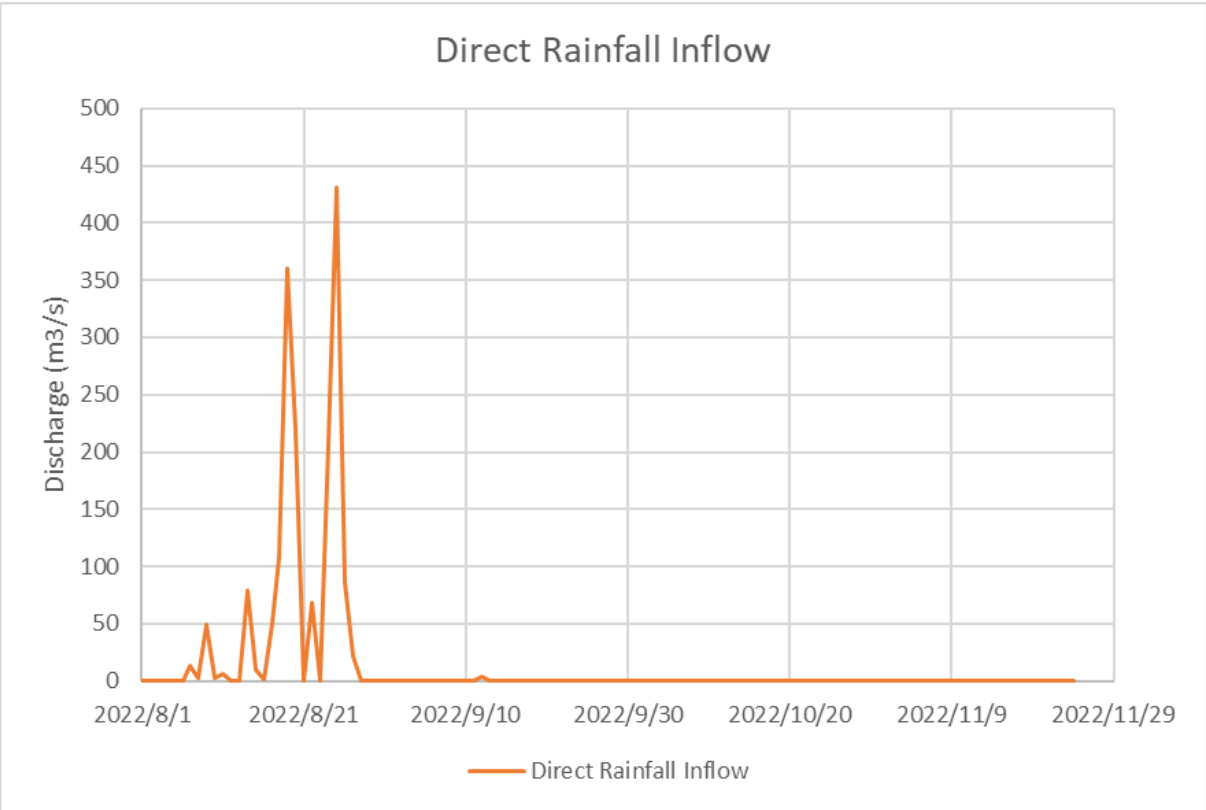
Figure 4.6.10 Relationship between HAV (Water Level, Surface Area, and Capacity) of Lake Manchar

(3) Calculation of Direct Inflow of Rainfall

The direct inflow of rainfall into Lake Manchar can be calculated by the following formula. Figure 4.6.11 shows the calculated direct inflow of rainfall. However, the direct inflow of rainfall is calculated using the rainfall data from the Nawabshah rainfall station (however, some periods will be supplemented by the Padidan rainfall station), which is closest to Lake Manchar. The inflow to Lake Manchar is set as positive.

$$Q_{Rain}(t) = R(t) \times S(t)$$

where Q_{Rain} is direct inflow of rainfall, R is rainfall in the station, S is the surface area of Lake Manchar, t is time.



Source: Advisory Team

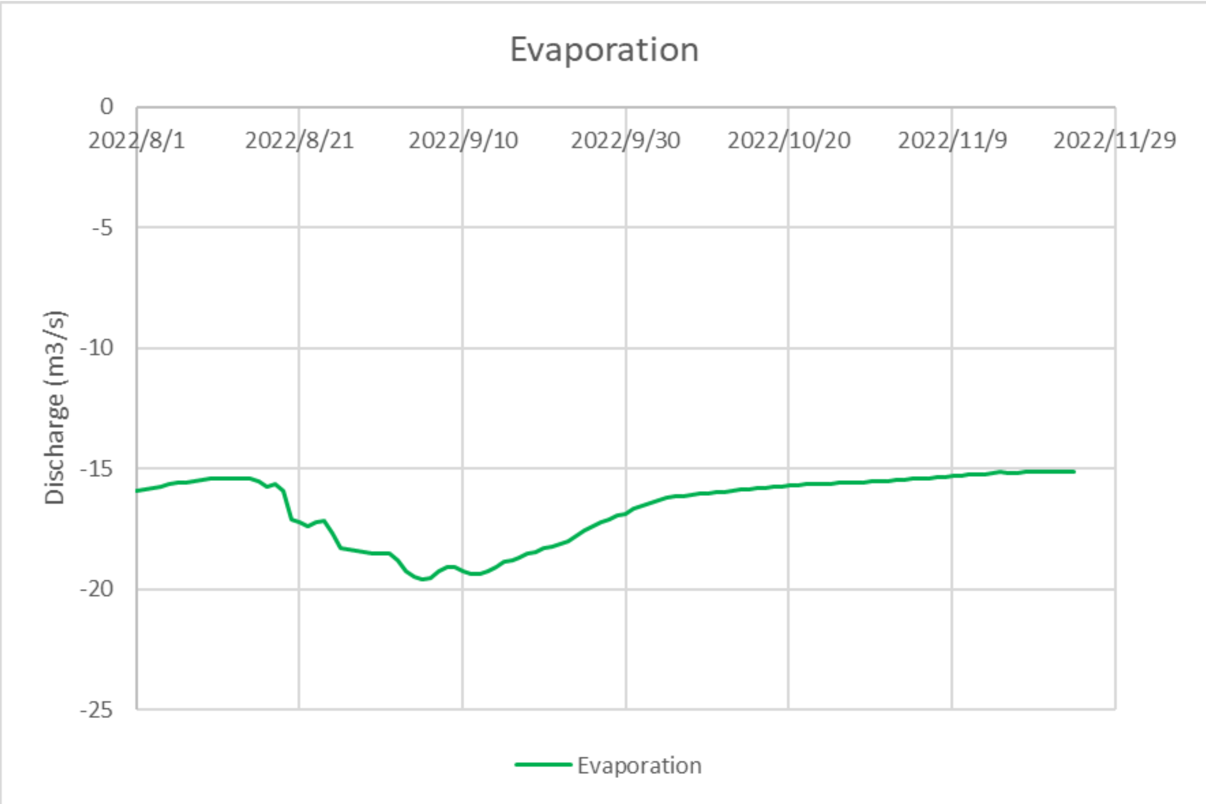
Figure 4.6.11 Direct Inflow to Lake Manchar

(4) Calculation of Evaporation

Evaporation in Lake Manchar can be calculated by the following formula. Figure 4.6.12 shows the calculated evaporation. The PAN evaporation was set to 2300 mm/day from the preliminary study of the Balochistan Flood Outflow Development Project (2003, JICA) and the basic design study report of the Mitawan Weir Construction Project (1997, JICA), and it was assumed that 0.8 times of that amount would evaporate. In addition, the inflow to Lake Manchar is set as positive.

$$Q_{Evaporation}(t) = 0.8 \times Pan\ Evaporation \times S(t)$$

where $Q_{Evaporation}$ is evaporation, S is the surface area of Lake Manchar, $t$this time



Source: Advisory Team

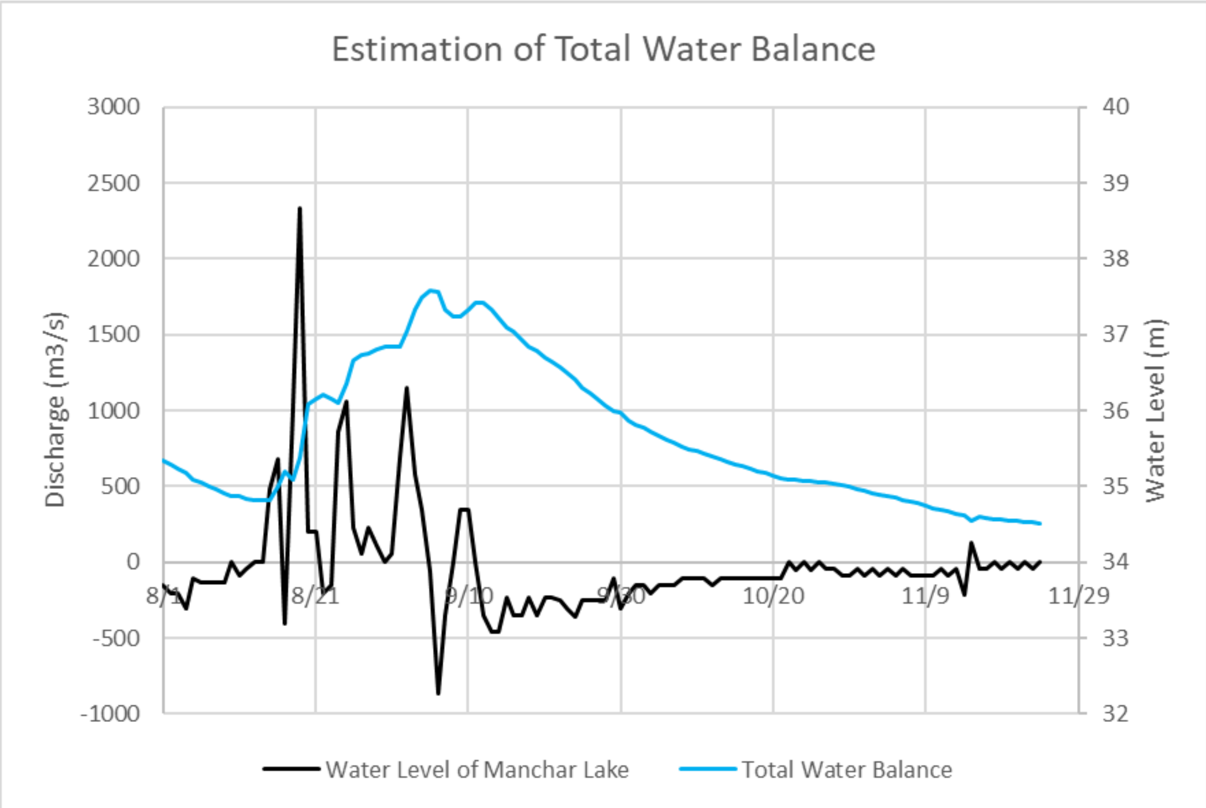
Figure 4.6.12 Evaporation in Lake Manchar

(5) Water Balance of Lake Manchar

Based on the actual water level data of Lake Manchar in the 2022 flood and the HV relationship, the water balance of Lake Manchar can be calculated by the following formula. Figure 4.6.13 shows this water balance.

$$Total\ Water\ Balance(t) = V_{Manchar}(t+1) - V_{Manchar}(t)$$
$$V_{Manchar}(t) = f\big(H_{Manchar}(t)\big)$$

where $V_{Manchar}$ is the capacity of Lake Manchar, $H_{Manchar}$ is the water level of Lake Manchar, t is time.



Source: Advisory Team

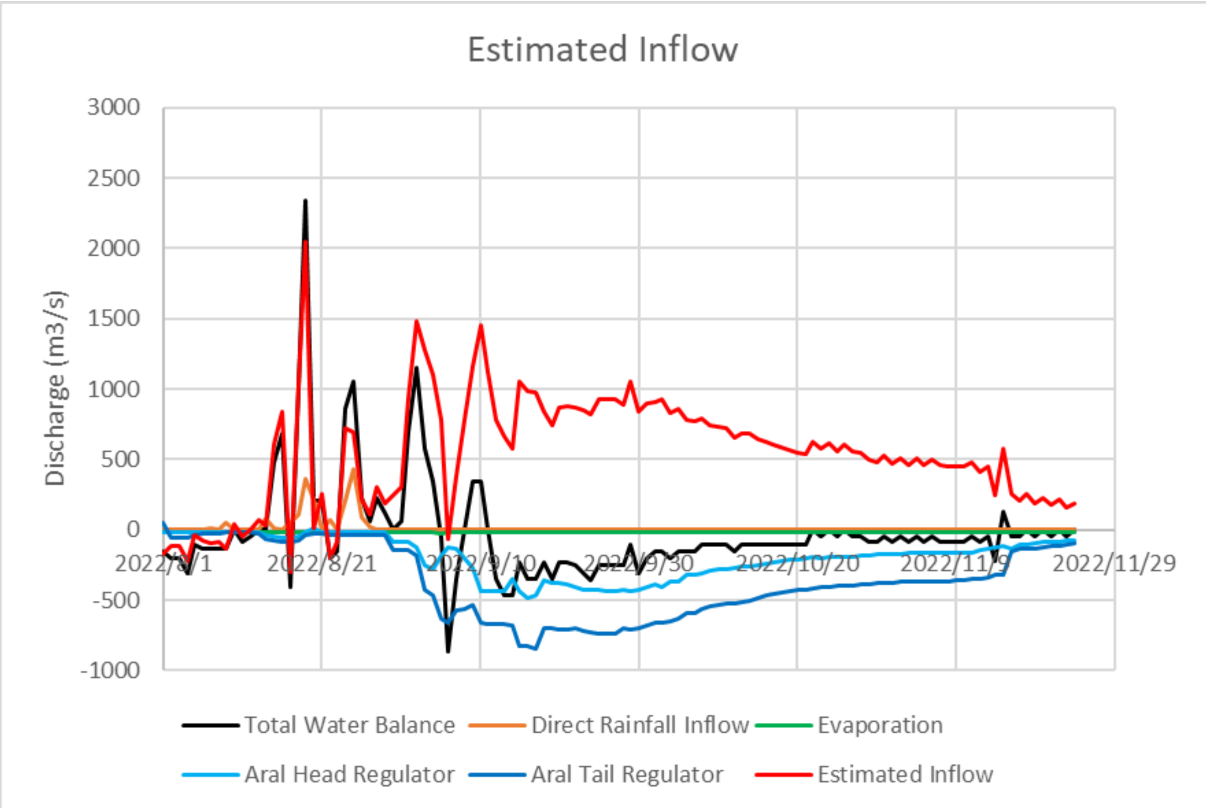
Figure 4.6.13 Water Balance of Lake Manchar

(6) Estimated Inflow

The following equations can be used to estimate the inflow based on the "discharge of each regulator," "direct inflow of rainfall," "evaporation" and "water balance of Lake Manchar." The estimated inflow is shown in Figure 4.6.14

$$otal\ Water\ Balance(t) = Q_{Aral-Head}(t) + Q_{Aral-Tail}(t) + Q_{Rain}(t) + Q_{Evaporation}(t) + Q_{Inflow}(t)$$

where $Q_{Aral-Head}$ is discharge of Aral Head Regulator, $Q_{Aral-Tail}$ is discharge of Aral Tail Regulator, Q_{Rain} is direct inflow of rainfall, $Q_{Evaporation}$ is evaporation, Q_{Inflow} is estimated inflow, t is time.



Source: Advisory Team

Figure 4.6.14 Inflow Estimation

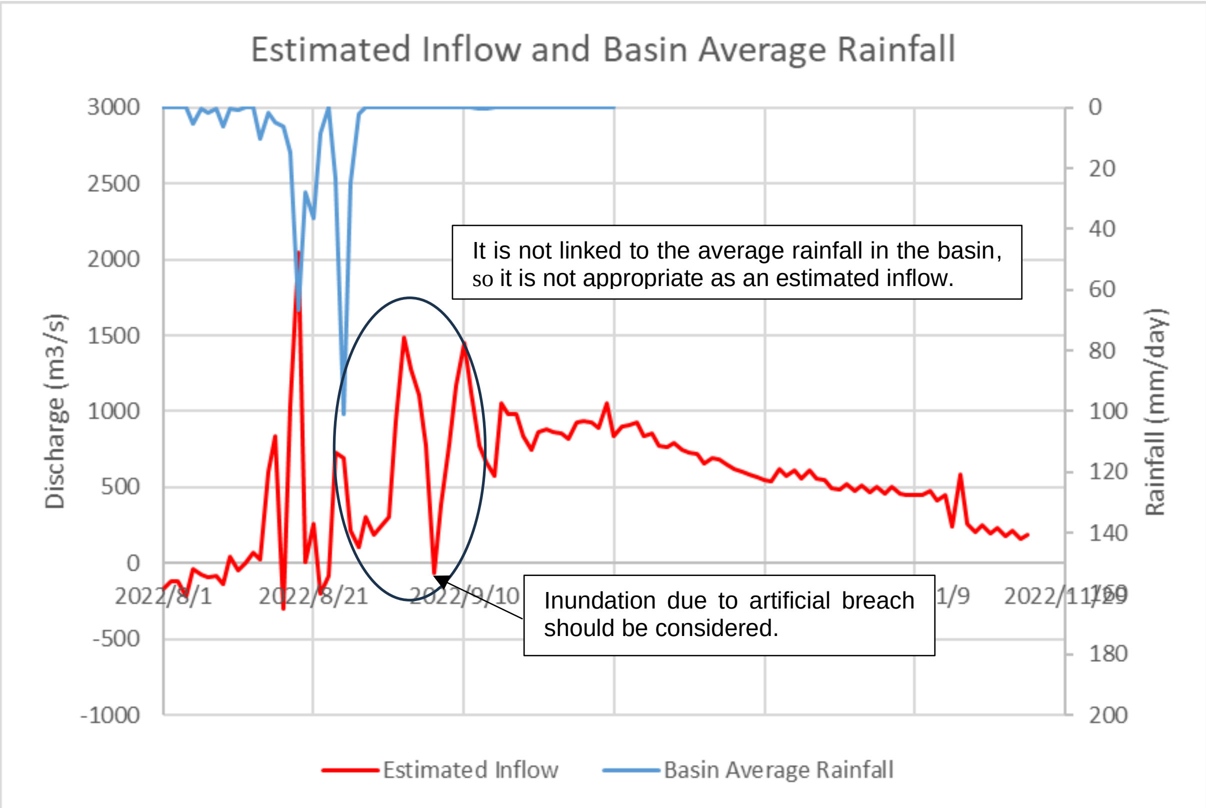
(7) Scrutinizing Inflow Waveforms

The estimated inflow in the preceding section was scrutinized in this section.

Figure 4.6.15 shows the overlap of the estimated inflow and the basin average rainfall. It is considered reasonable that the peaks of the estimated inflow and the basin average rainfall are almost the same at 8/19 and 8/25. On the other hand, the change of the estimated inflow between 8/26 and 9/10 is not considered reasonable because it is not linked with the basin average rainfall.

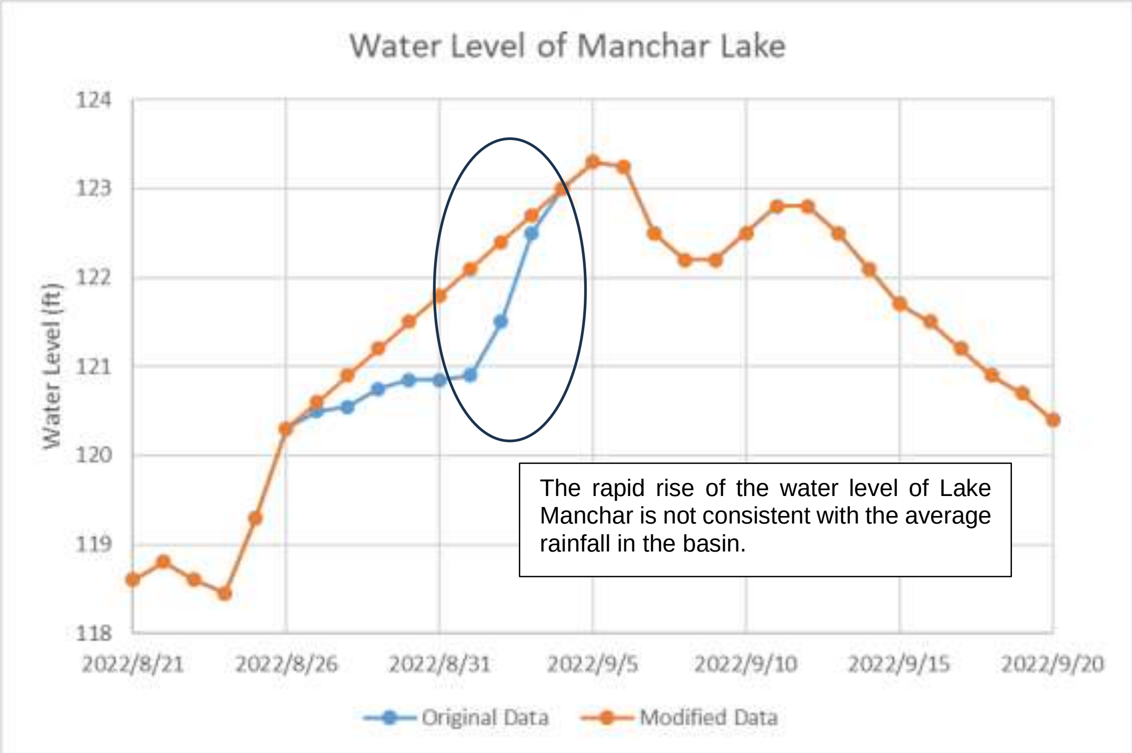
The sudden decrease of the estimated inflow around 9/6 is because the effect of the artificial breach is not considered, and the estimation of the overflow due to the artificial breach will be carried out in the following section.

The peak of the estimated inflow around 9/2 is because of rainfall around 8/25. In this case, the estimated inflow is not expected to rise rapidly. The cause of this rapid rise of estimated inflow is the rapid rise of the water level of Lake Manchar around 9/2. Figure 4.6.16 shows the water level correction of Lake Manchar, there is a rapid rise of the water level from 9/1 to 9/5, which is inconsistent with the average rainfall in the basin. Normally, the rain that falls in the mountainous part of the basin of Lake Manchar should flow out slowly, and in that case, the water level of Lake Manchar should rise like orange line shown in Figure 4.6.16. Therefore, this corrected water level of Lake Manchar will be used in this study. The estimated inflow is corrected as shown in Figure 4.6.17.



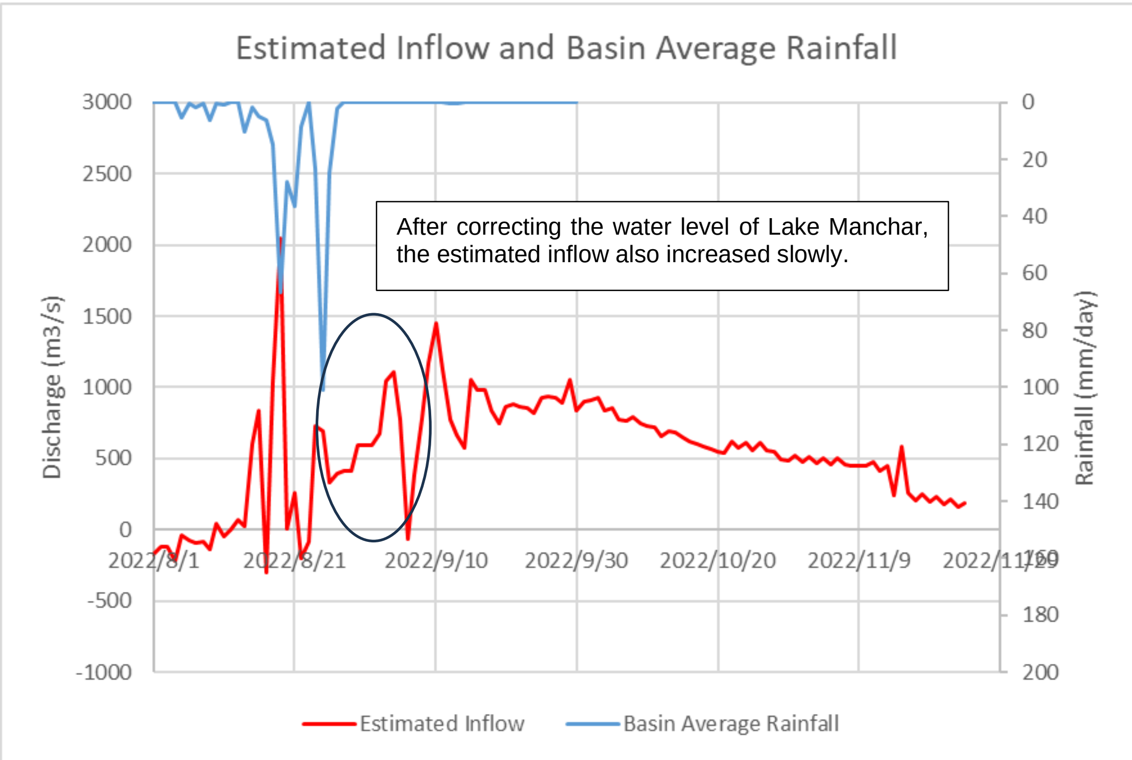
Source: Advisory Team

Figure 4.6.15 Scrutiny of Estimated Inflow



Source: Advisory Team

Figure 4.6.16 Water Level Correction of Lake Manchar



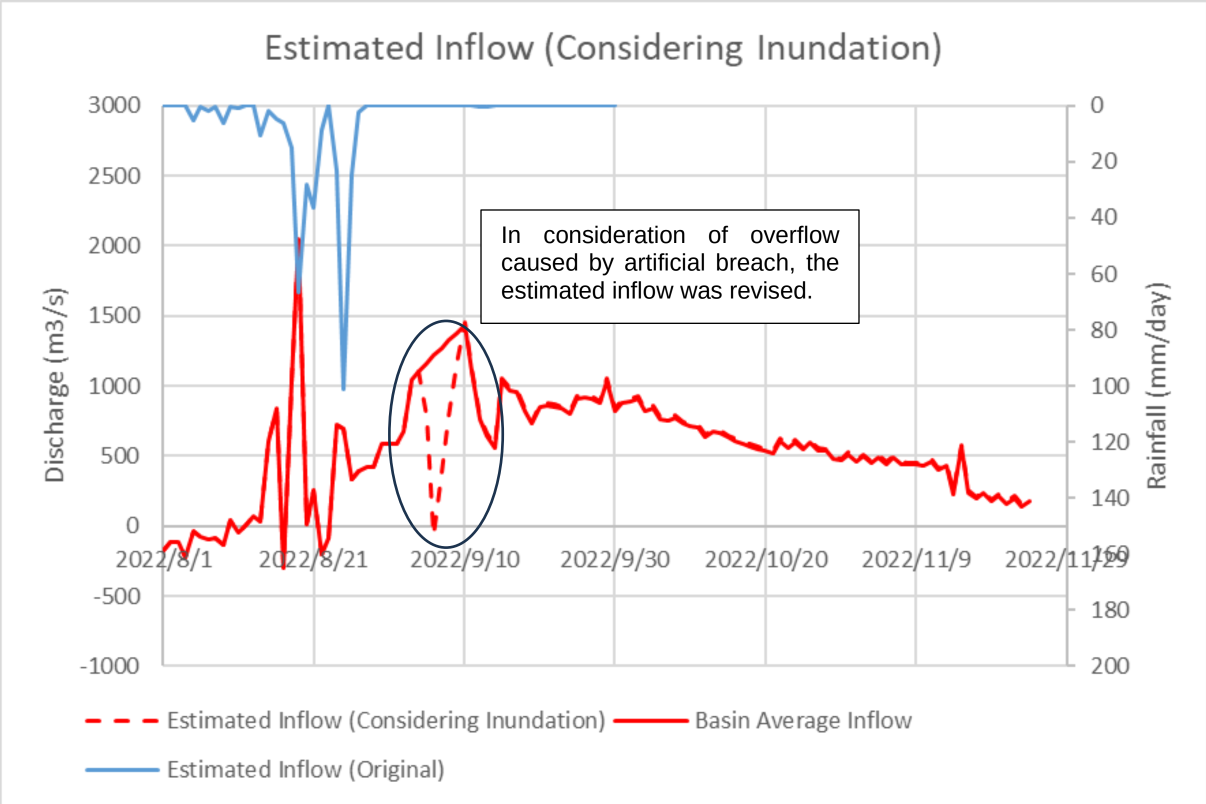
Source: Advisory Team

Figure 4.6.17 Revised Estimated Inflow

(8) Estimation of Overflow Due to Artificial Breach

In Lake Manchar, the artificial breach was carried out in early September. As a result of artificial breach, the water level decreased, and the estimated inflow greatly decreased in this period.

Without artificial breach, the estimated inflow would not decrease in this way, but would change as shown in Figure 4.6.18. Therefore, in this study, the estimated inflow is set as shown by the solid line in Figure 4.6.18. This overflow amount is estimated approximately 2.93 mil. m^3 (0.237MAF).



Source: Advisory Team

Figure 4.6.18 Estimation of Overflow Due to Artificial Breach

(9) Setting of Inflow Waveform

Depending on the water level data of Lake Manchar, the estimated inflow may be calculated to be less than 0 m^3/s. In particular, the estimated inflows of 8/1~8/11, 8/17, 8/22 and 8/23 are less than 0 m^3/s, so the inflow is set to 0 m^3/s for those days.

For this inflow waveform, the runoff rate can be calculated as shown in Table 4.6.3 and Figure 4.6.19, and the runoff rate is 0.647. This runoff rate is slightly high, and the following factors can be cited as causes.

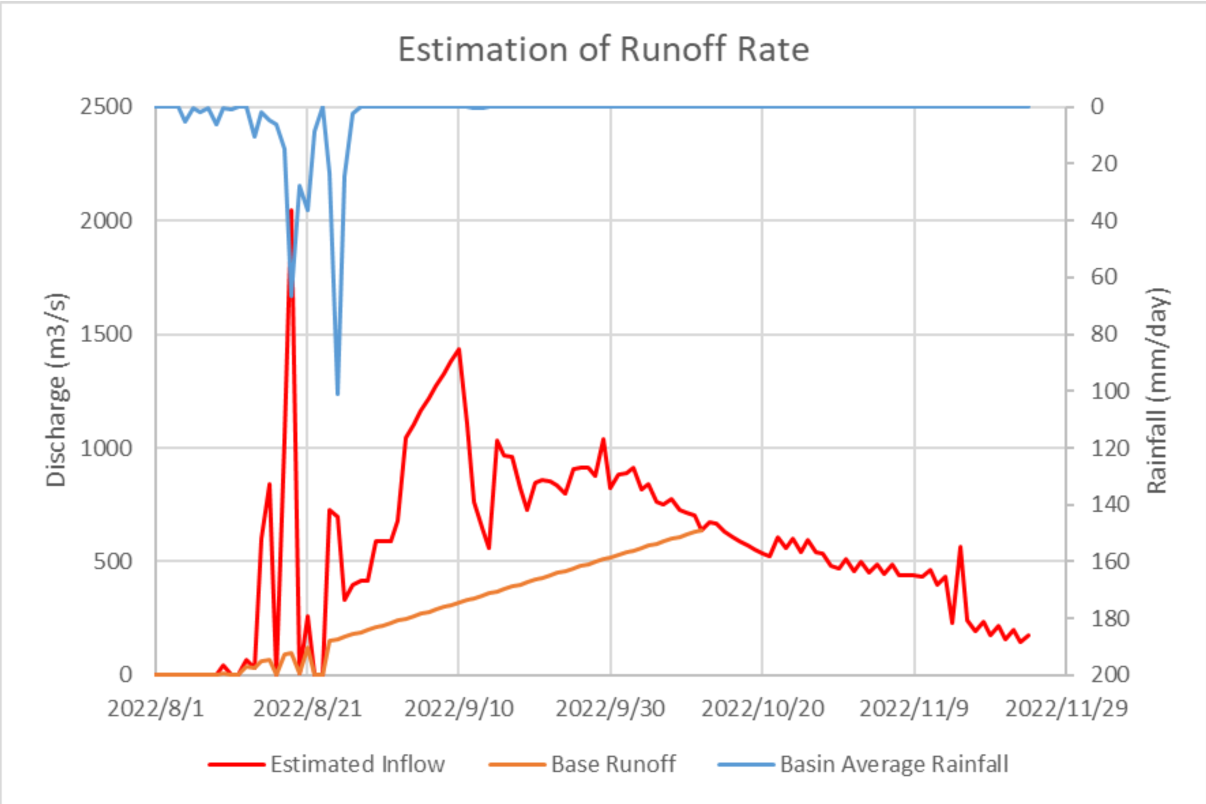
・There is a possibility of overestimating the overflow volume of the artificial breach.

・The inflow volume during the period when the estimated inflow volume was less than 0 m3/s was set to 0 m3/s (If the estimated inflow is calculated to be less than 0 $m^{3/}$s, there may have a problem with the water level data).

Table 4.6.3 Calculation of Runoff Rate

Target Period	2022/8/12～2022/10/12	
Total Rainfall	328.91	mm
Runoff Volume	2,348,235,886	m3
Basin Area	11,027.78	km2
Runoff Volume	212.94	mm
Runoff Rate	0.647	

Source: Advisory team



Source: Advisory Team

Figure 4.6.19 Calculation of the Runoff Rate

(10) Characteristics of Lake Manchar Basin and Necessity of Master Plan (M/P)

In this study, the inflow and overflow of the 2022 flood were calculated by back-calculation. However, the runoff process in the Lake Manchar basin is complex and is greatly affected by flood control measurements and developments in the upstream area. Therefore, it is necessary to create a Master Plan (M/P) that considers the entire basin and implement flood control measurements based on it.

Factors that affect the water level of Lake Manchar include the following. There was a delay in the rainfall response of the water level of Lake Manchar during the 2022 flood, this can be due to the complex runoff process mentioned here.

① Storage effect in the Hill Torrent basin.

② Dams or some other structures in the Hill Torrent basin.

③ Waterways in the MNVD (Main Nara Valley Drain) basin.

④ Inundation in the MNVD and its upstream areas

⑤ Storage effect of Lake Hamal and operation of regulators or some other structures.

⑥ Flow condition of the Indus River.

In addition, the following flood control measurements and developments can affect to the water level of Lake Manchar.

① Implementation of flood control measurements to prevent flooding in the upstream basin or other basins may increase the inflow of Lake Manchar.

② Improving the flow capacity of the Indus River may increase the water level of the Indus River, and it may reduce the drainage capacity from Lake Manchar to the Indus River.

③ As development progresses in the upstream basin (it means increase urbanization), the storage effect in the basin may decrease, the flood time lag may decrease, and the peak inflow may increase.

4.6.3 Setting the Target Probability Scale

4.6.3.1 Probability Scale of the 2022 Flood

According to the rainfall data of 3 rainfall stations (Khuzdar, Nawabshah, Mjo_Daro) in the Lake Manchar basin during the 2022 flood, there are 2 peaks of the rainfall, and it is reasonable to evaluate them in the period including these 2 peaks. Therefore, the probability scale was calculated using 7-day rainfall (Note that the rainfall in July was larger rainfall if using 1- to 3-day rainfall).

As shown in Table 4.6.4, the probability scale of the 2022 flood for 7-day rainfall, about 21-year at Khuzdar station, about 41-year at Nawabshah station, 95-year at Mjo_Daro station, and 29.4-year for basin average weighted by basin area. Table 4.6.5 shows the annual maximum rainfall at each station, which is the base data for the calculation of the probability scale, and Figure 4.6.20 shows the details of probability scale calculation at each station.

Table 4.6.4 Probability Scale of the 2022 flood (Rainfall Stations Around Lake Manchar, 7-Day Rainfall)

Observatory	Available Data	Probability Distribution	Rainfall in 2022	Return Period	X-years Rainfall							
					5-years	10-years	20-years	25-years	30-years	50-years	80-years	100-years
Khuzdar	31-years	Gev	184.70	20.8	95.2	133.8	181.6	199.5	215.2	264.5	318.3	347.0
Nawabshah	31-years	Gev	383.00	41.4	129.3	195.2	276.2	306.3	332.5	414.9	504.1	551.6
Mjo_Daro	29-years	Gev	573.01	95.0	88.2	146.3	229.1	262.7	293.3	396.6	519.8	590.0

Source: Advisory Team

Table 4.6.5 (1) Annual Maximum Rainfall (Khuzdar Rainfall Station, 7-Day Rainfall)

Year	Maximum Daily Rainfall	Year	Maximum Daily Rainfall	Year	Maximum Daily Rainfall
1992	148.60	2003	77.00	2014	53.00
1993	26.00	2004	23.20	2015	19.00
1994	93.70	2005	81.10	2016	34.00
1995	333.00	2006	24.70	2017	33.00
1996	65.00	2007	119.20	2018	38.00
1997	58.00	2008	65.90	2019	67.00
1998	54.00	2009	57.60	2020	114.30
1999	52.00	2010	78.91	2021	26.01
2000	29.10	2011	38.70	2022	184.70
2001	56.40	2012	50.00		
2002	17.70	2013	113.30		

Source: Created by the advisory team based on PID data

Table 4.6.5 (2) Annual Maximum Rainfall (Nawabshah Rainfall Station, 7-Day Rainfall))

Year	Maximum Daily Rainfall	Year	Maximum Daily Rainfall	Year	Maximum Daily Rainfall
1992	253.00	2003	138.60	2014	9.10
1993	29.20	2004	18.70	2015	69.00
1994	277.00	2005	26.30	2016	63.00
1995	171.90	2006	98.50	2017	45.00
1996	1.20	2007	105.11	2018	2.70
1997	33.80	2008	37.02	2019	138.20
1998	29.00	2009	59.00	2020	96.41
1999	8.30	2010	72.00	2021	30.30
2000	26.00	2011	288.50	2022	383.00
2001	27.00	2012	160.00		
2002	2.00	2013	39.00		

Source: Created by the advisory team based on PID data

Table 4.6.5 (3) Annual Maximum Rainfall (Mjo_Daro Rainfall Station, 7-Day Rainfall)

Year	Maximum Daily Rainfall	Year	Maximum Daily Rainfall	Year	Maximum Daily Rainfall
1992	156.00	2003	75.00	2014	—
1993	26.00	2004	15.00	2015	61.00
1994	130.60	2005	45.20	2016	3.80
1995	130.60	2006	—	2017	16.00
1996	11.00	2007	31.61	2018	2.00
1997	17.00	2008	86.50	2019	10.01
1998	10.10	2009	2.00	2020	260.00
1999	15.00	2010	27.50	2021	45.00
2000	66.20	2011	63.00	2022	573.01
2001	20.70	2012	97.01		
2002	15.40	2013	51.00		

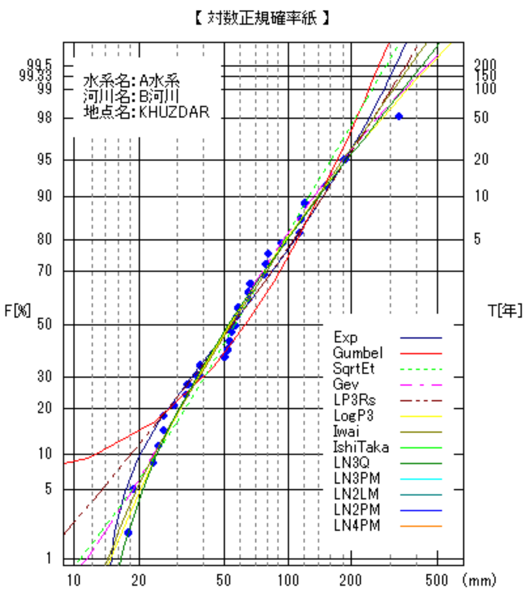
Source: Created by the advisory team based on PID data

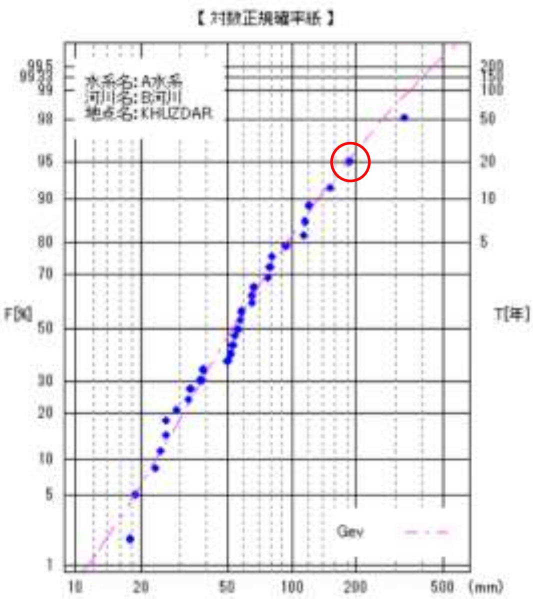
Rainfall Station Name: Khuzdar	Basin: Lake Manchar
Downstream Discharge Station: Kotri (Indus)	Latitude: 27.810°, Longitude: 66.610°

Selected Probability Distribution: Gev	Available Data: 31 Years
SLSC Value: 0.025	Jackknife Estimation Error (50 Years): 83.4 mm

Probability Distribution Selection:
Among Gumbel, Gev, and SqrtEt, Gev with the smallest SLSC value was selected. (SLSC value 0.040 or less)
※SLSC: Standard Least-Squares Criterion

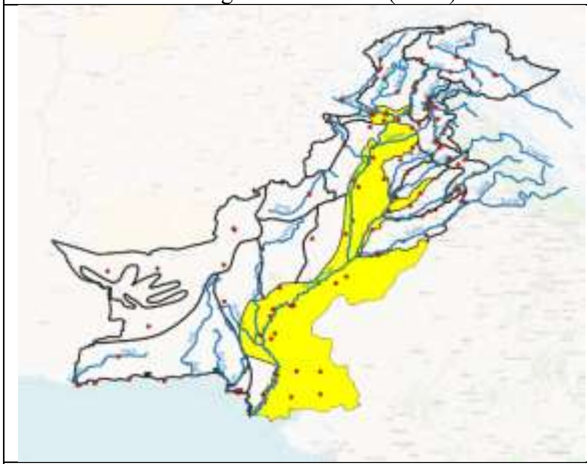
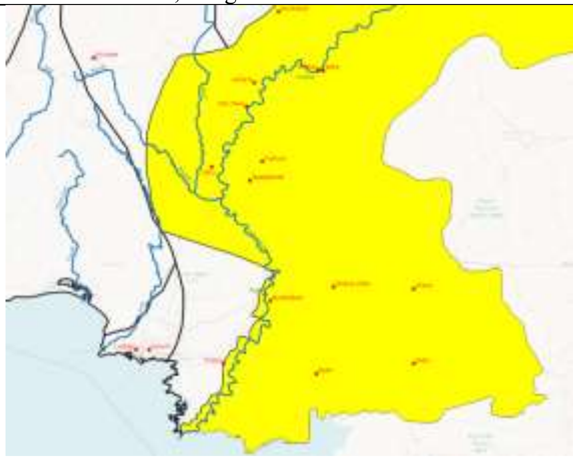
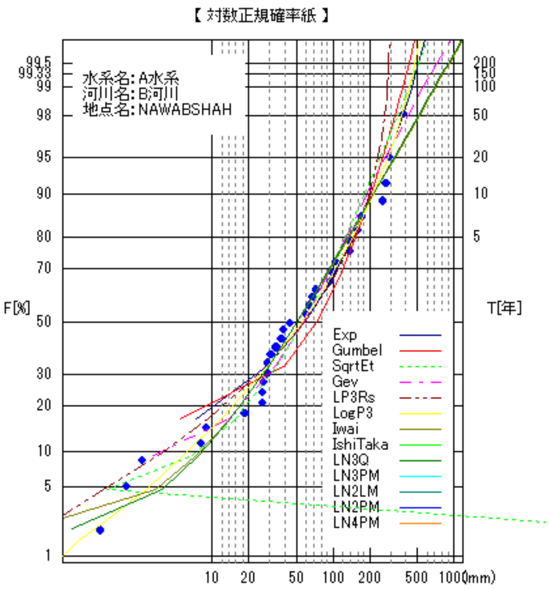
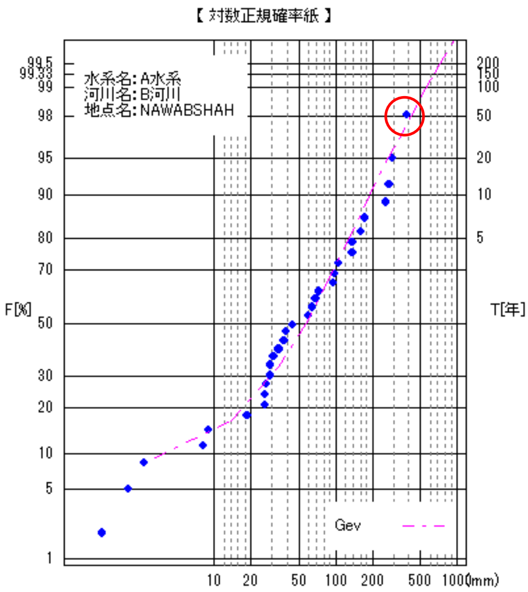
All Probability Distributions	Optimal Probability Distribution





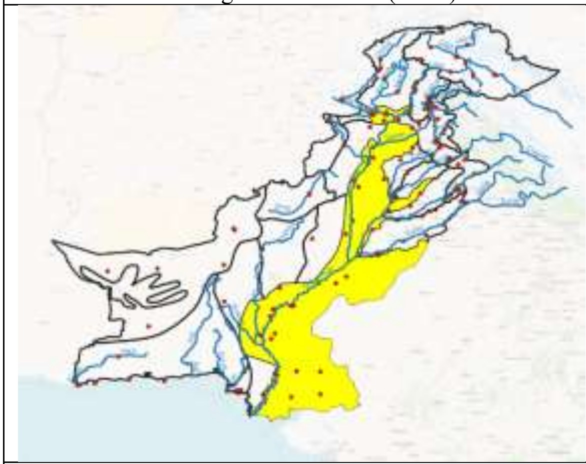
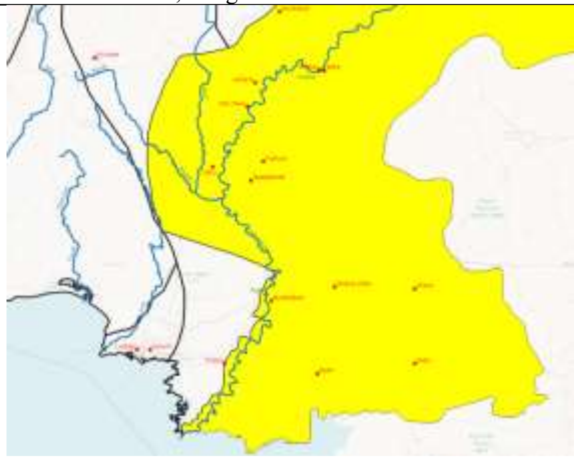
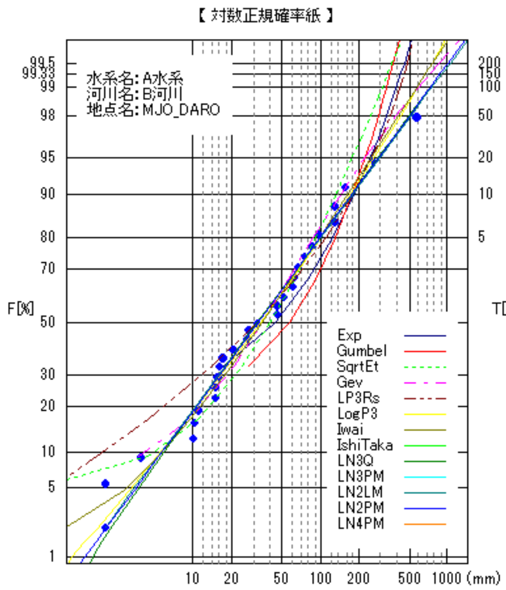
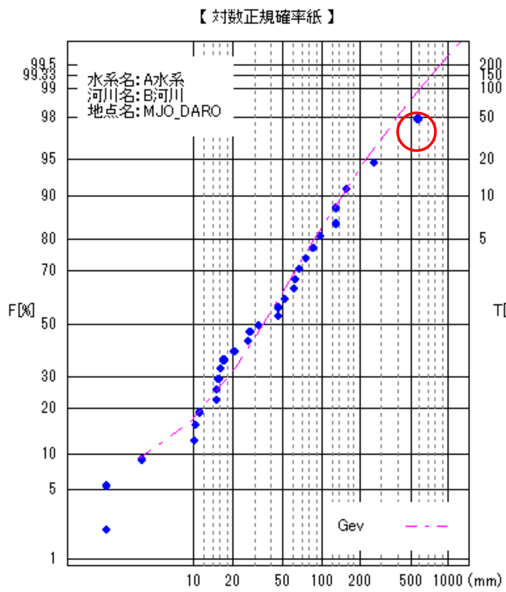
Source: Advisory Team

Figure 4.6.20 (1) Details of Probability Scale Calculation (Khuzdar Rainfall Station, 7-Day Rainfall)

<table>
<tr><td>Rainfall Station Name: Nawabshah</td><td>Basin: Lake Manchar</td></tr>
<tr><td>Downstream Discharge Station: Kotri (Indus)</td><td>Latitude: 26.580°, Longitude: 68.166°</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Selected Probability Distribution: Gev</td><td>Available Data: 31 Years</td></tr>
<tr><td>SLSC Value: 0.038</td><td>Jackknife Estimation Error (50 Years): 81.8 mm</td></tr>
<tr><td colspan="2">Probability Distribution Selection:
Among Gumbel, Gev, and SqrtEt, Gev with the smallest SLSC value was selected. (SLSC value 0.040 or less)
※SLSC: Standard Least-Squares Criterion</td></tr>
<tr><td>All Probability Distributions</td><td>Optimal Probability Distribution</td></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Source: Advisory Team

Figure 4.6.20 (2) Details of Probability Scale Calculation (Nawabshah Rainfall Station, 7-Day Rainfall)

Rainfall Station Name: Mjo_Daro	Basin: Lake Manchar
Downstream Discharge Station: Kotri (Indus)	Latitude: 27.320°, Longitude: 68.130°
	
Selected Probability Distribution: Gev	Available Data: 29 Years
SLSC Value: 0.032	Jackknife Estimation Error (50 Years): 158.5 mm
Probability Distribution Selection: Among Gumbel, Gev, and SqrtEt, Gev with the smallest SLSC value was selected. (SLSC value 0.040 or less) ※SLSC: Standard Least-Squares Criterion	
All Probability Distributions	Optimal Probability Distribution
	

Source: Advisory Team

Figure 4.6.20 (3) Details of Probability Scale Calculation (Mjo_Daro Rainfall Station, 7-Day Rainfall)

4.6.3.2 Problems in Lake Manchar During Flooding

Problems in Lake Manchar during flooding are summarized in Table 4.6.6. In order to solve these problems, the target inflow waveform was set and measurements are considered to improve drainage capacity.

Table 4.6.6 Problems in Lake Manchar During Flooding

No	Problem of Manchar Lake during Flood
1	Insufficient drainage capacity. Current system can deal with a 5 year flood, but it should deal with a 50 year flood from irrigation manual.
2	Breach was conducted in 2022 flood. It may cause damage to residents living near Manchar Lake.
3	Capacity of regulators are necks of drainage capacity. Aral Head Regulator is being improved, but Aral Tail Regulator doesn't have improvement plan.
4	Aral Head Regulator improvement is not enough. It can deal with a 20 year flood.
5	Sedimentation of canals may reduce drainage capacity. Excavation of canals may be required.

Source: Advisory Team

4.6.3.3 Setting the Target Inflow Waveform

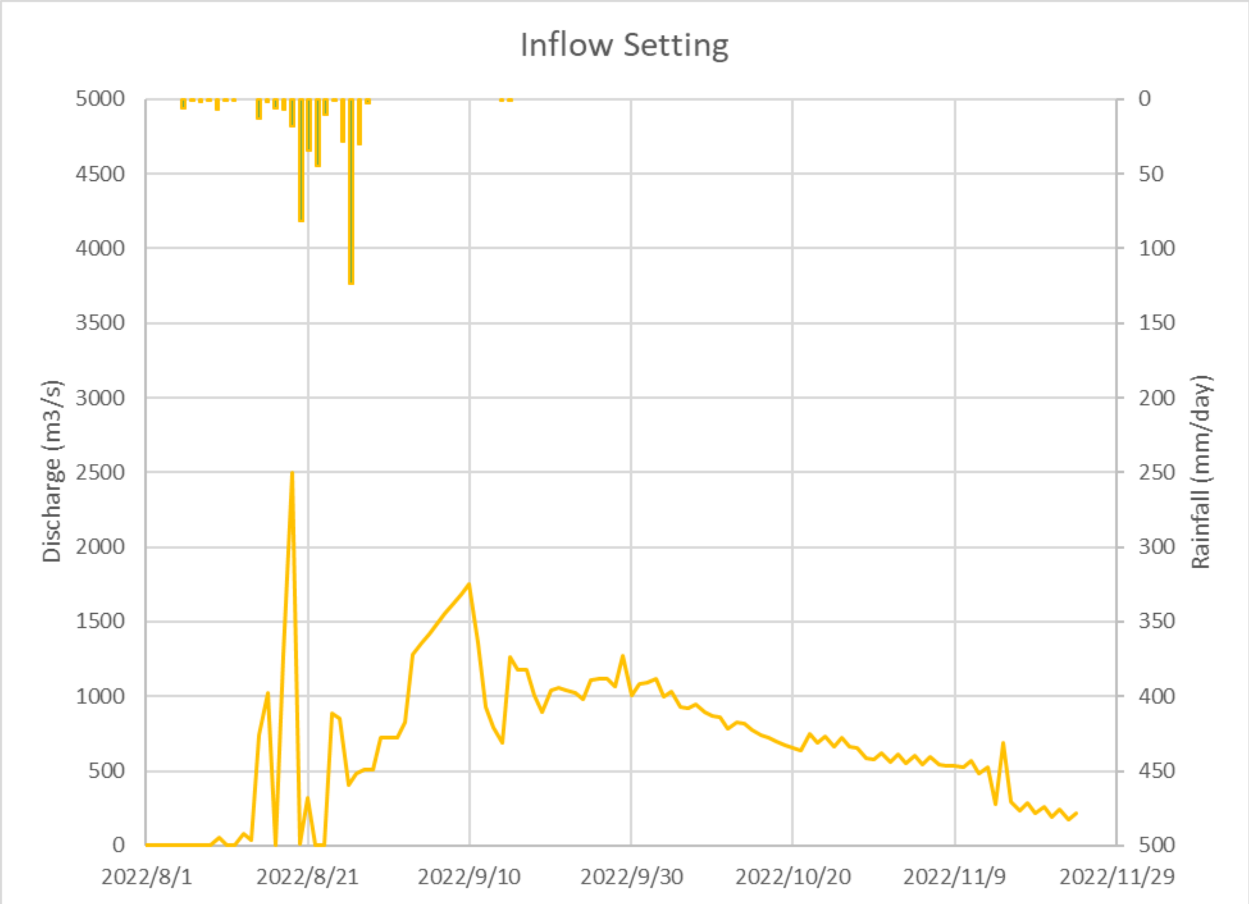
(1) The Result of Setting the Target Inflow Waveform

Table 4.6.7 shows the considerations for the target inflow waveform. The present drainage capacity, the description of the Irrigation Manual, and the feasibility of the measurements were examined, and the **50-year probability scale** was set as the target. The inflow waveform was set based on the 2022 flood, which the artificial breach was carried out, and was extended to the probability scale in 50 years. Figure 4.6.21 shows the target inflow waveform.

Table 4.6.7 Considerations for the Target Inflow Waveform

Item		Contents
Current drainage capacity	Without Aral Head improvement	It can deal with a 5 year flood
	With Aral Head improvement	It can deal with a 20 year flood
Description of Irrigation Manual		It is designed for a 50 year flood
Feasibility of drainage capacity improvement		Feasible by canal widening or construction of new canal

Source: Advisory Team



Source: Advisory Team

Figure 4.6.21 Target Inflow Waveform (50-Year Probability Scale, 2022 Flood Waveform)

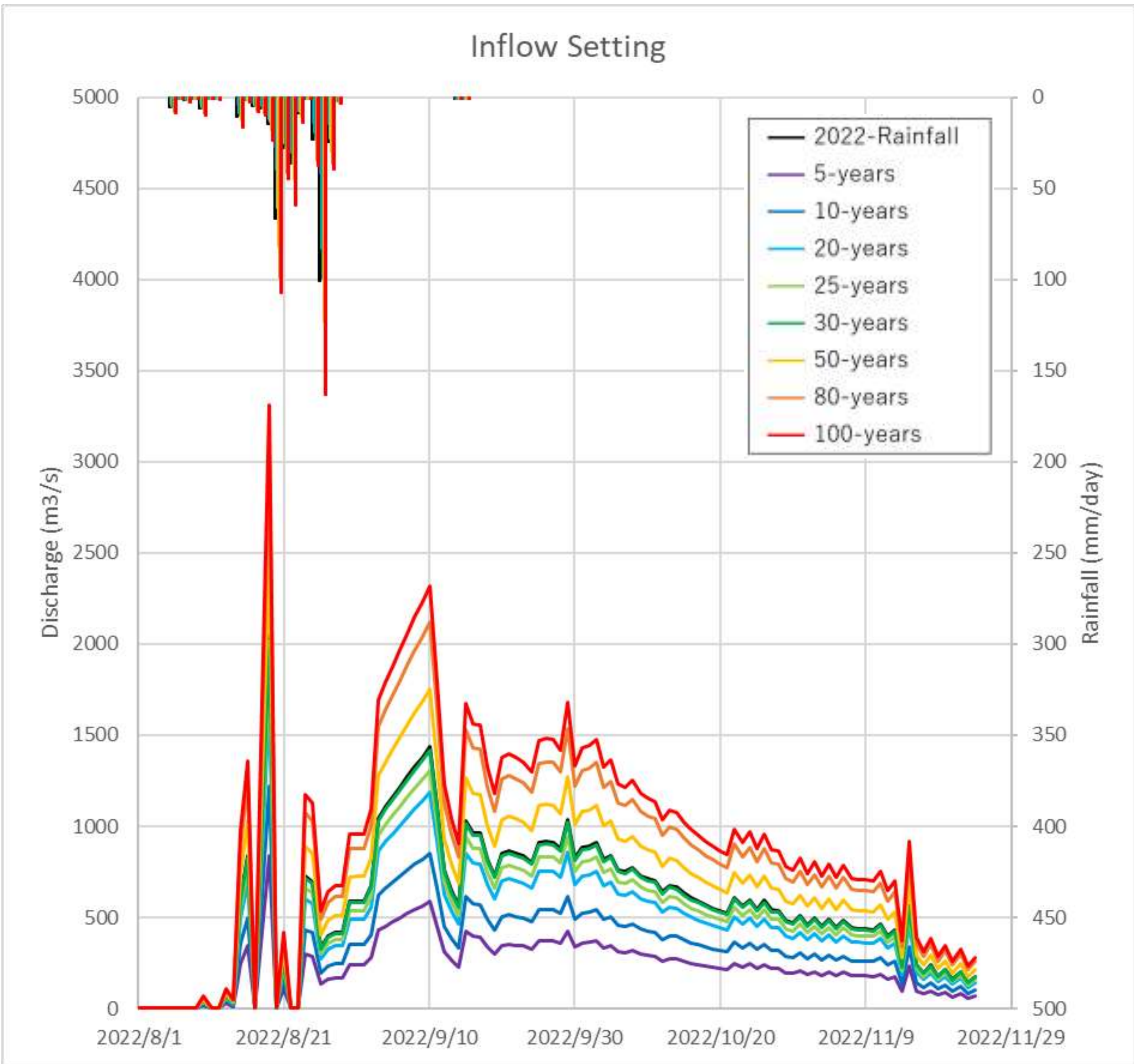
(2) Setting Probability Scale

In the preceding section, the probability scale of the 2022 flood was calculated as 29.4-year for 7-day rainfall and basin averaged. The inflow waveform is extended for each probability scale period as shown in Table 4.6.8 and Figure 4.6.22, assuming that the runoff rate does not change.

Table 4.6.8 Total Rainfall and Maximum Inflow at Each Probability Scale

Return Period	7-day Rainfall (mm)				Total Rainfall (mm)				Maximum Inflow (m3/s)
	Basin Average	Khuzdar	Nawabshah	Mjo_Daro	Basin Average	Khuzdar	Nawabshah	Mjo_Daro	
2022-Rainfall	263.75	184.70	383.00	573.01	328.91	218.90	494.70	765.01	2045.78
5-years	107.95	95.20	129.30	88.20	134.62	118.72	161.25	109.99	837.32
10-years	157.04	133.80	195.20	146.30	195.84	166.86	243.43	182.45	1218.12
20-years	217.74	181.60	276.20	229.10	271.53	226.47	344.44	285.70	1688.87
25-years	240.40	199.50	306.30	262.70	299.80	248.79	381.98	327.60	1864.71
30-years	260.23	215.20	332.50	293.30	324.52	268.37	414.65	365.76	2018.45
50-years	322.60	264.50	414.90	396.60	402.30	329.85	517.41	494.59	2502.24
80-years	390.51	318.30	504.10	519.80	486.99	396.94	628.65	648.22	3029.00
100-years	426.76	347.00	551.60	590.00	532.19	432.73	687.88	735.77	3310.16

Source: Advisory Team



Source: Advisory Team

Figure 4.6.22 Inflow Waveforms at Each Probability Scale

(3) Modeling Policy for Existing Waterways

For setting the target probability scale, it is necessary to grasp the probability scale that can be handled by the existing drainage capacity. For this purpose, a relational formula based on observation data (below: relational formula) was created to calculate the discharge at each regulator given the water level of Lake Manchar and the water level of each regulator for existing waterways.

In creating this relational formula, the shape of the gate of each regulator is fixed, so the key to determine the discharge is the flow velocity at the regulator. Basically, it is considered that the water level difference between Lake Manchar and each regulator greatly affects the flow velocity, and it is assumed that the flow velocity can be expressed by a quadratic formula of the water level difference from the following energy conservation formula.

$$H_X + \frac{{V_X}^2}{2g} + \frac{L}{n^2} \times \frac{1}{2}\left(\frac{{V_X}^2}{{R_X}^2} + \frac{{V_{X+1}}^2}{{R_{X+1}}^2}\right) = H_{X+1} + \frac{{V_{X+1}}^2}{2g}$$

where H_X is position head in the X section, V_X is flow velocity in the X section, g is the gravity acceleration, L is interval distance between the X section and X+1 section, n is the roughness coefficient, R_X is the diameter depth in the X section.

(4) Modeling of the Aral Head

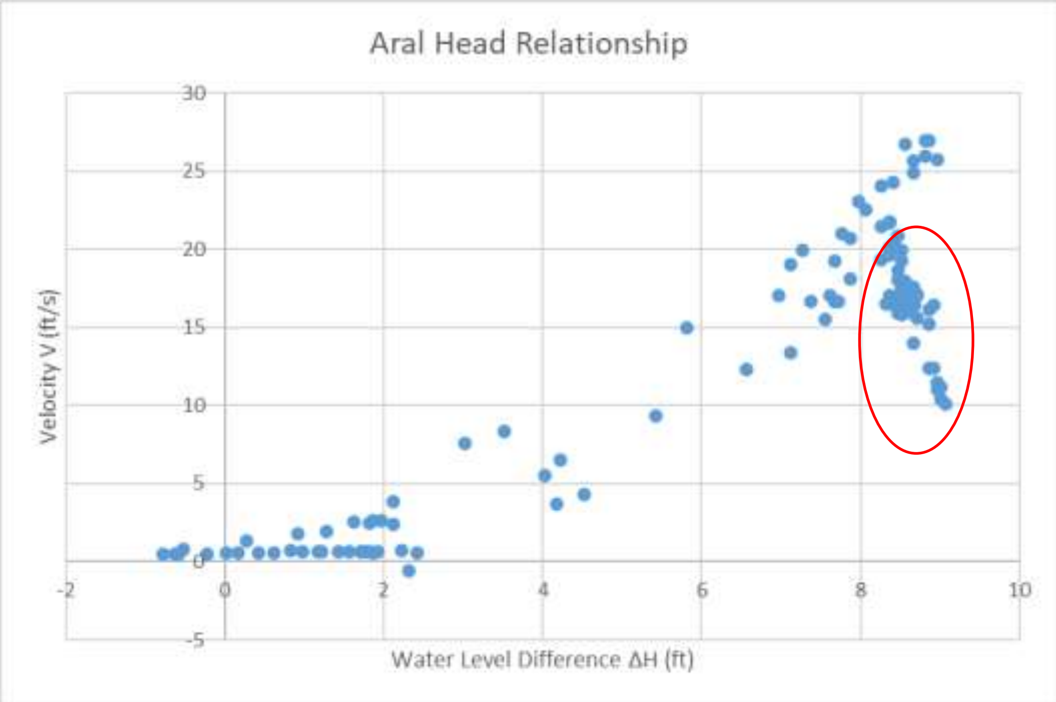
A scatter plot of the water level difference between Lake Manchar and the Aral Head Regulator and the flow velocity at the Aral Head Regulator is shown in Figure 4.6.23. This scatter plot shows that the flow velocity can be expressed as a quadratic expression of the water level difference in many data, however the data shown in a red circle require the other relational formula.

The case where the flow velocity can be expressed as a quadratic expression of the water level difference is set as Type1, and the case where the other relational formula is required is set as Type2. For Type1, as shown in Figure 4.6.24, the flow velocity can be expressed as a quadratic expression of the water level difference with high accuracy. For Type2, as shown in Figure 4.6.25, the flow velocity can be expressed as a first-order expression of the water depth in the Aral Head Regulator with high accuracy. As far as the actual data in the 2022 flood are confirmed, the relational formula Type1 can be used when the water depth in the Aral Head Regulator is 10 ft or more, and the relational formula Type2 can be used when the water level in the Aral Head Regulator is less than 10 ft.

In summary, the discharge in the Aral Head can be modeled using the following equation. Figure 4.6.26 shows the validation calculation of the relational formula of Aral Head Regulator.

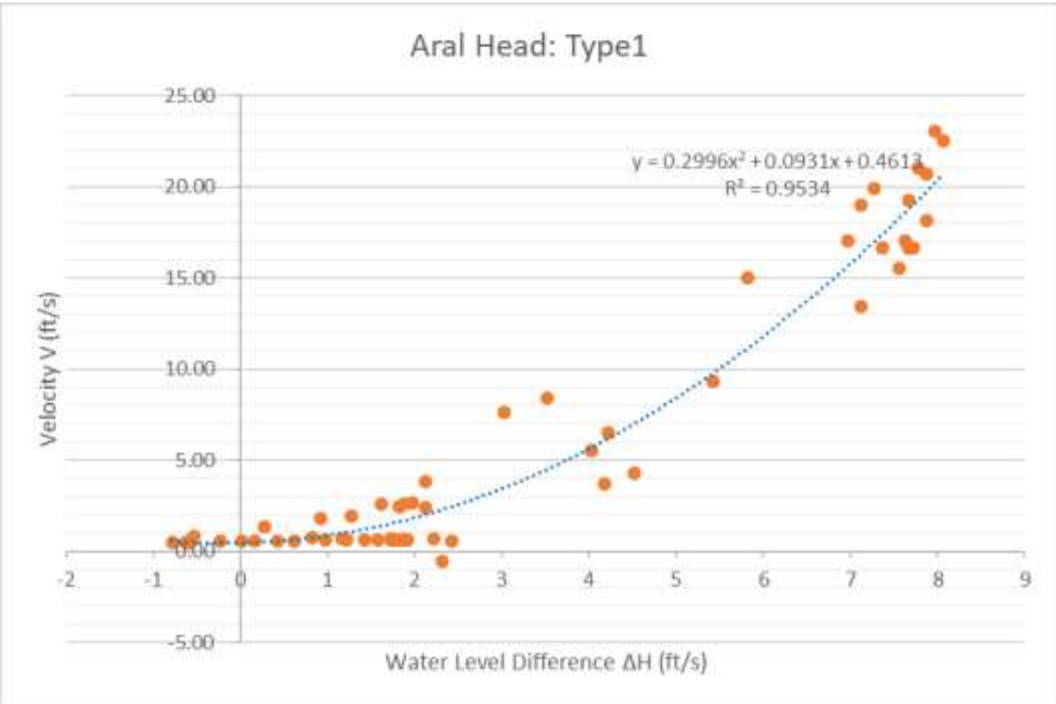
$$Q_{Aral-Head} = A_{Aral-Head}V_{Aral-Head} = B_{Aral-Head}H_{Aral-Head}V_{Aral-Head}$$
$$V_{Aral-Head} = 0.2996\Delta H^2 + 0.0931\Delta H + 0.4612 \quad (H_{Aral-Head} > 10ft)$$
$$V_{Aral-Head} = 2.5404H_R + 0.4909 \quad (H_{Aral-Head} < 10ft)$$

where $Q_{Aral-Head}$ is discharge in the Aral Head Regulator, $V_{Aral-Head}$ is the flow velocity of the Aral Head Regulator, $A_{Aral-Head}$ is the cross-sectional area of Aral Head Regulator, $B_{Aral-Head}$ is the sum of width of the gates of the Aral Head Regulator, $H_{Aral-Head}$ is the water depth of the Aral Head Regulator.



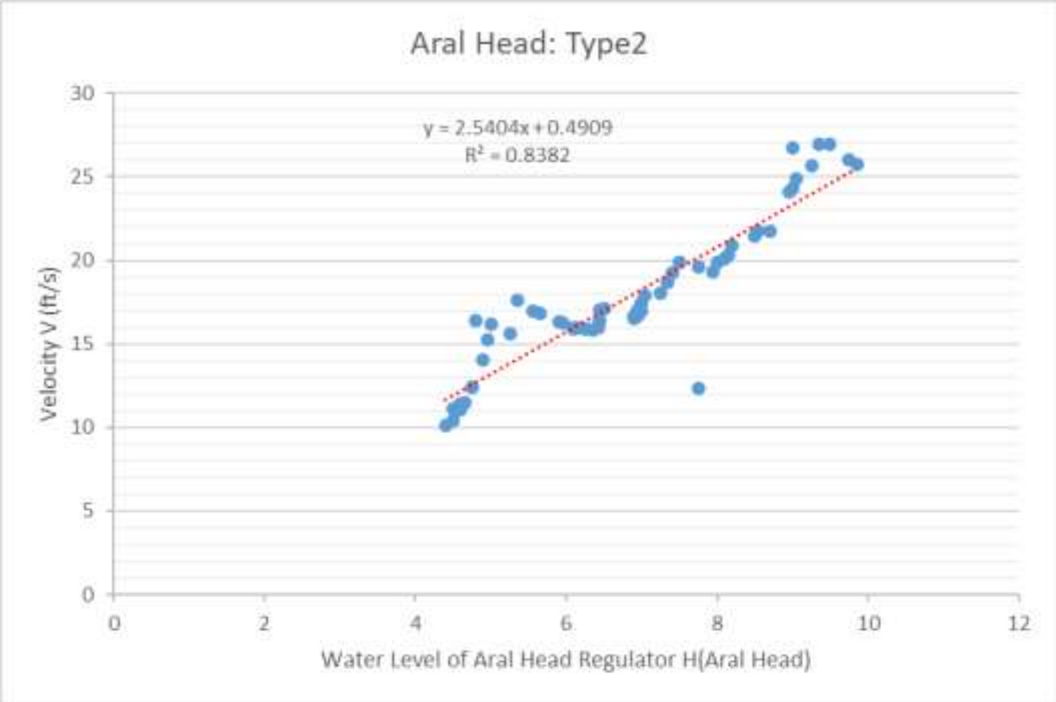
Source: Advisory Team

Figure 4.6.23 Scatter Plot of Water Level Difference and Flow Velocity in Aral Head Regulator



Source: Advisory Team

Figure 4.6.24 Relational Formula of Aral Head Regulator (Type1)



Source: Advisory Team

Figure 4.6.25 Relational Formula of Aral Head Regulator (Type2)

Source: Advisory Team

Figure 4.6.26 Validation Calculation of Relational Formula of Aral Head Regulator

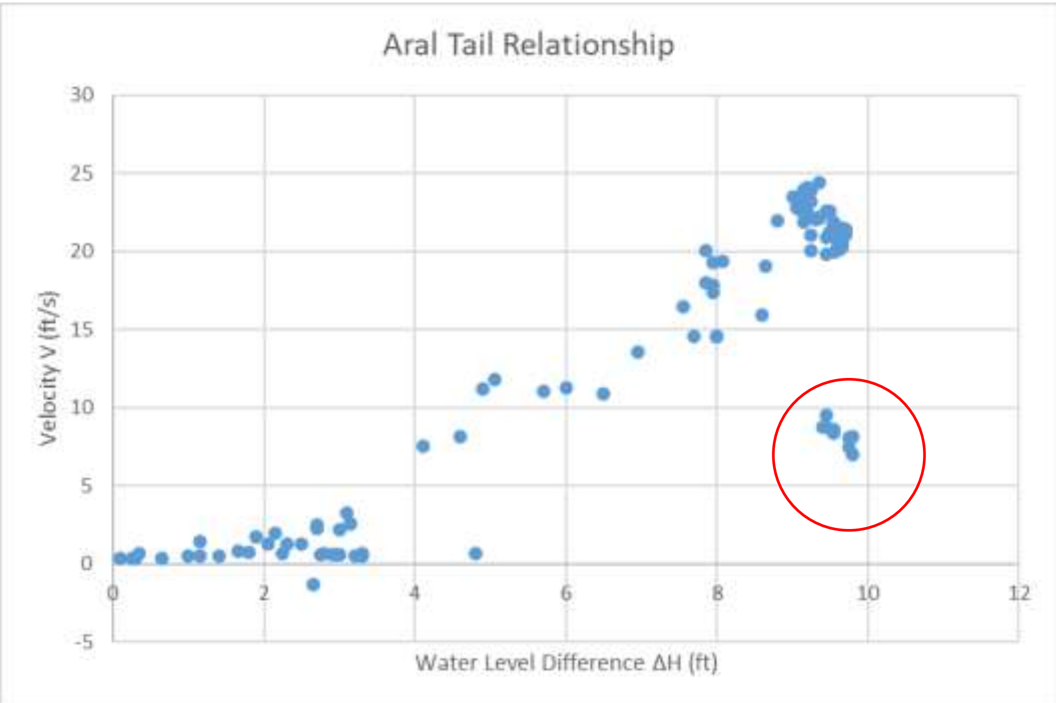
(5) Modeling of the Aral Tail

A scatter plot of the water level difference between Lake Manchar and the Aral Tail Regulator and the flow velocity at the Aral Tail Regulator is shown in Figure 4.6.27. This scatter plot shows that the flow velocity can be expressed as a quadratic expression of the water level difference in many data. There are few exceptions indicated by a red circle, however these data are not main period of the 2022 flood. Therefore, the relational formula is not prepared separately as in Aral Head.

As shown in Figure 4.6.28, the flow velocity can be expressed by the quadratic expression of the water level difference with high accuracy in the Aral Tail. From this result, the discharge in Aral Tail can be modeled using the following equation. Figure 4.6.29 shows the validation calculation of the relational formula of Aral Tail Regulator.

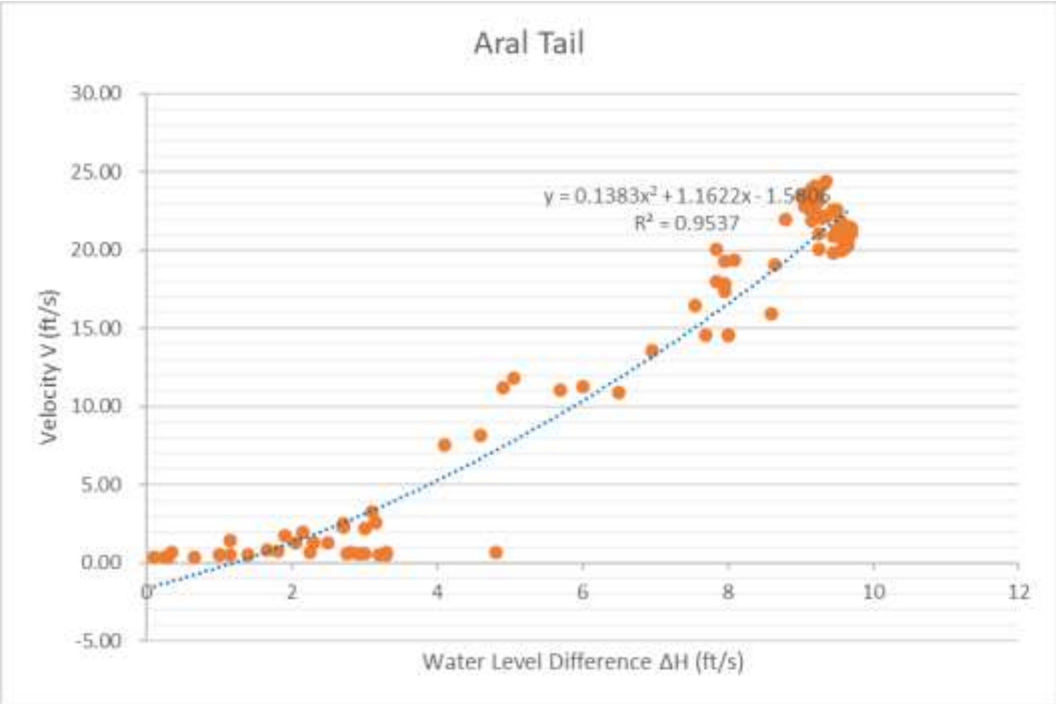
$$Q_{Aral-Tail} = A_{Aral-Tail}V_{Aral-Tail} = B_{Aral-Tail}H_{Aral-Tail}V_{Aral-Tail}$$
$$V_{Aral-Tail} = \max(0, 0.1383\Delta H^2 + 1.1622\Delta H - 1.5806)$$

where $Q_{Aral-Tail}$ is discharge in the Aral Tail Regulator, $V_{Aral-Tail}$ is the flow velocity of the Aral Tail Regulator, $A_{Aral-Tail}$ is the cross-sectional area of Aral Tail Regulator, $B_{Aral-Tail}$ is the sum of width of the gates of the Aral Tail Regulator, $H_{Aral-Tail}$ is the water depth of the Aral Tail Regulator.



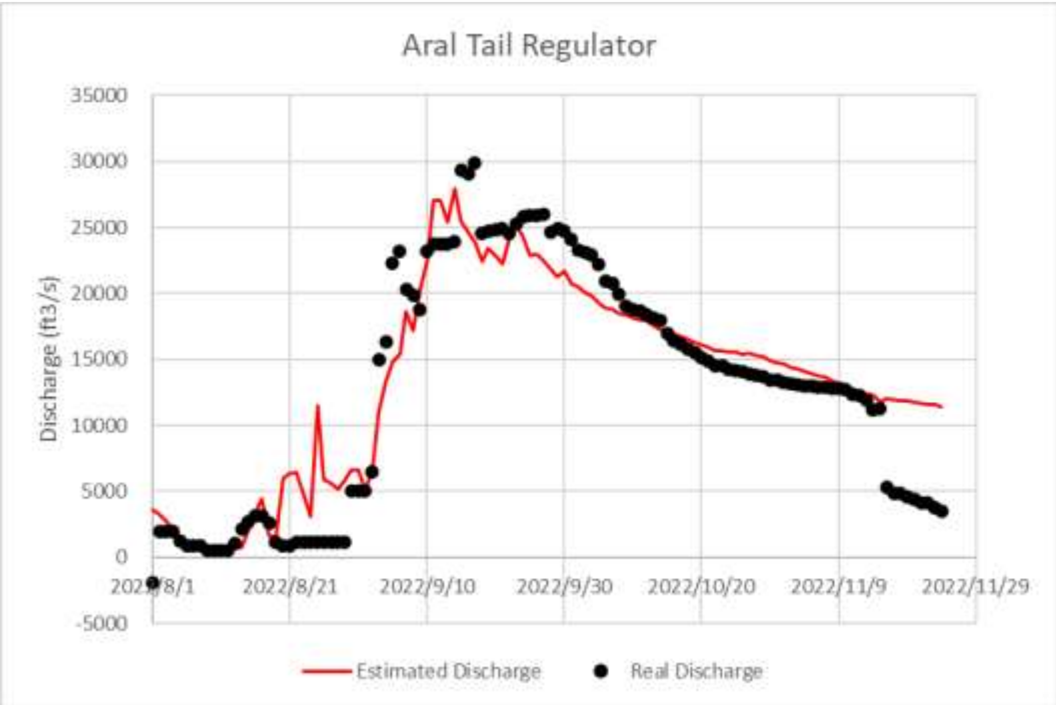
Source: Advisory Team

Figure 4.6.27 Scatter Plot of Water Level Difference and Flow Velocity in Aral Tail Regulator



Source: Advisory Team

Figure 4.6.28 Relational Formula of Aral Tail Regulator



Source: Advisory Team

Figure 4.6.29 Validation Calculation of Relational Formula of Aral Tail Regulator

(6) Current Drainage Capacity

The flood scale which can handle by the current drainage capacity under the conditions shown in Table 4.6.9 was examined. Here, "can handle" is defined as that the water level of Lake Manchar does not exceed the upper limit of water level: 123 ft (=37.49 m) during the flood period. As shown in Table 4.6.10, the current drainage capacity can handle 5-year probability scale flood, however it cannot handle more than 10-year probability scale flood. Figure 4.6.30 shows the calculation results of 5- to 100-year probability scale flood.

Table 4.6.9 Calculation Conditions (Current Drainage Capacity)

Setting	Contents	Memo
Inflow Scale	5 year flood～100 year flood	
Waveform	2022/8/1～2022/10/12	
Inflow and Outflow	Direct Rainfall Inflow	Nawabshah Rainfall Obsevatory
	Evaporation	0.8×2300mm/year
	Aral Head Regulator	Empirical Formula
	Aral Tail Regulator	Empirical Formula
Time Step	1-day	
HAV Relationship	2017 F/S Report	
Downstream Water Level	Aral Head Regulator	2022 Flood Data
	Aral Tail Regulator	2022 Flood Data

Source: Advisory Team

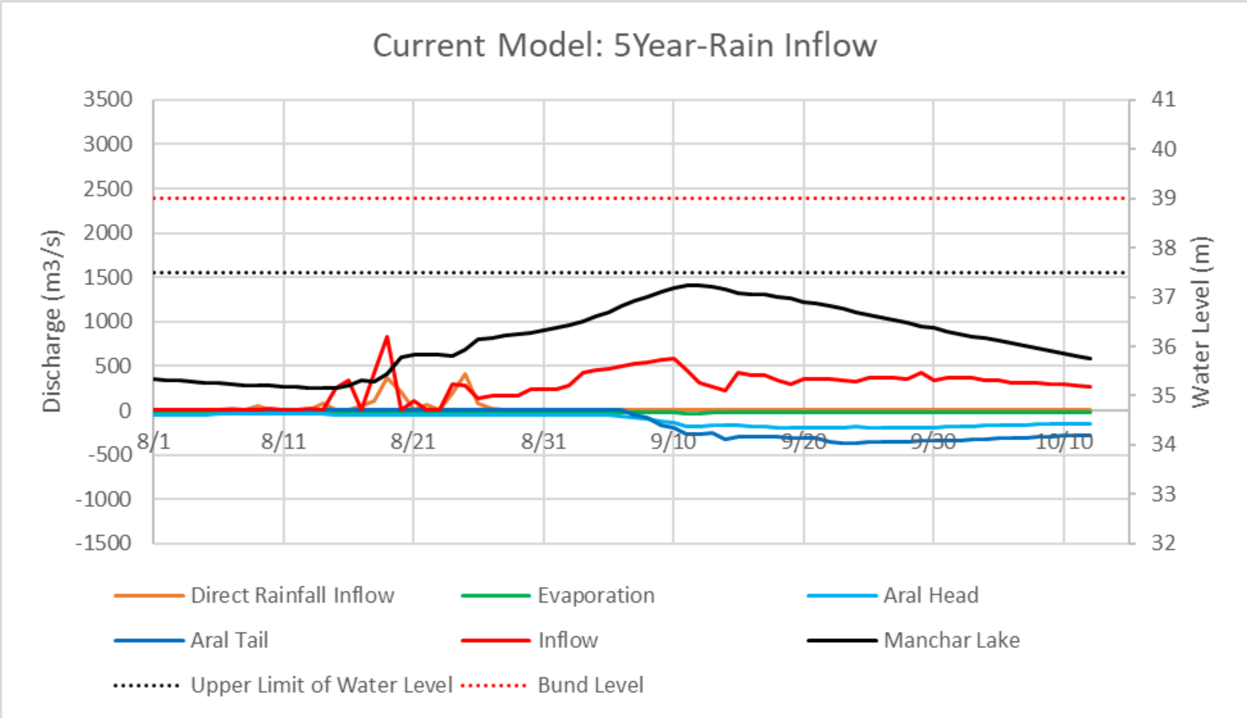
Table 4.6.10 Summary of Calculation Results (Current Drainage Capacity)

Inflow Scale	Manchar Lake					Maximum Discharge		
	Excess Water Level	Maximum Water Level	Upper Limit of Water Level	Bund Level	Excess Volume	Aral Head	Aral Tail	Total
	m	m	m	m	m3	m3/s	m3/s	m3/s
5-years	—	37.24	37.49	39.01	—	201.04	369.79	570.83
10-years	0.40	37.89			131,225,767	262.76	478.39	741.15
20-years	1.02	38.51			341,876,890	367.05	640.72	1007.77
25-years	1.22	38.71			408,907,854	403.77	704.57	1108.34
30-years	1.38	38.87			464,717,198	435.83	758.94	1194.77
50-years	1.87	39.36			632,820,480	540.55	929.38	1469.93
80-years	2.37	39.86			805,679,945	661.00	1115.07	1776.07
100-years	2.63	40.12			894,330,557	727.79	1214.41	1942.20

: Exceeded upper limit of water level

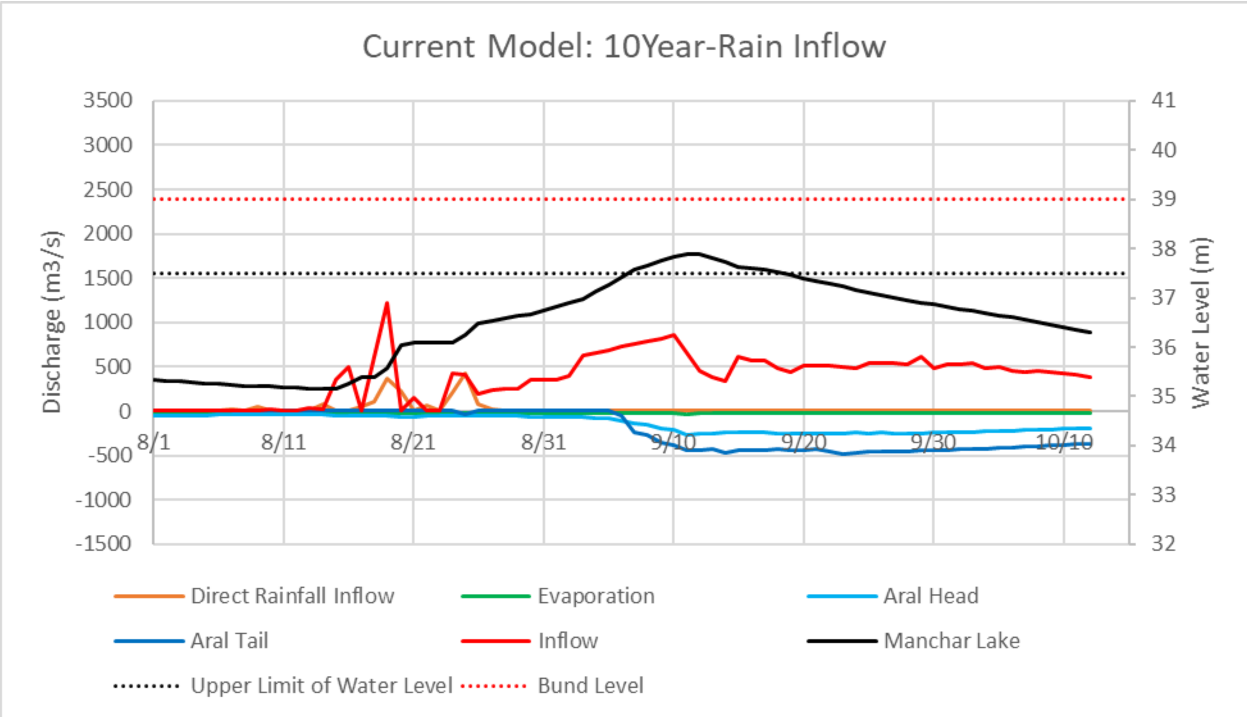
: Exceeded bund level

Source: Advisory Team



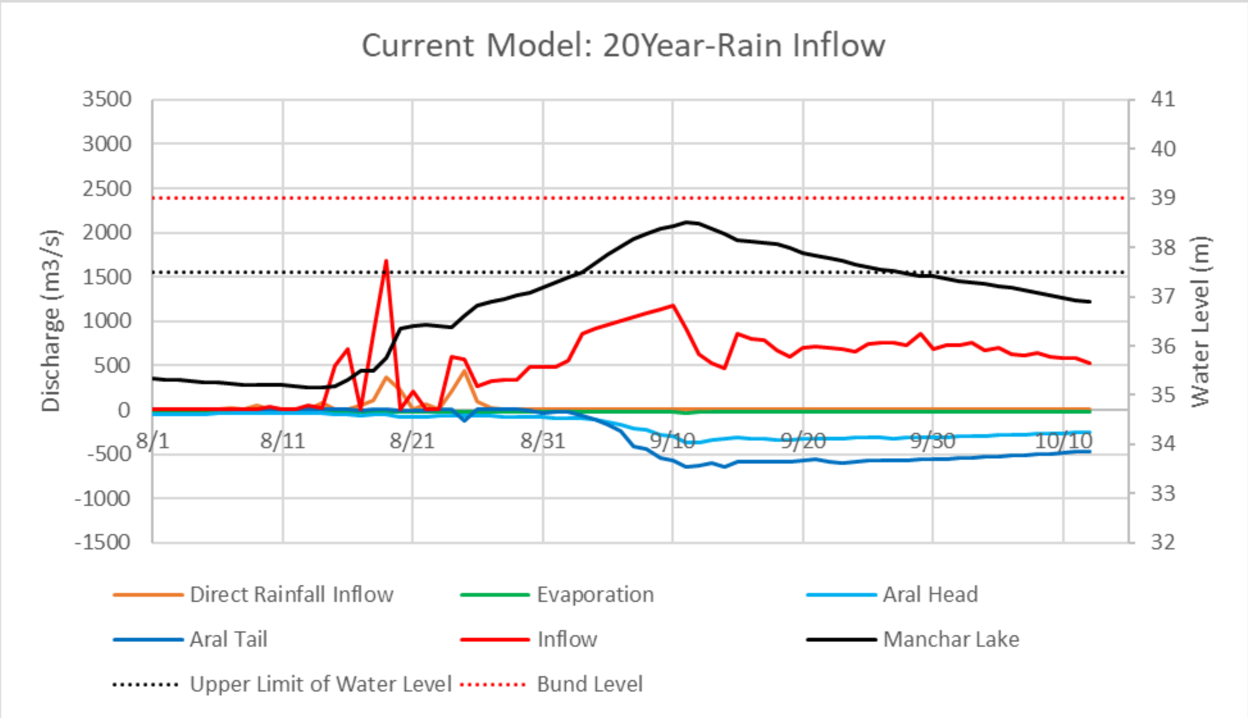
Source: Advisory Team

Figure 4.6.30 (1) Calculation Result (Current Drainage Capacity, 5-Year Probability Scale Flood)



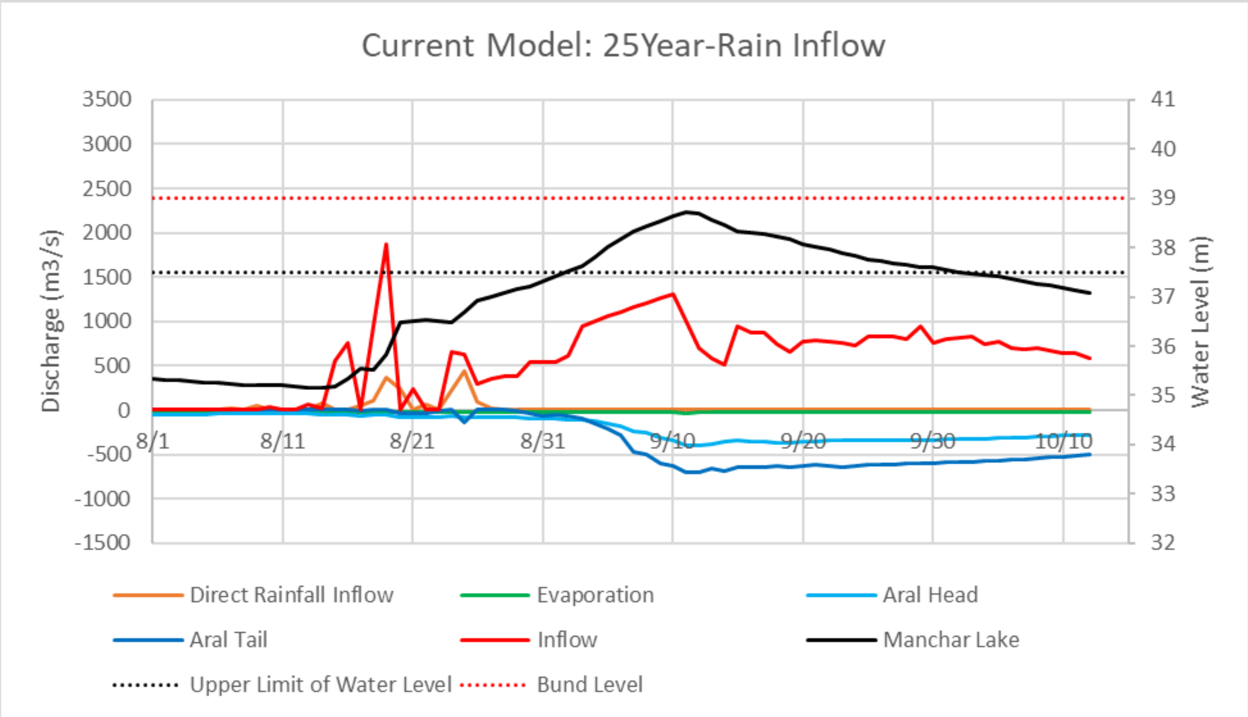
Source: Advisory Team

Figure 4.6.30 (2) Calculation Result (Current Drainage Capacity, 10-Year Probability Scale Flood)



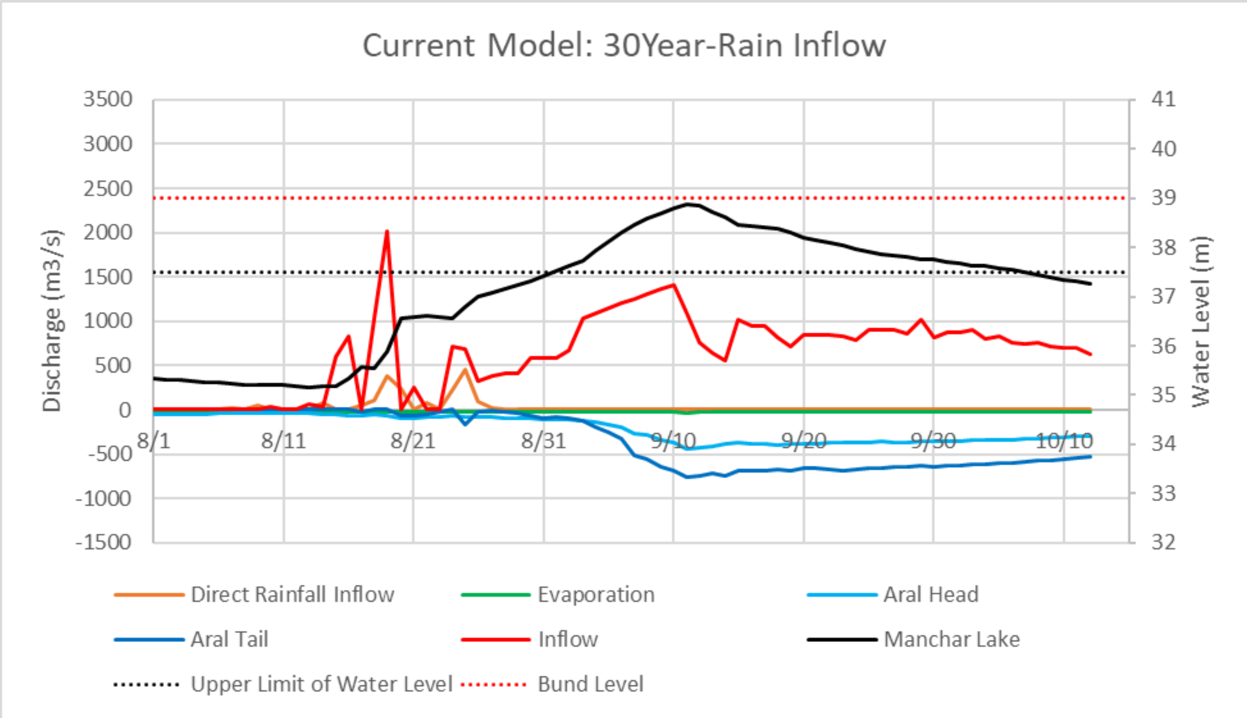
Source: Advisory Team

Figure 4.6.30 (3) Calculation Result (Current Drainage Capacity, 20-Year Probability Scale Flood)



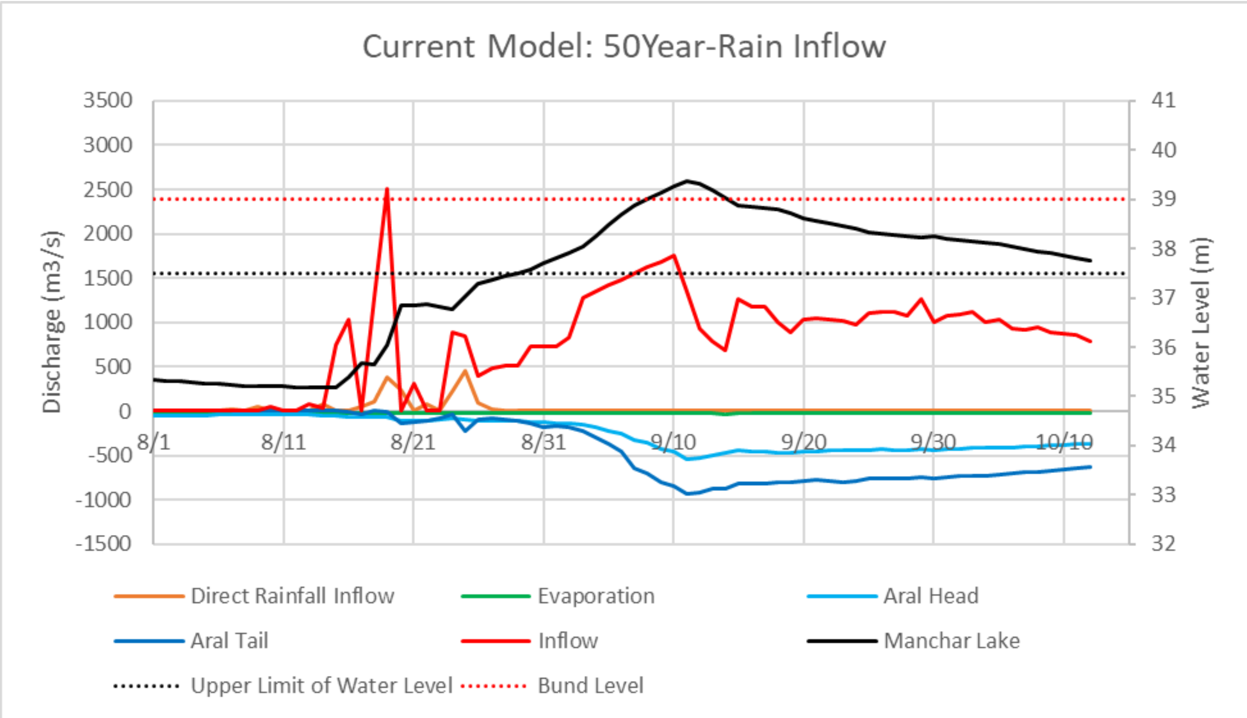
Source: Advisory Team

Figure 4.6.30 (4) Calculation Result (Current Drainage Capacity, 25-Year Probability Scale Flood)



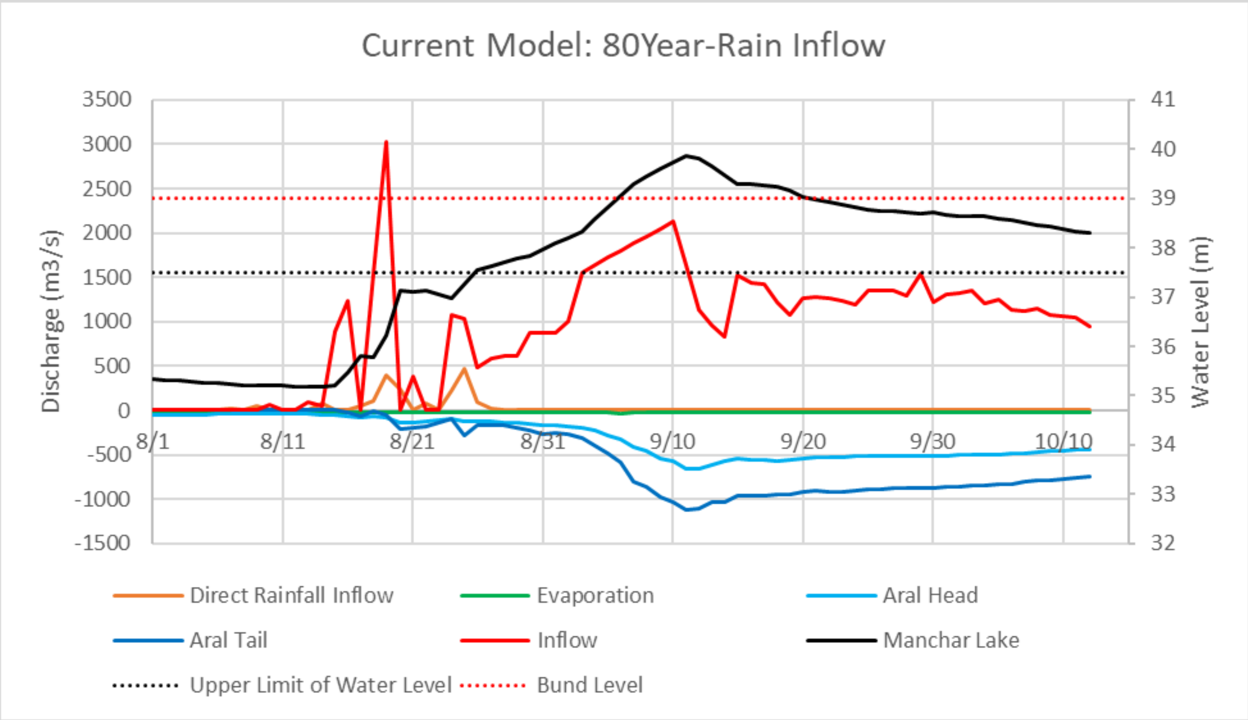
Source: Advisory Team

Figure 4.6.30 (5) Calculation Result (Current Drainage Capacity, 30-Year Probability Scale Flood)



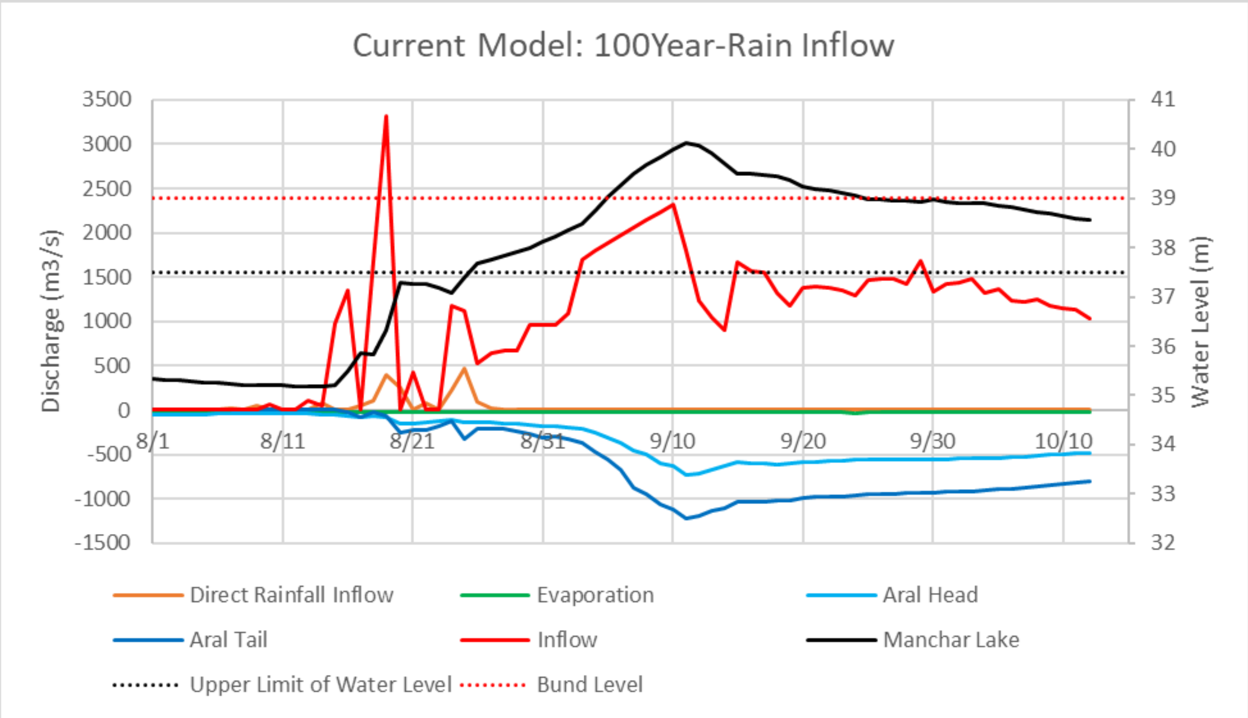
Source: Advisory Team

Figure 4.6.30 (6) Calculation Result (Current Drainage Capacity, 50-Year Probability Scale Flood)



Source: Advisory Team

Figure 4.6.30 (7) Calculation Result (Current Drainage Capacity, 80-Year Probability Scale Flood)



Source: Advisory Team

Figure 4.6.30 (8) Calculation Result (Current Drainage Capacity, 100-Year Probability Scale Flood)

(7) Aral Head Regulator Improvement (ALT0)

According to the data obtained from Sindh-PID, the Aral Head Regulator is under improvement as of September 2023, and the details of the improvement can be summarized as shown in Table 4.6.11, and Source: Created by Advisory Team base on the Information obtained by Sindh-PID

Figure 4.6.31 shows the location map of the Aral Head Regulator Improvement (ALT0).

This improvement greatly improves the discharge capacity of the Aral Head Regulator. In this study, the improvement of discharge capacity was expressed by changing the sum of width of the gates of the Aral Head Regulator from 60 ft (=18.3 m) to 280 ft (=85.3 m), which is included in the relational formula of the Aral Head Regulator shown in the following equation.

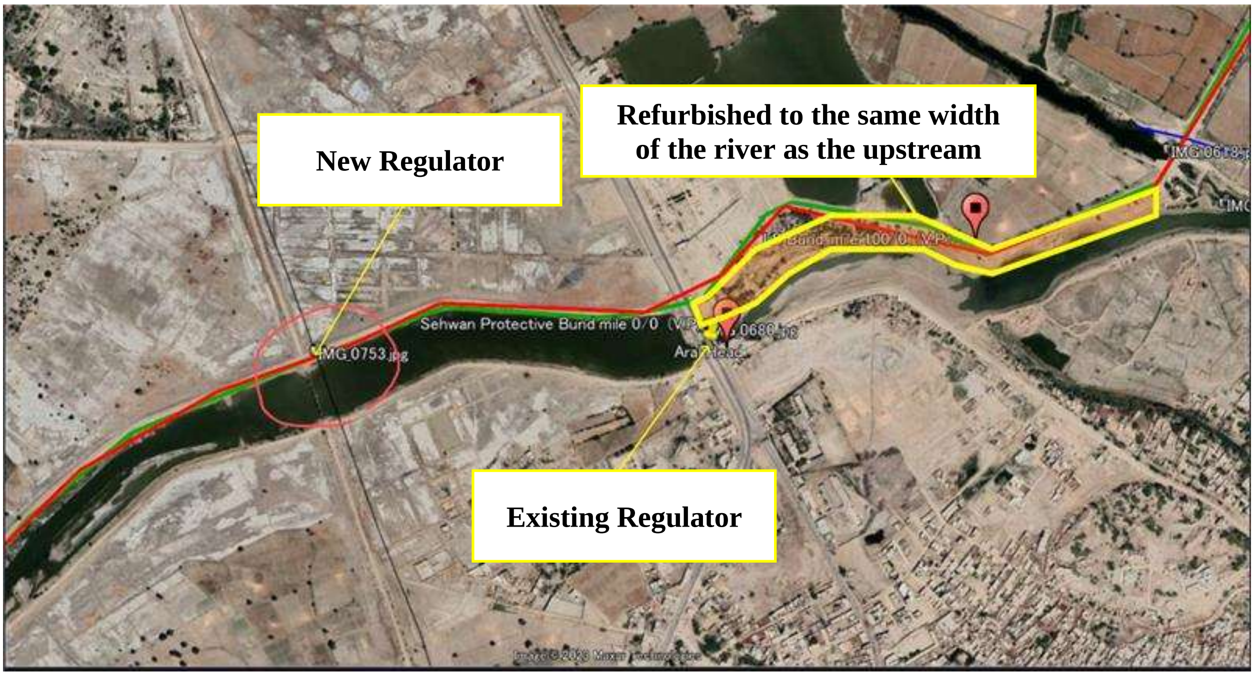
$$Q_{Aral-Head} = A_{Aral-Head}V_{Aral-Head} = B_{Aral-Head}H_{Aral-Head}V_{Aral-Head}$$
$$V_{Aral-Head} = 0.2996\Delta H^2 + 0.0931\Delta H + 0.4612 \quad (H_{Aral-Head} > 10ft)$$
$$V_{Aral-Head} = 2.5404H_R + 0.4909 \quad (H_{Aral-Head} < 10ft)$$

where $Q_{Aral-Head}$ is discharge in the Aral Head Regulator, $V_{Aral-Head}$ is the flow velocity of the Aral Head Regulator, $A_{Aral-Head}$ is the cross-sectional area of Aral Head Regulator, $B_{Aral-Head}$ is the sum of width of the gates of the Aral Head Regulator, $H_{Aral-Head}$ is the water depth of the Aral Head Regulator.

Table 4.6.11 Contents of the Aral Head Regulator Improvement (ALT0)

No	Contents
1	Remove and reinstallation of Aral Head Regulator is on going.
2	River widening of downstream of Aral Head Regulator is also on going.
3	Number of gates increase 3 to 14, and total width of gates increase 60ft to 280ft.
4	Drainage capacity is still depend on regulator capacity, because width of upstream of regulator (400ft) is wider than that of regulator.

Source: Created by Advisory Team base on the Information obtained by Sindh-PID



Source: Created by Advisory Team base on the Information obtained by Sindh-PID

Figure 4.6.31 Location Map of Aral Head Regulator Improvement (ALT0)

(8) Drainage Capacity Enhancement by Aral Head Regulator Improvement (ALT0)

The flood scale which can handle after Aral Head Regulator improvement (ALT0) under the conditions shown in Table 4.6.12 was examined. Here, "can handle" is defined as that the water level of Lake Manchar does not exceed the upper limit of water level: 123 ft (=37.49 m) during the flood period. As shown in

Table 4.6.13, for this situation, a 20-year probability scale flood can be handled, however, 25-year probability scale flood cannot be handled. Figure 4.6.32 shows the calculation results of a 5- to 100-year probability scale flood.

Table 4.6.12 Calculation Conditions (ALT0)

Setting	Contents	Memo
Inflow Scale	5 year flood～100 year flood	
Waveform	2022/8/1～2022/10/12	
Inflow and Outflow	Direct Rainfall Inflow	Nawabshah Rainfall Obsevatory
	Evaporation	0.8×2300mm/year
	Aral Head Regulator	Empirical Formula No of Gates: 14 (Current: 3)
	Aral Tail Regulator	Empirical Formula
Time Step	1-day	
HAV Relationship	2017 F/S Report	
Downstream Water Level	Aral Head Regulator	2022 Flood Data
	Aral Tail Regulator	2022 Flood Data

Source: Advisory Team

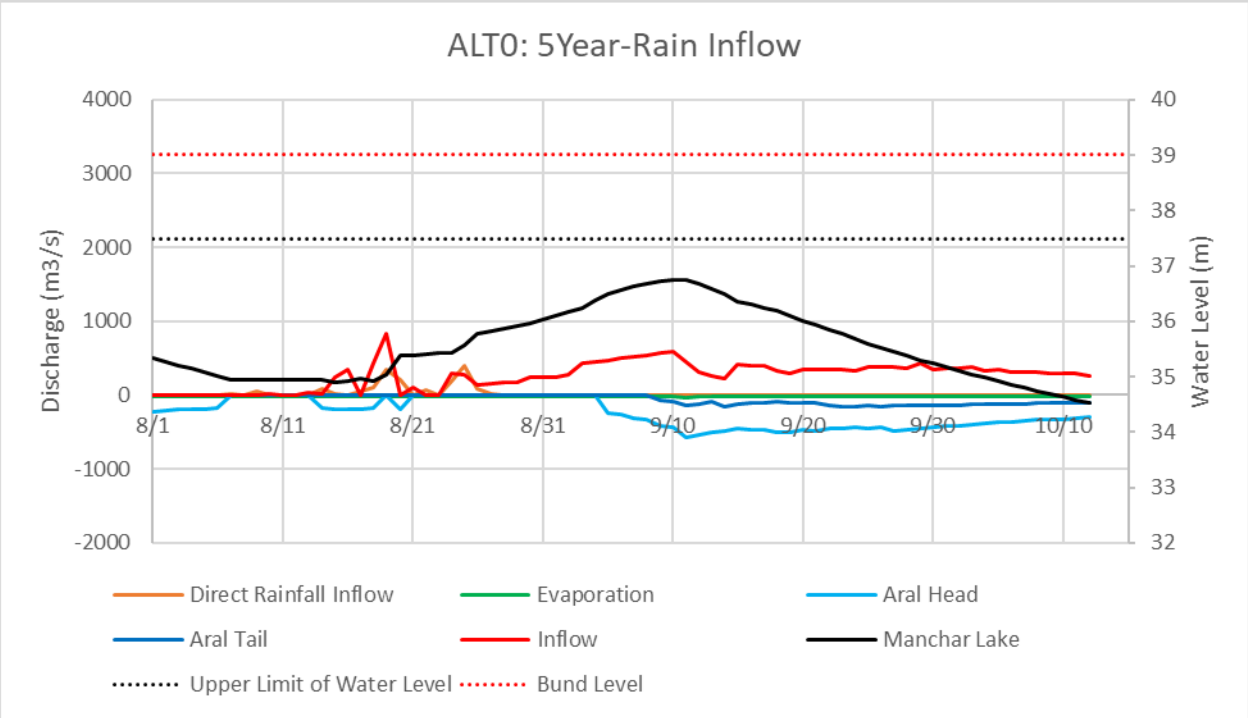
Table 4.6.13 Summary of Calculation Results (ALT0)

Inflow Scale	Manchar Lake					Maximum Discharge		
	Excess Water Level	Maximum Water Level	Upper Limit of Water Level	Bund Level	Excess Volume	Aral Head	Aral Tail	Total
	m	m	m	m	m3	m3/s	m3/s	m3/s
5-years	—	36.76	37.49	39.01	—	578.02	162.92	740.94
10-years	—	37.12			—	750.61	229.67	980.28
20-years	0.02	37.51			8,029,497	976.77	338.25	1315.02
25-years	0.19	37.68			61,878,617	1081.62	385.21	1466.83
30-years	0.33	37.82			107,322,634	1175.15	425.73	1600.88
50-years	0.69	38.18			228,206,573	1443.06	536.08	1979.14
80-years	1.02	38.51			341,958,454	1713.09	640.80	2353.89
100-years	1.19	38.68			397,735,355	1855.06	693.82	2548.88

: Exceeded upper limit of water level

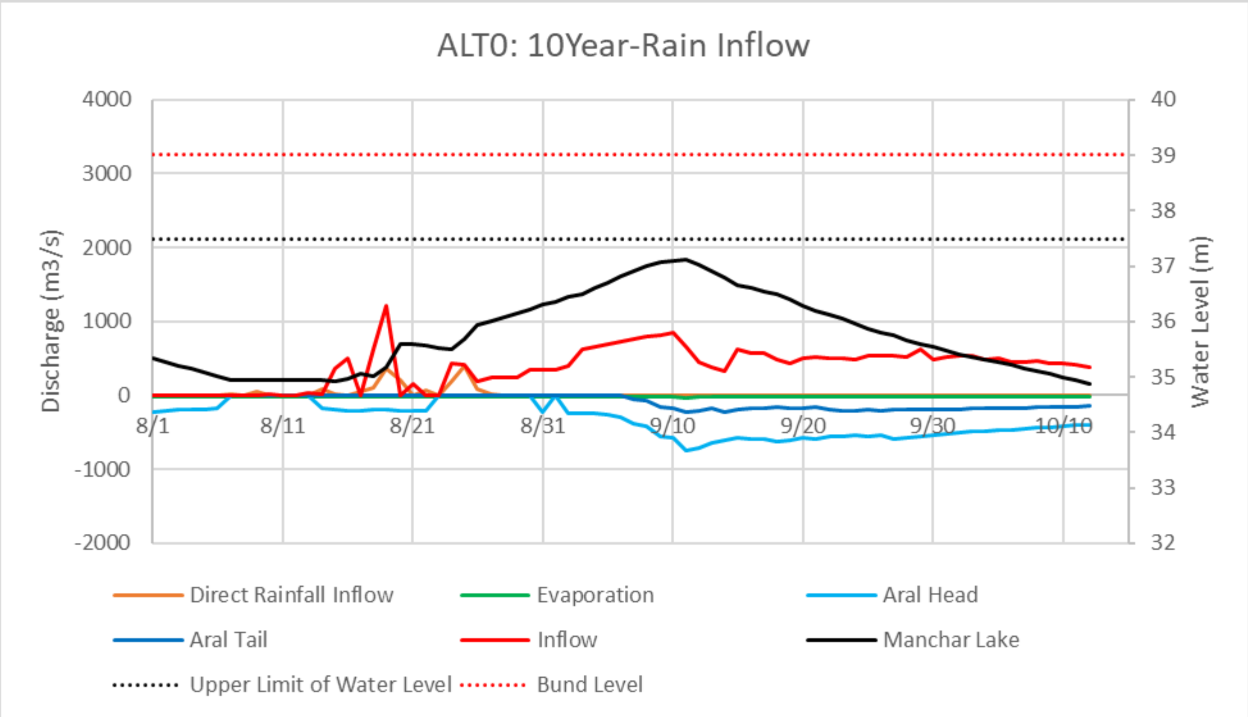
: Exceeded bund level

Source: advisory team



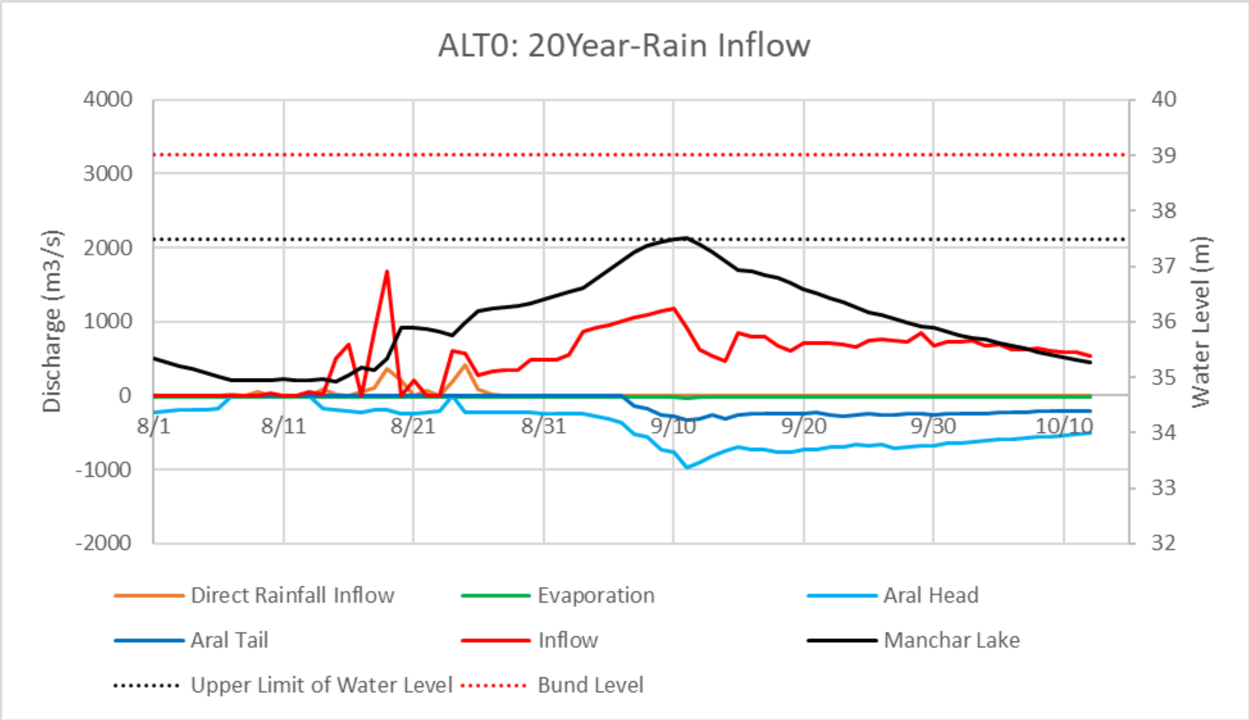
Source: advisory team

Figure 4.6.32 (1) Calculation Result (ALT0, 5-Year Probability Scale Flood)



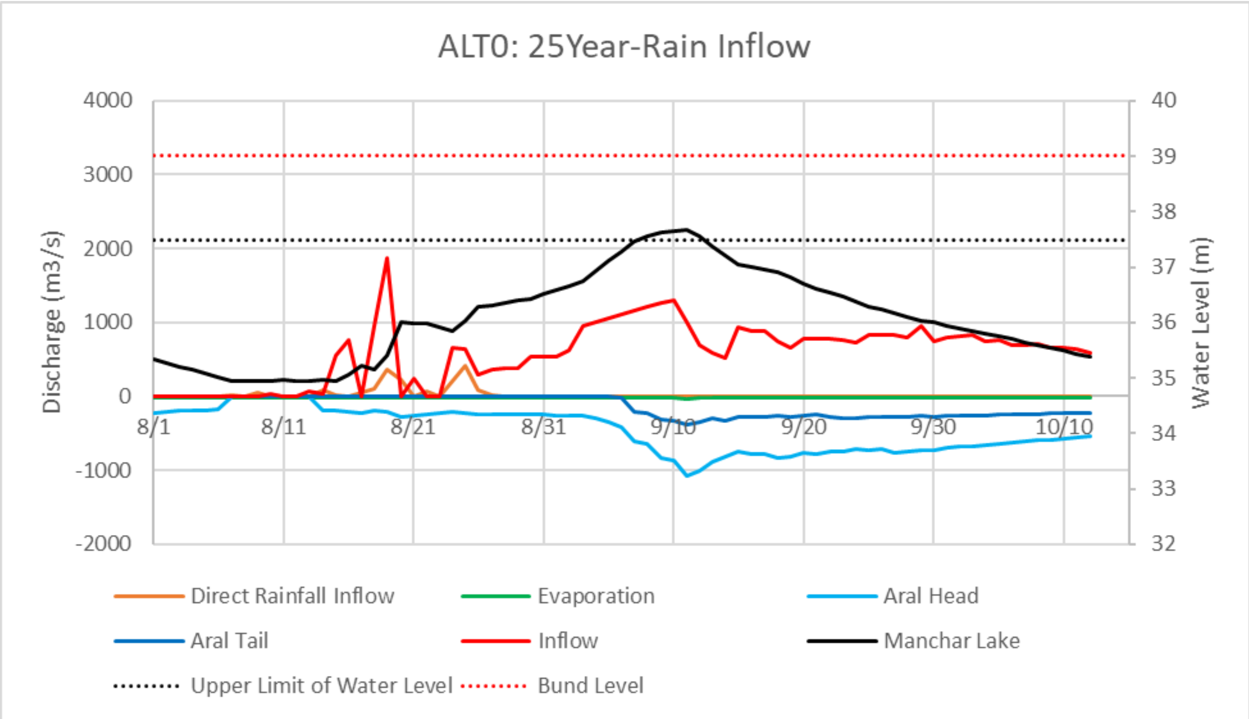
Source: Advisory Team

Figure 4.6.32 (2) Calculation Result (ALT0, 10-Year Probability Scale Flood)



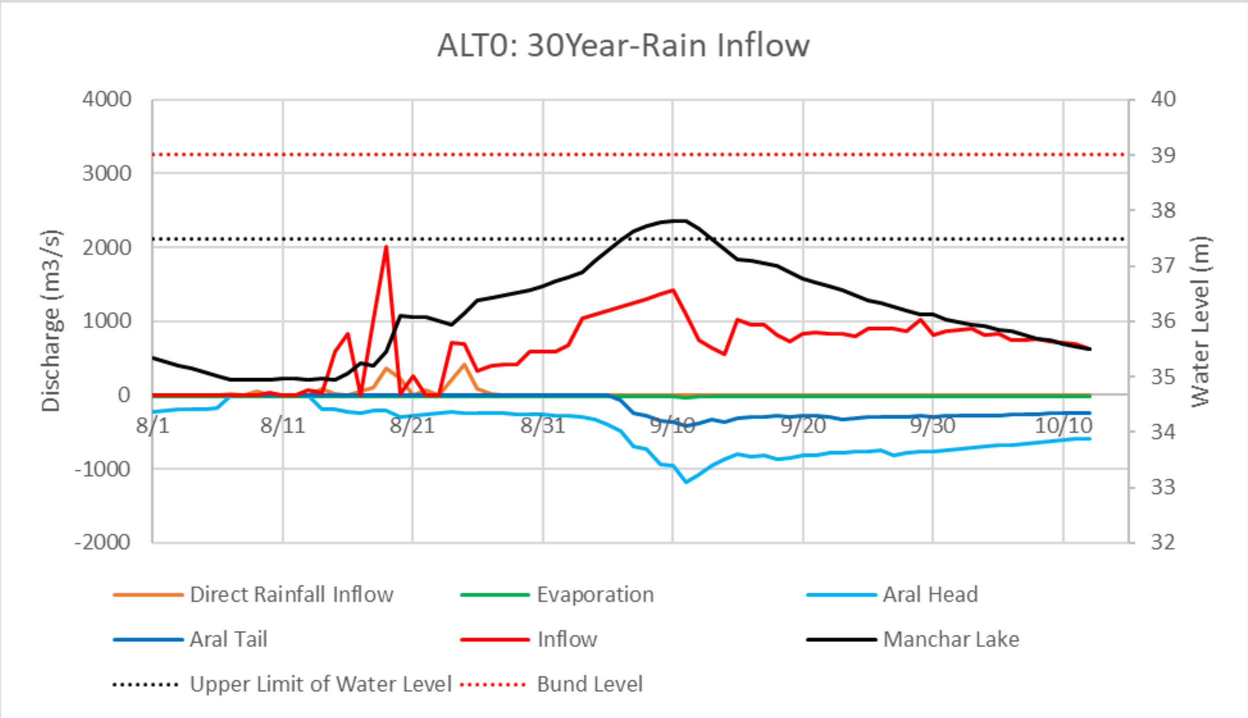
Source: Advisory Team

Figure 4.6.32 (3) Calculation Result (ALT0, 20-Year Probability Scale Flood)



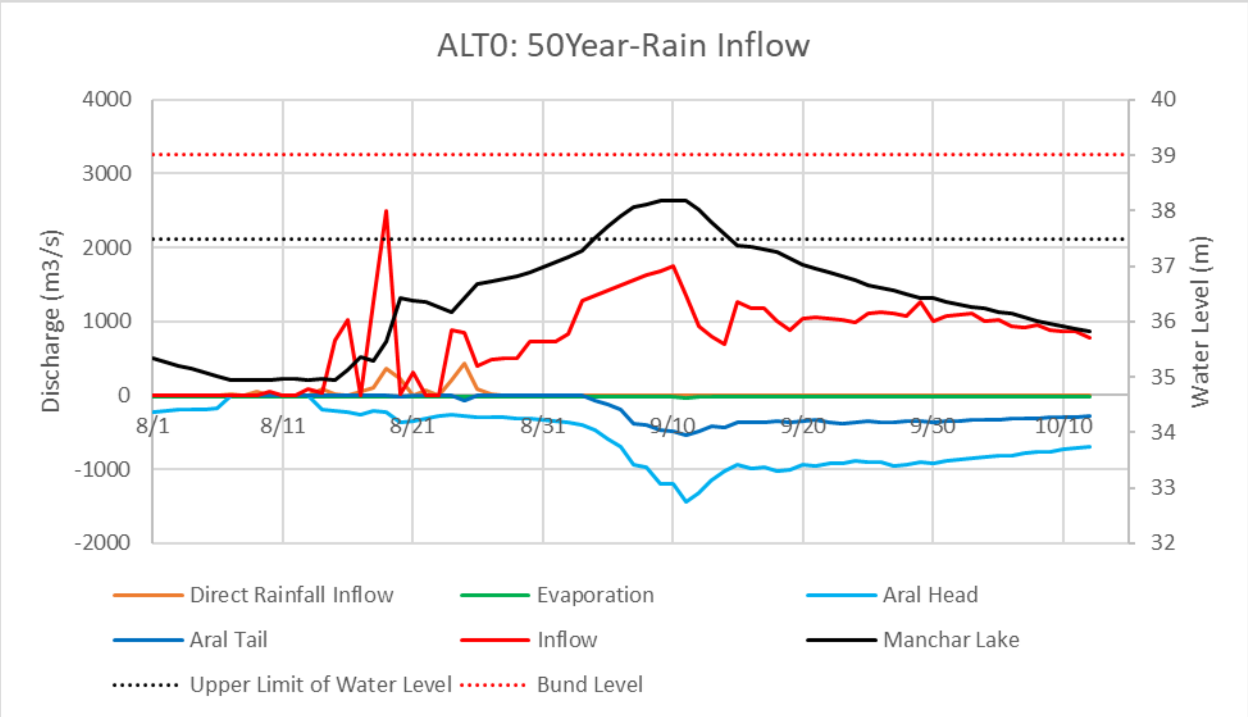
Source: Advisory Team

Figure 4.6.32 (4) Calculation Result (ALT0, 25-Year Probability Scale Flood)



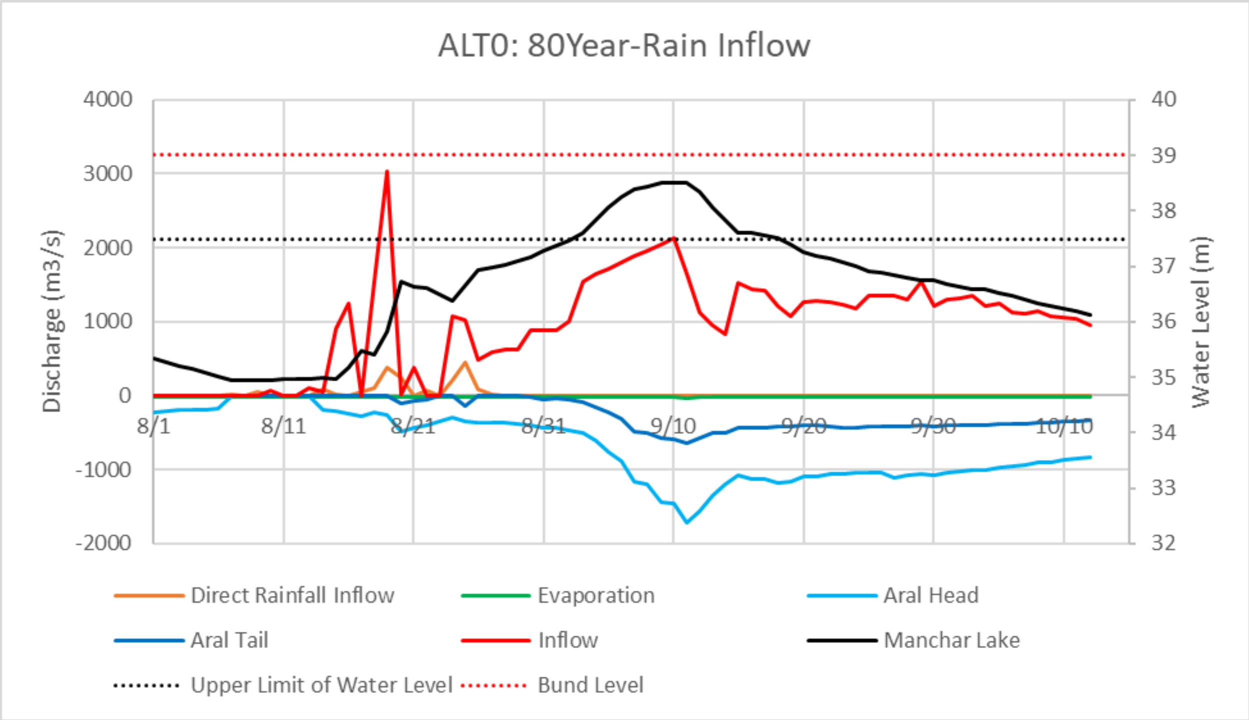
Source: Advisory Team

Figure 4.6.32 (5) Calculation Result (ALT0, 30-Year Probability Scale Flood)



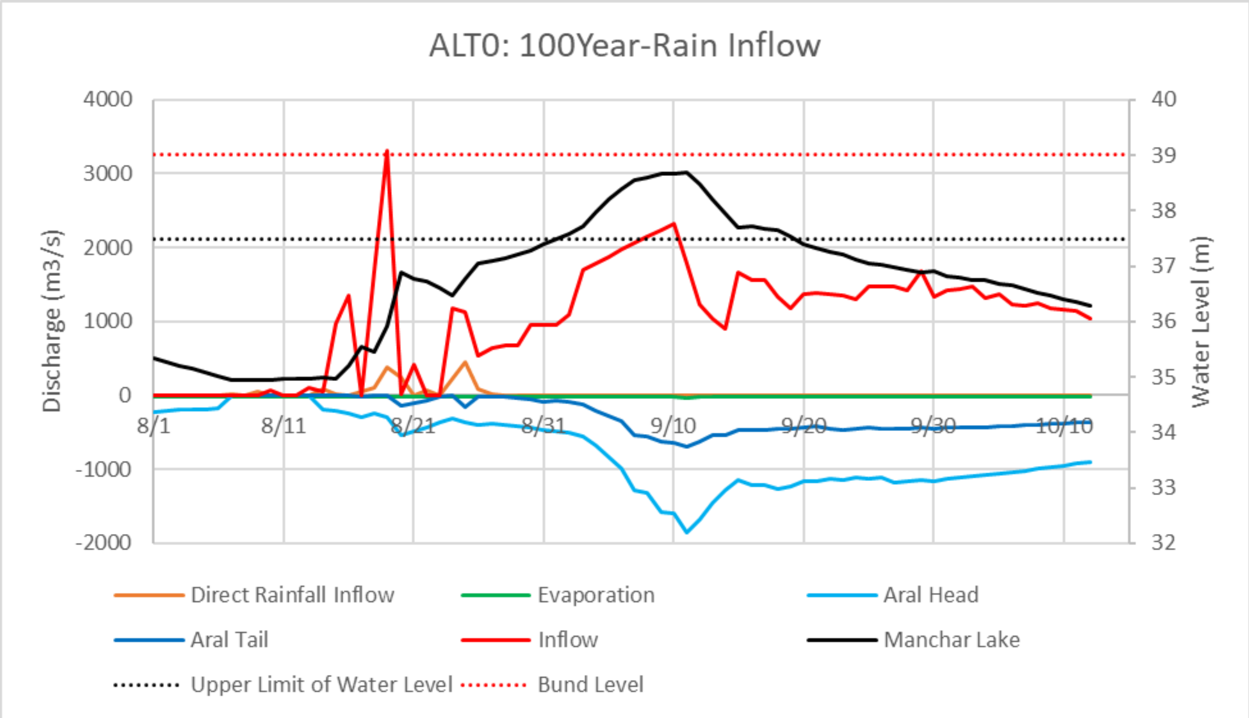
Source: Advisory Team

Figure 4.6.32 (6) Calculation Result (ALT0, 50-Year Probability Scale Flood)



Source: Advisory Team

Figure 4.6.32 (7) Calculation Result (ALT0, 80-Year Probability Scale Flood)



Source: Advisory Team

Figure 4.6.32 (8) Calculation Result (ALT0, 100-Year Probability Scale Flood)

(9) Determined Target Flood Scale

From the analysis described in the preceding section, it is possible to handle the current drainage capacity up to a probability scale of 5 years, and it increases to a probability scale of 20 years with the improvement of the Aral Head Regulator.

According to the description in the Irrigation Manual shown in Figure 4.6.33, the "Protection Levee" is planned for a probability scale of 50 years, considering that the bund of Lake Manchar is applicable for the "Protection Levee", the target flood scale should be 50-year.

Based on the calculation in the next section, if a new discharge channel is installed or an existing channel (Aral Tail) is widened as a measurement to handle with a probability scale of 50 years, the required river width is about 100 m(=328 ft), so it is considered to be possible to it in reality.

Based on the calculation in the next section, if a new discharge channel is installed or an existing channel (Aral Tail) is widened as a measure to cope with a probability scale of 50 years, the river width required is about 100 m(=328 ft), so it is possible to improve the drainage capacity in reality.

3. FLOOD PROTECTION, CONTAINING BUNDS / LEVEES

Flood bunds are man-made structures, usually earthen embankments designed and constructed to contain, or control the flow of water so as to provide protection from inundation and are considered to act as a barrier between flood water and protected area. Flood bunds provide only a reduction in risk of flooding and cannot be expected to afford total protection with zero flood risk. It can therefore be said that bunds provide protection with some risk, the extent of risk varying with prevailing site conditions, in respect of levee health (flood worthiness) and flow conditions.

3.1. Protection Levees

Given the fact that no bund/levee can provide full 100% protection, the level of anticipated protection is decided keeping the availability of resources and flood magnitude in view:

Presently the flood bunds in vulnerable reaches are designed for a return period of 50 years, while the guide and marginal bunds of barrages are designed to provide protection against floods of 100 years return period.

- In the recent past the design of flood bunds on natural streams corresponded to a return period of 40 years.
- On hill torrents with flash flows a return period of 25 years was used.
- Due to socio-economic environmental scenarios and improvement in design methods now the flood protection bunds are being designed for a 50 year flood.
- This level of protection may further be increased to design against 100 and 200 year flood due to further developments and industrialization and climate change effects in the vicinity of flood bunds.However, the present practice of providing a freeboard of 6 ft. above the highest recorded flood levels adequately covers this return period for open reaches.

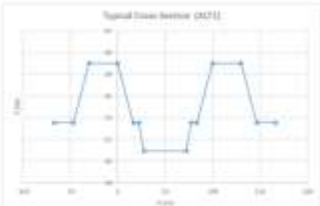
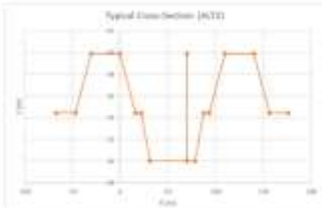
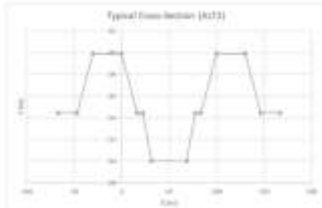
Source: Irrigation Manual

Figure 4.6.33 Contents of Irrigation Manual

4.6.4 Consideration of Alternatives to Improve Drainage Capacity

(1) Outline of the Study

Alternatives to improve drainage capacity for the target inflow waveform are determined in this section. There are 3 alternatives shown in Figure 4.6.34, the minimum channel width that can handle the target inflow waveform for each alternative was calculated by non-uniform flow calculation.

	ALT1	ALT2	ALT3
Measurements	New canal will be constructed on the south of Aral Tail. Total length of canal is 5.3km.	River widening will be conducted to Aral Tail and the flow will be split into 2 ways: original direction and RBOD2. Total length of canal is 6.5km.	River widening will be conducted to Aral Tail. Total length of canal is 5.0km.
Typical Cross-Section			
Map of Measurements			

Source: Advisory Team

Figure 4.6.34 Overview of Alternatives to Improve Drainage Capacity

(2) Modelling Method of Measures

The calculation of the newly constructed channel was based on the non-uniform flow calculation. Specifically, since the water level at the downstream boundary and the water level at the upstream boundary were known, trial calculations were conducted to determine the discharge of the channel by using following equations.

$$H_X + \frac{{V_X}^2}{2g} + \frac{L}{n^2} \times \frac{1}{2}\left(\frac{{V_X}^2}{{R_X}^2} + \frac{{V_{X+1}}^2}{{R_{X+1}}^2}\right) = H_{X+1} + \frac{{V_{X+1}}^2}{2g}$$

$$V_X = \frac{Q_{New-Canal}}{A_X}$$

$$R_X = \frac{A_X}{S_X}$$

where H_X is position head in the X section, V_X is flow velocity in the X section, g is the gravity acceleration, L isnterval distance between the X section and X+1 section, n is the roughness coefficient, R_X is the diameter depth in the X section, $Q_{New-Canal}$ is the channel discharge, A_X is the cross-sectional area in the X section, S_X is the wetted perimeter in the X section.

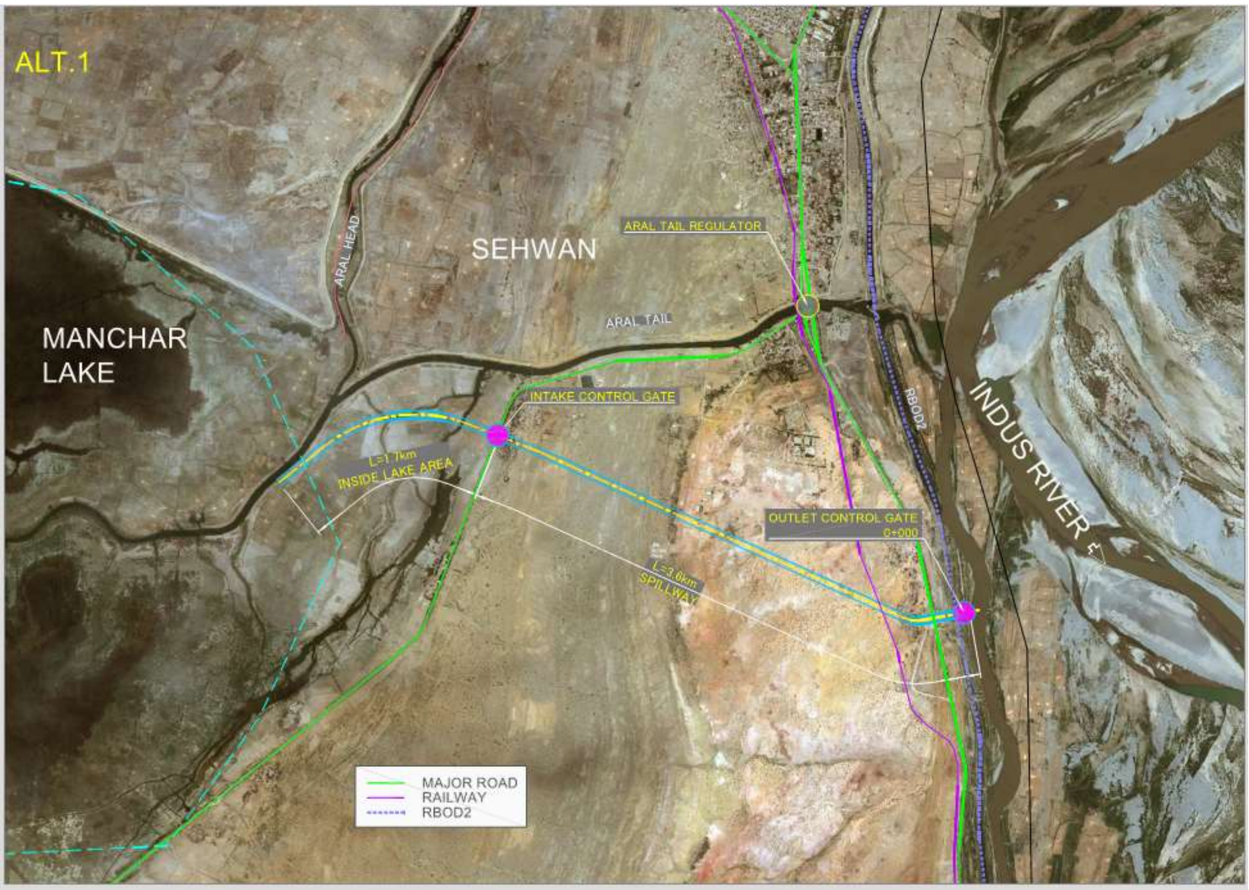
1) Construction of New Waterway (ALT1)

In ALT1, a new waterway will be constructed in the south of Aral Tail. Figure 4.6.35 shows the location map of the construction of the new waterway (ALT1). The section setting is shown in Table 4.6.14 and Figure 4.6.36. In addition, the profile and cross-sectional views are shown in Figure 4.6.37 and Figure 4.6.38.

Here, for the cross-sectional setting, the bund elevation and the flood fringe elevation are set at 131 ft (=39.93 m) and 113 ft (=34.44 m) at the upstream boundary of Spillway, which is the same as the present condition of Aral Tail. The riverbed elevation at the downstream boundary was set at 97.58 ft (=29.74 m) because the riverbed elevation of the Aral Tail Regulator was 98.5 ft (=30.02 m) and the downstream boundary of Spillway was 2.5 km (=1.55 mi) downstream along the Indus River from this point, and the riverbed slope of this section was 1/9000.

The slope in the new channel was set as the slope of 1/1500 to prevent sediment accumulation and would not significantly reduce the drainage capacity. In addition, the flood fringe elevation at the downstream boundary must be higher than the normal water level of the Indus River, so the slope was set as 1/2000.

The lake portion was not modeled and set at the same water level as Lake Manchar.



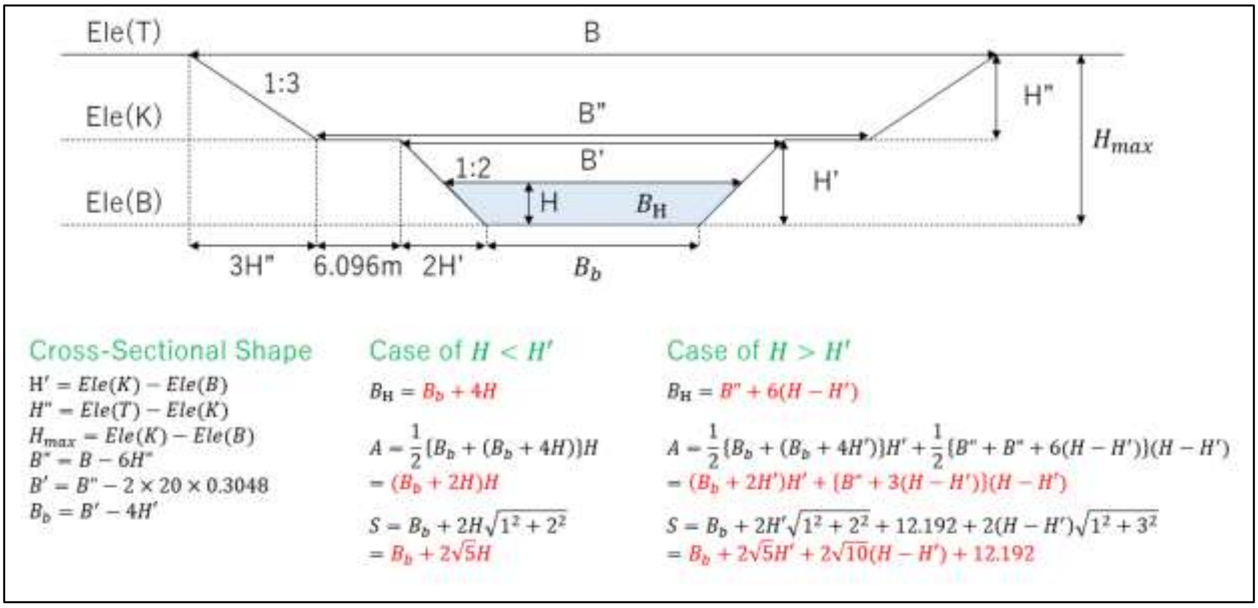
Source: Advisory Team

Figure 4.6.35 Location Map of Construction of New Waterway (ALT1)

Table 4.6.14 Section Setting of Construction of New Waterway (ALT1)

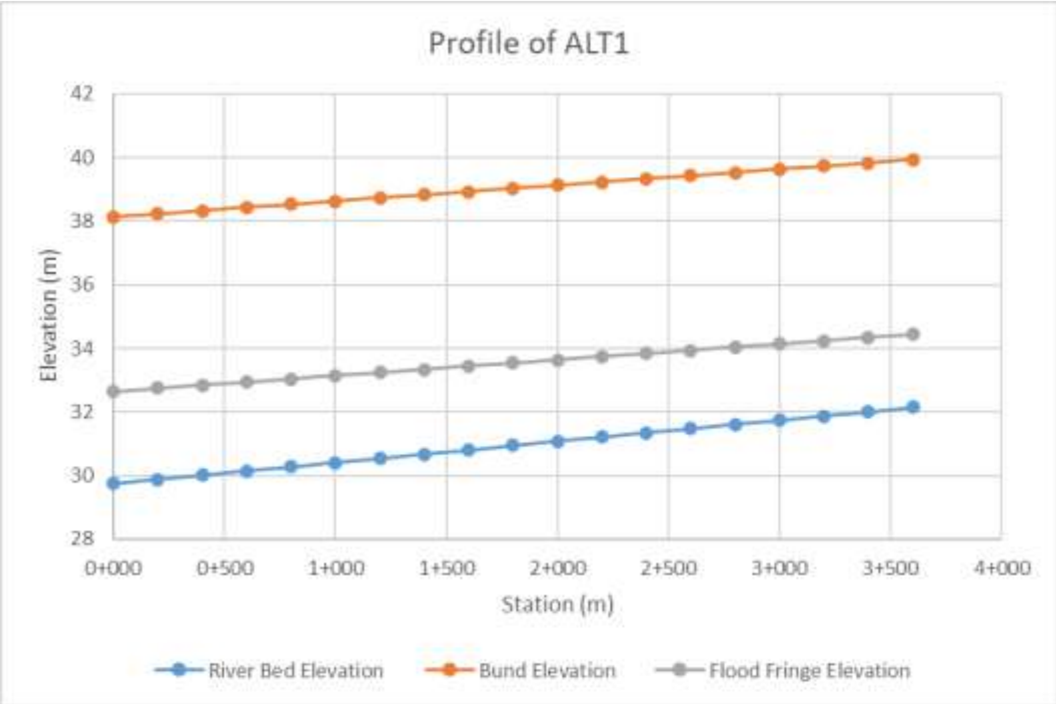
Part	Station	Cross-Sectional Form	
Spillway	0+000~3+600	Bund Elevation	131ft at 3+600 Bund height decreases by slope of 1/2000 toward downstream
		Flood Fringe Elevation	113ft at 3+600 Flood fringe height decreases by slope of 1/2000 toward downstream
		River Bed Elevation	97.58ft at 0+000 River bed height increases by slope of 1/1500 toward upstream
Inside Lake	3+600~5+300	—	Not modeled. Water level sets the same as Manckar Lake

Source: Advisory Team



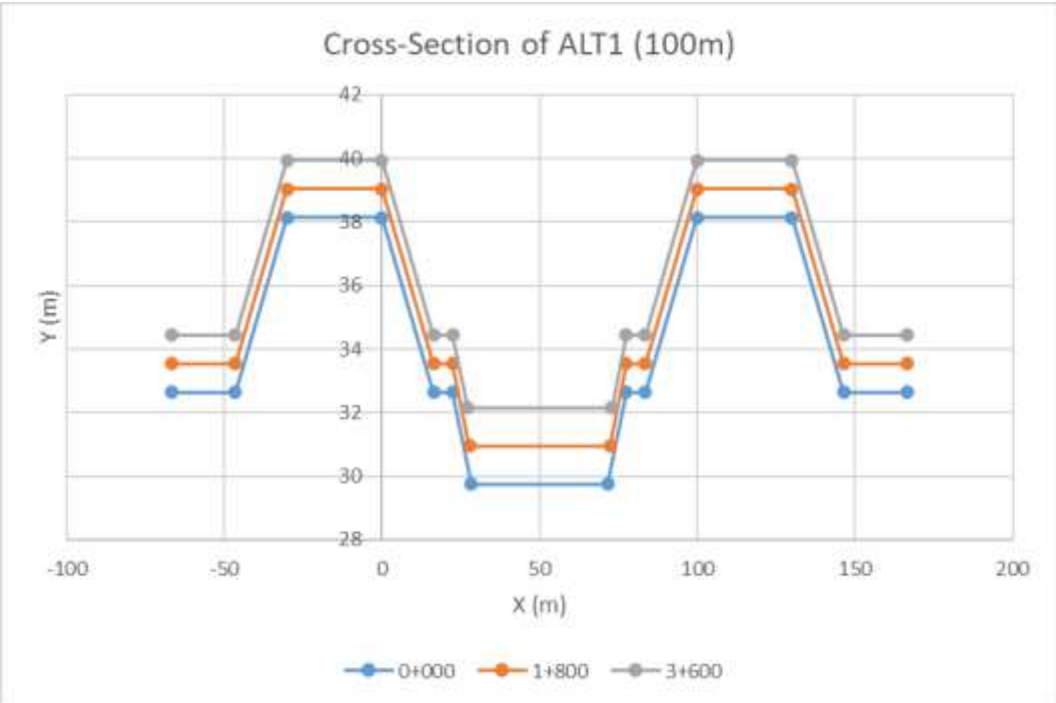
Source: Advisory Team

Figure 4.6.36 Section Setting of Construction of New Waterway (ALT1)



Source: Advisory Team

Figure 4.6.37 Profile of Construction of New Waterway (ALT1)



Source: Advisory Team

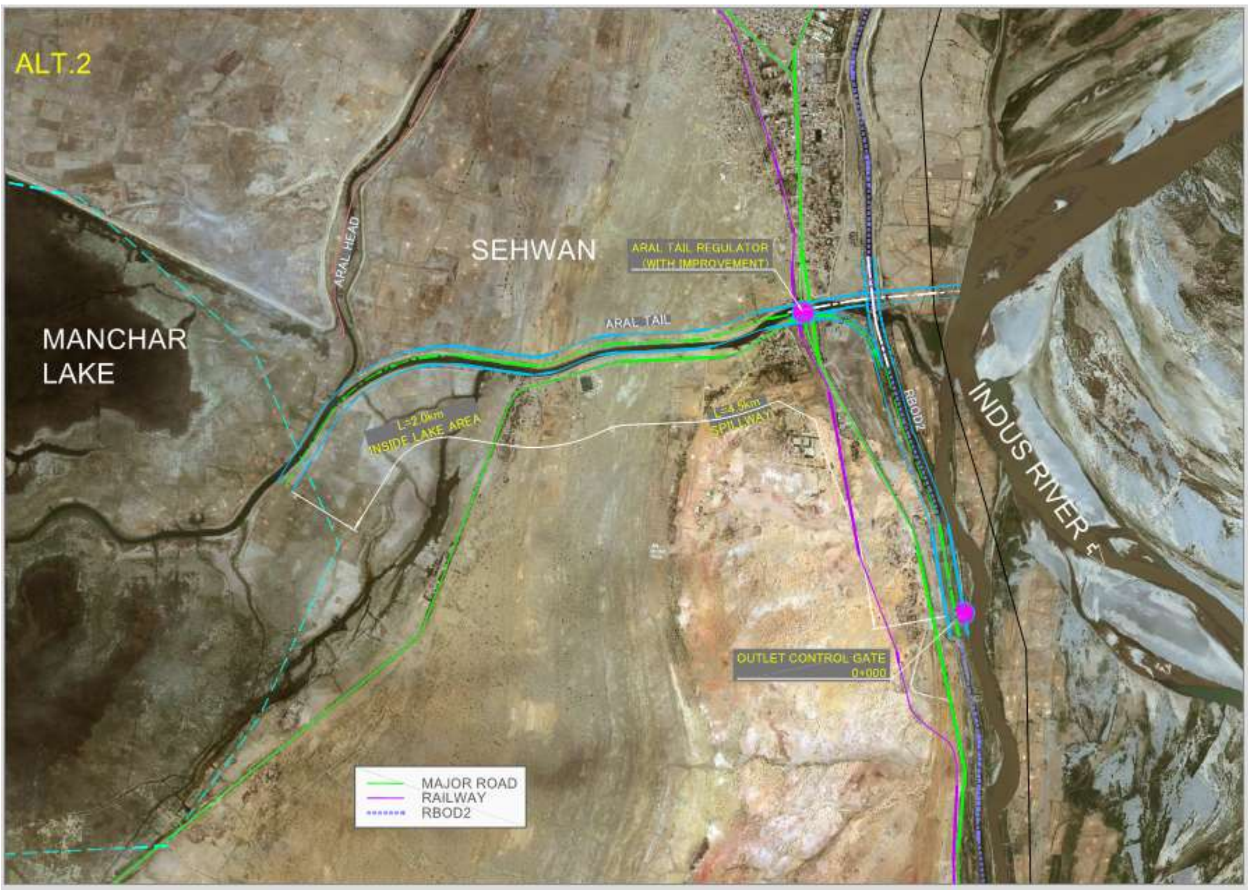
Figure 4.6.38 Cross-Sectional View of Construction of New Waterway (ALT1)

2) Widening of the Existing Waterways (Aral Tail and RBOD-II) (ALT2)

In ALT2, the Aral Tail and RBOD-II are widened, and it is divided 2 ways near the Aral Tail Regulator. Here, in this study, non-uniform flow calculation was conducted as 2 channels with one side straight wall (one is the flow goes to Aral Tail, the other is the flow goes to RBOD-II). Figure 4.6.39 shows the location map of the widening of the existing waterways (Aral Tail and RBOD-II) (ALT2). The section setting is shown in Table 4.6.15 and Figure 4.6.40. In addition, the profile and cross-sectional views are shown in Figure 4.6.41 and Figure 4.6.42.

Here, for the Aral Tail section, the bund elevation was set to 131 ft (=39.93 m) and the flood fringe elevation was set to 113 ft (=34.44 m), which were the same as the existing settings. The riverbed elevation was set to 98.5 ft (=30.02 m) assuming that excavation of the riverbed will be conducted for the Aral Tail Regulator. The RBOD-II section was set as the slope of 1/9000 by the Indus River.

The lake portion was not modeled and set at the same water level as Lake Manchar.



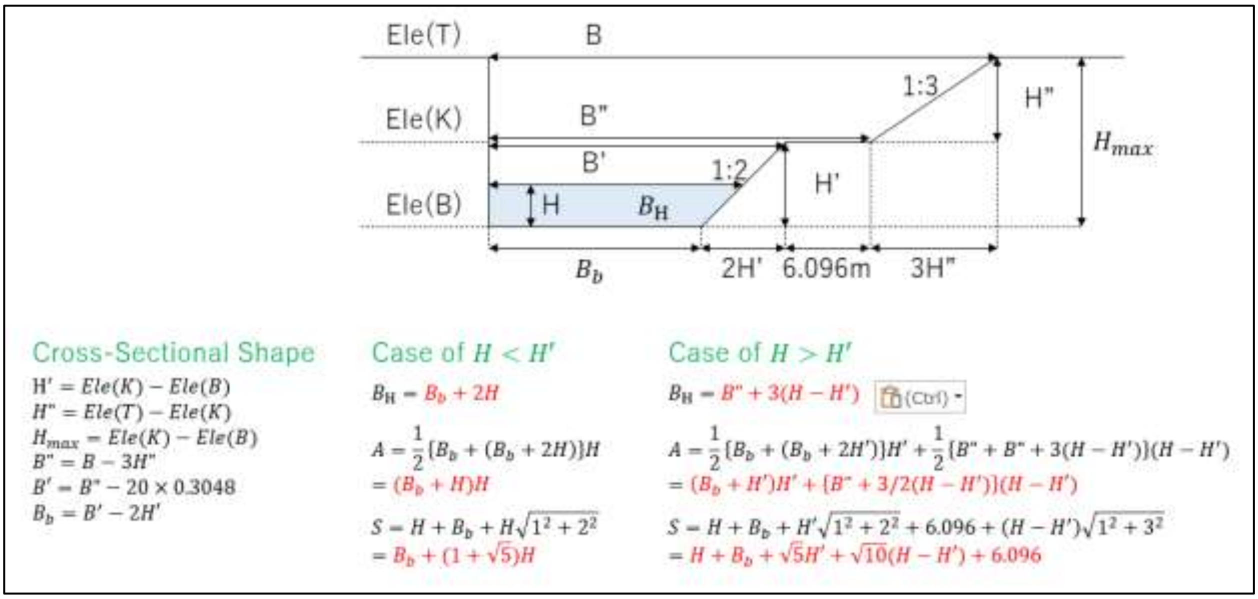
Source: Advisory Team

Figure 4.6.39 Location Map of Widening of the Existing Waterways (Aral Tail and RBOD-II) (ALT2)

Table 4.6.15 Section Setting of Widening of the Existing Waterways (Aral Tail and RBOD-II) (ALT2)

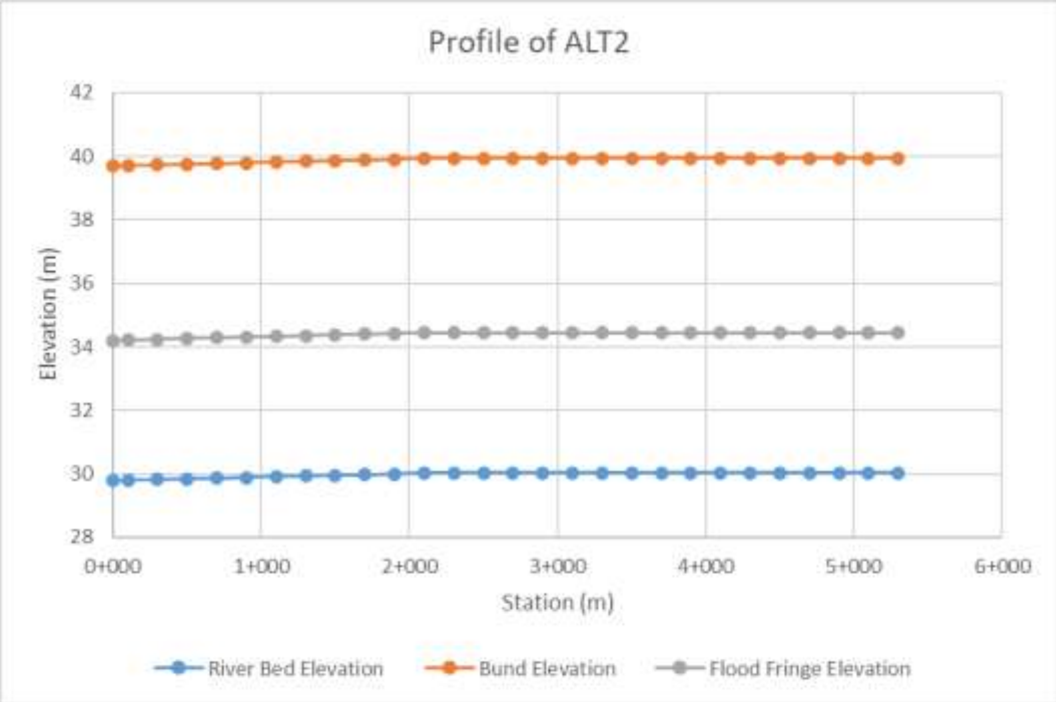
Part	Station	Cross-Sectional Form	
Method	–	–	Non uniform flow calcuration is conducted as 2 separate canals (original direction and RBOD2)
RBOD2	0+000~2+100	Bund Elevation	131ft at 2+100 Bund height decreases by slope of 1/9000 toward downstream
		Flood Fringe Elevation	113ft at 2+100 Bund height decreases by slope of 1/9000 toward downstream
		River Bed Elevation	98.5ft at 0+000 River bed height increases by slope of 1/9000 toward upstream
Aral Tail	2+300~5+300	Bund Elevation	131ft (the same as current height)
		Flood Fringe Elevation	113ft (the same as current height)
		River Bed Elevation	98.5ft (the same as bed level of Aral Tail Regulator)
Inside Lake	5+500~6+500	–	Not modeled. Water level sets the same as Manckar Lake

Source: Advisory Team



Source: Advisory Team

Figure 4.6.40 Section Setting of Widening of the Existing Waterways (Aral Tail and RBOD-II) (ALT2)



Source: Advisory Team

Figure 4.6.41 Profile of Widening of the Existing Waterways (Aral Tail and RBOD-II) (ALT2)

Source: Advisory Team

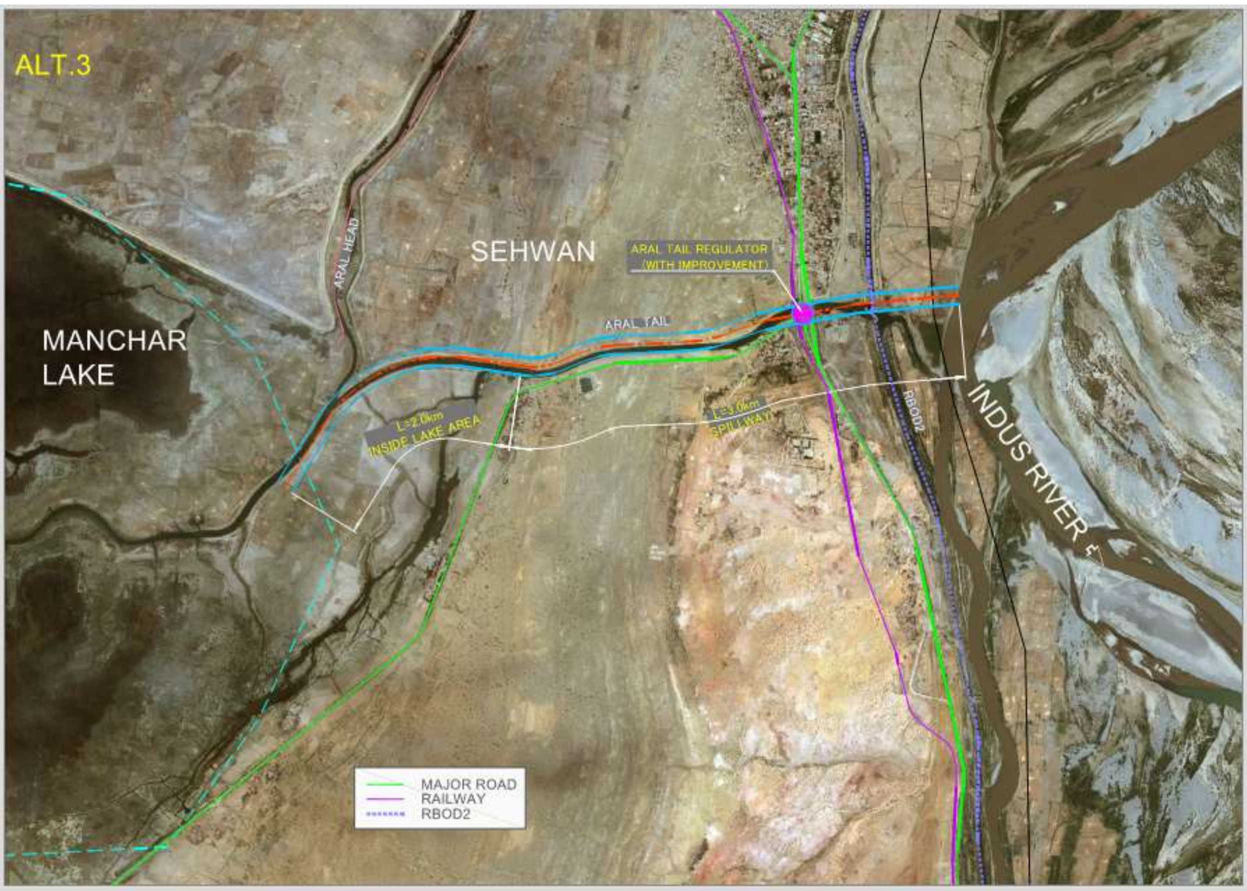
Figure 4.6.42 Cross-Sectional View of Widening of the Existing Waterways (Aral Tail and RBOD-II) (ALT2)

3) Widening of the Existing Waterway (Only Aral Tail) (ALT3)

In ALT3, only the Aral Tail is widened. Here, in this study, non-uniform flow calculation was conducted for the Aral Tail after improvement. Figure 4.6.43 shows the location map of the widening of the existing waterway (only Aral Tail) (ALT3). The section setting is shown in Table 4.6.16 and Figure 4.6.44. In addition, the profile and cross-sectional views are shown in Figure 4.6.45 and Figure 4.6.46.

Here, for the Aral Tail section, the bund elevation was set to 131 ft (=39.93 m) and the flood fringe elevation was set to 113 ft (=34.44 m), which were the same as the existing settings. The riverbed elevation was set to 98.5 ft (=30.02 m) assuming that excavation of the riverbed will be conducted for the Aral Tail Regulator.

The lake portion was not modeled and set at the same water level as Lake Manchar, and the Indus River portion was also not modeled and set at the same water level as the Indus River.



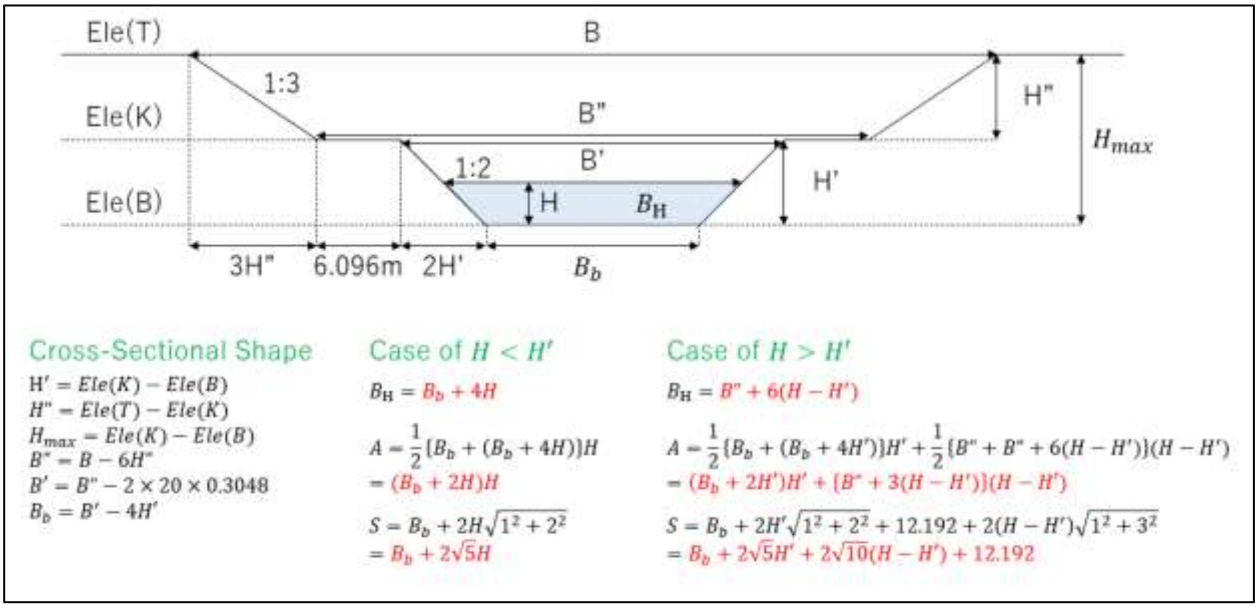
Source: Advisory Team

Figure 4.6.43 Location Map of Widening of the Existing Waterway (Only Aral Tail) (ALT3)

Table 4.6.16 Section Setting of Widening of the Existing Waterway (Only Aral Tail) (ALT3)

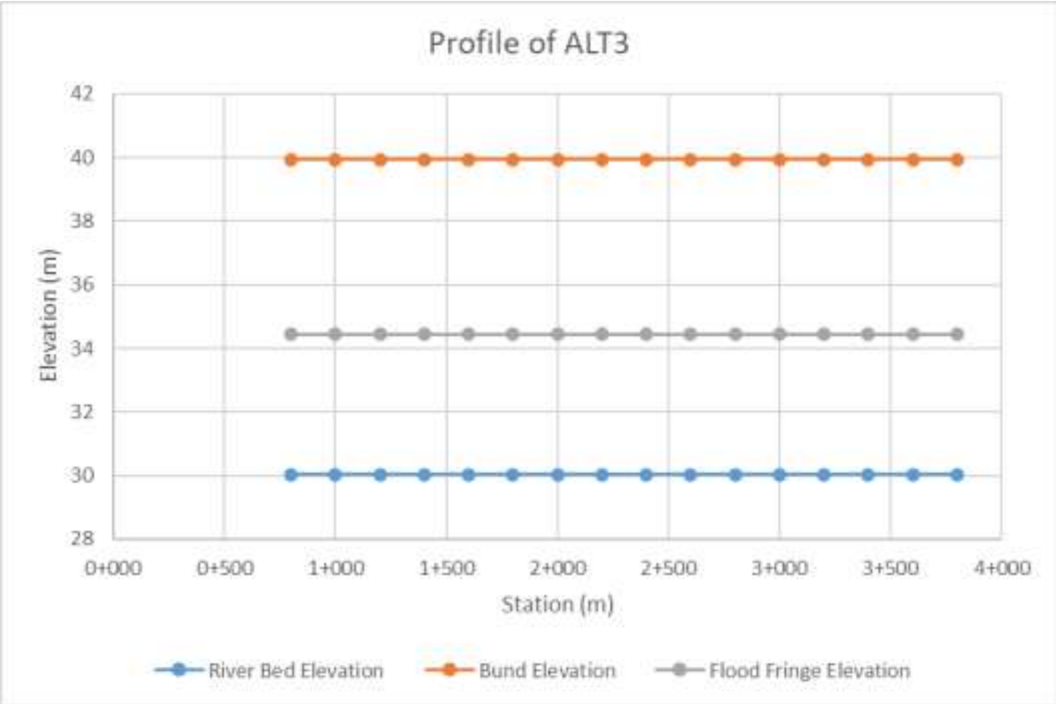
Part	Station	Cross-Sectional Form	
Indus River	0+000~0+600	—	Not modeled. Water level sets the same as Aral Tail Regulator
Aral Tail	0+800~3+800	Bund Elevation	131ft (the same as current height)
		Flood Fringe Elevation	113ft (the same as current height)
		River Bed Elevation	98.5ft (the same as bed level of Aral Tail Regulator)
Inside Lake	4+000~5+000	—	Not modeled. Water level sets the same as Manckar Lake

Source: Advisory Team



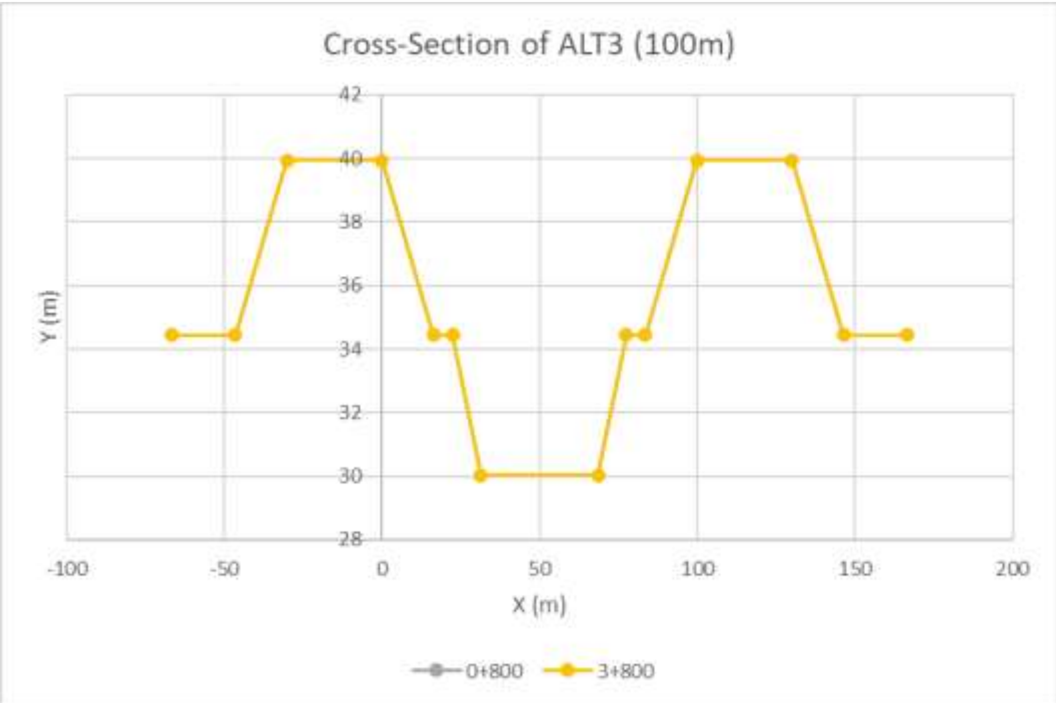
Source: Advisory Team

Figure 4.6.44 Section Setting of Widening of the Existing Waterway (Only Aral Tail) (ALT3)



Source: Advisory Team

Figure 4.6.45 Profile of Widening of the Existing Waterway (Only Aral Tail) (ALT3)



Source: Advisory Team

Figure 4.6.46 Cross-Sectional View of Widening of the Existing Waterway (Only Aral Tail) (ALT3)

(3) Summary of Calculation Results for Each Alternative

Table 4.6.17 summarizes the calculation results for each alternative.

Table 4.6.17 Summary of the calculation results for Each Alternative

		ALT1	ALT2	ALT3
Maximum water level of Manchar		37.39m	37.44m	37.49m
Upper Limit of Water Level		37.49m		
Required canal width		100m	110m	100m
Maximum discharge	Aral Head	901m3/s	929m3/s	959m3/s
	Aral Tail	303m3/s	692m3/s	806m3/s
	New Canal	706m3/s	159m3/s	—
Memo		ALT1 can prevent sedimentation.		The cost will be lower than ALT1 and ALT2

Source: Advisory Team

1) Construction of New Waterway (ALT1)

The trial calculation was conducted to determine the minimum river width of ALT1 that can handle the inflow waveform that extended the 2022 flood to the probability scale of 50 years. Table 4.6.18 shows the calculation conditions of ALT1. Here, “can handle” is defined as the water level of Lake Manchar does not exceed the upper limit of water level: 123 ft (=37.49 m) during the flood period.

Table 4.6.19 summarizes the calculation results. If the river width is more than 100 m (=328 ft), ALT1 can handle the target inflow waveform. Figure 4.6.47 shows the calculation result (time series of the water level of Lake Manchar and each inflow and outflow) when the river width is set at 100 m, and Figure 4.6.48 shows the profile of the waterway.

Table 4.6.18 Calculation Conditions (ALT1)

Setting	Contents	Memo
Inflow Scale	50 year flood	
Waveform	2022/8/1～2022/10/12	
Inflow and Outflow	Direct Rainfall Inflow	Nawabshah Rainfall Obsevatory
	Evaporation	0.8×2300mm/year
	Aral Head Regulator	Empirical Formula No of Gates: 14 (Current: 3)
	Aral Tail Regulator	Empirical Formula
	New Canal	Non-Uniform Flow Calculation
Time Step	1-day	
HAV Relationship	2017 F/S Report	
Downstream Water Level	Aral Head Regulator	2022 Flood Data
	Aral Tail Regulator	2022 Flood Data
	New Canal	Aral Tail Regulator - 0.28m

Source: Advisory Team

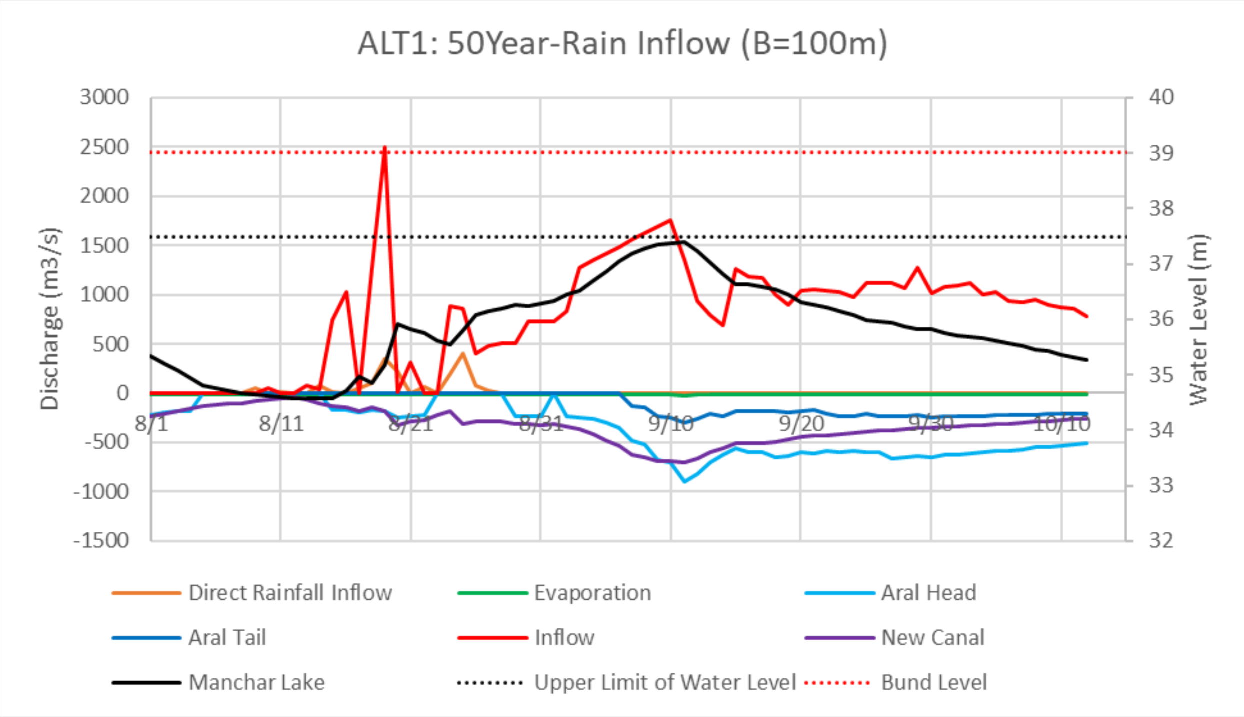
Table 4.6.19 Summary of Calculation Results (ALT1)

Case	Manchar Lake					Maximum Discharge			
	Excess Water Level	Maximum Water Level	Upper Limit of Water Level	Bund Level	Excess Volume	Aral Head	Aral Tail	New Canal	Total
	m	m	m	m	m3	m3/s	m3/s	m3/s	m3/s
ALT0	0.69	38.18	37.49	39.01	228,206,573	1443.06	536.08	—	1979.14
ALT1(B=80m)	0.14	37.63			44,767,758	1047.60	370.17	494.32	1912.09
ALT1(B=90m)	0.01	37.50			3,058,368	967.42	333.97	603.09	1904.48
ALT1(B=100m)	—	37.39			—	900.58	302.92	706.39	1909.89
ALT1(B=110m)	—	37.28			—	837.09	272.58	801.86	1911.53

: Exceeded upper limit of water level

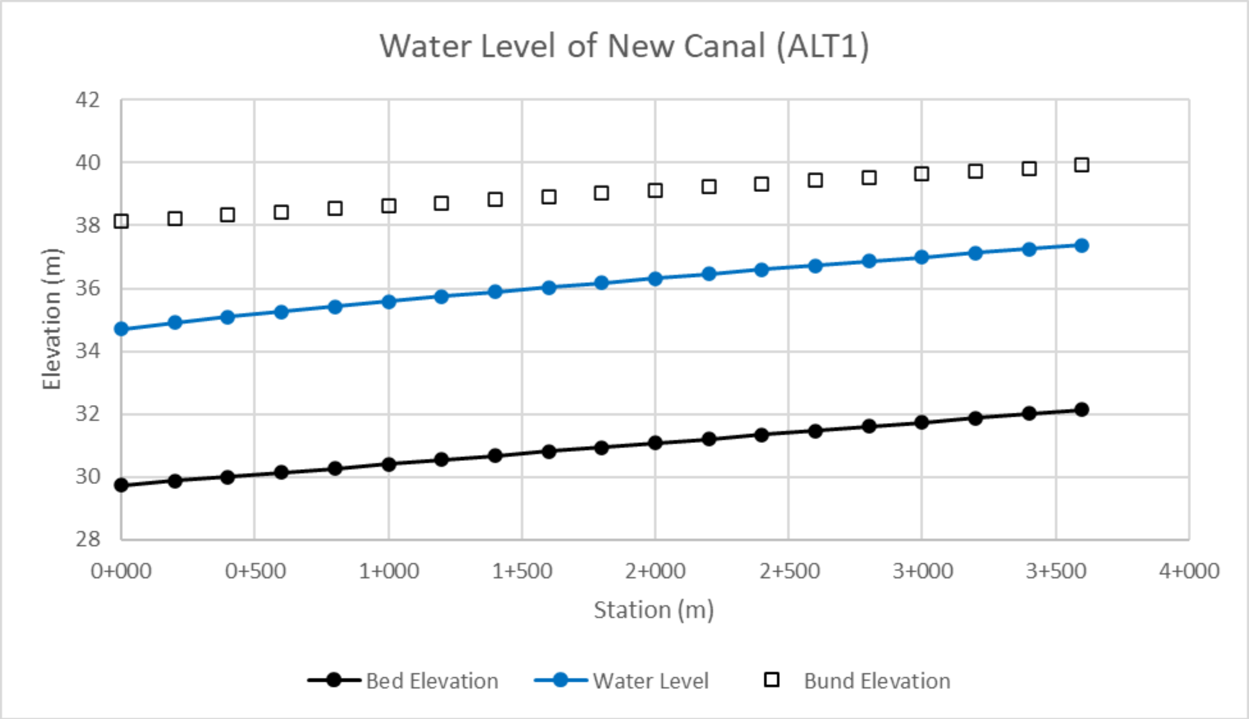
: Exceeded bund level

Source: Advisory Team



Source: Advisory Team

Figure 4.6.47 Calculation Result (ALT1, 50-Year Probability Scale Flood, River Width: 100 m)



Source: Advisory Team

Figure 4.6.48 Profile of the Waterway (ALT1, 50-Year Probability Scale Flood, River Width: 100 m)

2) Widening of the Existing Waterways (Aral Tail and RBOD-II) (ALT2)

The trial calculation was conducted to determine the minimum river width of ALT2 that can handle the inflow waveform that extended the 2022 flood to the probability scale of 50 years. Table 4.6.20 shows the calculation conditions of ALT2. Here, "can handle" is defined as the water level of Lake Manchar does not exceed the upper limit of water level: 123 ft (=37.49 m) during the flood period.

Table 4.6.21 summarizes the calculation results. If the river width is more than 110 m (=361 ft), ALT2 can handle the target inflow waveform. In these cases, the best case is the width of the Aral Tail part is 70 m (=230 ft) and the width of the RBOD-II part is 40 m (=131 ft), which is the lowest maximum water level of Lake Manchar. Figure 4.6.49 shows the calculation result (time series of the water level of Lake Manchar and each inflow and outflow) when the river width is set as in this case, and Figure 4.6.50 shows the profile of the waterways.

Table 4.6.20 Calculation Conditions (ALT2)

Setting	Contents	Memo
Inflow Scale	50 year flood	
Waveform	2022/8/1～2022/10/12	
Inflow and Outflow	Direct Rainfall Inflow	Nawabshah Rainfall Obsevatory
	Evaporation	0.8×2300mm/year
	Aral Head Regulator	Empirical Formula No of Gates: 14 (Current: 3)
	Aral Tail	Improved and Split to RBOD2 (Non-Uniform Flow Calculation)
Time Step	1-day	
HAV Relationship	2017 F/S Report	
Downstream Water Level	Aral Head Regulator	2022 Flood Data
	Aral Tail Regulator	2022 Flood Data
	RBOD2	Aral Tail Regulator - 0.23m

Source: Advisory Team

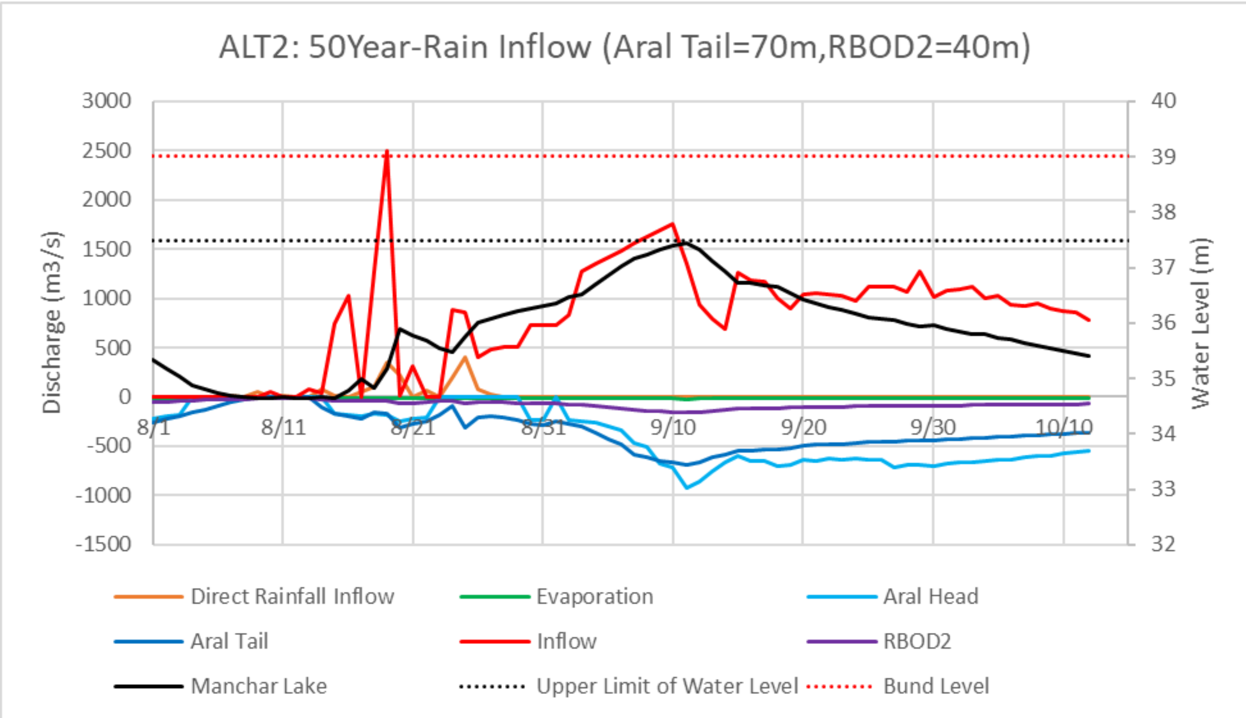
Table 4.6.21 Summary of Calculation Results (ALT2)

Case	Manchar Lake					Maximum Discharge			
	Excess Water Level	Maximum Water Level	Upper Limit of Water Level	Bund Level	Excess Volume	Aral Head	Aral Tail	New Canal	Total
	m	m	m	m	m3	m3/s	m3/s	m3/s	m3/s
ALT0	0.69	38.18			228,206,573	1443.06	536.08	—	1979.14
ALT2(Aral Tail=40m、RBOD2=40m)	0.49	37.98			159,609,919	1288.49	239.01	196.15	1723.65
ALT2(Aral Tail=50m、RBOD2=40m)	0.29	37.78			96,224,527	1151.88	399.11	182.45	1733.44
ALT2(Aral Tail=60m、RBOD2=40m)	0.10	37.59			34,113,404	1026.75	549.77	169.64	1746.16
ALT2(Aral Tail=70m、RBOD2=40m)	—	37.44			—	928.50	692.48	159.06	1780.04
ALT2(Aral Tail=40m、RBOD2=50m)	0.31	37.80			102,043,070	1164.05	223.98	329.68	1717.71
ALT2(Aral Tail=50m、RBOD2=50m)	0.14	37.63			45,719,271	1049.47	378.06	310.50	1738.03
ALT2(Aral Tail=60m、RBOD2=50m)	—	37.47			—	951.22	526.95	293.43	1771.60
ALT2(Aral Tail=70m、RBOD2=50m)	—	37.31	37.49	39.01	—	855.33	662.23	276.08	1793.64
ALT2(Aral Tail=40m、RBOD2=60m)	0.15	37.65			50,556,394	1059.04	210.91	459.83	1729.78
ALT2(Aral Tail=50m、RBOD2=60m)	—	37.49			—	959.76	359.05	435.58	1754.39
ALT2(Aral Tail=60m、RBOD2=60m)	—	37.34			—	870.72	501.57	412.96	1785.25
ALT2(Aral Tail=70m、RBOD2=60m)	—	37.19			—	786.81	632.76	390.63	1810.20
ALT2(Aral Tail=40m、RBOD2=70m)	0.02	37.51			5,894,771	972.75	199.71	584.59	1757.05
ALT2(Aral Tail=50m、RBOD2=70m)	—	37.35			—	880.94	341.67	554.36	1776.97
ALT2(Aral Tail=60m、RBOD2=70m)	—	37.22			—	803.70	479.68	527.83	1811.21
ALT2(Aral Tail=70m、RBOD2=70m)	—	37.07			—	726.45	605.69	499.88	1832.02

: Exceeded upper limit of water level

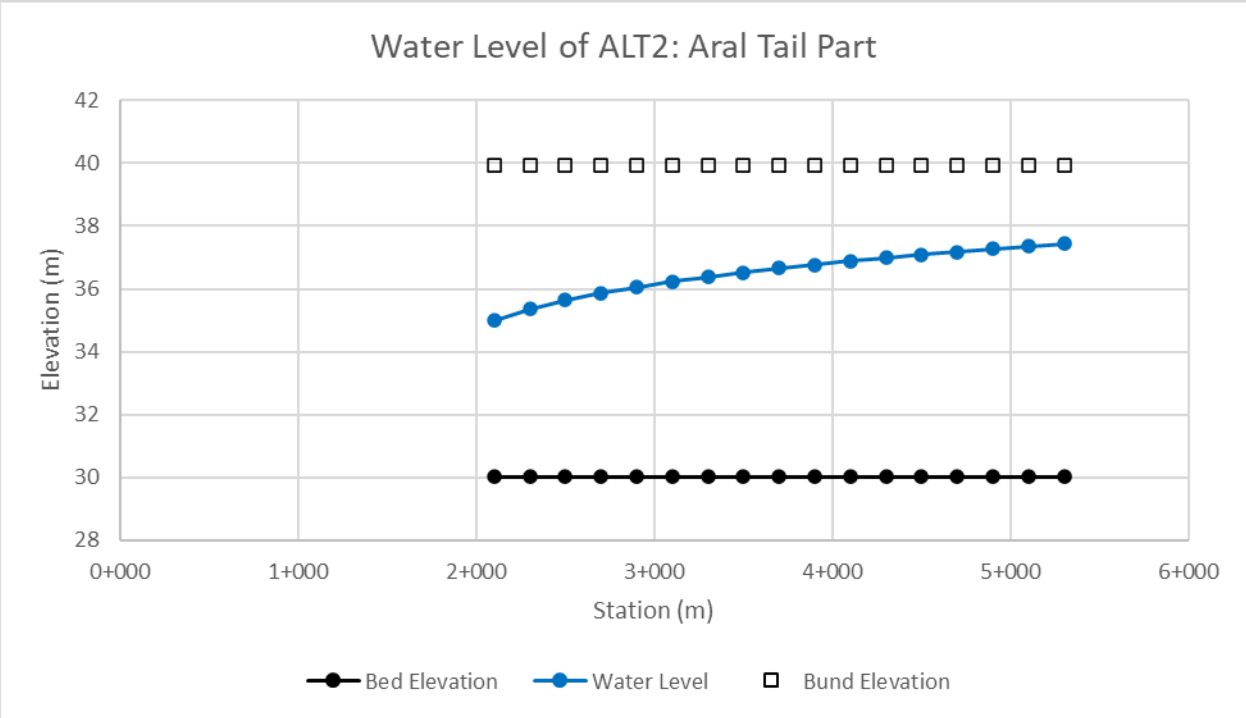
: Exceeded bund level

Source: Advisory Team



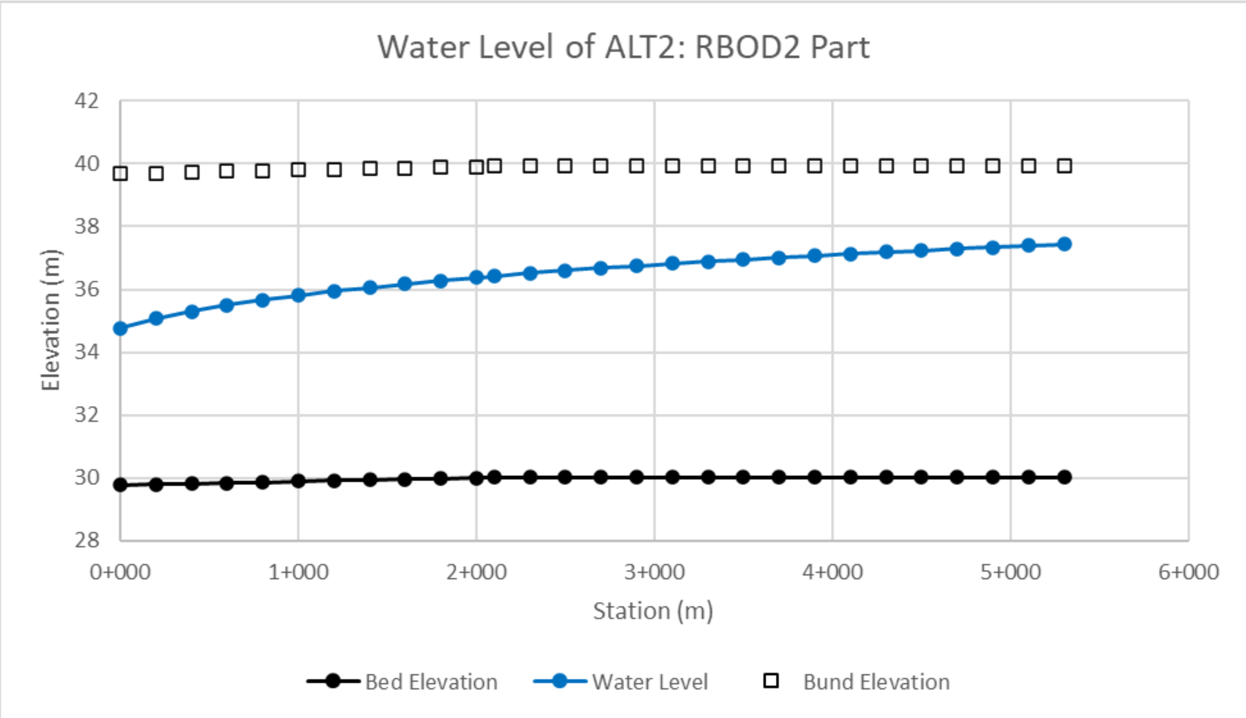
Source: Advisory Team

Figure 4.6.49 Calculation Result (ALT2, 50-Year Probability Scale Flood, River Width: 110 m, Aral Tail: 70m, RBOD-II: 40m)



Source: Advisory Team

Figure 4.6.50 (1) Profile of the Waterway (ALT2, 50-Year Probability Scale Flood, Aral Tail Part: 70 m)



Source: Advisory Team

Figure 4.6.50 (2) Profile of the Waterway (ALT2, 50-Year Probability Scale Flood, RBOD-II Part: 70 m)

3) Widening of the Existing Waterway (Only Aral Tail) (ALT3)

The trial calculation was conducted to determine the minimum river width of ALT3 that can handle the inflow waveform that extended the 2022 flood to the probability scale of 50 years. Table 4.6.22 shows the calculation conditions of ALT3. Here, "can handle" is defined as the water level of Lake Manchar does not exceed the upper limit of water level: 123 ft (=37.49 m) during the flood period.

Table 4.6.23 summarizes the calculation results. If the river width is more than 100 m (=328 ft), ALT3 can handle the target inflow waveform. Figure 4.6.51 shows the calculation result (time series of the water level of Lake Manchar and each inflow and outflow) when the river width is set at 100 m, and Figure 4.6.52 shows the profile of the waterway.

Table 4.6.22 Calculation Conditions (ALT3)

Setting	Contents	Memo
Inflow Scale	50 year flood	
Waveform	2022/8/1～2022/10/12	
Inflow and Outflow	Direct Rainfall Inflow	Nawabshah Rainfall Obsevatory
	Evaporation	0.8×2300mm/year
	Aral Head Regulator	Empirical Formula No of Gates: 14 (Current: 3)
	Aral Tail	Improved (Non-Uniform Flow Calculation)
Time Step	1-day	
HAV Relationship	2017 F/S Report	
Downstream Water Level	Aral Head Regulator	2022 Flood Data
	Aral Tail Regulator	2022 Flood Data

Source: Advisory Team

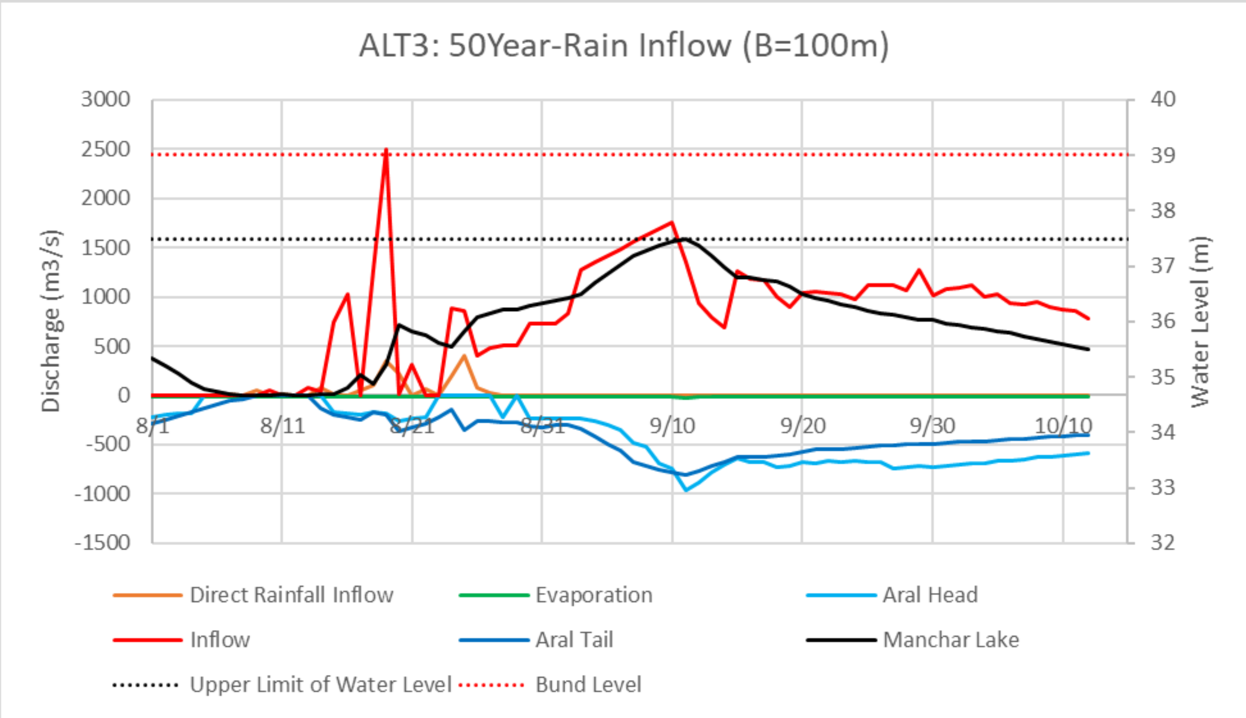
Table 4.6.23 Summary of Calculation Results (ALT3)

Case	Manchar Lake					Maximum Discharge			
	Excess Water Level	Maximum Water Level	Upper Limit of Water Level	Bund Level	Excess Volume	Aral Head	Aral Tail	New Canal	Total
	m	m	m	m	m3	m3/s	m3/s	m3/s	m3/s
ALT0	0.69	38.18			228,206,573	1443.06	536.08	—	1979.14
ALT3(B=80m)	0.37	37.86			120,914,217	1204.02	527.13	—	1731.15
ALT3(B=90m)	0.18	37.67	37.49	39.01	57,289,070	1072.43	672.24	—	1744.67
ALT3(B=100m)	—	37.49			—	959.27	805.85	—	1765.12
ALT3(B=110m)	—	37.33			—	867.36	931.63	—	1798.99

: Exceeded upper limit of water level

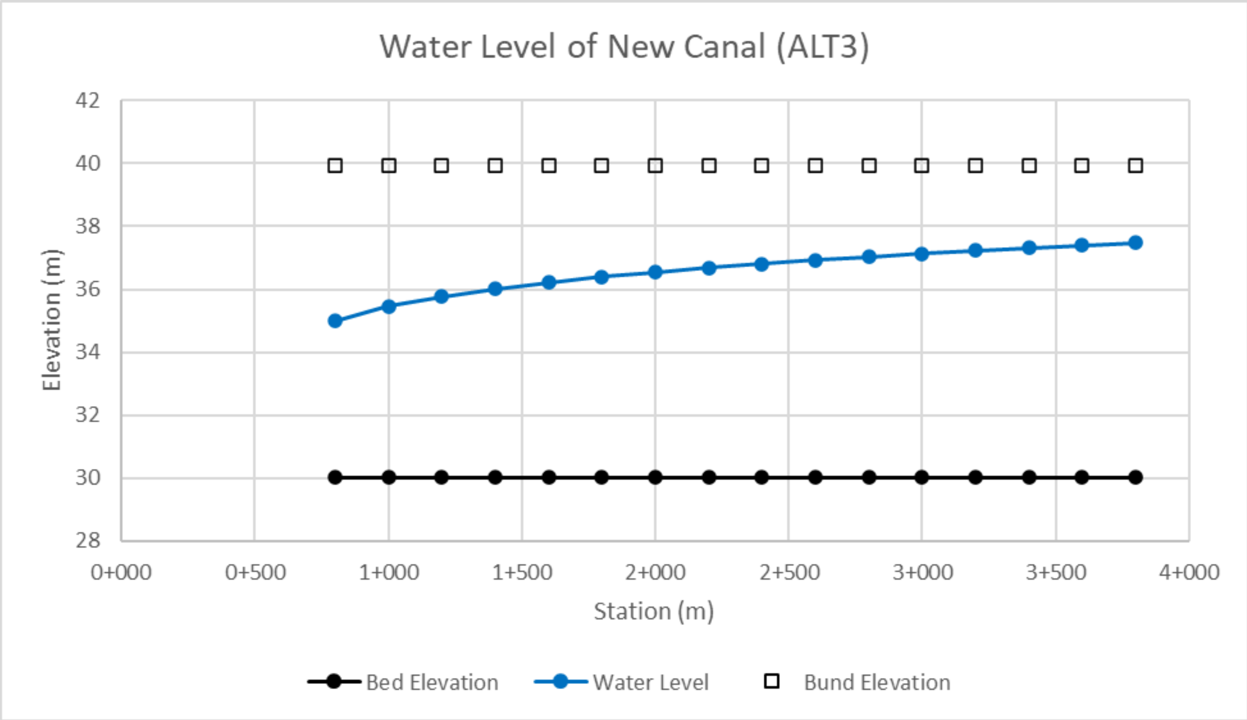
: Exceeded bund level

Source: Advisory Team



Source: Advisory Team

Figure 4.6.51 Calculation Result (ALT3, 50-Year Probability Scale Flood, River Width: 100 m)



Source: Advisory Team

Figure 4.6.52 Profile of the Waterway (ALT3, 50-Year Probability Scale Flood, River Width: 100 m)

4.7 Alternatives for Enhancement of Manchar Lake Drainage System

4.7.1 Extraction of Alternatives

4.7.1.1 Primary Selection of Alternatives

The following options would be extracted as measures for enhancing drainage systems at the sites subject to this study.

- New Spillway
- Widening Existing Canal(Aral Head)
- Widening Existing Canal(Aral Tail)
- New Drainage Pumping Station

In addition to the above, there are methods to increase the capacity of the lake with the following measures, although not by increasing the drainage capacity.

- Raising of Manchar Lake Containing Bund(MCB)
- Excavation/Dredging in Manchar Lake

The characteristics of the above options and their applicability in the case of Manchar Lake are summarized in Table 4.7.1.

Based on the summary shown in Table 4.7.1, it can be said that "New Spillway" and "Widening Existing Canal(Aral Tail)" are more applicable than the others. Therefore, measures for enhancing the drainage system of Manchar Lake are extracted mainly from these two options, and their characteristics and issues will be compared.

Table 4.7.1 Primary Selection of Alternatives

No.	Alternative Measures	Summary	Applicability	
Increasing Drainage Capacity				
1	New Spillway	Construct a new spillway separated from the existing canal to discharge the flood water into the Indus River	· The least impact on the existing canals and related facilities. · There is sufficiently available land on the south side of Aral Tail.	○
2	Widening Existing Canal(Aral Head)	Widen the existing channels (Aral Head) to increase drainage capacity	· Considering longitudinal slope and length, <u>widening the Aral Tail is more efficient</u>. · As of August 2023, rebuilding of the existing regulator and widening of the canal is in progress.	△
3	Widening Existing Canal(Aral Tail)	Widen the existing channel (Aral Tail) to increase drainage capacity	· Improvement of the Aral Tail Regulator is necessary. However, it is sufficiently practical.	○
4	New Drainage Pumping Station	Increase drainage capacity by installing drainage pumps.	· <u>The required drainage capacity is too large to discharge, and it is not practical.</u> · Operation and maintenance of the pumps need labor and cost.	△
Increasing Storage Capacity				
5	Raising of Manchar Lake Containing Bund(MCB)	Raise the existing MCB to the height with the freeboard to confine the discharge volume corresponding to the target return period	· Since there is a relatively spacious and available land behind the bund to raise the bund height. However, raising even along the existing canals (Aral Head and Aral Tail) and to rebuild of the existing regulator are needed, and <u>the numbers of the existing facilities that are affected are the most</u>.	△

No.	Alternative Measures	Summary	Applicability	
6	Excavation/Dredging in Manchar Lake	Increase the storage capacity by excavating the bottom of the lake not to exceed the HFL(High Flood Level) of the lake corresponding to the target return period	・ The maintenance water level (RL. 105 ft) of the lake from the environmental aspect and water utilization aspect shall be maintained. This option affects the level of the lake in the dry season.	×

Legend: ○... Applicable, △... Lowt applicable, × ... Not applicable
Source: Advisory Team

4.7.1.2 Extraction of Alternatives to Studied

As mentioned above, alternatives to study will be extracted, focusing on "New Spillway" and "Widening Existing Canal (Aral Tail)."

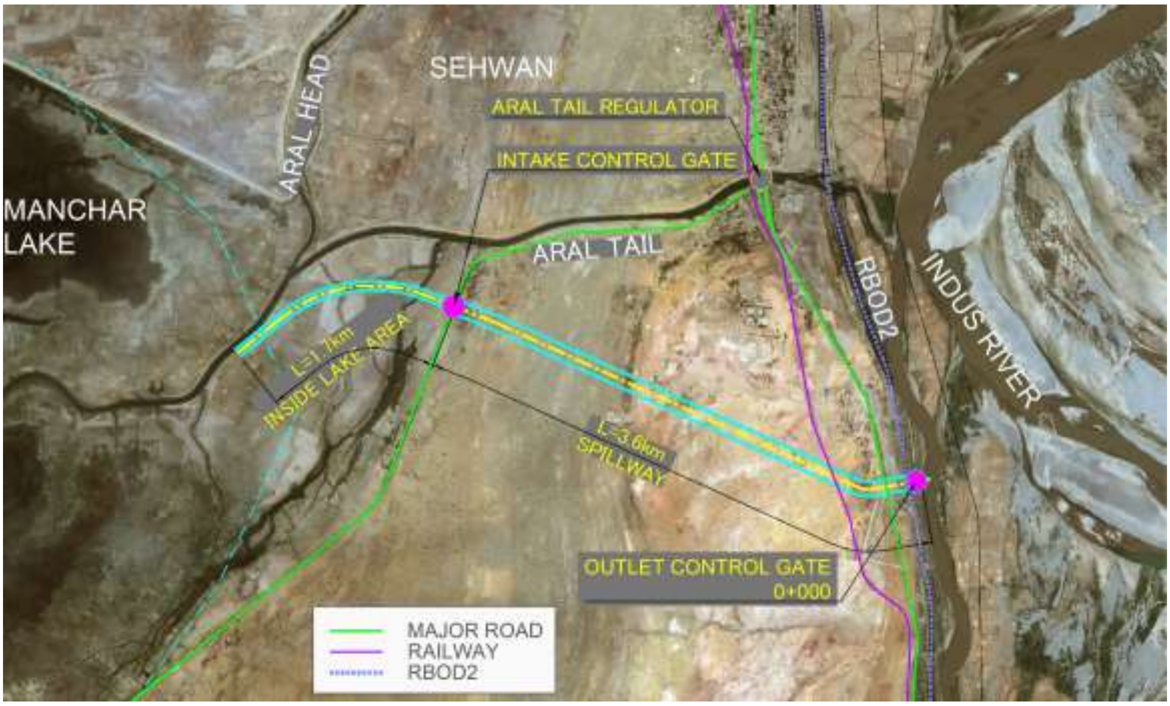
(1) Alternative 1: New Spillway

- To establish a spillway to discharge flood water directly from the eastern shore of Manchar Lake to the Indus River by natural flow.
- Considering that the channel would be used only when the water level of Manchar Lake is high, a water gate would be installed on the inlet side (on the Manchar Lakeside) and the outlet side (on the Indu's Riverside).

Table 4.7.2 List of Necessary Facilities (New Spillway)

Item	Quantity/Dimensions	Remarks
New Spillway	L=3.6 km + (Lake Area) 1.7 km Canal Width W= 100 m	The east side of Manchar Lake has a higher lake bed and is a wetland. Hence, the excavation shall be implemented to secure the waterway upstream of the Inlet Control Gate. It is necessary to study the extension of the canal in the lake area with the result of bathymetry surveys in the subsequent stage.
Inlet Control Gate	1 unit/5 gates x 15 m x 7.8 m	Normal: Full close, Flood in Manchar Lake: Full open Since it is necessary to secure a certain amount of discharge even at the start of discharge (initial flood), it is controlled by gates instead of an overflow bund system.
Outlet Control Gate	1 unit/5 gates x 15 m x 8.3 m	Normal: Full open, during Flood in Indus River: Full close There is also an option to install a bunk for the backwater from the Indus River instead of the gates. Depending on the HFL in the Indus River, this facility may be unnecessary.
Railway Bridge	1 nos./ L=150m, W=5m	Assumed from Google Earth
Road Bridge	1 nos./ L=100m, W=20m	Assumed by Google Earth

Source: Advisory Team



Source: Advisory Team, Source of Satellite image: Bing Map, Microsoft Corporation

Figure 4.7.1 Alternative 1: New Spillway

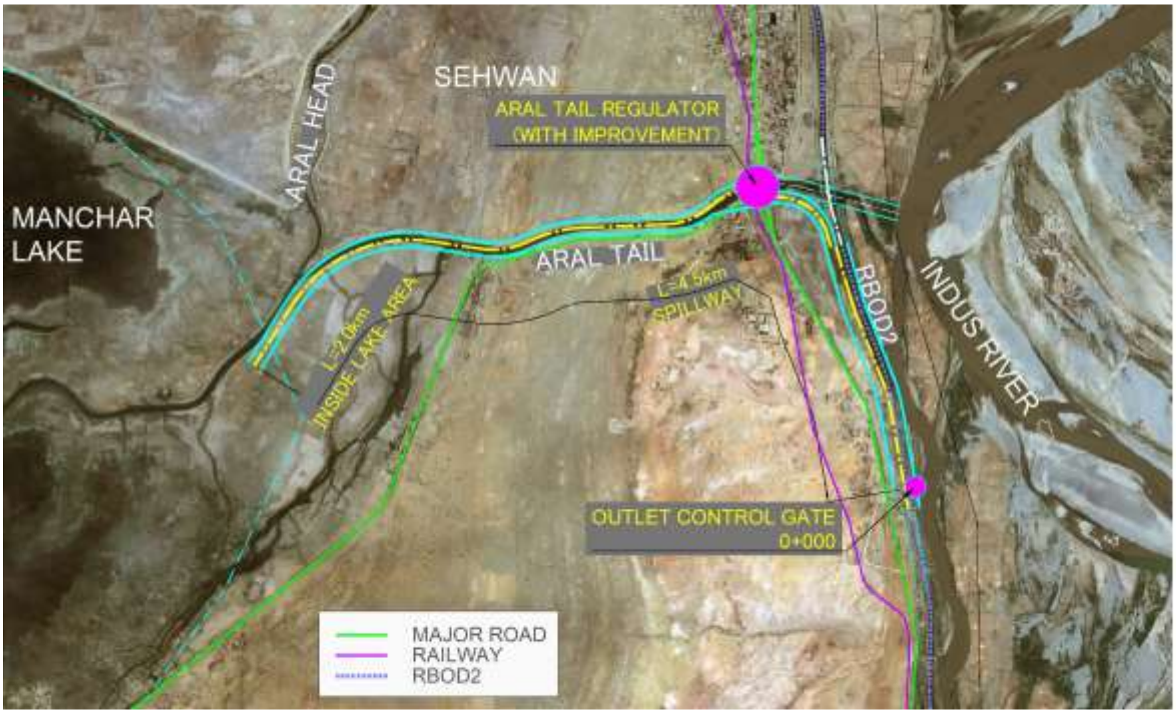
(2) Alternative 2: Widening of Existing Canal 1(Aral Tail + RBOD-II)

- Widening of Aral Tail and RBOD to discharge flood water by natural flow into the Indus River via these existing canals from the eastern shore of Manchar Lake
- The purpose of this alternative is to avoid a cut section needed in the middle of the "Alternate 1: New Spillway" and to set the outlet downstream along the Indus River via RBOD to ensure a longitudinal slope.

Table 4.7.3 List of Necessary Facilities (Widening of Existing Channel 1(Aral Tail + RBOD-II))

Item	Quantity/Dimensions	Remarks
Discharge Canal	L=4.5 km + (Lake Area) 2.0 km <Aral Tail Section > Canal width W= 80 m → 110 m <RBOD-II Section > Canal width W= 100 m → 140 m	The east side of Manchar Lake has a higher lake bed and is a wetland. Hence, the excavation shall be implemented to secure the waterway upstream of the Inlet Control Gate. It is necessary to study the extension of the canal in the lake area with the result of bathymetry surveys in the subsequent stage.
Improvement of Aral Head Regulator	5 gates x 6 m x 7.3 m → 6 Gates x 15 m x 7.3 m	Normal: (Existing Section) Full or Intermediate Open (Expanded Section) Full Close Flood in Manchar Lakes: Full Close, Flood in Indus River: Full Close In ordinary times, the expanded section is fully closed to reduce inflow to the RBOD-II.
Outlet Control Gate	1/2 gates x 15 m x 8.3 m	Normal: Full Close, Flood in Manchar Lake: Full Open Flood in Indus River: Full Close RBOD-II is a facility that should be located inside the bund. Hence, it is necessary to prevent inflow from the Indus River.
Railway Bridge	1 nos./ L=130m, W=5m	Assumed from Google Earth
Road Bridge	2 nos./ L=130m, W=12m	Assumed from Google Earth

Source: Advisory Team



Source: Advisory Team, Source of Satellite image: Bing Map, Microsoft Corporation

Figure 4.7.2 Widening of Existing Canal 1(Aral Tail + RBOD-II)

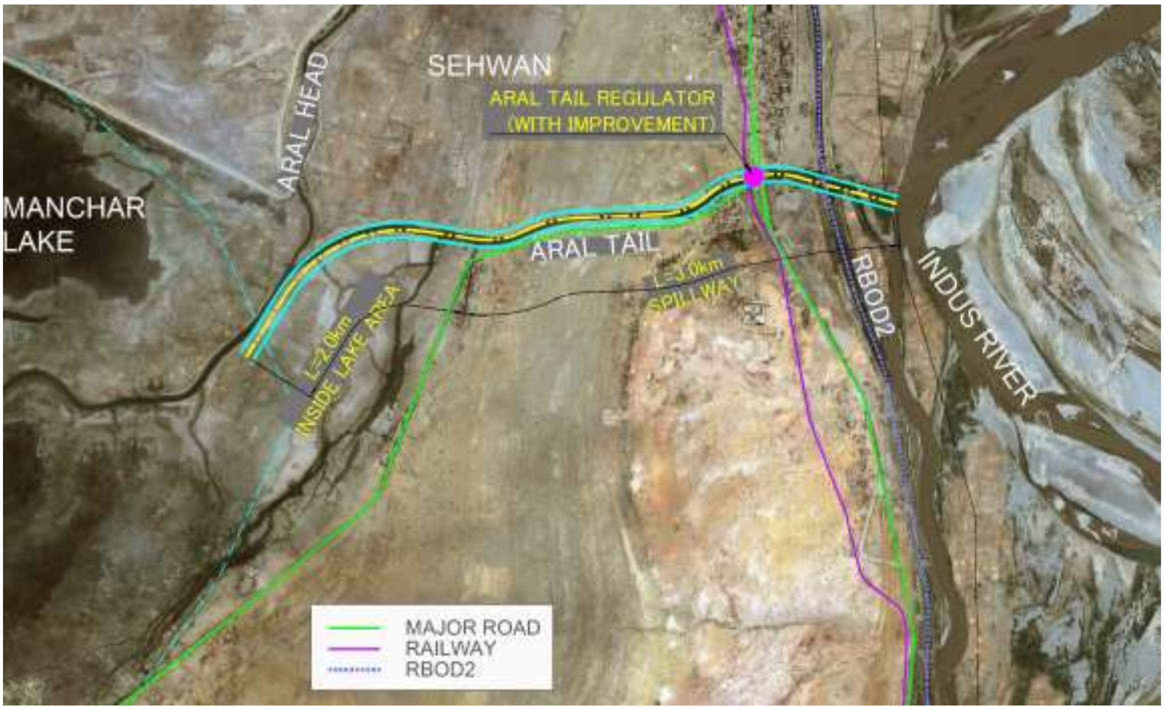
(3) Alternative 3: Widening of Existing Canal 2(Aral Tail)

- Widen the Aral Tail and discharge the flood water naturally into the Indus River via an existing canal from the eastern shore of Manchar Lake
- The purpose of this alternative is to avoid a cut section needed in the middle of the "Alternate 1: New Spillway" and to utilize the existing canal effectively.

Table 4.7.4 List of necessary facilities (Proposed widening of existing waterway 2(Aral Tail))

Item	Quantity/Dimensions	Remarks
Discharge Canal	L=3.0 km + (Lake Area) 2.0 km Canal Width W= 80 m → 100 m	The east side of Manchar Lake has a higher lake bed and is a wetland. Hence, the excavation shall be implemented to secure the waterway upstream of the Inlet Control Gate. It is necessary to study the extension of the canal in the lake area with the result of bathymetry surveys in the subsequent stage.
Improvement of Aral Head Regulator	5 gates x 6 m x 7.3 m →5 gates x 15 m x 7.3 m	Normal: Full or intermediate open Flood in Manchar Lake: Full open Flood in Indus River: Full close In ordinary times, it is necessary to adjust the opening considering water utilization (Same as the present).
Railway Bridge	1 nos./ L=100m, W=5m	Assumed by Google Earth
Road Bridge	2 nos./ L=100m, W=12m	Assumed from Google Earth

Source: Advisory Team



Source: Advisory Team, Source of Satellite image: Bing Map, Microsoft Corporation

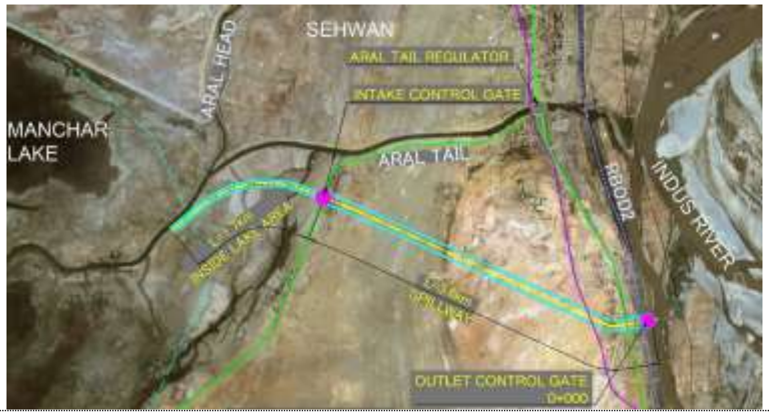
Figure 4.7.3 Widening of Existing Canal 2(Aral Tail)

4.7.2 Evaluation of Each Alternative

About the three alternatives, the characteristics of each, the impact on the surrounding area, and the cost are compared. Table 4.7.5 on the next page shows a comparison table of each alternative. Although it is necessary to pay attention to deposition in the existing canal, "Alternative 3: Widening of Existing Canal 2(Aral Tail)" is the most likely option due to the large cost gap.

However, "Alternative 1: New Spillway" would be also an option to be considered, although the cost is high, because Alternative 1 can be implemented without affecting the structure and operation of existing facilities, and it can reduce concerns caused by deposition in the existing canal. Therefore, in the F/S and the subsequent stage and beyond, it is necessary to further consider Alternative 1 and Alternative 3 and select the optimum alternative, considering the cost of excavation of the canal to maintain the flow area of Aral Tail and the maintenance management structure.

Table 4.7.5 Comparison of Enhancement of Manchar Lake Drainage System

<table>
<tr><th></th><th colspan="2">Alternative 1: New Spillway</th><th colspan="2">Alternative 2: Widening Existing Canal(Aral Head)</th><th colspan="2">Alternative 3: Widening Existing Canal(Aral Tail)</th></tr>
<tr><td>Overview (Plan)</td><td colspan="2">
</td><td colspan="2">
</td><td colspan="2">
</td></tr>
<tr><td>General</td><td colspan="2">・ Establish a spillway to discharge directly from the eastern shore of Manchar Lake to the Indus River by natural flow
・ Assuming that the channel would be used only when the water level of Manchar Lake is high, water gates will be installed on the inlet side (on the Manchar Lakeside) and the outlet side (on the Indus Riverside).
・ The existing Aral Tail and Regulator will remain as they are.</td><td colspan="2">・ Widen the Aral Tail and RBOD and release the flood water naturally into the Indus River via these existing canals from the eastern shore of Manchar Lake.
・ The purpose is to avoid a cut section in the middle of "Alternative 1: New Spillway" and to set the outlet towards the downstream side along the Indus River via the RBOD-II to ensure a longitudinal slope.</td><td colspan="2">・ Widen the Aral Tail and discharge the flood water to the Indus River by natural flow via an existing canal from the eastern shore of Manchar Lake
・ The purpose is to avoid a cut section in the middle of "Alternative 1: New Spillway" and to use the existing canal effectively.</td></tr>
<tr><td>Route</td><td colspan="2">・ Route connecting the eastern shore of Manchar Lake to the right bank of the Indus River which is 2.5 km downstream from the confluence of Aral Tail.</td><td colspan="2">・ The route connecting the right bank of the Indus River which is 2.5 km downstream from the confluence of Aral Tail via Aral Tail and RBOD-II</td><td colspan="2">・ Same route as Aral Tail</td></tr>
<tr><td>Canal Dimensions</td><td colspan="2"><table><tr><th></th><th>Canal Width (m)</th><th>Slope</th><th>Length (km)</th></tr><tr><td>Spillway</td><td>100</td><td>1/1500</td><td>3.6</td></tr><tr><td>Lake Area</td><td></td><td>LEVEL</td><td>1.7</td></tr><tr><td></td><td></td><td>Total</td><td>5.3</td></tr></table></td><td colspan="2"><table><tr><th></th><th>Canal Width (m)</th><th>Slope</th><th>Length (km)</th></tr><tr><td>Widening RBOD-II</td><td>140</td><td>1/9000</td><td>2.0</td></tr><tr><td>Widening Aral Tail</td><td>110</td><td>LEVEL</td><td>2.5</td></tr><tr><td>Lake Area</td><td></td><td>LEVEL</td><td>2.0</td></tr><tr><td></td><td></td><td>Total</td><td>6.5</td></tr></table></td><td colspan="2"><table><tr><th></th><th>Canal Width (m)</th><th>Slope</th><th>Length (km)</th></tr><tr><td>Widening Aral Tail</td><td>100</td><td>LEVEL</td><td>3.0</td></tr><tr><td>Lake Area</td><td></td><td>LEVEL</td><td>2.0</td></tr><tr><td></td><td></td><td>Total</td><td>5.0</td></tr></table></td></tr>
<tr><td>Facility Dimensions</td><td colspan="2"><table><tr><th>Item</th><th>Quantity/Dimensions</th></tr><tr><td>Inlet Control Gate</td><td>1 unit/ 5 gates x 15 m x 7.8 m</td></tr><tr><td>Outlet Control Gate</td><td>1 unit/ 5 gates x 15 m x 8.3 m</td></tr><tr><td>Railway Bridge</td><td>1 nos./ L =150m, W=5m</td></tr><tr><td>Road Bridge</td><td>1 nos./ L =100m, W=20m</td></tr></table></td><td colspan="2"><table><tr><th>Item</th><th>Quantity/Dimensions</th></tr><tr><td>Rebuilt of Aral Head Regulator</td><td>1 Unit/ 6 gates x 15 m x 7.8 m</td></tr><tr><td>Wastewater side sluice</td><td>1 Unit/ 2 Gates x 15 m x 8.3 m</td></tr><tr><td>Railway Bridge</td><td>1 nos./ L =110m, W=5m</td></tr><tr><td>Road bridge</td><td>2 nos./ L=110m, W=12m</td></tr></table></td><td colspan="2"><table><tr><th>Item</th><th>Quantity/Dimensions</th></tr><tr><td>Rebuilt of Aral Head Regulator</td><td>1 Unit/5 Gates x 15 m x 7.8 m</td></tr><tr><td>Railway Bridge</td><td>1 nos./ L =100m, W=5m</td></tr><tr><td>Road bridge</td><td>2 nos./ L=100m, W=12m</td></tr></table></td></tr>
<tr><td>Structure</td><td>・ There is a cut section of about 2.5 km, and the height of the cut is 10 to 15 m from the existing ground to the top of the canal, and the excavation cost will be high when the original ground of contains rock materials.
・ It is necessary to have a multi-level crossing with RBOD-II near the Outlet Control Gate.</td><td>○</td><td>・ It is necessary to improve the existing regulator (Aral Head Regulator).
・ Since the outlet control gate is installed along RBOD-II, it is necessary to consider whether to install a diversion facility together with the outlet control gate or to install a multi-level crossing with RBOD-II, which complicates the structure.</td><td>△</td><td>・ It is necessary to improve the existing regulator (Aral Head Regulator).
・ It is necessary to improve(extension) the multi-level; crossing with the existing RBOD-II.</td><td>◎</td></tr>
<tr><td>Maintenance</td><td>・ Since the bed height of the spillway is higher than the lakebed, the reduction of flow area caused by deposition is less concern than the other alternatives.</td><td>◎</td><td>・ Since the existing Aral Tail is used, the canal bed is almost the same as the lakebed. Therefore, deposition is likely to occur in the canal as in the existing condition.</td><td>○</td><td>・ Same as the Left</td><td>○</td></tr>
<tr><td>Operation</td><td>・ Compared to other alternatives, it is simpler because it would be operated only during floods.</td><td>○</td><td>・ When it merges with RBOD-II, the discharge will be affected by the water level of RBOD-II, and operation is complicated.</td><td>△</td><td>・ Same operation as the present.
・ Capacity can be increased also in the intake of water from the Indus River to Lake Mancha</td><td>○</td></tr>
<tr><td>Construction</td><td>・ Work in the dry condition is possible except for the control gates in the outlet and inlet side, and the workability is better than the other alternatives.</td><td>◎</td><td>・ It is necessary to improve the existing regulator (Aral Tail Regulator) with a cofferdam to cut the half width of the canal because the operation of the Aral Tail even during construction is required.
・ A Cofferdam is also needed for the replacement of existing bridges.</td><td>○</td><td>・ Same as the Left</td><td>○</td></tr>
<tr><td>Socio-environment</td><td>・ As it is apart from the city area, the number of houses affected is smaller than the other alternatives.</td><td>◎</td><td>・ Around the existing Aral Tail Regulator, it is necessary to relocate houses (it is assumed that there will be no more than 50 houses).</td><td>○</td><td>・ Around the existing Aral Tail Regulator, it is necessary to relocate houses (it is assumed that there will be no more than 50 houses).</td><td>○</td></tr>
<tr><td>Construction Cost (PKR)</td><td>Construction cost 43.6 billion</td><td>3</td><td>Construction cost 39.2 billion</td><td>2</td><td>Construction cost 27.1 billion</td><td>1</td></tr>
<tr><td>Evaluation</td><td colspan="2">・ Due to the lot of excavation volume and facilities, the cost is higher than the other alternatives. (In subsequent studies, if the water gates can be consolidated from two locations to one location, the cost may be significantly reduced.)
・ Better in the aspect of structure, operation and maintenace</td><td colspan="2">・ The largest impact on the structure and operation of existing facilities.
・ The structure is also complex, making it difficult to regulate the amount of drainage.
・ It is necessary to pay attention to the drainage capacity which can be easily affected by deposition in existing canals.</td><td colspan="2">・ The existing Aral Tail is affected, but the cost is the lowest.
・ The operation of the facility is the same as the current situation, but it is necessary to pay attention to the drainage capacity which can be easily affected by deposition in the existing canal.</td></tr>
<tr><td></td><td colspan="2">Second Option for Further Study after the Alternative 3.</td><td colspan="2">Not Recommend</td><td colspan="2">Most Recommended Option for Further Study</td></tr>
</table>

Legend:◎... Preferred; ○ ... No problem; △... There is an issue. In the case of numbers, the ranking among the alternatives is shown.
Source: Advisory Team, Source of Satellite image: Bing Map, Microsoft Corporation

4.8 Proposed Project

4.8.1 Feature of the Project

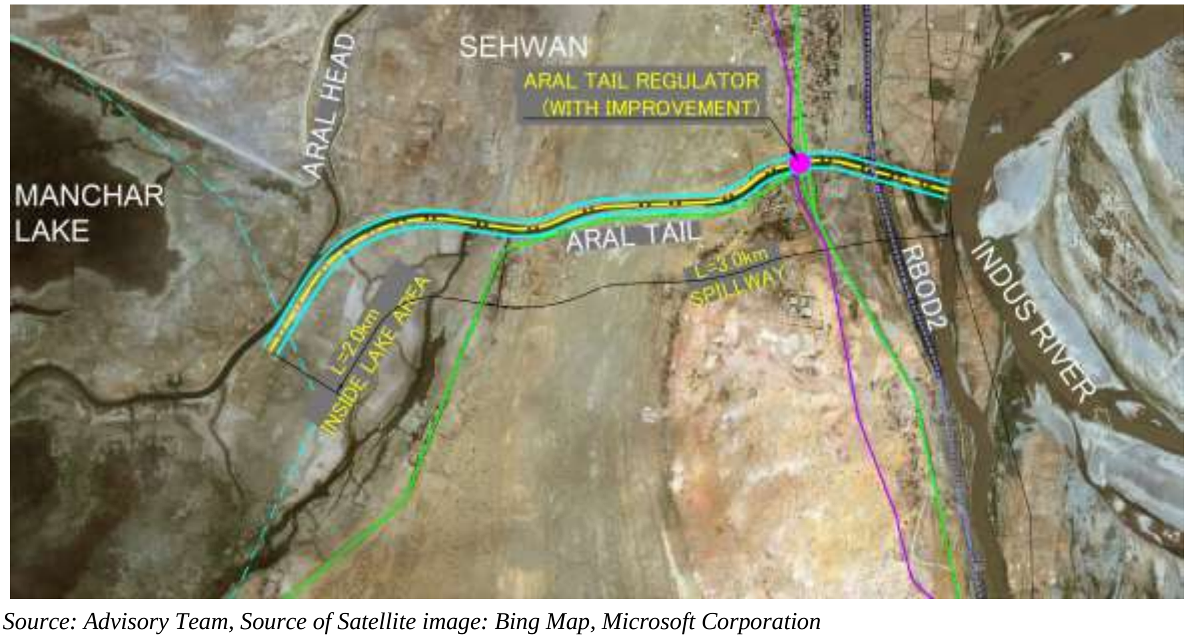
Based on the comparison shown in Table 4.7.5 above, "Alternative 3: Widening of Existing Canal 2(Aral Tail)" is the most recommended in this study. The features of the alternative are relisted below.

- ✓ widen the Aral Tail and discharge flood water naturally to the Indus River via the existing channel from the eastern shore of Manchar Lake
- ✓ The operation of the facility will not be changed from the present situation. However, attention shall be paid because the drainage capacity is easily affected by deposition in the existing canal.
- ✓ Improvement of the Aral Tail Regulator and rebuilding of one railway bridge and two road bridges are required.
- ✓ The east side of Manchar Lake has a higher lakebed and is a wetland. Hence, the excavation shall be implemented to secure the waterway upstream of the Inlet Control Gate.
- ✓ Construction cost: 27.1 Billion PKR

Table 4.8.1 List of Necessary Facilities (Widening Existing Canal 2 (Aral Tail))

Item	Quantity/Dimensions	Remarks
Discharge Canal	L=3.0 km + (Lake Area) 2.0 km Canal Width W= 80 m → 100 m	The east side of Manchar Lake has a higher lake bed and is a wetland. Hence, the excavation shall be implemented to secure the waterway upstream of the Inlet Control Gate. It is necessary to study the extension of the canal in the lake area with the result of bathymetry surveys in the subsequent stage.
Improvement of Aral Head Regulator	5 gates x 6 m x 7.3 m →5 gates x 15 m x 7.3 m	Normal: Full or intermediate open Flood in Manchar Lake: Full open Flood in Indus River: Full close In ordinary times, it is necessary to adjust the opening considering water utilization (Same as the present).
Railway Bridge	1 nos./ L=100m, W=5m	Assumed by Google Earth
Road Bridge	2 nos./ L=100m, W=12m	Assumed from Google Earth

Source: Advisory Team



Source: Advisory Team, Source of Satellite image: Bing Map, Microsoft Corporation

Figure 4.8.1 Widening Existing Canal 2(Aral Tail)

4.8.2 Construction Schedule

(1) Construction Types

The following is a summary of the main construction procedures for Plan 3, which aims to improve the flow capacity of the existing canal.

The main construction types are as follows based on Table 4.8.1.

1) Canal widening (see Figure 4.8.2)

・Canal widening: Excavation to expand the river width from 80m to 100m, dredging of the canal bottom

・Canal bund construction; embankment

Source: Advisory Team, Source of Satellite image: Bing Map, Microsoft Corporation

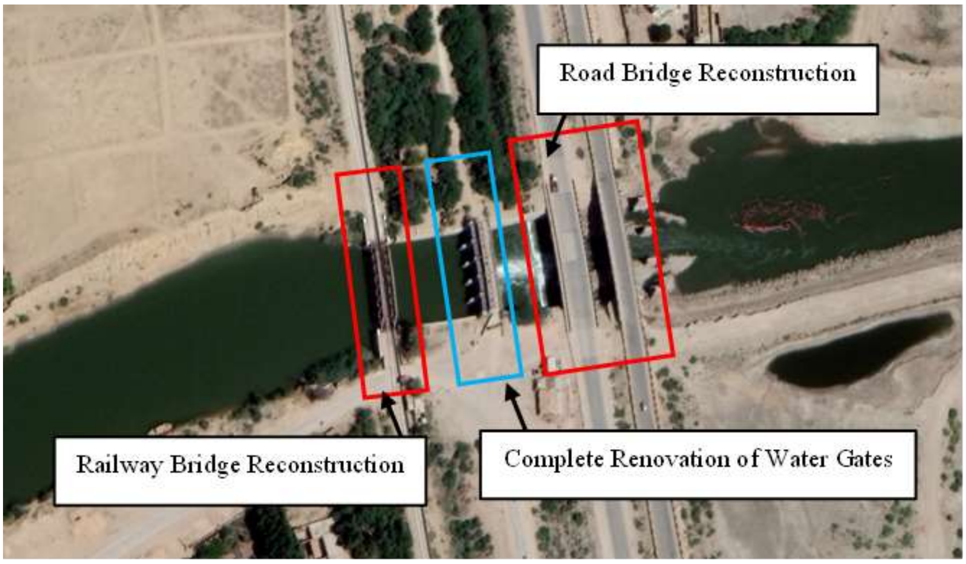
Figure 4.8.2 Canal Widening Range

2) Water gate repair and bridge replacement (see Figure 4.8.3)

・Complete renovation of water gates; basic, removal of existing water gates, installation of new water gates

・Reconstruction of 2 road bridges; removal of existing bridges and construction of new ones

・Replacement of 1 railway bridge; removal of existing bridge, construction of new bridge



Source ; Google earth, Advisory Team

Figure 4.8.3 Complete Water Gate Renovation and Bridge Replacement Location

(2) Construction schedule

The canal widening will be carried out in parallel with the water gate and bridge related works. Regarding water gate and bridge related works, the construction order will be adjusted as the site will be complicated. Construction will be carried out under the following conditions.

1) Canal widening

- Basically, construction will be carried out from October to June when the water level is low.
- Separate the construction area and construct a cofferdam to secure the flow path.
- The construction road will be installed inside the widening bund.
- The work yard will be located on flat land within the bund adjacent to the work area.
- Materials and equipment will basically be procured in the adjacent Sehwan (L=1km).

Figure 4.8.4 shows the construction location and the neighboring city of Sehwan.

Source ; Google earth, Advisory Team

Figure 4.8.4 Sewan and Canal Widening Locations

- Construction Procedure

The steps of the construction process are as follows.

1. Preparation work
2. Removal work
3. Excavation work
4. Embankment work
5. Foundation work
6. Concrete cladding
7. Crown work

8. Split stone masonry (inside embankment; dry masonry)
9. Top paving work (crushed stone pavement)

2) Water gate expansion and renovation

· Basically, construction will be carried out from October to June when the water level is low.

· A cofferdam will be installed and half-river construction will be carried out to secure the flow canal.

· Existing roads will be used as construction roads.

· The work yard will be located on flat land within the adjacent bund.

· Materials and equipment will basically be procured in the adjacent Sehwan (L=1km).

· Construction Procedure

The steps of the construction process are as follows. ② to ⑨ will be construction in half-river.

1. Preparation work
2. Removal work
3. Excavation work
4. Main body work (including door body)
5. Water taper
6. Embankment work
7. Bank protection work (including foundation work)
8. Split stone masonry (inside bund; dry masonry)
9. Top paving work (crushed stone pavement)

3) Bridge replacement

· Construction of bridge piers in the waterway will be carried out from October to June when the water level is low.

· Basically, a new bridge will be constructed on a different route.

· A cofferdam will be installed and half-river construction will be carried out to secure the flow canal.

· Existing roads will be used as construction roads.

· The work yard will be located on flat land within the adjacent bund.

· Materials and equipment will basically be procured in the adjacent Sehwan (L=1km).

· Construction Procedure

The steps of the construction process are as follows. ② to ⑥ will be construction in half-river.

1. Preparation work

2. Removal work
3. Excavation work
4. Substructure
5. Bed protection work
6. Embankment work
7. Superstructure
8. Bank protection work (including foundation work)
9. Split stone cladding (inside the bank; empty cladding)
10. Top paving work (crushed stone pavement)

4.8.3 Construction Cost

Calculate the construction costs for the three options considered. Compensation costs for land acquisition, house relocation, etc. are not included. The results are shown in Table 4.8.2. Detailed results are summarized in the appendix.

Table 4.8.2 Construction Cost for Manchar Lake Drainage System Improvement

Case name	Construction length (m)	Canal section (m)	Lake interior (m)	Project Cost (million PKR)	Notes
ALT 1	5,080	3,520	1,560	43,594	Diversion canal plan
ALT 2	6,380	1,920 (RBOR2) 2,460	2,000	40,448	RBOR2 widening plan
ALT 3	3,940	1,960	1,980	27,013	Aral Tail widening plan

Source: Advisory Team

4.8.4 Evaluation of the Recommended Project

Table 4.8.3 summarizes the evaluation and validity of various features of the Widening Existing Canal(Aral Tail) recommended in this study and the New Spillway which is the second option. From the comparison in Table 4.8.3, it can be said that it is valid to implement the Widening Existing Canal(Aral Tail) recommended in this study. On the other hand, it is recommended that the New Spillway be considered as one of the options in the F/S stage and that a comparative study be conducted again after studying more in detail.

Table 4.8.3 Evaluation of the Project on Enhancement of Drainage System of the Manchar Lake Basin

Item	Alternative 3: Widening Existing Canal(Aral Tail)	Alternative 1: New Spillway	Remarks
Structure Measure	Spillway: L=3.0km+(Lake Area)2.0km Canal Width: W= 80 m → 100m Improvement of Aral Head Regulator: 5 Gates x 6 m x 7.3 m → 5 Gates x 15 m x 7.3 m Railway Bridge：1 nos./ L=100m, W=5m Road Bridge：2 nos. / L=100m, W=12m	Drainage Canal: L=3.6km+(Lake Area)1.7km Canal Width W= 100m Inlet Control Gate： 1 Unit / 5 Gates x 15 m x 7.8m Outlet Control Gate： 1 Unit / 5 Gates x 15 m x 8.3m Railway Bridge：1 nos. / L=150m, W=5m Road Bridge：1 nos. / L=100m, W=20m	
Effect To Reduce Damages	・ It is expected to have the effect of reducing flood damage for the entire basin of Manchar Lake.[1)] ○	Same as the Left ○	
Socio-Environment	・ Although relocation of houses is necessary, there are no densely populated areas within the project-affected area. ・ Affects the operation of the existing Aral Tail Regulator and the use of road bridges and railway bridges, but is not fatal. ○	・ The number of houses targeted for relocation is small. ・ Does not affect the operation of the existing Aral Tail Regulator or the use of road bridges and railway bridges. ◎	
Construction/ Difficulty	・ Can be constructed using locally available materials and common construction methods. ・ Since the construction will be carried out with the operation of the existing Aral Tail, it will be necessary to consider the construction timing, construction methods, and temporary construction work. ○	・ Can be constructed using locally available materials and common construction methods ・ Construction is easy as it will be a newly constructed canal. ◎	It is assumed that the gates can be procured within Pakistan, but it is necessary to consider the use of stainless steel gates (imported from Japan or a third country) in the subsequent stage, considering maintenance after installation.
Cost	・ Suitable scale for Yen Load ・ The scale of the facilities is small and the cost is low. 27.1 Billion PKR ○	・ Due to the scale of the structures, the cost is high. ・ Depending on the soil characteristics (Rock), the excavation cost of the high ground in the middle of the spillway route may be increased. ・ If the number of the control gates is reduced from 2 to 1, this option may be the most optimum. 43.6 Billion PKR △	Costs may increase due to consideration of climate change adaptation measures The feasibility of reducing the number of control gates in Alt.1: The New Spillway channel needs to be verified from safety and operational aspects, considering the water level and duration of floods on the Indus River, the ground height on the land side, and the bund height.
Validity	Valid ・ Most recommended in this study	Inferior due to the Cost Efficiency ・ Recommend as one of the most likely options	

Note: 1） This study does not include the calculation of the quantitative damage reduction effects or economic analysis.
Legend: ◎. preferable; ○. No Problem; △.With Issues
Source: Advisory Team

TECHNICAL ADVISOR
ON
FLOOD MANAGEMENT
IN
ISLAMIC REPUBLIC OF PAKISTAN

FINAL REPORT
VOLUME-2
PRELIMINARY FEASIBILITY STUDY
APPENDIX

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CHAPTER 1 RECORD OF SITE SURVEY

1.1 Site Survey Result, Sukkur Barrage Downstream, Right Bank of Indus River, August 2023

1.1.1.1 Selection of Site Survey Location

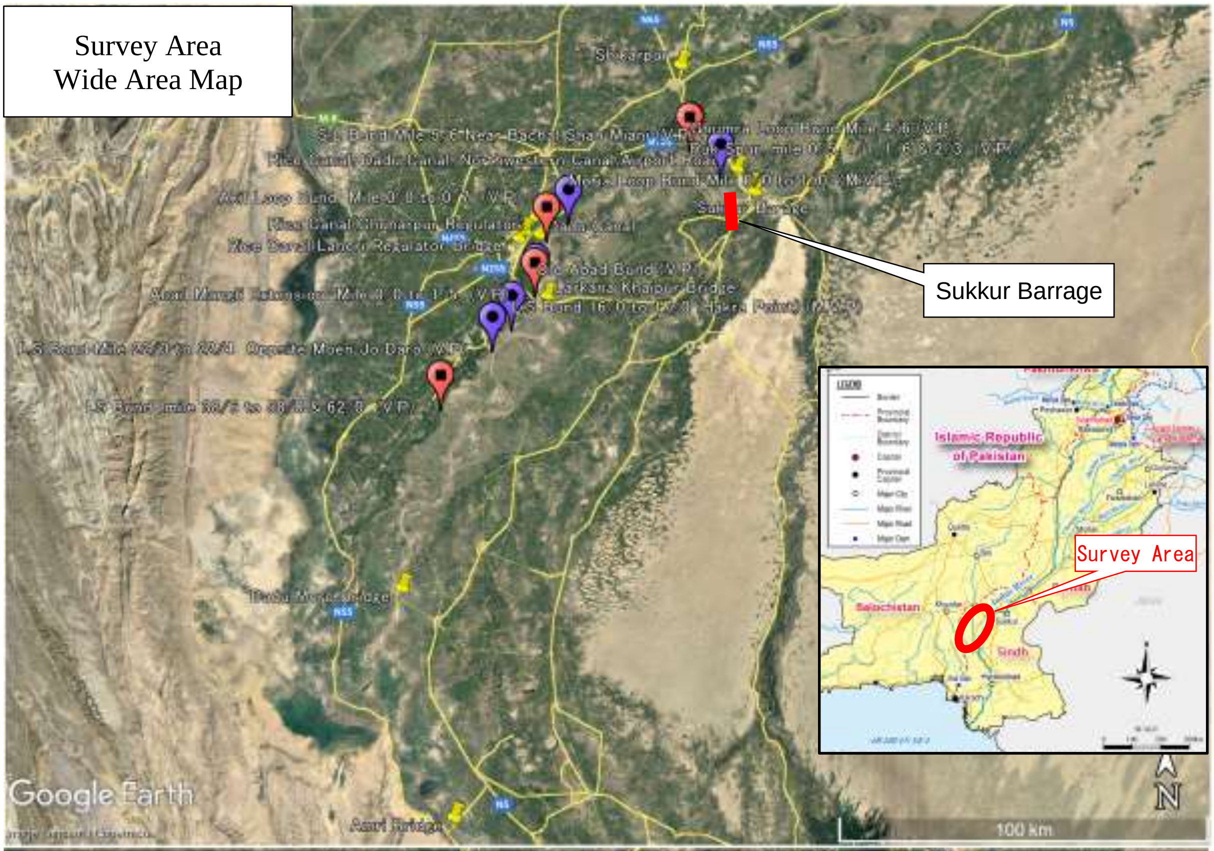
Target area of site survey is RBOD area which is in the downstream of the Sukkur Barrage on the right bank of the Indus River in Sindh Province. Areas identified as high risk for bund breach were selected for field survey.

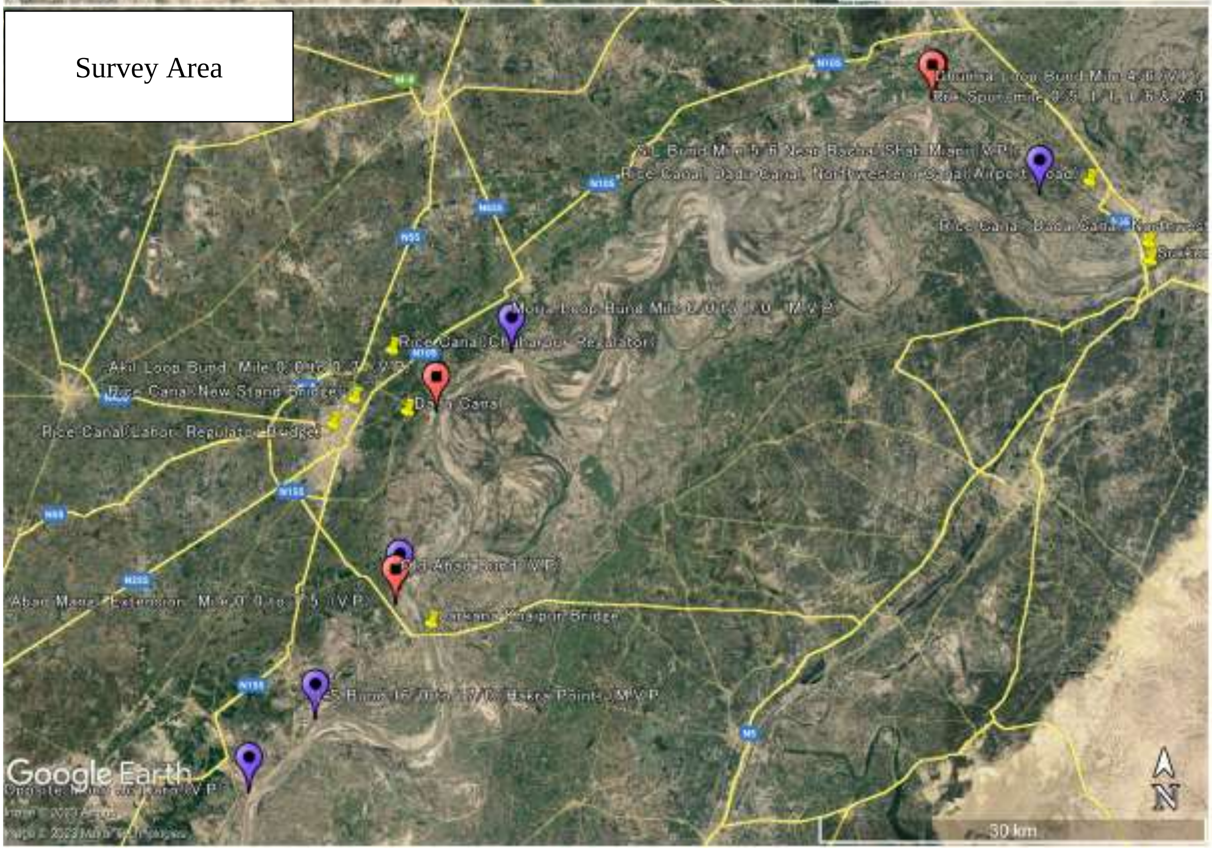
In order to analyze the risk of existing bund breach, satellite image analysis was conducted with reference to the list of vulnerable bunds prepared by the vulnerability study of Sindh Irrigation Department (conducted in the Sindh Contingency Plan,2023).

Table 1.1.1 Field Survey Schedule

Date	Schedule, Survey Area
August 1, 2023 (Tue) - Travel Day	Islamabad (15:40)→[PIA 631]→Sukkur (18:00)
August 2, 2023 (Wed) - Field Survey	Sukkur·Area (Sukkur Barrage, Indus River Right Bank) 1-1. Sukkur Barrage, Chief Engineer's Office 1-2. Ruk Spur, mile 0/5, 1/1, 1/6, 2/3 (V.P.) 1-3. Ghumra Loop Bund, mile 4/6 (V.P.) 1-4. S.L.·Bund, mile·5/6 Near·Bachal Shah Mianji (V.P) 1-5. Rice Canal, Dadu Canal, Northwestern Canal (Airport Road)
August 3, 2023 (Thu) - Field Survey	Larkana & Dadu Area (Indus River Right Bank) 2-1. Moria Loop Bund, mile 0/0 to 1/0 (M.V.P) 2-2. Akil Link Bund, mie 0/0 to 0/7 (V.P) 2-3. Rice Canal (Chuharpur Regulator) 2-4. Rice Canal (New Stand Bridge) 2-5. Rice Canal (Lahori Regulator Bridge) 2-6. Old Abad Bund (V.P) 2-7. Larkana Khairpur Bridge
August 4, 2023 (Fri) - Field Survey - Travel Day	Larkana Area (Indus River Right Bank) 3-1. Abad Mangli Extension, mile 0/0 to 1/5 (V.P) 3-2. L.S. Bund, mile·16/0 to 17/0 (Hakra Point) (M.V.P) 3-3. L.S. Bund, mile·22/0 to 22/4, Opposite Moen Jo Daro (V.P) Sukkur (18:50)→[PIA 632]→Islamabad (20:50)

Note: V.P: Vulnerable Point, M.V.P: Most Vulnerable Point



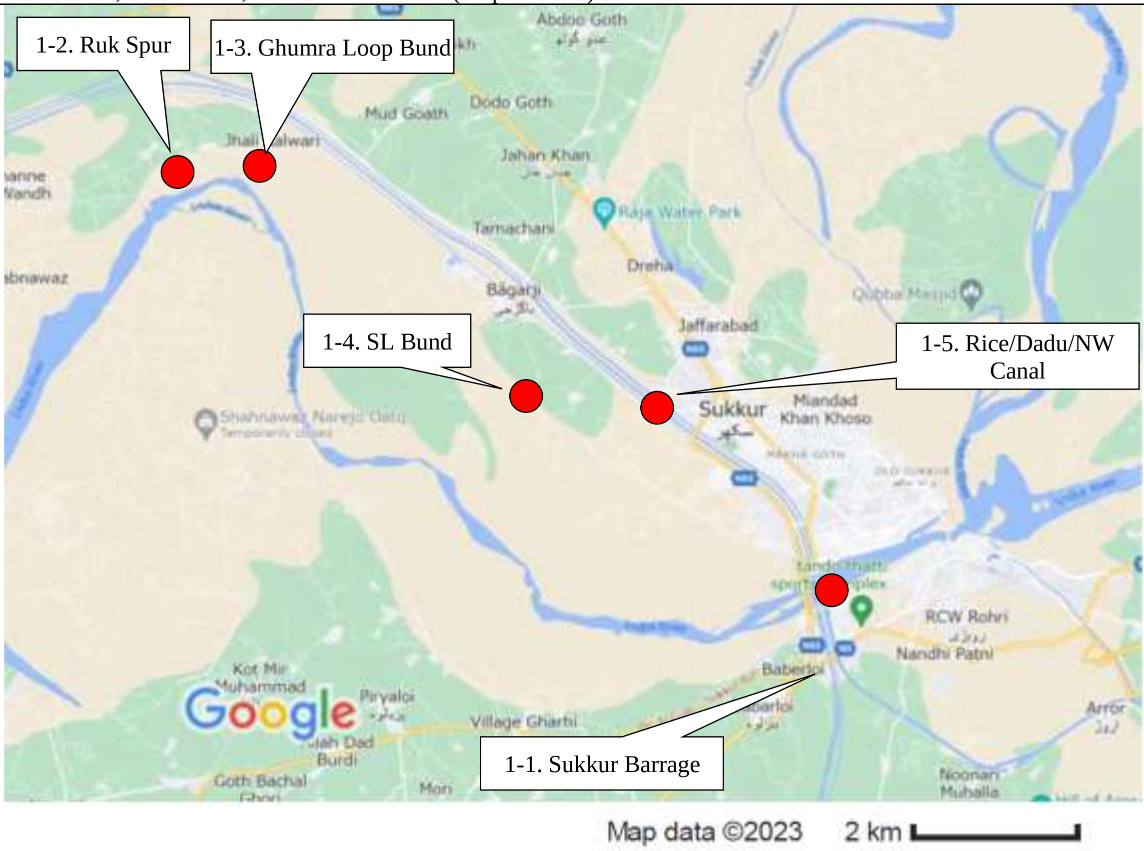


Source : Advisor Team Prepared based on the image obtained from Google Earth

Figure 1.1.1 Location Maps of Field Survey, August 2～4, 2023

1.1.1.2 August 2, 2023: Sukkur· Area (Sukkur Barrage, Indus River Right Bank)

1-1. Sukkur Barrage, Chief Engineer's Office 1-2. Ruk Spur, mile 0/5, 1/1, 1/6, 2/3 (V.P.) 1-3. Ghumra Loop Bund, mile 4/6 (V.P.) 1-4. S.L.·Bund, mile·5/6 Near·Bachal Shah Mianji (V.P) 1-5. Rice Canal, Dadu Canal, Northwestern Canal (Airport Road)



Source : Advisor Team Prepared based on the image obtained from Google Map

Figure 1.1.2 Location Maps of Field Survey in Sukkur Area, August 2, 2023

(1) 1-1. Sukkur Barrage, Chief Engineer's Office

1) Sukkur Barrage

Sukkur barrage was completed in 1932. 10 of the 66 gates in Sukkur barrage were closed in 1944.

Table 1.1.2 Discharge Volume at Sukkur Barrage

Item	Discharge Volume
Original Design	1.5 million cusec (42,450 cu.m/sec)
After Gate Closer	0.9 million cusec (25,470 cu.m/sec)
Flood in 2010	1.2 million cusec (33,960 cu.m/sec)

Note: 1foot = 0.3048m = 12inch, 1cubic foot = 0.0283cubic meter

Main irrigation canal taking water from Sukkur Barrage are follows.

Right Bank, Irrigation Canal

- NWC (Northwestern (Kirthar) Canal)
- Rice Canal
- Dasu Canal

Left Bank, Irrigation Canal

- Nara Canal
- Rohri Canal
- KFE (Khairpur Feeder East) Canal
- KFW (Khairpur Feeder West) Canal

- Elevation and distance from Guddu Barrage to Arabia Sea are as follows.

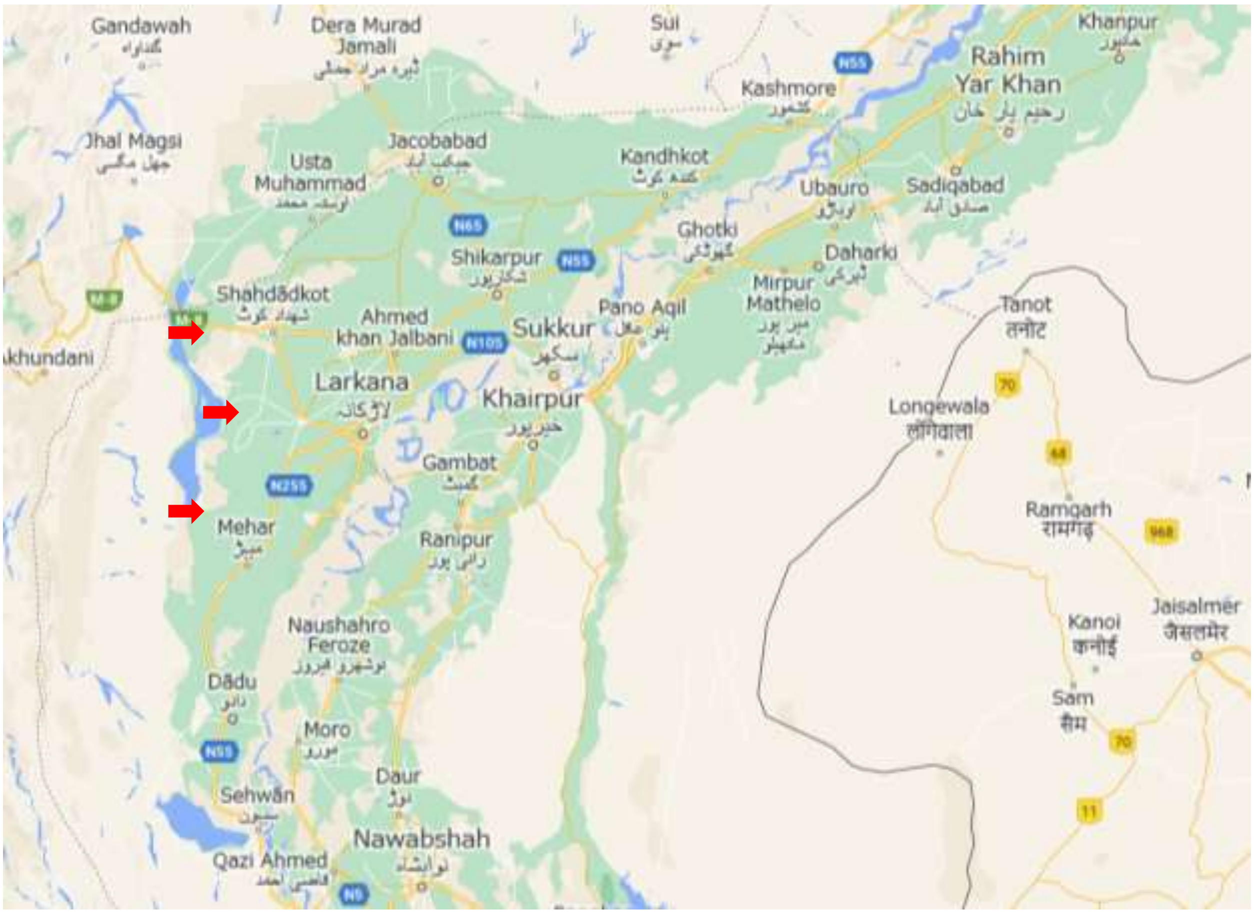
Location	Elevation	Distance
Guddu Barrage	RL 252	
	(dRL 80)	100 miles
Sukkur Barrage	RL 172	
	(dRL 105)	286 miles
Kotri Barrage	RL 67	
	(dRL 67)	143 miles
Arabian Sea	RL 0	

2) Interview at Chief Engineer's Office, Sukkur Left Bank Region

Mr. Syed Sardar Ali Shah, Chief Engineer, Sukkur Barrage Left Bank Region

- 2023 was a drought year. Irrigation water was insufficient from May 15 to June 15, 2023.
- During the 2022 flood, runoff from the Sulaiman Mountains flowed through DG Khan into the Indus River. (Those flood water did not come to the RBOD area.)
- In RBOD area, following facts were occurred during the 2022 flood:
  ① Some breaches of dikes and overflow of canal were occurred in Balochistan province which is located in the north of RBOD area.
  ② Three breaches were occurred at FP Bund RD 440, 348 and 200.
  ③ Three breaches also occurred at the north bank of Lake Manchar (one natural breach caused by overtopping and two artificial breach)

1mile = 1.609344km = 1,760 yard	3feet = 1yard = 0.9144m	1RD = 5,000feet = 1,524m



Source ：Advisor Team Prepared based on the image obtained from Google Map

Figure 1.1.3 Breach Locations in FP Bund during 2022 Flood (3 locations: RD 440, 348, 200)

3) Mr. Shah Fayaz: Superintending Engineer, Khairpur Irrigation Circle

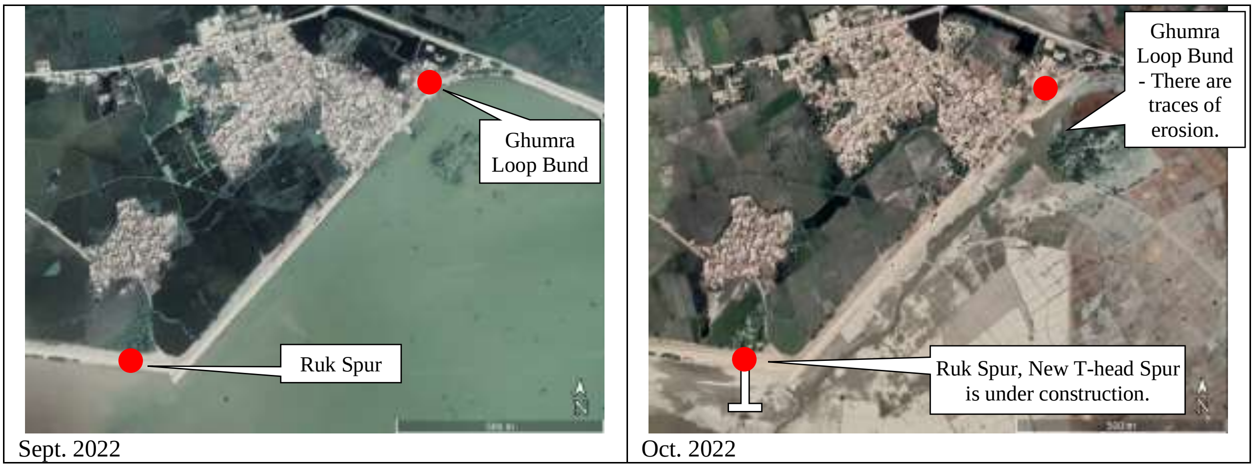
⇒in charge of Sukkur Barrage Downstream Left Bank Irrigation Network

- There are about 8~10 Vulnerable Points in the range from Sukkur to 64mile downstream on the left bank.

(2) 1-2. Ruk Spur, mile 0/5, 1/1, 1/6, 2/3 (V.P.), 1-3. Ghumra Loop Bund, mile 4/6 (V.P.)

A new T-Head Spur Dike is being constructed in Ruk Loop Bund. The construction material, limestone, is being brought from a quarry in Mount Arror, Rohri (southeast of Sukkur).

In Ghumra Loop Bund, Stone Pitching on the slope and Stone Aprons on the slope bottom (foot of the dike) are required.



Source : Advisor Team Prepared based on the image obtained from Google Earth

Figure 1.1.4 Ruk Spur and Ghumra Loop Bund, Condition during 2022 Flood

Source : Advisor Team

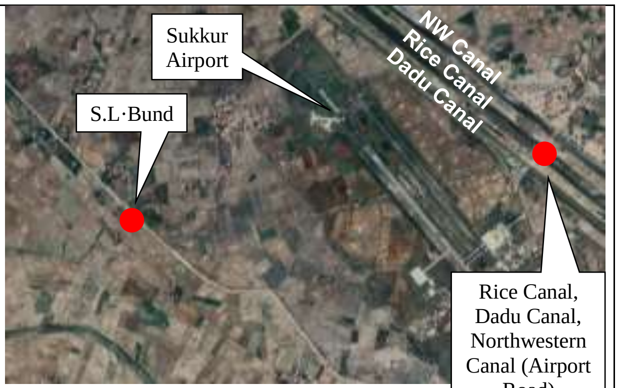
Photo 1.1.1 Ruk Spur, August 2, 2023

Source : Advisor Team

Photo 1.1.2 Ghumra Loop Bund, August 2, 2023

(3) 1-4. S.L.·Bund, mile·5/6 Near·Bachal Shah Mianji (V.P), 1-5. Rice Canal, Dadu Canal, Northwestern Canal (Airport Road)

S.L.-Bund can be considered an important bund to protect the Sukkur airport from river flood, and although it was categorized in vulnerable point, no major problems were found in the field survey.



Source : Advisor Team Prepared based on the image obtained from Google Earth

Figure 1.1.5 Locations of S.L Bund, Dadu/Rice/NW Canal, Sukkur Airport

Gully erosion of slope on outer (land) side of bund

Thin sections of bund width

Source : Advisor Team

Photo 1.1.3 S.L Bund, August 2, 2023

Bridge across three major irrigation canals

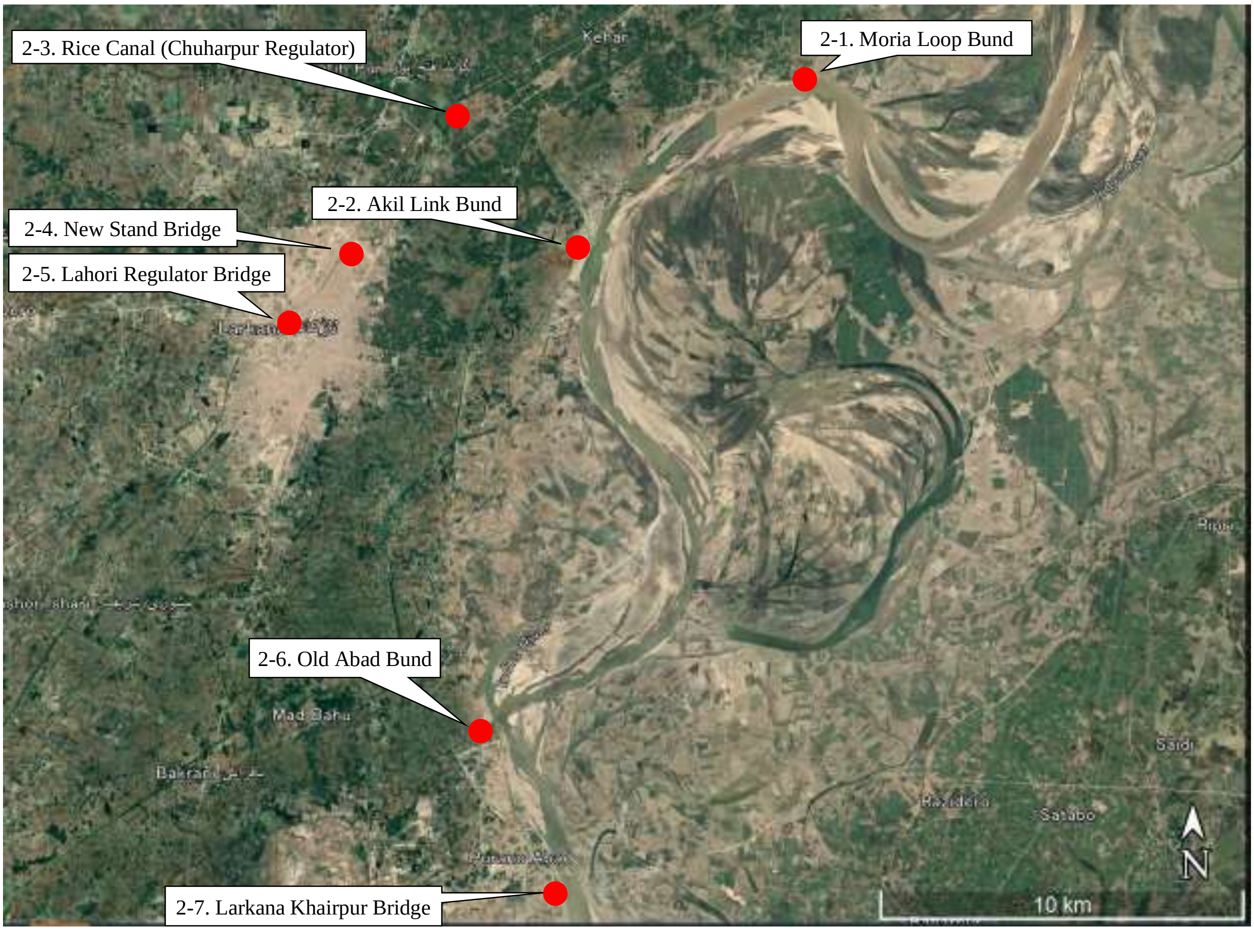
Uneven pier heights, tilted abutments/piers

Source : Advisor Team

Photo 1.1.4 Dadu Canal, Rice Canal and NW Canal, August 2, 2023

1.1.1.3 August 3, 2023: Larkana & Dadu Area (Indus River Right Bank)

2-1. Moria Loop Bund, mile 0/0 to 1/0 (M.V.P) 2-2. Akil Link Bund, mie 0/0 to 0/7 (V.P) 2-3. Rice Canal (Chuharpur Regulator) 2-4. Rice Canal (New Stand Bridge) 2-5. Rice Canal (Lahori Regulator Bridge) 2-6. Old Abad Bund (V.P) 2-7. Larkana Khairpur Bridge

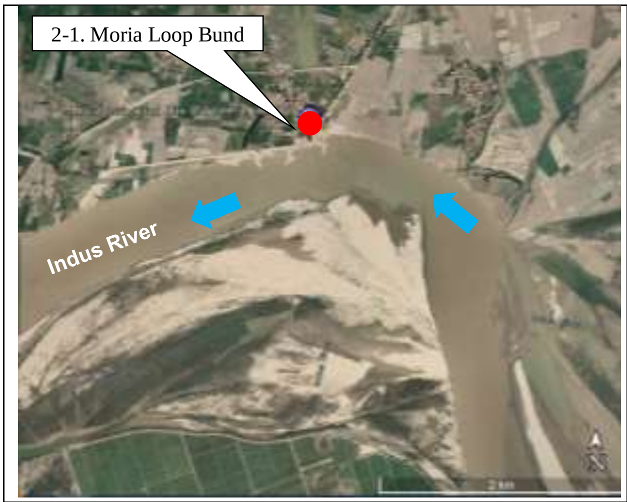


Source：Advisor Team Prepared based on the image obtained from Google Earth

Figure 1.1.6　Location Maps of Field Survey in Larkana & Dadu Area, August 3, 2023

(1) 2-1. Moria Loop Bund, mile 0/0 to 1/0 (M.V.P)

Rehabilitation of the T-Head Spur Dike, which was constructed in 2018 and damaged by the 2022 flood, is underway at Moria Loop Bund.



Source：Advisor Team Prepared based on the image obtained from Google Earth

Figure 1.1.7　Location of Moria Loop Bund and Spur Dike

Restoration works of T-Head Spur


Design plan of Spur Dike under restoration

Source : Advisor Team

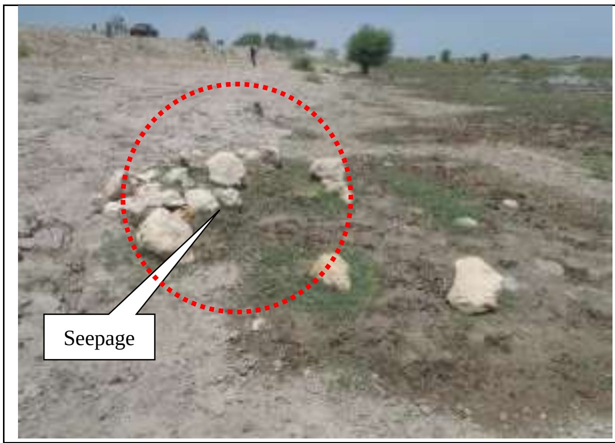
Photo 1.1.5 T-Head Spur Dike under restoration at Moria Loop Bund, August 3, 2023

(2) 2-2. Akil Link Bund, mie 0/0 to 0/7 (V.P)

In Akil Link Bund, seepages are observed at the land side slope of bund.

Source : Advisor Team Prepared based on the image obtained from Google Earth

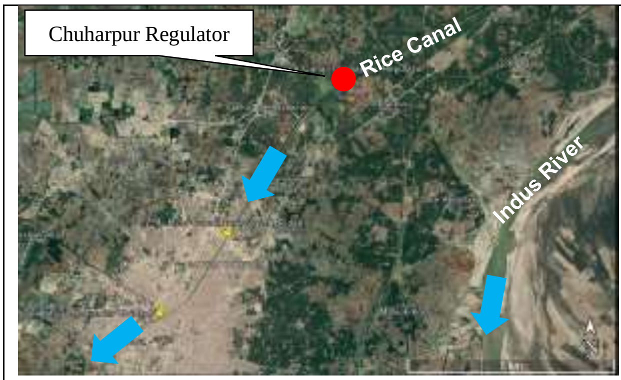
Figure 1.1.8 Condition around Akil Link Bund



Source : Advisor Team

Photo 1.1.6 Akil Link Bund, August 3, 2023

(3) 2-3. Rice Canal (Chuharpur Regulator)



Source : Advisor Team Prepared based on the image obtained from Google Earth

Figure 1.1.9 Location of Rice Canal, Chuharpur Regulator

Chuharpur Regulator

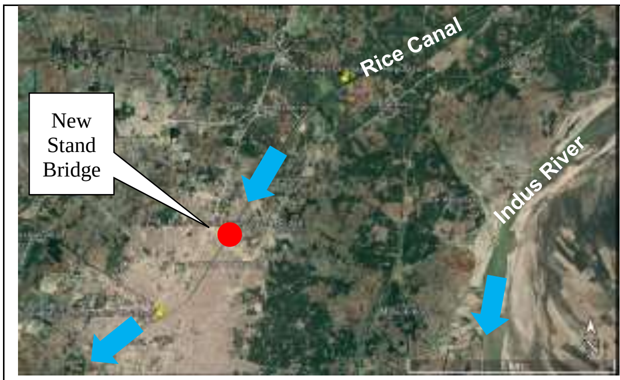
Banks of branch canal are eroding.

Banks of branch canal are eroding.

Source : Advisor Team

Photo 1.1.7 Rice Canal, Chuharpur Regulator, August 3, 2023

(4) 2-4. Rice Canal (New Stand Bridge)



Apr. 2023

Apr. 2023

Source : Advisor Team Prepared based on the image obtained from Google Earth

Figure 1.1.10 Location of Rice Canal, New Stand Bridge

Downstream view of Rice Canal from New Stand Bridge

Upstream view of Rice Canal from New Stand Bridge

Source : Advisor Team

Photo 1.1.8 Rice Canal, New Stand Bridge, August 3, 2023

(5) 2-5. Rice Canal (Lahori Regulator Bridge)

Source : Advisor Team Prepared based on the image obtained from Google Earth

Figure 1.1.11 Location of Rice Canal, Lahori Regulator Bridge

Lahori Regulator on Rice Canal

Ghar Branch Intake

Source : Advisor Team

Photo 1.1.9 Rice Canal, Lahori Regulator Bridge, August 3, 2023

(6) 2-6. Old Abad Bund (V.P)

Old Abad Bund is experiencing scour and erosion due to water flow of Indus River.

Source : Advisor Team Prepared based on the image obtained from Google Earth

Figure 1.1.12 Condition around Old Abad Bund

Source : Advisor Team

Photo 1.1.10 Old Abad Bund, August 3, 2023

Embankment work in progress

Reed screen to prevent erosion by waves

Source : Advisor Team

Photo 1.1.11 Construction Works at Old Abad Bund, August 3, 2023

(7) 2-7. Larkana Khairpur Bridge

Larkana-Khairpur Bridge was opened for public in 2009. Prior to that, there were no transportation facilities across Indus River in the approximately 150 km section between Sukkur Barrage and Dadu Moro Bridge.

Source : Advisor Team Prepared based on the image obtained from Google Earth

Figure 1.1.13 Location of Larkana Khairpur Bridge

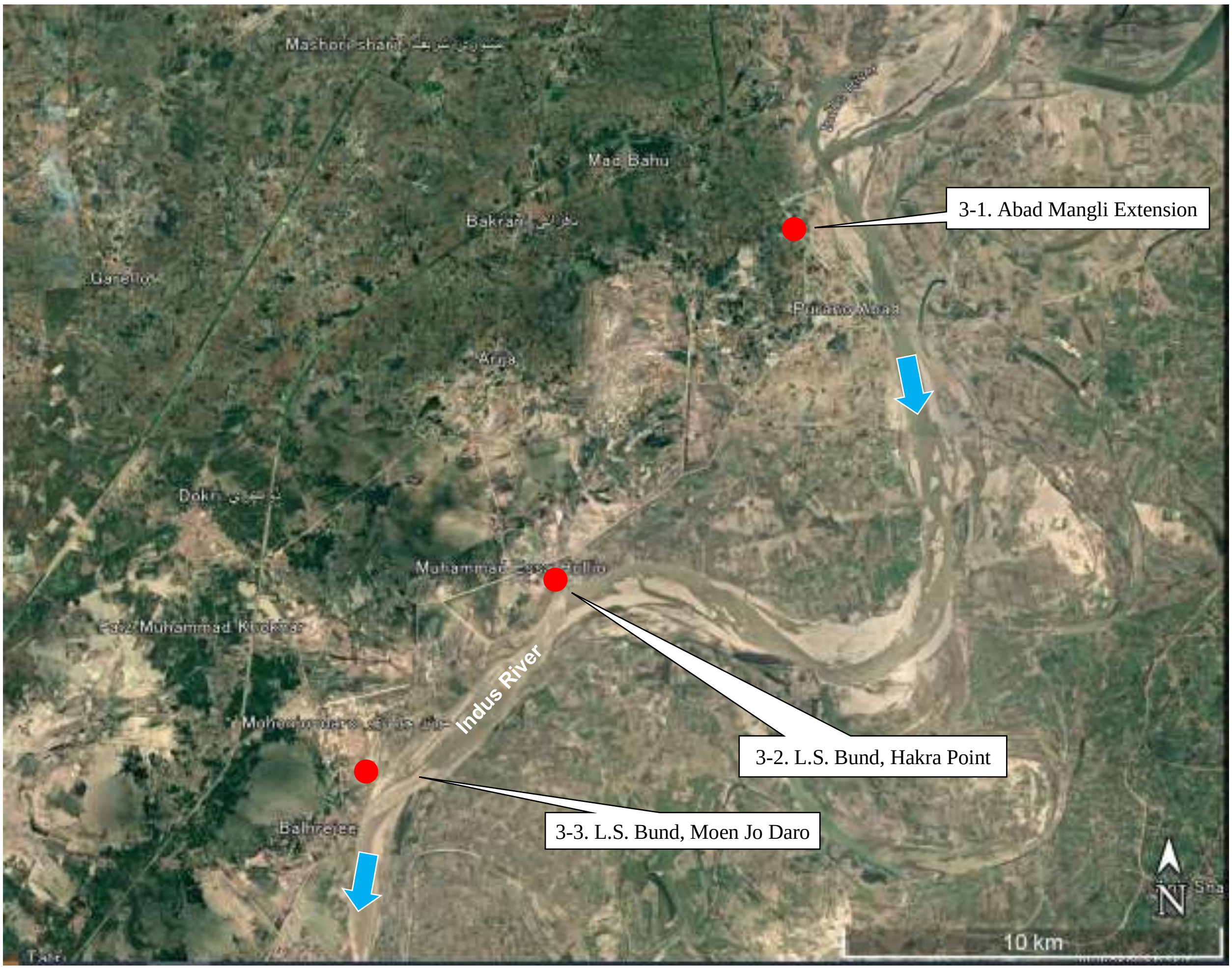
River side slope of Guide Bund is protected by stone pitching.

Source : Advisor Team

Photo 1.1.12 Larkana Khairpur Bridge and Guide Bund, August 3, 2023

1.1.1.4 August 4, 2023: Larkana Area (Indus River Right Bank)

3-1. Abad Mangli Extension, mile 0/0 to 1/5 (V.P)
3-2. L.S. Bund, mile·16/0 to 17/0 (Hakra Point) (M.V.P)
3-3. L.S. Bund, mile·22/0 to 22/4, Opposite Moen Jo Daro (V.P)



Source : Advisor Team Prepared based on the image obtained from Google Earth

Figure 1.1.14 Location Maps of Field Survey in Larkana Area, August 4, 2023

(1) 3-1. Abad Mangli Extension, mile 0/0 to 1/5 (V.P)

According to PID Sindh, restoration of stone pitching and stone aprons on dike slopes are required, but due to the effect of J-Head Spur located downstream of Abad Mangli Extension, the risk of erosion caused by river flow was not so high and the restoration work was not considered to be urgent.

Source : Advisor Team Prepared based on the image obtained from Google Earth

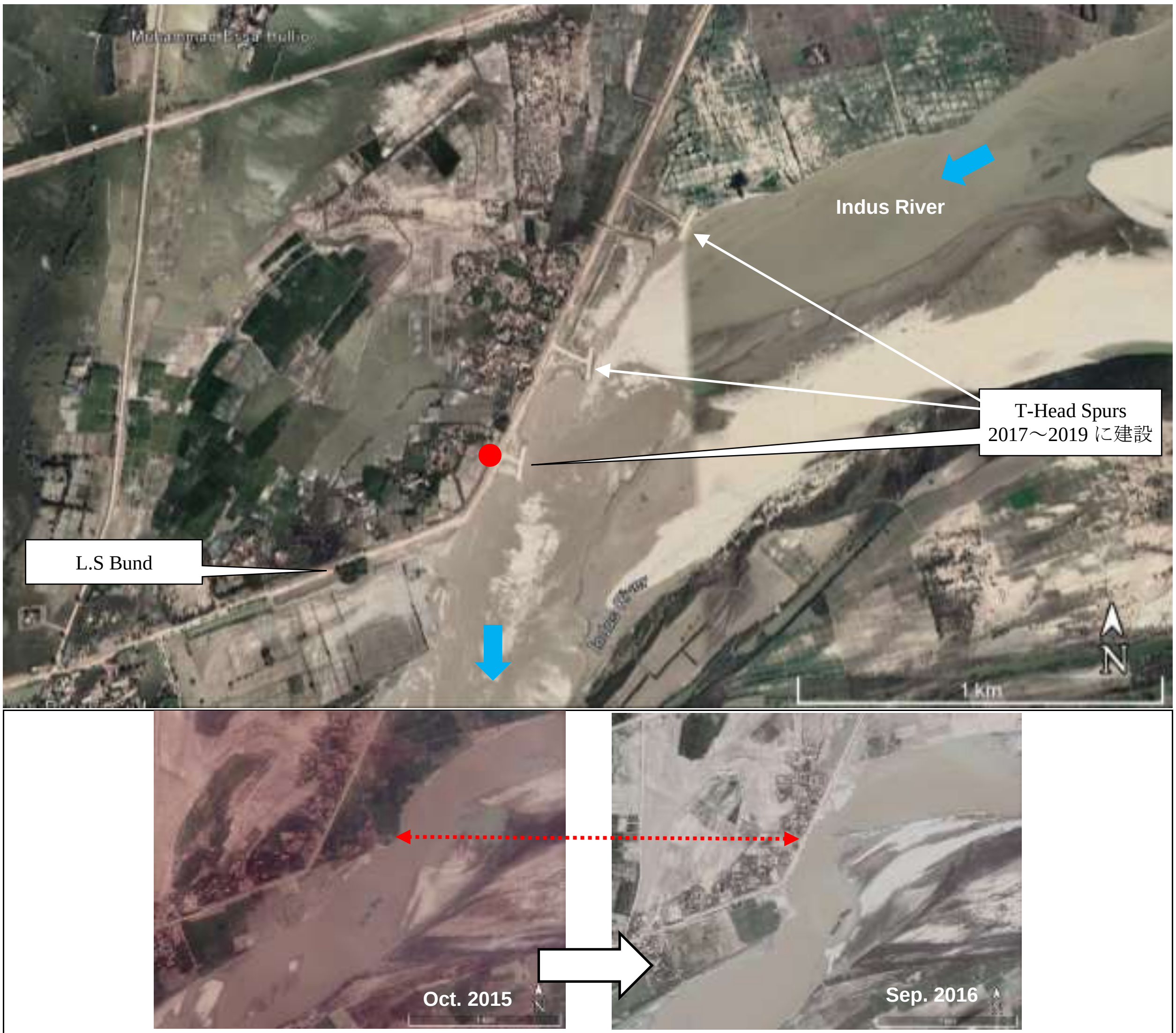
Figure 1.1.15 Location of Abad Mangli Extension, August 4, 2023

Source ：Advisor Team

Photo 1.1.13　Abad Mangli Extension, August 4, 2023

(2) 3-2. L.S. Bund, mile·16/0 to 17/0 (Hakra Point) (M.V.P)

Around 2016, Indus River flow started hitting this location of bund directly, and several T-Head Spurs have been constructed to protect bund. Spur Dikes have been properly maintained.



Since 2016, sediment in front of bund (on river side) has been washed away, exposing bund directly to the flowing water.

Source ：Advisor Team Prepared based on the image obtained from Google Earth

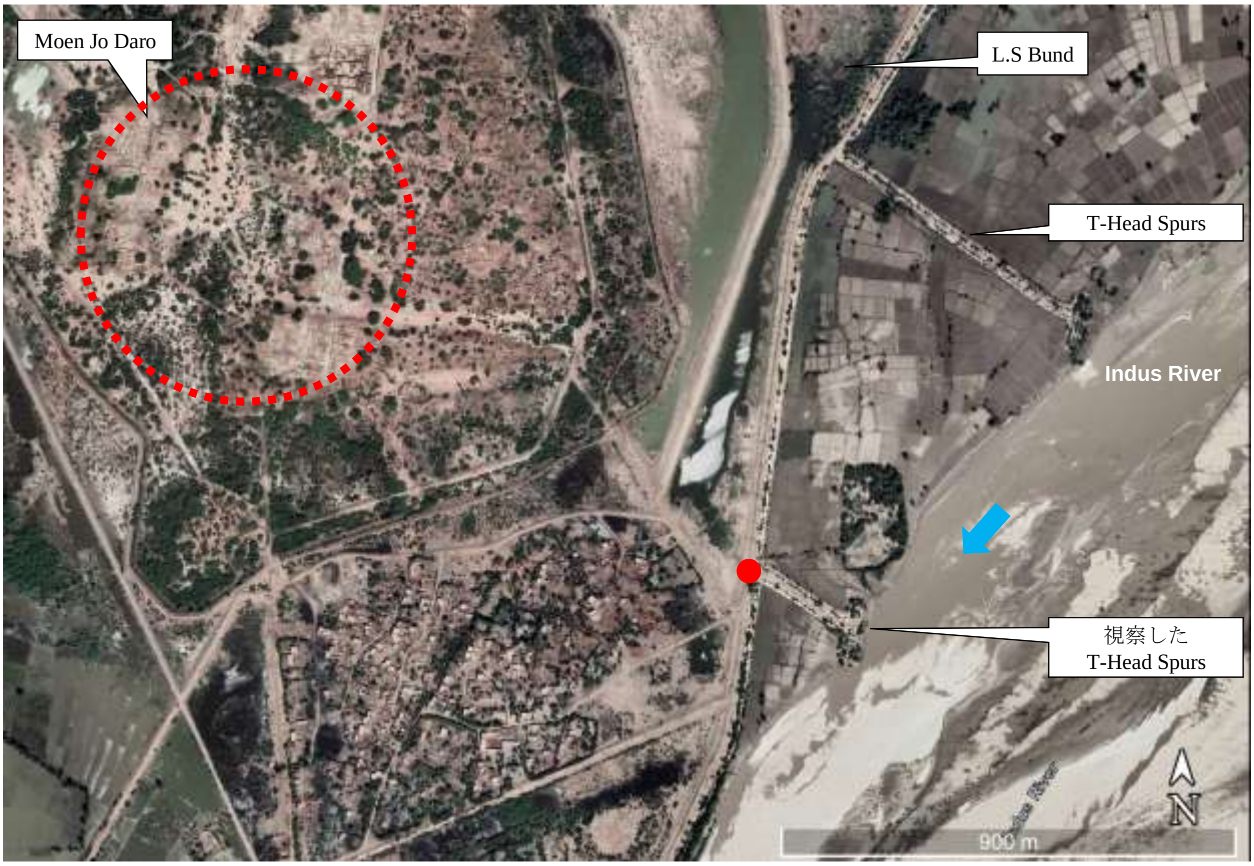
Figure 1.1.16　Location of L.S. Bund, Hakra Point, August 4, 2023

Source : Advisor Team

Photo 1.1.14 T-Head Spur at L.S. Bund, Hakra Point, August 4, 2023

(3) 3-3. L.S. Bund, mile·22/0 to 22/4, Opposite Moen Jo Daro (V.P)

This part of L.S Bund is located a few hundred meters from the Archaeological Ruins at Moen Jo Daro, one of the largest urban ruins of Indus civilization and a World Heritage, the bund plays an important role in protecting the Moen Jo Daro and the surrounding town. The vegetation taking root on the Spur Dike indicates that it has not often suffered from washing away or erosion in recent years. The multiple Spur Dikes control the flow path of Indus River, and although the L.S Bund and Indus River are in close proximity, L.S Bund appears to be safely protected.



Source ：Advisor Team Prepared based on the image obtained from Google Earth

Figure 1.1.17 Location of L.S. Bund, Opposite Moen Jo Daro, August 4, 2023

L.S Bund

Moen Jo Daro is visible from L.S Bund.

Source ：Advisor Team

Photo 1.1.15 L.S. Bund, Opposite Moen Jo Daro, August 4, 2023