DRAFT FEASIBILITY

ON

REHABILITATION AND IMPROVEMENT OF LBOD DRAINAGE INFRASTRUCTURE

LBOD RD 789

VOLUME I

MAIN REPORT

CONVERSION FACTORS AND STANDARD DRAIN BED SLOPES

Length

1m	=	3.281 ft				
1 km	=	1000 m	=	3281 ft	=	0.621 mile

Area

1 m^2	=	10.765 ft^2	
1 ha	=	2.471 acres	
1 km^2		100 ha	0.386 $mile^2$

Volume

1 m^3	=	35.320 ft^3

Velocity

1 m/sec	=	3.281 ft/sec

Flow Rate

1 m^3/sec		35.32 ft^3/sec

Standard Drain Bed Slopes

1:1000	=	0.001	(100 mm fall in 100 m)
1:2000	=	0.0005	(50 mm fall in 100 m)
1:3000	=	0.00033	(33 mm fall in 100 m)
1:4000	=	0.00025	(25 mm fall in 100 m)
1:5000	=	0.0002	(20 mm fall in 100 m)
1:8000	=	0.000125	(12.5 mm fall in 100 m)
1:10000	=	0.0001	(10 mm fall 'in 100 m)

Glossary

Annual Cropped Area	The sum of the areas under Kharif and Rabi crops plus twice the area under perennial crops.
Bund	Embankment for retaining water. A large artificial embankment which protects agricultural land from river floods.
Cropping Intensity	The cropped area expressed as a percentage of the CCA.
Cropping Pattern	The proportion of cropland devoted to each crop during the year.
Crop Water Requirements	The total quantity of water regardless of source required by crops for normal growth under field conditions, including irrigation, precipitation and ground water available to the crop.
cfs	cubic feet of water per second.
Cultivable Commanded Area (CCA)	That portion of the cultivable area which is commanded by canal irrigation.
Fresh Ground water (FGW)	Ground water of salinity less than 1400 µs/cm which can be used directly for irrigation.
Gross Area (GA)	The total area within the extreme limits set by a project, system or canal.
Hari	Share cropper
Kharif	Summer crop season (mid April to mid October)
Maund	Unit of measures (40 kg).
Non-perennial Area	An area which receives allocations of canal water during part of the year only, usually from 16 April to 15 October.
Perennial Area	An area which receives allocations of canal water throughout the year.
Rabi	Winter cropping season (mid October to mid April)
Saline Ground Water (SGW)	Ground water of salinity greater than 1400 µs/cm which cannot be used for irrigation unless mixed with other water to reduce the salinity to below 1400 µs/cm

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Executive Summary

1. Introduction

LBOD Stage-I project area is located in Sindh, in the Lower Indus Basin. It lies between latitudes 24º 10' and 26º 40' N and Longitudes 68º 09' and 69º 26' E in the districts of Shaheed Benazirabad, Sanghar and Mirpur Khas. The project is located on the Left Bank of River Indus in the command of Sukkur Barrage. Major towns of the project area are Shaheed Benazirabad, Sanghar and Mirpur Khas. All the major towns of the area are either connected by metalled roads or by railway line.

The area served by the LBOD Drainage Network is given below: -

Drainage Component	GA (Acres)	CCA (Acres)
Nawabshah Component	626,000	554,500
Sanghar Component	424,000	362,500
Mirpur Khas Component	376,000	358,800
Badin Component	593,496	458,723
Total	**2019,496**	**1734,523**

2. Description of Project

The salient data of LBOD Network are given below: -

Sr. No.	Type of Drain	Total Nos.	Length in Miles
1	Sub-Drains	99	629.31
2	Branch Drains	6	130.82
3	Main Drains	5	207.934
4	Spinal Drains	1	131.4
5	DPOD	**1**	25.4
6	KPOD	**1**	36.08
7	Tidal Link	**1**	24.72

The drainage system of LBOD comprises of the following main drains: -

- Surface Drainage Network of Nawabshah Component.
- Surface Drainage Network of Sanghar Component.
- Surface Drainage Network of Mirpur Khas Component.
- Surface Drainage Network of Badin Area
- Spinal Drain
- Dhoro Puran Link Drain
- Dhoro Puran Outfall Drain (DPOD)
- Kadhan Pateji Outfall Drain (KPOD)
- Fuleli Guni Outfall Drain
- Karo Ghungro Outfall Drain
- Tidal Link

In the Lower Indus Report, drainage was considered at two levels. The first was within individual projects where only local drainage problems were considered, solved and the second concerned the disposal of drainage water outside the projects by means of a system of main drains discharging into an outfall drain. Branch and sub-drains would dispose the effluents of tube wells, tile drains and/or storm water runoff, within individual project areas. These were constructed as part of these projects. The construction of the main and outfall drains was a separate project built in stages to match the overall development program of the region.

3. Data Collection and Review of Previous Work on LBOD

The secondary data regarding planning, design, construction, operation & maintenance and monitoring of LBOD Network was collected from WAPDA, Sindh Irrigation Department, SIDA, NGOs and District Administration and other National Buildings Departments of Sindh Government at Hyderabad. The following important reports were also collected for their review: -

- Lower Indus Report (1966).
- Feasibility Study - National Drainage Program (1995).
- Pre- feasibility Study National Surface Drainage System (2003).
- Review Report: International Panel of Experts (IPOE) on Drainage Master Plan (2004).
- Drainage Master Plan of Pakistan (2005).
- Final Report. International Panel of Experts on Left Bank outfall Drainage System (2005).
- Inspection Panel Report on NDP (2006).
- Transition of SCARP Tube Wells to Private Sector (2008).
- Feasibility Report – Redesign of LBOD Stage-1 Badin Area Drainage System (2010).

4. Identifications of the Problems and Proposed Solutions

Problems of LBOD

Following are the major draw-backs and constraints of the LBOD drainage network to perform during heavy rain storm flows of 2003, 2006 and 2011.

- ➢ The existing drainage network is unable to drain the catchment areas of all three sub components of LBOD Project within a period of 3 to 5 days to minimize damage to standing crops, mostly cotton during Kharif.
- ➢ The inadequate F.B resulted in breaches at weak sections of Spinal Drain and over flowing at bridges and other structures.
- ➢ Inundation of low lying areas and towns due to breaches in irrigation and drainage network.
- ➢ There was submergence of main drains due to less working head like Mirpur Khas Main Drain, LBOD Branch drain and other direct drains out falling at their point of confluence with the Spinal drain.
- ➢ The rain-fall pattern in lower Sindh has been modified due to climate change phenomena with the result that the extreme events of rain fall have been recorded and those causing wide spread inundation in the cropped areas would continue to do so in future also.
- ➢ Due to weak sections and breaches the number of structures like Water Course- Crossings, Inlets and Bridges were completely washed away.
- ➢ Increased sea intrusion and entry of salt water at control points of Outfall Drains.
- ➢ Absence of control structure to check tidal effect.
- ➢ The irrigation water of escapes and breaches of the irrigation distribution network when added with the storm water played havoc with the neighboring Towns and Villages and Abadies and damaged infra structure in the area i.e. road network and protections bunds.
- ➢ Fishing Nets installed all over drainage network are damaging prism of drains.
- ➢ Absence of On-Farm Drainage.

Proposed Solutions

Following are the proposed structural measures: -

- ✓ Rehabilitate the Sub Drains, Main and Branch Drains and Spinal Drain for a return period of 20 years with actual rain fall intensity recorded during storm water flows of 2011.
- ✓ Raising and strengthening banks of drainage network to provide F.B to water levels of 2011 to avoid over flow and breaches to the system.

- ✓ Re-activation of Dhoro Puran, the old natural river course to restore natural drainage.
- ✓ Off loading of Spinal Drain with the minimum discharge of 3000 cfs by constructing 03 side weirs.
- ✓ Provide inlets at the sites of relief cuts made by the farmers for early evacuation of storm water along main drainage system.
- ✓ Construct siphons at outfall points of MMD and LBOD Branch Drains to divert storm water flows into Old Dhoro Puran natural drainage water way and this will release presser from Spinal Drain.
- ✓ Construct additional Inlets on Sub Drains to support On–Farm Drainage.
- ✓ Construct additional new Bridges as per need of the area.
- ✓ Construct a Tidal Control Structural at RD 22 of KPOD to cut off entry of sea water into the LBOD system and to protect ecosystem of adjoining areas.
- ✓ Contract a Gated Structure at RD 52 of KPOD to off load 1000 cfs from KPOD to Runn of Kutch.
- ✓ Increase the design capacity of DPOD to 6000 cfs for diverting maximum storm water of Spinal Drain.
- ✓ Increase the design capacity of KPOD to 7000 cfs for diverting maximum storm water of Spinal Drain for the benefit of locals.
- ✓ Provide Mobile Pumping Stations for drainage of low lying areas of Badin
- ✓ Provide Permanent pumping station at RD 792 of Spinal Drain to pump 1000 cfs into Jamarao Canal. This would also solve drainage problem of Nawabshah component.
- ✓ Provide On-Farm Drainage through community. This is must for extreme event of rainfall in the project area.

5. Hydrology of Project Area

Flowing are the Hydrologic parameters adopted for the redesign of the LBOD drainage network:

- ✓ Return period for the estimation of storm water flows. 20 Year
- ✓ 24 hour rainfall at Badin for 20 year return period. 196 mm
- ✓ Estimated storm water flow at RD 159 of Spinal Drain. 9,000 cfs
- ✓ Total storm water flow from the project for above return period. 12,000 cfs

The results obtained for drainage coefficient by using HEC-HMS model are given below: -

Sr. No.	Drainage Component	Design Drainage Coefficient (cfs/sq.mile)	Required Drainage Coefficient (cfs/sq.mile)	
			10 Years	20 Years
1.	Nawabshah	0.72	2.4	3.0
2.	Sanghar	1.53	2.6	2.9
3.	Mirpur Khas	0.93	3.8	6.1
4.	Badin	2 – 3	4.5	7.0

The drainage capacity of existing system is to be enhanced to accommodate storm water flows of 20 year return capacity.

6. Hydraulic Aspects of LBOD Project

The system has been redesign to pass a maximum discharge of 9,000 cfs at RD 159 of Spinal Drain and a minimum free board of 2 feet has been provided from maximum water level achieved during storm flows of 2011. The last design water level and other hydraulic parameters would remain unchanged.

Using HEC-RAS model the Spinal Drain required parameters for rehabilitation of are given blow: -

RD	Flow Area	Water Surface Elevation	Discharge in Reach of Spinal Drain	Top Surface Width Required	Flow Depth	Flow Velocity
	sq.ft	ft	Cfs	ft	ft	ft/sec
815	925.12	69.81	2200	126.6	9.43	2.38
780	923.66	66.07	2200	126.54	9.42	2.38
722	1363.22	60.89	2700	163.82	11.39	1.98
638	1724.23	53.61	4330	208.68	13.11	2.52
295	2237.21	26.29	6128	212.86	15.69	2.76
203	3261.58	21.42	8120	240.25	16.72	2.5
164	3395.9	18.73	9000	263.79	16.68	2.77

The revised width of IP ranges from 20 to 50 feet and the width of the berms adopted as 20 to 30 feet with Free Board of 2 feet from maximum water level of 2011.

Rehabilitation of the Main and Branch Drains

A minimum berm width of 20 feet has been adopted for design of Main and Branch Drains with IP width ranging from 30 to 20 feet on both banks of the drains and also a minimum FB of 2 feet has been adopted for computing the dimensions of the above network. A value of Manning Roughness Coefficient of 0.025 has been used for determining the design capacity of the proposed Cross-Sections of above drains.

Rehabilitation of Sub Drains of LBOD Area

The sub-drains have been designed with the required drainage coefficient and with clear berm width of 15 feet on either side and the width of the IP as 20 feet along both the banks. The sub-drains would be provided with drainage inlets to facilitate the on farm drainage after every second RD along the length of sub drain.

Re-Design of KPOD of LBOD Area

It is proposed to redesign the KPOD with a outfall discharge of 7000 cfs and with berm width of 30 feet on either side and with IP width of 50 feet on both the banks and also a minimum FB of 2 feet has been provided for 2011 water levels. In order to check the tidal effect into KPOD a gated tide control structure is purposed at RD 22 of KPOD with complete protection works to its point of outfall with Tidal Link and with proper protection against bank erosion.

Re-Design of DPOD of LBOD Area

It is proposed to re-design the DPOD link from RD 127+000 to RD 110+000 with an outfall discharge of 6000 cfs. The berm width provided is 30 feet on either side and with IP width of 30 feet. The balance reach of the DPOD is covered under Draft Feasibility Study of Revival of Dhoras.

7. Engineering Design

Bridges

Three types of bridges are provided. District Road bridges are designed for class AA loading and have a carriage way width of 24 feet. Village Road Bridges have a carriage way width of 18 feet and are designed to carry class “A” loading on the sub-drains and branch drains where there is no bridge within 4 miles then a 12 feet span Culvert has been provided to give access to farmers owning irrigation lands across both banks.

Fluming at New Bridges

The present design involves no expenditure or protection of bed and side slopes against scours, and with thinking that fluming would also reduce the cost of the structure itself. This apparent saving is much less to additional pitching and abutment works actually required for safety of bridges. So no fluming is recommended at sites of new bridges.

Water-Course Aqueducts

The existing water-course aqueducts on spinal drains in outfall reach caused all breaches and over flows of spinal drain and inundation of adjoining villages during storm flow of 2011 as such from RD 297 to RD 159, the Terminal Point, the existing Box type Water Course Aqueducts have been replaced with pipe type and this should be repeated at all dangerous point of LBOD network. A typical design is shown in the accompanying Drawings.

The foundations of aqueducts are similar to those for existing bridges. At sites where the soffit of an aqueduct structure is below maximum water level in the sub-drain, inverted siphons will be used. Pipe siphons are preferred to cast-in-situ and most suitable for sub drains.

Drain Junctions

Drain junction structures are provided in order to prevent damage to the larger drain, when it is empty, by water flowing into it from smaller drain and also to provide a continuous access road along the drain. At sub-drain junctions a pipe structure and outlet boxes are employed, Stone pitching is provided around the inlets and outlets. For larger junctions a box culvert is recommended for sub-drains.

Drain Inlets

A structure of considerable interest is the drainage inlet which serves to pass the storm run-off through the drain bund into the drain. For this a simple pipe inlet is suggested. The diameter of the pipe is chosen by considerations of (i) the difference of head between water pounded behind the bund and that in the drain, (ii) the run-off in cfs per square mile and, (iii) the catchment area which drains to the particular inlet. Each inlet can be designed on this consideration. It is recommended that a drainage inlet is provided at each low point on the drain and in any case at the rate of one for every 2000 feet to 3000 feet of sub drain on each bank side.

The whole catchment should be divided into parts based on different irrigation system boundaries and the boundaries of the minor catchments. It is recommended that farmers should not be allowed to construct inlets of their own and no one should be permitted to cut banks of drainage network for immediate evacuation of rain water from their cropped area. The big landlords are particularly asked to stay away from drainage network. In case of repeated cutting of banks of drains, the drains in their area shall not be maintained.

8. Provision of Mobile Pumping Station for Badin Area

During the heavy monsoon rains of 2003, 2006 and 2011 storm water flooding and overtopping of drain embankments was reported. As a result vast areas of Shaheed Benazirabad, Sanghar, Mirpur Khas and Badin components were submerged with storm water. This was due to the fact that the storm water flows generated by the rains was more than the maximum capacity of drains and the situation was further aggravated by obstructions constructed by the locals, over a period of time, within the waterway of LBOD Branch Drain and Mirpur Khas Main Drain and other drains.

In order to drain out trapped water, pumps are to be procured and water channels are to be excavated for disposal of rainwater. To exercise economy option efforts put in should be consolidated. However, pumps should be switched over to solar energy to guard against pilferage of fuel/electricity. The type of the pump recommended is PNW of propeller type KSP Pumps of German mark.

9. Improvements to Outfall Conditions of LBOD/KPOD

During the designing/planning stage it was expected that seawater would penetrate up to 19 km from its outlet upstream into the Tidal Link, to an area about 11 km downstream of the Cholri Weir. Whereas it is evident from the NIO Karachi, observations, that erosion and intrusion of seawater in the Tidal Link commenced just after its completion. Later on storms in 1998 and in 1999 'Cyclone 2A' further worsened the situation.

The storm, in July 2003, was the final blow and destroyed the already deteriorating Tidal Link now it is turned to be a tidal creek rather an outflow drain. During the post storm inspections (GOS Technical Review Committee) 56 breaches were recorded, it was an almost complete disaster of the outlet system of the LBOD. A Tidal Control Gated Structure has been proposed at RD 22 of KPOD to guard against sea intrusion. Action is recommended against all those responsible for providing faulty design of Tidal Link.

10. Environmental Impact Assessment of LBOD Project

The proposed intervention will address the issue of drainage in the project area by disposing flood/drainage water into sea. It is environment friendly and supportive in reducing water accumulation thereby helping to address the water logging issue. It has positive effect on environment of the area, with only minor negative impacts.

11. Project Costs

The following table describes the project costs for rehabilitation of infrastructure for LBOD drainage network.

A. Baseline Costs		**(Rs. Millions)**
1.	Drainage Infrastructure	12,583.925
2.	Drainage Management	800
3.	Project management Unit	900
	Total Baseline Costs	14,283.925
B. Contingencies		
	Physical Contingencies	1027.50
	Price Contingencies	4795.00
C. Total Costs to be Financed		19522.50
D. Financing Charges during Implementation		1952.25
	Total Project Coast	**21474.75**
	Say Rs.	**21475**
	US$ (Million)	**224**

12. {Economic Analysis by Mr. Syed A. Hussain}

13. Implementation Schedule

It is planned to implement the suggested long term measures starting from July 2014 and it will be completed by June 2020. The entire project for the purpose of biding has been divided in 07 packages for implementation and is to be executed through international and national bidding in a competitive manner insuring full transparency. The construction works are to be supervised for quantity and quality through renowned International and National Consultants of repute.

14. Conclusion

The foregoing technical feasibility and economic analysis clearly indicate that the project is technically and economically viable with EIRR exceeding ________ % and is recommended for execution.

CHAPTER 1: INTRODUCTION

1 Introduction

1.1 Study Background

In the Lower Indus Report, drainage was considered at two levels. The first was within individual projects where only local drainage problems were considered, solved and the second concerned the disposal of drainage water outside the projects by means of a system of main drains discharging into an outfall drain. Branch and sub-drains would dispose the effluents of tube wells, tile drains and/or storm water runoff, within individual project areas. These were constructed as part of these projects. The construction of the main and outfall drains was a separate project built in stages to match the overall development program of the region.

Provision was also made for storm drainage in the southern part of the catchment, in addition to providing drain capacity to cope with the drainable surplus. The capacity was designed to accommodate the flow from a once in five year with five day rainfall storm. The quantum of runoff was calculated by analysis of losses on a typical unit catchment. Direct ingress of runoff to the drain is impractical because it would require an excessively large channel. For this reason pipe inlets were planned to control the unrestricted flow into the drain. The flexibility of tube well pump age together with the use of pipe inlets for storm water drainage has allowed a large measure of control of inflow into the drain. However, with many years of operational experience, the performance is satisfactory though not optimum.

The alignment presented in the LBOD report shows the spinal drain starting in the Khairpur area and running for some two hundred and seventy miles to the tidal flats of the Runn of Kutch. Its capacity was designed to take the drainable surplus from nearly six million acres of land as well as the storm water runoff from the areas south of Shaheed Benazirabad district The ultimate discharge to the Runn of Kutch was estimated to be about 18,000 cfs.

Construction of the LBOD and its main drains was phased over three Five-Year Plans from 1970 to 1985. This phasing of the construction was dependent on and integrated with the development of individual projects in the catchment. It was proposed that in the first phase the outfall drain to about half the final capacity should be built from its outlet into the sea to its junction with the South Rohri Main Drain. The South Rohri and the East Nara Main Drains were to be constructed to full capacity and approximately two thirds of their final lengths. The cost of this work, based on average link canal earthwork rates, was estimated at Rs 330 million. Because of financial difficulties in implementing the overall construction program for the Lower Indus Project the individual projects cannot be undertaken on the proposed schedule. In the absence of internal drainage the construction of main and outfall drains would be meaningless as no benefits could accrue from such an investment. The special provision of funds made during September 1970 in the Fourth Five-Year Plan for the LBOD system was not adequate to meet the construction costs of the first phase of the Outfall Drain and ancillary works within the catchment as planned. It was therefore, found necessary to revise the first phase of the LBOD and produce a project plan that would match the available financial resources with reduced scope of work. Because the subsoil drainage projects are not likely to be taken up in the near future, a scheme has to be prepared for the speedy disposal of storm water from areas that are subjected to high storm intensities and at present lack drainage facilities. By reducing the main and outfall drain capacities, the saving in expenditure was then directed to the construction of the essential network of branch and sub-drains in the carefully selected catchments.

1.2 Objectives of the Project

- ✓ Ensure safe, timely, and unconstrained disposal of drainage and storm water.
- ✓ Rehabilitate and improve the existing LBOD infrastructure.
- ✓ Divert storm water of extreme rainfall events to Dhoras and Thar Area for local use.
- ✓ To encourage and sustain, increased agriculture production and improve agriculture productivity.
- ✓ To alleviate poverty and improve quality of life.
- ✓ To ensure equitable sharing of benefits accruing from investment and as far as possible, to target these benefits towards the disadvantaged class.

- ✓ To encourage beneficiary participation in project formulation, operation and Maintenance.
- ✓ To reduce O&M liability of the government to a minimum level.
- ✓ To minimize and mitigate adverse environmental impacts.
- ✓ To improve knowledge base of the planners, designers, executives and operators of projects.

1.3 The Project

The project area lacks natural drainage and the few existing natural drainage lines, were severed by the network of irrigation canals built in 1932 or subsequently and also by construction of road infrastructure. The poor drainage conditions coupled with perennial irrigation supplies have resulted in the rise of water table in commands of left bank area.

A small scheme comprising network of open shallow drains was executed by the Irrigation Department in the Makhi Dhand area which lies between Jamrao, Mithrao and Nara canals to check the rising water table. In absence of any proper outfall, the effluent from this system is being pumped into Mithrao canal but due to shallow depth of drains, control of water table could not be achieved.

In the extreme southern catchment, namely Badin area, open surface drains were constructed by Irrigation Department during 1960 within Kotri Barrage Command to cater for storm water drainage and excess effluent from rice fields. The system has been provided with the outfall through Kadhan Pateji Outfall Drain (KPOD) on to the mud flats and Pateji Dhand in Runn of Kutch.

To check the rising water table and to provide relief from surface runoff generated by rainfall in Nawabshah (now Shaheed Benazirabad), Sanghar and Mirpur Khas areas, extensive networks of surface drains, drainage tube wells, tile drains and interceptor drains along the major canals were constructed (1985-2002) by WAPDA during the implementation of LBOD Stage-1 Project.

The overall objective was to raise agriculture production through higher yields by alleviating water logging, salinity and reclamation of saline lands. The system covered Nawabshah (now Shaheed Benazirabad) , Sanghar and Mirpur Khas areas. Among the components of the project are:-

- ➢ A network of surface drains discharging to the sea via a spinal drain and tidal link.
- ➢ Deep tube-wells to intercept seepage water and control the groundwater table by groundwater into the surface drainage network.
- ➢ Interceptor drains beside canals to recover fresh water seepage for use in irrigation.
- ➢ Buried tile drains to control groundwater tables where drainage tube-wells are not feasible.
- ➢ Additional power capacity at seven (2x Nawabshah, 2x Sanghar & 3x Mirpur Khas) existing grid stations (required for the operation of 1700 x tube-wells with 1.0 to 1.5cfs discharge).
- ➢ A network of power supplies to tube wells and drainage pumping stations.
- ➢ Remodeling canals (Nara Canal) to increase capacity (in order to provide irrigation water for the reclaimed land from water logging and salinity).
- ➢ Construction of Chotiari Reservoir to provide system storage allowing secure supplies to the Lower Nara Canal System. The purpose of linking LBOD project with Chotiari Reservoir was to utilize the stored water for Rabi season crops (November to May) in LBOD benefited area.
- ➢ On Farm Water Management to improve watercourses and water use practices.

Hierarchy of the surface drainage system of LBOD Stage-1 Project comprise; Sub-drains, Branch drains, Main drains, Spinal drain, Outfall drains and Tidal link out falling into the Arabian sea. Geographical units, where this surface drainage system is located, are: -

- ➢ Nawabshah Component.
- ➢ Sanghar Component.
- ➢ Mirpur Khas Component.
- ➢ Badin Component.

The area served by above drainage components is given below: -

Drainage Component	GA (Acres)	CCA (Acres)
Nawabshah Component	626,000	554,500
Sanghar Component	424,000	362,500
Mirpur Khas Component	376,000	358,800
Badin Component	593,496	458,723
Total	**2019,496**	**1734,523**

In addition to the above three components, there are several drainage systems of Badin area out falling into Spinal Drain and KPOD. Surface drainage systems of LBOD Stage-1 Project and Kotri Surface Drainage comprise of:

- Surface Drainage Network of Nawabshah Component Project.
- Surface Drainage Network of Sanghar Component Project.
- Surface Drainage Network of Mirpur Khas Component Project.
- Surface Drainage Network of Badin Area.
- Spinal Drain.
- Dhoro Puran Link Drain.
- Dhoro Puran Outfall Drain (DPOD).
- Kadhan Pateji Outfall Drain (KPOD).
- Fulleli Guni Outfall Drain
- Karo Ghungro Outfall Drain
- Tidal Link.

The surface drains are intended to carry two different types of effluents. The first type is designated as "Base Flow", which is the drainage effluent discharge by sub-surface facilities like drainage tube wells and tile drains. Base flow is supposed to be highly saline. The second type is the "Storm water flow", which is generated by rainfall over the catchment area. The chemical quality of the storm water is non-saline. Apart from the surface drains, several escape channels carrying surplus water from the irrigation system also contribute to the drain flows.

1.4 Major Tasks Covered

The RPS is one of the subcomponent of the Sindh Water Sector Improvement Project Phase-I (WSIP-I). The WSIP-I has four components, namely, i) community development and capacity building; ii) improvement of irrigation and drainage system; iii) management plan for irrigation and drainage infrastructure; iv) project monitoring, evaluation, and supervision of environmental management plan; and v).project coordination, monitoring, technical assistance and training. One of the subcomponent of component iii) is ‘preparation of regional plan to deal with floods and drainage issues on left bank of Indus river and designing measures for improvement of the Indus delta and the coastal zone.

The six year duration project, with a funding support from the World Bank was launched in December 2007, terminating in April 2013. The main objectives of the WSIP-I includes: i) strengthening and fast tracking the institutional reforms that are already underway in Sindh; ii) improving the irrigation system in a systematic way covering key hydraulic infrastructure, main and branch canals, and distributaries and minors; and iii); enhancing long term sustainability of the irrigation system through participatory irrigation management and developing institutions for improving operation and maintenance (O&M) of the system and cost recovery.

The main objective and scope of the RPS is to prepare for the Government of Sindh (GoS) a regional plan for addressing the flood issues and proving proper drainage to the area on the left bank of Indus River through appropriate structural and nonstructural measures, including remedial measures for any outstanding deficiencies in the Left Bank Outfall Drainage (LBOD) system; measures for retention and/or safe disposal of drainage, storm and flood water, and improvement of wetlands in the delta area and in the coastal zone recognizing their environmental importance and considerable economic potential for the local communities. The RPS is designed to be completed in four phases. The scope of each of the four phases of the study includes.

The task comprises of remodeling of various surface drainage schemes in Badin area which includes LBOD Branch Drainage System, Tando Bago drainage System and Remaining Drainage System out falling into KPOD, Spinal drain, KPOD, DPOD, Tidal Link, LBOD Stage-II Drainage Schemes. The key components of the TORs of Regional Plan study relating to LBOD Project are as under: -

i. Particular interest is to be directed to the assessment of deficiencies in the Left Bank Outfall Drain System (LBOD). This was further divided into assessment of drainage collection, drainage conveyance and drainage disposal.
ii. The study considered combined collection, transport and disposal of both drainage water and excess flood water. This is similar to studies in urban areas where combined collection of waste water and storm water require remediation before the combined polluted water flow can be safely discharged to existing water courses.
iii. Particular attention was directed to improvement of the wetland environment in the Indus River Delta and Coastal Zone.
iv. Any remedial measures selected to address issues and problems were to include both structural and non-structural options
v. The study was based on an assessment of Issues and Problems; to be followed by proposed Options and Solutions.
vi. All efforts were to be based on extensive consultations with stakeholders: i) to identify issues and problems; ii) to analyse options and solutions; to design remedial measures;
vii. Development of O&M guidelines for LBOD drainage network.

CHAPTER 2: REVIEW OF PERVIOUS STUDIES AND DATA COLLECTION

2 Review of Pervious Studies and Data Collection

In accordance with the outlined planning criteria, the consultant collected, reviewed and analysed extensive secondary data and reports. Publications, documents and reports consulted are listed in the bibliography. Stake holders associated with each topic were identified and consulted during the process of data collection. Stakeholders included beneficiaries, affected communities, NGOs, influential local people and staff of government line departments.

Literature review and collected data provided a firm base for an understanding of the project area, its infrastructure and prevailing social conditions. The secondary sources also were important for identification of strengths and gaps of past and ongoing projects, structural and non-structural, and for identification of the core issues.

2.1 Major Drainage Studies Reviewed By the Consultants

- ✓ Lower Indus Report (1966).
- ✓ Feasibility Study - National Drainage Program (1995).
- ✓ Pre- feasibility Study National Surface Drainage System (2003).
- ✓ Review Report: International Panel of Experts (IPOE) on Drainage Master Plan (2004).
- ✓ Drainage Master Plan of Pakistan (2005).
- ✓ Final Report. International Panel of Experts on Left Bank outfall Drainage System (2005).
- ✓ Inspection Panel Report on NDP (2006).
- ✓ Transition of SCARP Tube Wells to Private Sector (2008).
- ✓ Feasibility Report – Redesign of LBOD Stage-1 Badin Area Drainage System (2010).

2.1.1 Lower Indus Report

Lower Indus Project investigations were started in 1959 to provide a plan for the optimal development of the water resources. As a result of these investigations extending over a period of six years, the Lower Indus Report was prepared in 1966 by Hunting Technical Services Ltd and Sir M. MacDonald & Partners for WAPDA which provided benchmark data as well as comprehensive plan of intensive development of the land and water resources of the province to ensure that agricultural production meets the growing internal demands and export targets. The plan envisaged interrelated projects for both additional water supplies and drainage to be carried out in a program phased over a period of 25 years. The Lower Indus Report covers the irrigated area from commands of three barrages of Sindh viz Guddu, Sukkur and Kotri. The Consultants drilled 142 exploratory bore holes and 42 test wells. The investigations that carried out pertained to:

2.1.2 Feasibility Study – National Drainage Program

Chronic problems of implementation, operation and maintenance, management, fiscal, social and environmental were experienced in the Drainage Sector. To tackle these problems more effectively with involvement of end beneficiaries and all stakeholders a program approach was introduced under National Drainage program (NDP), a new approach was developed integrating all important factors considered to contribute for realization of objectives. New interventions proposed were

- ✓ Shift from project formulation to program approach to allow freedom of re-adjustment.
- ✓ Improve O&M through farmer and private sector participatory management.
- ✓ Improve monitoring and evolution of drainage Schemes and long term research in drainage.
- ✓ Undertake policy and institutional reforms including strategic review of key drainage institutions.
- ✓ Promote investment in drainage to rehabilitate the existing facilities expedite completion of priority works.
- ✓ Revisit completed projects and remove short falls in order to improve efficiency.
- ✓ Endeavour to achieve a desirable salt balance in the root zone. And more towards achieving balance between the salt coming into the System and going out to the Sea at basin level.

- ✓ Improve knowledge base of Water Sector institutions through research and training.

2.2 Pre- Feasibility Study National Surface Drainage System

A Pre-feasibility study was carried out under NDP to study the technical, economic and environmental aspects of the National Surface Drainage System (NSDS). The objective of the NSDS was to collect and dispose surplus saline effluent, primarily from the upper Indus Basin to the sea. It envisaged an interconnected system of outfall drains traversing the entire Indus Basin Irrigation System (IBIS).

Total length of drains as proposed in the pre feasibility was around 910 miles (1,464 km), and total discharge of Systems 2,004 cfs and the area served was 2.1 Ma. The estimated construction cost was Rs 33 billion.

An international Panel of Experts (IPOE) was constituted jointly by the World Bank and Netherlands Water Partnership Program (BNWP) to carry out a careful review of the Pre-feasibility study of the NSDS before proceeding to the envisaged next phase of preparing a feasibility report.

The plans for this Out Fall Drain were reviewed by IPOE, which concluded that need was not urgent. This conclusion was widely shared and the data provided in Drainage Master Plan provided even stronger support to this conclusion. Therefore IPOE recommended that Trans Boundary Out-Fall Drain (TBOD) may not be considered any more.

2.2.1 Drainage Master Plan of Pakistan

Need for preparation of Master plan was based on the experience gained from implementation of previous projects which were mainly subsurface drainage projects and surface drainage was not emphasized in SCARPs. Due to inefficient surface drainage, recharge to groundwater was excessive which placed huge burden on the operational Cost of Subsurface drainage. Disposal of Saline effluent created severe environmental implication to adjoining areas as such holistic approach was adopted to provide facility for disposal of saline effluent generated from Indus Basin to Sea.

2.2.2 Objectives of Master Plan

- ✓ To encourage and sustain, increased agriculture production and improve agriculture productivity.
- ✓ To alleviate poverty and improve quality of life.
- ✓ To ensure equitable sharing of benefits accruing from investment and as far as possible, to target these benefits towards the disadvantaged.
- ✓ To encourage beneficiary participation in project formulation, operation and Maintenance.
- ✓ To reduce O&M liability of the government to minimum level.
- ✓ To minimize and mitigate adverse environmental impacts.
- ✓ To improve knowledge base of the planners, designers, executives and operators of projects.

Drainage works have been proposed for each drainage basin for Saline Water logged areas Surface drainage, pipe drainage and Bio-saline technologies have been proposed and for fresh water logged areas Subsurface drainage with private Tubewells is proposed. Six drainage Basins 2 in each barrage on Left and Right side commands have been proposed for Sindh. The works proposed in Study area Left Bank of River Indus in Left Bank Command areas of Guddu, Sukkur and Kotri Barrages are illustrated in following table.

Table-1: Proposed Works under Master Plan in Study Area (1,000 Acres)

Barrages			Proposed Works				
Barrages	Water logged Area (0-150 cm)		Surface Drainage	Pipe drainage	Bio Saline Agricultures	Private Tube well Development	No. of Tube wells
	Total Area	Saline					
Guddu Left Bank	41.070	25.820	16.009	8.263	1.549	15.249	610

Sukkur Left Bank	1083.057	461.793	286.312	147.774	27.708	576.264	23051
Kotri Left Bank	1067.054	882.209	546.970	282.307	52.933	184.845	7394

2.2.3 Diagnostic Study of Water Management of the Left Bank Canal AWB

The IRC Consultants carried out a 'Diagnostic Study Water Management of the Left Bank Canal AWB' which included recommendations with respect to water management practices at AWB level, compliant with the Water Reforms currently implemented in Sindh. The study includes an analysis of the current situation in the AWB; recommendations to adjust the irrigation and drainage infrastructure to the needs of the FOs and the new AWB; improved water management functions of the AWB With the infrastructure and water management functions redefined; necessary changes of the organizational structure of the AWB and very tentative estimates for investment - and recurrent costs.

The principal findings of this study relating to irrigation and drainage infrastructure are summarized below:

- ✓ Insufficiency of canal capacities: This is caused by the heavy sediment load especially during Kharif and the deferred of maintenance.
- ✓ Impact of direct outlets and tampering of structures: Direct outlets escape from any control through rotations and are mostly tampered to increase discharge way beyond the authorized level. This makes it very difficult to supply irrigation water to tail end users.
- ✓ Insufficiency of drain capacities is caused through lack of maintenance.
- ✓ Tidal influence occurs along the downstream reaches of the KPOD.
- ✓ Lack of drainage infrastructure in the area irrigated through the Matli and Murad Wah branches.
- ✓ Funds available for maintenance are insufficient.
- ✓ The available funds are not allocated under objective allocation criteria.
- ✓ Routine maintenance gives insufficient results.
- ✓ Office equipment (computers, printers, faxes, copiers, etc.) are insufficient
- ✓ Water management equipment (flow meters, EC-meter, etc.) is insufficient
- ✓ Transport facilities and POL are insufficient
- ✓ Communication facilities are insufficient
- ✓ Funding of operations is insufficient.

2.2.4 Review Report: International Panel of Experts (IPOE) on Drainage Master Plan.

The draft report of DMP was reviewed by an International Panel of Experts (IPOE) in September 2004. The IPOE did not support the concept of Trans Basin Outfall Drain (TBOD) presented in the DMP IPOD recommended that TBOD may not be considered any more. The IPOE recommended the DRAINFRAME approach to provide a structuring mechanism for integrated analysis of water resource management issues in drainage basins, and as a means to establish linkages to socioeconomic values and consequently to stakeholders. The IPOE concurred with the preparation of the separate Drainage Development and Water Management Plans (DDWMPs) proposed in the DMP for the 20 identified drainage basins, and recommended Kotri Left Bank Drainage Basin (KLBDB) in Sindh and the Chaj Drainage Basin (CDS) in the Punjab as the first two basins for the development of these plans through the application of DRAINFRAME concepts.

During the visit to Sindh, the IPOE held meetings and workshops at Karachi, Hyderabad and Badin. The area of Kotri Left Bank Drainage Basin was visited. Based on these activities the following observations were made by the POE: (i) drainage issues play an important role and are heavily debated in the area; (ii) there are surface irrigation and drainage systems throughout more or less the whole area. However, the density of the drains is relatively low to meet the demands; (iii) the drainage system does not include on-farm drainage and has not been designed for multifunctional use (e.g. cattle drenching, reuse); (iv) a number of the drainage systems are being rehabilitated under the NDP; (v) a good record is available of the alignments, dimensions and design criteria of the irrigation and drainage systems; (vi) there is a considerable potential of drainage water reuse; (vii) the water sector reform is accepted, but the implementation will need more time than originally envisaged. The new organizations: Area Water Boards

(AWB) and Farmers Organizations (FO) would have to play an important role in the water management in their areas, but their capacities are still weak; (viii) the importance of an integrated basin approach is broadly accepted; (ix) Sindh Province wants to take the lead in the preparation of the DDWMP for Kotri Left Bank Drainage Basin; (x) plans need to be developed in intensive consultation with the local communities, and need their consent prior to implementation.

The IPOE recommended development of a DDWMP for the Kotri Left Bank Drainage Basin on a DRAINFRAME-type of approach. In the development of this plan the Provincial Irrigation and Power Departments (IPD) would have to play the leading role jointly with the Sindh Irrigation and Drainage Authority (SIDA) as the implementing agency. However, the IPD/SIDA would have to develop the plans in close cooperation with the other involved departments, especially Provincial Agriculture and Environment Departments, the Area Water Boards (AWB), the Farmers Organizations (FO) and the concerned Municipal Authorities. In the development of the plans intense consultation with the local government and the range of local stakeholders would be required.

The DMP will have to reflect the issues, problems and developments at National and basin level and to address issues that cannot be addressed at basin level and need a decision-making or management at federal or provincial level. The interaction between the DMP and the DDWMPs requires that these plans be developed in cooperation with WAPDA and IWASRI.

The IPOE gave the following recommendations on the DDWMP for Kotri Left Bank Drainage Basin: (i) apply an integrated approach in developing the plan, including strong stakeholder participation (DRA1NFRAME); (ii) use the opportunities of the water sector reform; (iii) improve irrigation management - including rethinking the high irrigation duties; (iv) include in the role of drainage also water quality and flood management; (v) locate outfall structures in the main drains at carefully selected places and apply outfall structures that are suited to the local tidal conditions; (vi) consider coastal protection works; (vii) respect international biodiversity and wetland conventions; (viii) apply where reasonably possible rainwater harvesting techniques and sustainable reuse of drainage water; (ix) promote that wastewater is treated and/or reused, before it is disposed in drains and canals, particularly since the drains and canals are often the source of drinking water supply; (x) develop options for drinking water supply in tail-end areas; (xi) take care that in the design of the coastal road due attention is being given to drainage aspects as well as to its possible additional function for coastal protection.

The IPOE concluded that the new organizations formed in the Kotri Left Bank Drainage Basin, in particular the Left Bank AWB and the FOs, provide, in principle, a good basis for integrated water management, because they combine both irrigation and drainage and provide the platform for water management at the lowest appropriate level. The new organizations in theory may be able to generate the revenue that is required for adequate O&M. The capacity building and political support to these new organizations, however, needs much more emphasis than what has been given so far.

The IPOE suggested that the preparation of the DDWMPs for Kotri Left Bank should be prepared and that this would require the action: (i) the Secretary Irrigation and the Managing Director (MD) SIDA should establish a multidisciplinary plan development team, preferably consisting of representatives of the related sectors, in particular IPD/SIDA, Agricultural Department, Environmental Protection Agency (EPA), Public Health Engineering Department (PHED), Department of Industries, Fisheries Department and the concerned municipalities. Based on an integrated approach the task of this team would be to lead the planning process, organize the stakeholder consultations, identify problems, priorities and solution packages, obtain approval within the concerned Departments, and coordinate with the WAPDA and IWASR1 DMP team; (ii) IPD/SIDA/Provincial Government provide the necessary resources and logistics (e.g. budget, office facilities, transportation); (iii) IPD/SIDA appoint a technical secretariat to carry out day-to-day work, field investigations, preparation of reports and working papers; (iv) the plan development team prepares a detailed work plan for completing the DDWMP in about a year.

2.2.5 Feasibility report: Transition of SCARP Tube wells to Private Sector

The Government Sindh in the light of the successful transition of Moro-Sakrand unit of SCARP North Rohri project decided to privatize 3692 freshwater public Tubewells of Six SCARP divisions namely

Ghotki division (1091), Rato Dero (530), Khairpur (275), Naushahro Feroze (576) North Rohri Project, Hala-I(480), Hala-II (740) South Rohri Project.

Government of Sindh through Irrigation and Power Department engaged consultant M/s B.M Consulting Engineers for preparation of feasibility Report. Contract agreement was signed on 27.5.2007 with completion date January 15, 2008. There were 24 Terms of References given to the consultants for this Study. Some of the more important highlights of the TOR included.

- Suggest the mode of transition i.e. replacement of SCARP Tubewells (3692) by construction of private Tubewells of 0.5 cfs and 1.0 cfs capacity equivalent to the capacity of 3692 SCARP tube wells with machinery to communities and transfer of bore holes to the farmers.
- Suggest suitable incentive package for the farmers so that they come forward and install their private Tubewells.
- Carry out tube well to tube well survey for preparing complete inventory.
- Provide estimated cost of installation of PTWs and determine Operation and maintenance cost. Collect agriculture data, carry out initial environmental examination, prepare implementation schedule for transition and carry out socio-economic survey etc.

The consultants carried out detailed survey and collected necessary data from field as well reviewed the available reports, record and made analysis of the data. Consultant recommended action plan for the transition of 3629 fresh water public Tubewells to private Sector mainly the end users/ farmers.

2.3 Study of Feasibility Report of Re-Design for LBOD Stage-I Badin Area Drainage System by NESPAK

2.3.1 Feasibility Report: Redesign of LBOD Stage-1 Badin Area Drainage System.

Feasibility Study for Re-design of LBOD Stage-1 Badin Area Drainage System was conducted by WAPDA through Consultants M/S NESPAK-ACE-DMC (JV) under directive of President of Pakistan as "WAPDA in consultation with Government of Sindh should carryout feasibility Studies for re-designing of the system for the benefit of people of Badin district and adjacent low lying area, which were badly affected during un-expected extra-ordinary rainfall in 1994 and 2003 monsoon with intensity between 200 mm to 304 mm" .

Contract agreement was signed by WAPDA with Consultants a August 17,2007 to complete the assignment in 12 months, with provision of 109 Man Months at total Coat Rs. 29.849 million. The consultants submitted inception report in Oct 2007 and also submitted Midterm report in Feb 2008 and final feasibility report in Feb 2010.

The Consultant reviewed all reports, records available and prepared feasibility report in accordance with the Terms of Reference which were finalized by the Government of Sindh.

The reports submitted by the Consultants were thoroughly reviewed by the SIDA and the Stakeholders and extensive interaction was maintained among the W APDA, SIDA, Stakeholders, NGOs and the concerns were recorded by the Consultants. A committee comprising representative of Irrigation Power Department, W APDA, NGOs, and Stakeholders was constituted with Managing Director SIDA as Chairman of the committee meeting of the committee were held at Hyderabad, Badin.

Following works were recommended by the stake holders during meeting held on June 29, 2009.

- ✓ Remodelling of Spinal drain to carry 7,300 cusec minor remodeling of DPOD to discharge 3,000 cusec.
- ✓ Remodelling of KPOD to flow 4,300 cusec at RD 159; and to discharge 6,400 cusec at outfall point in Tidal Link. Maximum storm water flow in project = 9,400 cusec.
- ✓ Widening the cross-section; and raising the surface water level of the remodeled SD, DPOD and KPOD by 2 feet above the last design water level.
- ✓ Plugging of creeks and reconstruction of embankment along the southern side (Indian border side) of Tidal Link.
- ✓ Plugging of Tidal Link near RD-145, Plugging of Tidal Link at -110 as a back up to plug at RD -145, Plug top elevation = 0.0 ft amsl.
- ✓ Provision of a structure with flap gates near RD-13 of KPOD.
- ✓ Flood protection bund for villages and cropped areas in the north of achh, Sainhri & Addah Dhands.
- ✓ Flood protection bund for village Khan Bahadur Lund located near RD 28 of KPOD.
- ✓ Flood protection bund between RD -15 of KPOD and the tail of Mirwah Minor.
- ✓ Flood protection bund between the tail of Mirwah Minor and the outfall of Fuleli Guni drain.
- ✓ Access road cum bund in between Dhand system and the sea.
- ✓ No new drain.

CHAPTER 3: DESCRIPTION OF PROJECT AREA OF LBOD NETWORK

3 Description of Project Area of LBOD Network

3.1 Hydro- Geological Setup

The Left Bank of Indus from North to South is about 550 km long, with varying breadth of between 50 km and 100 km (East to West). The topography is generally flat with deep alluvial and deltaic deposits sloping towards Arabian Sea. Soils are mostly calcareous silt-loam. Soils in Badin and Thatta districts are generally saline. Eastern part is predominantly desert; with inter dunal valleys and alluvial flats. There are isolated limestone rock formations, found near Sukkur and Hyderabad. In the southeastern corner, Karonjhar/Ravalli range is situated. Along the coast, rocks are oceanic in nature. The coastal areas have about 17 major creeks/lagoons. Historically Indus delta region has been continuously growing reclaiming lands during the ancient times, but more recently shrinking due to sea encroachment. The delta is spread over 41.4 thousand square kilometers and consists of clayey and swampy terrain.

The project area is relatively flat, particularly in Mirpur Khas project which is predominantly cover flood plain. Elsewhere, some relief is provided by the channel remnants and bar deposits left by old courses of the river and its distributaries, particularly, in the western part of the Nawabshah project component and also along the alignment of the Spinal Drain in the Sanghar project area. Ground surface elevations range from 125 feet above mean sea level (amsl) in the north of Nawabshah to 30 feet amsl in the south of Mirpur Khas. In Badin area the ground surface elevations range between 7 to 30 feet amsl. The general fall of the land is 0.75 feet/mile (0.014 %) southward and away from the present course of the River Indus. Natural drainage is usually ill-defined and often blocked by irrigation bunds, roads etc. the classification of landforms in Nawabshah, Sanghar and Mirpur Khas components is given in map in volume III of Draft Feasibility Report of LBOD Project.

Gravity survey conducted in the Lower Indus Plain region (Glennie, 1955; Balkrishan, 1977) and borehole data from oil exploration wells indicate that in Badin area, basement is overlain by Mesozoic to Tertiary sedimentary rocks, which are fairly thick in the lower part of Indus Plain. These rocks are overlain by unconsolidated Quaternary sediments up to 600 [88t thick in the lower region of Indus Plain.

A subsurface geological cross-section study between Nabisar and Thatta passing through the Badin indicates that in Badin area, the buried channel of the Indus overlies a relatively thick, hard succession of clay inter bedded with very thin lenses of fine sand. The clay is laminated, ranges in color from dark grey, brown, greenish brown to grayish white. It is calcareous and at places contains abundant mollusk shells resembling the present day deltaic deposits.

Since, the sub-surface strata of the project was deposited in delta environment of River Indus, therefore, sub-surface strata in the project area comprises dominantly of sandy silt/silt having high porosity with low permeability.

During regional hydro-geological investigations in Lower Indus Plain in early sixties, a number of test bores were drilled, which had shown that hydro-geological conditions in the project area are very poor, strata comprises fine material and groundwater is highly saline.

3.2 Climate

Sindh is part of the subtropical Asian region and is predominantly arid. The mean maximum temperature in summers is around 45° Celsius. During April and August, the mercury touches as high as 48°C to just above about 52°C. During December and January, the minimum average temperature is about 10°C. In the winters, frost is common in the middle and upper part of the Province. The climate of lower Sindh (Lar) is milder and humid than middle Sindh (Wicholo), while the upper Sindh (Siro), witnesses extremes.

The climate is arid, with an average annual precipitation is between 100 mm to 250 mm. Some years are very wet, with up to 500 mm, while the province also experience prolonged drought. The main rainy season is during the July and September, during which monsoon comes into from Southeast and deflects to the Northwest. December and January receives occasional rains. The coastal belt has mild climate and gets relatively severe towards the north.

In Badin, the area has large seasonal fluctuations of temperature and rainfall. The hottest months are May and June when the men monthly temperatures range from 33ºC to 38 ºC respectively. December and January are the coldest months with mean monthly temperatures of 19.4 ºC and 18.1 ºC respectively. The average monthly relative humidity is maximum during August (65%) and minimum during April (42%). Average annual precipitation ranges from 150 to 225 mm of which 85% of the rainfall occurs in July to September. Although the annual precipitation is low the project area is subjected to severe rainstorms due to climate change. Such extreme rainstorms have occurred during the years 1967, 1970, 1973, 1976, 1978, 1979, 1988, 1992, 1993, 1994, 2003, 2006 and 2011. The important features of climate change due to global warming are as under:

- ✓ The most recent scientific assessment by the Intergovernmental Panel on Climate Change (IPCC) estimates that the global average surface temperature on Earth will increase by 1 to 3.5 ºC (about 2 to 6 ºF) by the year 2100, with an associated rise in sea level of 15 to 95 cm (about 6 to 37 inches).
- ✓ The harmful impacts of this global warming effect are resulting in events like storms, tornadoes, floods and droughts, all of which have been mounting in frequency and intensity. As a result, the world today suffers around 400-500 natural disasters on average in a year, up from 125 in the 1980s (Disaster Risk Reduction: Global Review 2007).
- ✓ According to the fourth IPCC Assessment report, the evidence of predicted impacts of climate change is slowly unfolding. There is also evidence of accelerating recession of most glaciers on Earth, rainfall variability, changes in marine ecosystems and reduced freshwater availability.

3.3 Land Use

Present Land use in the catchment is dictated by the existing salinity and water logging status of the soil. This in turn is related to the comparatively recent history of water supplies and the level of the water table. The typical pattern of land salinisation is well illustrated in the Rohri and Nara Commands.

Following the opening of Sukkur Barrage the water supplied by the canals could not be immediately used by the farmers. It ran on to unused land and percolated to the water table which consequently rose rapidly. On nearing the surface, continual evaporation from fallow land and from land that had never been cultivated, brought salts into the root zone. Eventually the upper soil profile became so saline that the never cultivated land could not be brought in to use and some of the cultivated land had to be abandoned. Thus in the areas of high water table, the present land use pattern is one of distinct areas of used and unused land. The unused land is either saline or waterlogged and the cropped land is relatively less affected by these conditions. This pattern is particularly prevalent in the Nara Command where cultivated land is interspersed between areas of abandoned land.

In marked contrast are the larger contiguous areas of land under cultivation in the Rohri Command, where the water table is relatively deep. Here the small islands of never cultivated or abandoned land, which increase in size and become more frequent at the tail of the system, are associated with irregular water supplies and under watering. Insufficient water is applied to the crops to maintain a net downward movement of water; thus the salts are not leached, but concentrate in the upper soil. The results can be seen in the fields where small, irregular shaped, saline patches can be observed. This type of salinisation is not associated with a high water table.

The present depth to water table fluctuates over the year reaching its lowest point at the end of April and the highest in October. The land plan map is shown in Figure 13 Volume III.

Table-2: Present Land Use of Nawabshah, Sanghar and Mirpur Khas Components

Land Description	Area (Sq.miles)	Percent
Gross Area	2228	100.0
Culturable Commanded Area (CCA)	1994	89.4
Cultivated Area	1046	47
Cultivable Area	708	32
Non Cultivable Area	474	21

Table-3: Distribution of Land Classes in the Project Area

Land Class	Gross area in Acres				Percent
	Nawabshah	Sanghar	Mirpur Khas	Total	
1	32,600	58,100	29,700	120,400	8.4
2s	367,700	231,500	266,100	856,300	60.7
3s	42,000	49,200	13,900	105,100	7.4
3sd	47,000	20,800	58,700	126,500	8.9
Sub-total	489,300	359,600	368,400	1,217,300	85.3
6	136,500	63,600	7,100	207,200	14.5
Urban	600	800	800	2,200	0.2
Total	626,400	424,000	376,300	1,426,700	100
CCA	554,500	362,500	358,800	1,276,000	89.4

Table-4: Distribution of the Classes for Lands

Class	Description
Class-1	By definition this land has no limitations and therefore no subclasses.
Class-2s	Land which has minor soil limitations in the form of fine medium subsoil texture, (0-150 cm dominated by group H of H/V)
Class-3s	Land which as moderate limitations of unfavorable textures. (L or V groups dominate between 0-150 cm) or high salinity combined with H or V textural groups.
Class-3sd	Land which has one of all of the above limitations and in addition substratum textures in the V group which would require closer drain spacing.
Class-6	Land which is out of command of the irrigation system and has limitations of uneven topography due to sand deposition. Former channels which are topographic depressions may also occur as a minor part of this unit. The sandy soil textures also introduce a soil limitation.

s = soil deficiency; d= costly to drain; t= topographic limitation.

3.4 Rainfall

3.4.1 Rainfall Behavior during Extreme Storm Years

The rainfall quantities measured over one and two days periods during five extreme rainfall events of moderate to strong intensity are shown in Table 5. The daily rainfall data of these meteorological stations is plotted in Figure-1 to Figure-4. The daily maximum precipitation data are traditionally considered equal to 24 hour maximum. However, both of these data could be different. The floods of 2011 were the most severe followed by 1994, 2003 and 2006. Moderately wet year of 2010 was within management limits of the system. The rainfall patterns determine intensity and spread of floods, evacuation period and longer response of the command area. Understanding of this behavior is important for operation of the systems (drainage as well as irrigation systems) for better flood management.

Table-5: Extreme Rainfall Events

MET Station	1994 (Aug, Sep)		2003 (July, Aug)		2006 (Aug)		2010 (Jul, Aug)		2011 (Aug, Sep)	
	1 day (24 hr)	2 day (48 hr)	1 day (24 hr)	2 day (48 hr)	1 day (24 hr)	2 day (48 hr)	1 day (24 hr)	2 day (48 hr)	1 day (24 hr)	2 day (48 hr)
Badin	176.5	247	150	218	58	63	102	109	148	295
Nawabshah	143	189	61	96	72	72	70	72	108	125
Hyderabad	76.7	82	45	68	43	71	38	39	153	153
Mirpur Khas	-	-	-	-	-	-	-	-	190	288
Chhor	81.3		137	198	141	168	55	74	129	270

Years of Maximum Rain Fall in LBOD Network Area

1994: Rains in 1994 occurred during August and September like 2011. The Badin and Nawabshah had intensive one and two days rains (higher than 2011). Three episodes of rains occurred in Badin, Figure 1. The rains were wide-spread, events were longer in duration and re-occurred during two months. September storms generated heavy runoff volume because the catchment was already saturated and depression filled with water during August. The irrigated lands growing rice, sugarcane and cotton have maximum saturation in September. The drainage contribution from Nawabshah and Mirpur Khas was 1200 and 1050 cfs respectively (WAPDA – NESPAK). The rains in the upper region (Sukkur, Nawabshah) generated large quantities of storm water, which passed through Badin. The land evacuation from some pockets took a long time, which is linked to in-land water balance and accumulation in low lying areas because of limited gross evacuation capacity of the system. The irrigation surplus contributed to the drainage excess.

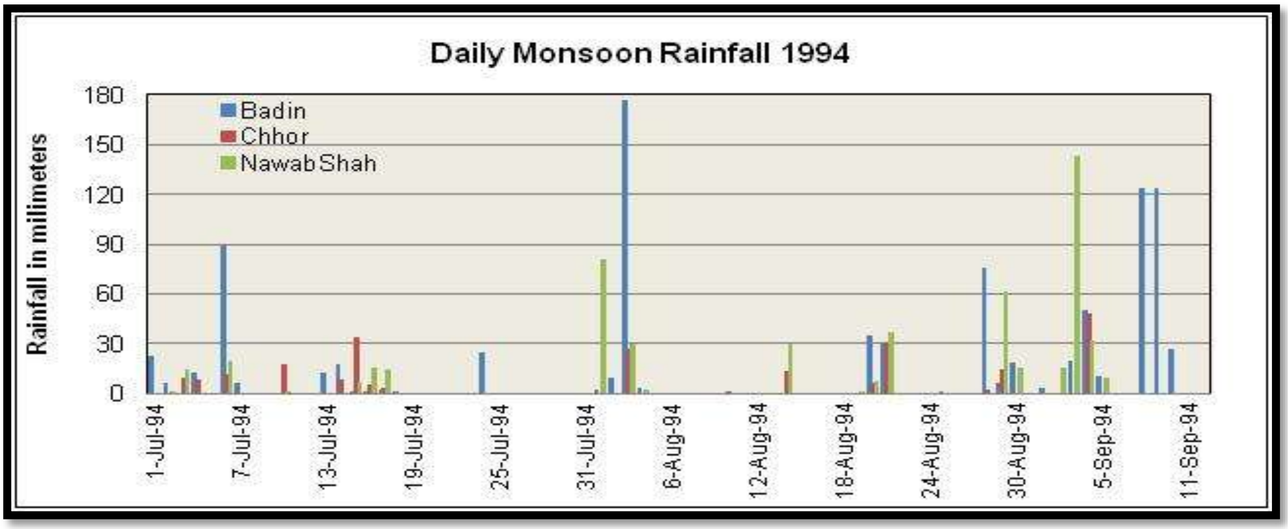


Figure 1: Daily Rainfall in LBOD Service Area the Monsoon Of 1994

2003: As shown in Figure 2, rains occurred in July and August. Rains were less severe in the upper region (Nawabshah) .One wide spread rain event occurred on 25-29th of July and the second event in the lower region on 26th of August. Major contribution to the drainage effluent came from Mirpur Khas and Sanghar. The failure of the drainage supportive systems and Irrigation contribution played a major role in over loading LBOD. The drainage system of LBOD could not function properly, especially, the natural water ways like Dhoras and the Outfall structures of KPOD and DPOD. The canals were not closed when July rains started and farmers made cuts to drain out their field. The Dhoro Puran flooded in Mirpur Khas and tail sections. Most of the breaches occurred in MMD and LBOD Spinal below RD 295.

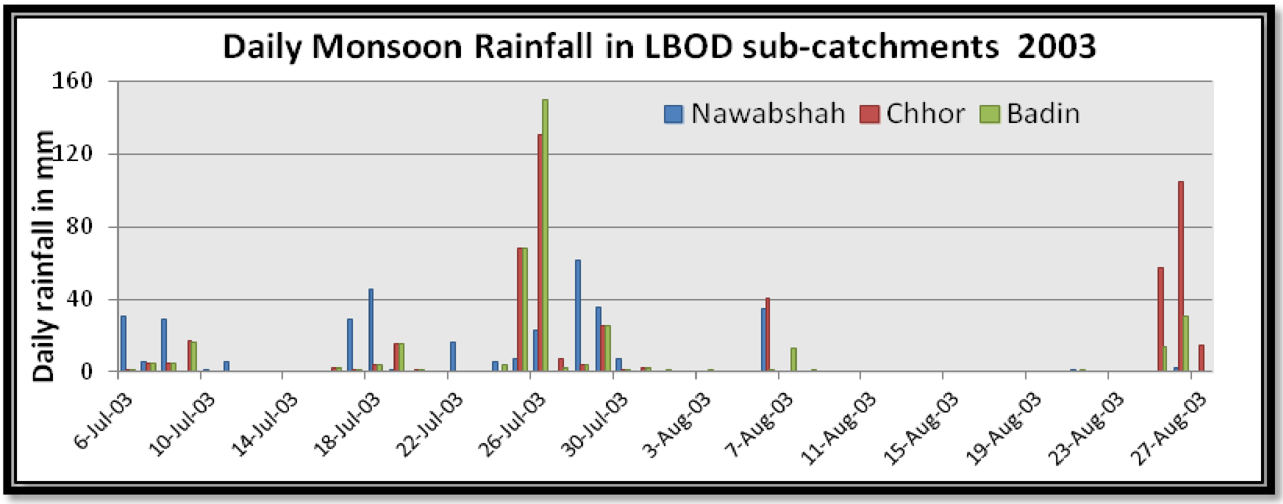


Figure 2: Daily Rainfall during Monsoon of 2003

2006: Floods of 2006 provides few important lessons to learn about performance of the network and institutional scope of storm water management. As shown in Table 6, it was a wet year with scattered rainfall of low intensity. Only at Chhor, a major storm event of 10 years return period occurred. No rain-gauge was available at Mirpur Khas in 2006. Badin received 148 mm rain during 11 days (11 to 21st of August) and 298 mm during the monsoon. The maximum daily rain recorded at Chhor met-station was 141 mm, equivalent to twenty (20) years return period. While, weekly rainfall at Chhor was 255 mm. The largest runoff was generated in Mirpur Khas component area and apparently in Sanghar area as well. Based on 2003's experience, overtopping and relief cuts were allowed in MMD, up and downstream its outfall (RD 295) at RDs 435, 306- 300, 298-248 and again upstream of the confluence of LBOD-branch at RD 214. The peak flows generated in MMD catchment were beyond the operational capacity of the main and spinal drain.. The inundated areas and evacuation periods were much smaller compared to 2003. Closure of irrigation channels helped in controlling the flood volumes.

The flood levels of 2006 (and 2010) indicate the boundary conditions and threshold level of the system in terms of physical capacities and operational management of the monsoon rains.

- The peaks storms were not spatially wide spread, heavy rains in different areas had sufficient time gap, hence, not overloading the drainage network, especially tail sections of the LBOD system.
- Breaches in the middle section practically offloaded the LBOD, providing a relief to the tail.
- The canal operations were properly controlled, avoiding irrigation discharges into the drainage system.
- Unplanned interventions by the farmers were minimum

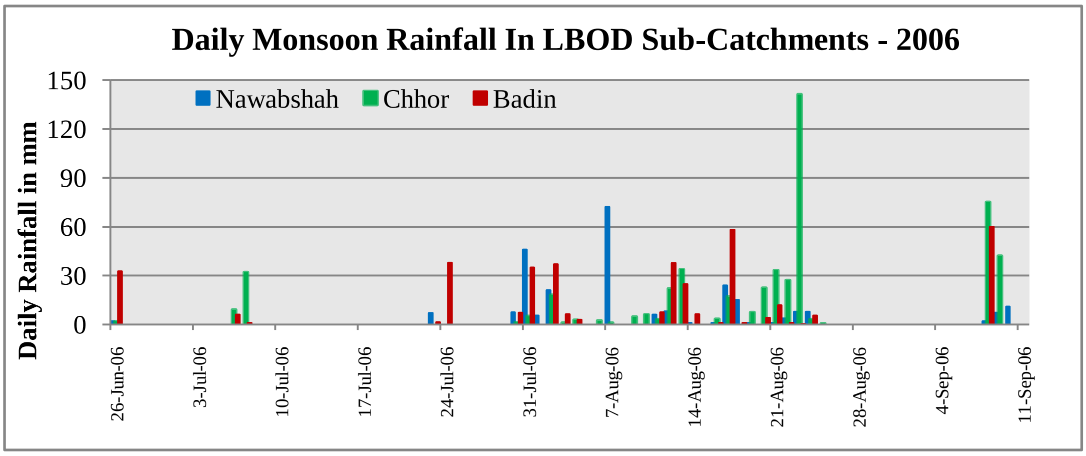


Figure 3: Daily Rainfall during Monsoon of 2006

Table-6: Percent Deviation of Monsoon 2011

Region	Area Weighted Monsoon Rainfall		
	Normal (mm)	**2011 (mm)**	**Departure %**
Pakistan	137.5	236.5	72
KPK	225.2	249.2	11
Punjab	235.7	348.7	48
Balochistan	58.8	81.9	39
Sindh	127.5	443.9	248

2011: The rainfalls and floods of 2011 have been unique in their intensity, spread and simultaneous recurrence of rainstorm in all catchments. The temporal span and spatial extent of heavy rains was the largest in history. A recent technical paper by Meteorological Department Pakistan (Arif Mehmood et.al, Special Report on Pakistan's Monsoon 2011 Rainfalls, Technical Rep # 5/2012) identifies anomalous synoptic features occurred in 2011: -

i. The position of the seasonal low mostly remained over Northern part of Balochistan. Thish made monsoon lows to penetrate in Sindh causing lower than the average pressure and could be one of the reason to attract low-pressure systems.
ii. A number of mid-tropospheric cyclones (MTC) formed over Northeastern Arabian Sea and adjoining Saurashra (India) and Kuch regions during August and September contributed to heavy rains in Sindh.
iii. The position of the monsoon trough, which usually extends from Eastern parts to northwestern parts of India. During this monsoon season, particularly in August/September the orientation of monsoon trough remained east-west in lower latitudes over India. The lows/depressions formed over Head Bay of Bengal, moved westwards instead of their normal northwest movement which ultimately resulted in heavy rains persistence over Sindh.
iv. A prominent sub-tropical high pressure was observed at Tibetian Platu, with its orientation Northeast t to southeast. At the same time sub-tropical high pressure was lying over southern Pakistan, which resulted into prominent easterly flow our southern region.

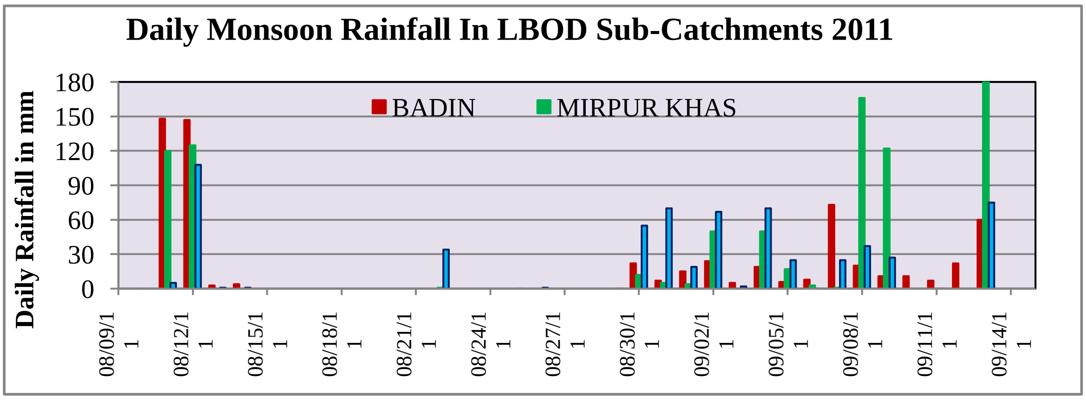


Figure 4: Daily Rainfall in August and September 2011

Changes in weather pattern of the Indus Left bank and coastal region have become more frequent during last twenty years. A wet cycle in the southern region is obvious from above-normal rainfall every fourth year. While, two years (2000, 2001) of severe draught just middle of the wet cycle highlight increasing uncertainty from year to year.

According to FAO and SUPARCO estimates, about 1.83 million acre (2850 sq. miles) land was inundated in four districts on 1st of October, after 2 weeks of last rainfall event. Other than Nawabshah, where it was 32% of the area supported by LBOD, inundated land was more than the areas provided with drainage through LBOD. Obviously, some inundated area was outside the LBOD command. On 18th of October, estimated inundated area was about 1600 sq. miles or 57%. Other than evacuation through LBOD network, water moved to the lower areas, pumped out to irrigation channels by the farmers. The areas with trapped water decreased slowly, mostly through pumpage because discharge through gravity declined.

Two additional factors influenced drainage operation, but are beyond the design perceptions of the system. Large quantities of runoff generated outside the network found evacuation route through LBOD network. Breaches in irrigation channels and direct irrigation discharges into drainage network substantially added to the local flooding. The irrigation canals were operating at high Kharif levels (close to 40,000 cfs water) in mid August, when the first episode of rains occurred. Flows of only few canals in Badin area were reduced in August following a forecast. Because of long length and large tertiary network, effective closure of the system takes few days. Satellite images by SUPARCO shows six large breaches in irrigation channels during rains.

Summarizing excessive runoff and flood patterns: -

1. The monsoon rains in the region are spread over the months of July to September, however, historical data shows that heavy rains causing floods normally occur in August and September.
2. The monsoon wind direction is normally from South-East to North-West. It causes first monsoon spells in Badin district while clouds move inland. A less often inland monsoon path could be enhanced by other factors like the local depression in the coastal region.
3. The rains causing runoff above the local capacity for two successive days have been most detrimental. Because of limited local cushions (surface water ways, groundwater storage potential) and way outs for water, it starts accumulating in low lying areas, locally moving around and causing infrastructure damages.

Continuous rains of lower than the design intensity can cause floods, affecting downstream systems and areas.

3.5 Soils of Project Area

The soils of the catchment are virtually all Indus alluvium. They are pedagogically immature and have not developed weathering characteristics. There has been little translocation of clay particles within the soil profile and alluvium layers deposited centuries ago are still well defined. As a result soil textures are closely related with landforms and tend to be lighter in the meander flood-plains and heavier in the cover flood-plains where flood waters usually accumulate. This relationship of soil textures and geomorphology is discussed in detail in the Lower Indus Report (1966). Experiments and field trials have shown the soils to be potentially fertile and with good crop husbandry very high yields can be obtained provided the soil is neither saline nor water-logged.

An important factor affecting irrigation and drainage practice is the rate at which water enters the soil and moves through it. Investigations of infiltration rates showed a wide variation not only due to different textures but also to such factors as the state of the soil surface (cultivated, fallow or never cultivated), soil salinity and the depth of water-table. The data is summarized in Table 7.

Table-7: Terminal Infiltration Rates - (Inches per Hour)

Textural Group	Maximum	Minimum	Median	Mean
L	1.75	0.25	0.75	0.85
M	1.05	0.00	0.20	0.29
H	1.00	0.00	0.06	0.13
V	0.06	0.01	0.02	0.02

L Group — sand and loamy sand.

M Group — sandy loam, fine sandy loam, light loam and light silty loam.

H Group — heavy loam, heavy silty loam, clay loam, sandy clay loam and silty clay loam.

V Group — silty clay, sandy clay and clay.

The table shows that almost all textures have some rates which are very low. The median figures are those of planning interest. Broadly speaking it is desirable that a four-inch irrigation application should enter the soil completely in 24 to 48 hours, corresponding to rates of 0.16 and 0.08 inches an hour. Because the majority of the soils have textures which bring them into the M group and the coarser part of H group the values of infiltration rates are sufficient to achieve this.

The permeability was investigated and using the open auger hole method. The aim was to relate permeability to texture and profile composition. Three basic variations of textural profiles were considered:

1. Profiles, the textures of which are reasonably constant within the depth treated;
2. Profiles dominantly of similar texture types but not necessarily homogeneous, which comprise by far the largest group encountered;
3. Completely heterogeneous profiles which include layers of quite different textures.

The heterogeneous profiles were classified according to their major constituents. From the examination in detail of 600 results it was concluded that each composite soil classification group has, for practical purposes, the permeability of soil texture group one stage finer than its own dominant group. For example, a profile classified as dominantly coarse has a permeability corresponding to the coarse medium group. This simplification has the disadvantage of disregarding the reduced vertical permeability of high anisotropic soils, but on the other hand there is an under estimate of permeability in homogeneous soils. The results of the investigations are given in Table 8.

Table-8: Permeability of Soil Profile **-** (ft /day)

	Soil Texture Group		
	Coarse	**Medium**	**Fine Medium and Fine**
Apparent Permeability	6.9	3.6	1.9
Horizontal Permeability	10.0	5.2	2.9
Vertical Permeability	1.4	0.7	0.4

The clay minerals consist of elite intergrades of chlorite vermiculite and chlorite montmorillonite. Due to their intergrades nature they show higher Base Exchange capacities than the individual minerals. The cation exchange capacities vary between 7.5 and 10 milligram equivalents per 100 grams of soil. Agriculturally the soils have ample quantities of exchangeable and available calcium, magnesium and potassium. However, the level of sodium in this form is often higher than is desirable, but the nature of the clay mineral provides some protection against the effects of alkalinity. In a considerable number of field leaching experiments, alkaline conditions could not be produced. Soil survey results show that only one percent of the soils fall into the potentially hazardous non-saline alkali group. It appears therefore that reclamation will be achieved merely by continuous leaching.

The survey also showed that boron is present in toxic quantities only in highly saline soils. such soils require reclamation, and boron will be leached out with the other salts but at a slower rate. Thus, isolated instances of boron toxicity may occur after the normal processes of reclamation have been completed.

Nitrogen, phosphate and organic matter contents of the soils are low, and all crops including legumes usually respond to applications of artificial fertilizers or animal manure. However, few responses to potassium have been recorded. This is an expected result in view of the large amounts of potassium present in exchangeable form and as weathered minerals.

3.6 Irrigation in LBOD Area

Irrigation in Sindh Province of Pakistan has a history of several thousand years. Irrigation Canals were extended and improved during the late 1800s. Later on a major program for improvement and construction of new inundation canals was undertaken in the later half of the nineteenth century but it was not until 1932 that barrage commanded irrigation was introduced with the construction of Sukkur Barrage system commanding a gross area of some eight million acres on the left bank of the River Indus. Later two barrages, Kotri (1955) and Guddu (1962) completed the system as it is today.

The irrigated agriculture is mainly concentrated in the alluvial plains along either side of the Indus; while the rain fed cultivation is in the Thar and Nara desert, along the eastern provincial boundary, and arid Khirthar range along the western boundary. The main source of irrigation is the Indus River, diverted into irrigated areas through a network of three barrages, namely, Guddu, Sukkur, and Kotri. The irrigation supplies to the left bank of Indus are through 08 main canals. Between 62% and 65% of the total water diverted by the three barrages feed the command area of the left bank. In the total cropped area, the share of irrigated area is over 90 percent, and within irrigated areas canal irrigated area is about 95 percent, while about 5 percent is irrigated from shallow wells, tubewells, lift irrigation, ponds, etc.

The Guddu sub-region gets in canal supplies from Ghotki Feeder off taking from Guddu Barrage. The main canals in the Sukkur sub-region include Khairpur Feeder East, Khairpur Feeder West, Nara, and Rohri canals, off taking from the Sukkur Barrage. The Kotri sub-region include three canals: Akram Wah (Lined Channel), Fuleli canal (New Fuleli), and Pinyari Feeder (Old Fuleli), off taking from Kotri Barrage.

LBOD Stage-I component projects are located in the perennial command of Sukkur Barrage. Nawabshah component is served by the Rohri Canal, whereas, Sanghar and Mirpur Khas components by the Nara canal. Most of the Nawabshah component (82% of its total area) is in the command of Nasrat Branch, a former Inundation canal which now off-takes from the Rohri canal. The Sanghar and Mirpur Khas are mainly in the command of Jamrao canal which off-takes from Nara canal at RD 574.8 and which had perennial supplies since 1901 (except for the Shahu branch command which until 1932, was served separately from a river off-take south of Sakrand). The rest of Sanghar and Mirpur Khas components are served from Mithrao canal which off-takes from the Nara canal at Makhi Weir (RD 729+700).

The Ghotki canal off takes from the Guddu barrage and serves parts of Ghotki and Sukkur districts. The GCA of this canal is 411.7 thousand ha, while the CCA is 347 thousand ha. During 2009/10 about 2.11 bcm was diverted to the commanded area. The detail of major barrages of Sindh is given in Table 9.

Table-9: Major Barrages of Sindh

Barrage	Year of Completion	Max. Design Discharge	Area Commanded Lac Acres	Total Design Withdrawals For Canals	Actual in
		(cfs)		(cfs)	(cfs)
Guddu	1962	1,200,000	29	36,500	46,120
Sukkur	1932	1,500,000	76	47,530	65,933
Kotri	1955	875,000	28	41,595	38,878

Source: Sindh Irrigation Department (2009)

The four canals that off take from Sukkur barrage includes: Khairpur Feeder (West), Khairpur Feeder (East), Nara canal, and Rohri canal. They provide irrigation supplies to parts of Khairpur, Naushero Feroze, Shaheed Benazirabad, Hyderabad, Matiari, Tando Allahyar, Tando Mohammed Khan, Sanghar, Mirpur Khas, and Umerkot, districts. The GCA and CCA of the abovementioned four canals is 2.49 million ha and 2,292 thousand ha, and about 12.9 bcm was diverted in to the canal systems in 2009/10.

The three canals in the Kotri sub-region are Lined Channel/Akram Wah, Fuleli canal, and Pinyari canal irrigate Badin and eastern parts of Thatta districts. The GCA and CCA of these canals together are 942.1 thousand ha and 888 thousand ha respectively, and about 5.14 bcm was diverted to the canals.

A review of past canal diversions suggests that the water availability at canal heads declined over time. This is largely due to shortfall in the river flows. It also reflects per CCA acre availability. As the cropped area has not declined commensurate with water availability, it suggests under-watering of crops, relative to the previous years.

3.6.1 Groundwater

Generally, the left bank is underlain with saline groundwater unsuitable for agriculture and domestic and potable use. The fresh groundwater is mostly restricted to the narrow corridor along the Indus river, and occasional lenses and perched water. In the freshwater zone, freshwater is mostly pumped by the private tub wells to supplement the canal supplies. In the saline groundwater zones the public sector tubewells drain out groundwater to dispose that into canals or in to the drainage network.

During the three year period (2004/05 through 2006/07), 13,2 thousand tube wells were installed in the left bank of Indus. Out of these, 12.9 thousand tube wells (98%) are fresh groundwater tube wells, while the balance 382 were installed by the public sector in the saline groundwater zone. The table also shows that during the three-year period most of the fresh groundwater tube wells (12.4 thousand) were in the Sukkur sub-region, followed by 392 tube wells in the Kotri sub-region. The balance 99 tubewells were installed in Guddu sub region. The saline tube wells were installed in Thar Parkar and Mirpur Khas districts.

The sudden surge in the increase in private sector tube wells may be explained as a coping strategy to supplement shortages in the river/canal flows. In the absence of data on quality of underground water and pumpage, it is difficult to predict the soil fertility and overall environmental consequences. As most of these tubewells are shallow wells tapping perched water, they would soon be run out, unless canal supplies are back to earlier flows, or recharged with heavy rains and or canal seepage. The groundwater maps are shown in Figure 14 & 15 Volume III.

Quality of Groundwater

The water to be drained will undoubtedly be saline; effluent from tile drainage can vary from 3000 to about 10,000 ppm and that from tube wells can be twice as saline. The problem is to remove the water without affecting good agricultural land. Salinity effects of conveying water from tube wells to an outfall can be minimized by careful design. However, the problem of disposal is difficult, the choices being the Thar Desert, the River Indus the Runn of Kutch or Arabian Sea. Disposal into the first two can be discounted from cost hydraulic and environmental considerations. Outfall into either the Runn of Kutch or Arabian Sea is technically feasible but, as the latter has the more satisfactory environmental and hydraulic performance; it has been adopted as the outfall for LBOD. In addition it isolates the discharge from Indian Territory.

Since the sediments of the project area were deposited in sea environment, therefore, groundwater quality in the project area is highly saline and cannot be used for irrigation. Seepage from the water bodies of irrigation system in the area has improved the shallow groundwater quality to some extent, especially in the northern part of Sanghar component, where saline water is overlain by a significant thickness of fresh to marginal quality groundwater (EC less than 2.0 d/cm). However the thickness of improved water quality is generally less than 250 feet and fresh groundwater cannot be recovered efficiently by ordinary tube wells, because tube wells in the area generally go saline due to the intrusion of underlying saline water. Therefore, for subsurface drainage in the project area, where improved quality of groundwater overlies the deep saline groundwater, scavenger wells have been installed to control the mixing of saline and fresh groundwater.

The salinity of tube wells in all the three components is different. At the time of project preparation, average salinity of the tube wells was predicted as 23 dS/m in Nawabshah component, 30 dS/m in Sanghar component and 35 dS/m in Mirpur Khas component. The salinity data, observed during the post project monitoring of tubewells, shows that the average salinity of groundwater for Nawabshah and Sanghar components are quite close to the predicted values, whereas, the value for Mirpur Khas component is far higher than the predicted value. The groundwater quality reported by SMO for the year 2006-2007 is given in Table 10.

Table-10: Groundwater Quality for LBOD Stage - 1 (2006-2007)

Component	Monitoring Points	Type	Groundwater Quality (dS/m)		
			Min	Max.	Average
Nawabshah	112	Drainage Wells	0.47	42.7	20.4
	151	Scavenger (Fresh)	0.5	7.9	5.2
		Scavenger(Saline)	0.6	16.8	5.8
Sanghar	169	Drainage Wells	1.3	58.6	33.5
	115	Scavenger (Fresh)	0.4	8.5	1.9
		Scavenger (Saline)	0.4	43.8	6.1
Mirpur Khas	55	Drainage Wells	8.9	87.2	52.6

Source: SMO (WAPDA), Hyderabad – 2009

Consultants have tested ground water quality for the period 2010 – 2012 in the project area and the results can be referred in Main Report, Volume I - Present Situation.

Change in Groundwater Quality

Groundwater quality (EC) was measured during the final acceptance tests after the construction of tube wells. During the operation of the project, water quality from the tube wells is being annually monitored by SMO. A comparison of the previous and present groundwater qualities is given in Table 10. From this table, it can be seen that groundwater quality from drainage wells more or less remains the same in Sanghar and Mirpur Khas components, whereas in Nawabshah component the quality has deteriorated. Similarly, water quality from scavenger wells in Sanghar component has also deteriorated and salinity has increased from 4.6 to 6.1 dS/m within a period of 10 years.

Table-11: Change in Groundwater Quality

Well Type	EC (dS/m) 1995-1997			EC (dS/m) 2006-2007		
	Min.	Max.	Av.	Min.	Max.	Av.
Nawabshah – Drainage Wells	1.27	36.5	14.8	0.47	42.7	20.4
Nawabshah – Scavenger (Fresh)	-	-	-	0.5	7.9	5.2
Nawabshah – Scavenger (Saline)	-	-	-	0.6	16.8	5.8
Sanghar – Drainage Wells	3.4	53.0	36.6	1.3	58.6	33.5
Sanghar – Scavenger (Fresh)	0.3	18.2	2	0.4	8.5	1.9
Sanghar – Scavenger (Saline)	0.3	20.0	4.6	0.4	43.8	6.1
Mirpur Khas – Drainage Wells	14.1	150.1	51.6	8.9	87.2	52.6

3.6.2 Ground Water Depth in Badin Area

SCARPs Monitoring Organization (SMO) WAPDA office, Hyderabad monitors the water table bi-annually in the project area. For this purpose a network of piezometers has been established. The latest map showing different water table zones of Badin area, prepared for April 2007 by SMO, given as Figure 3.2, has been used to estimate the percentage of total area under different water table zones and the same is given in Table 12.

Table-12: Water Table Conditions in Badin Area

Groundwater Depth Zones		Area	Percentage
(mm)	(ft)	(acres)	
0-90	0-3	1,485	0.25
90 -150	3-5	59,258	9.98
150 - 300	5-10	466,691	78.63
300 -450	10-15	66,062	11.13

Consultants have tested ground water quality for the period 2010 – 2012 in the project area and the results can be referred in Main Report, Volume I - Present Situation.

It is surprising that table shows only 0.25 % of the total area under less than 3 feet water table, whereas, much more area is found with water table depth less than 3 feet during field visits and covered with marshes, lakes and fish ponds.

3.6.3 Groundwater Quality in Badin Area

Groundwater underlying Badin area is generally saline and cannot be used for irrigation. However, somewhere along the irrigation canals and at shallow depths sweet water due to canal seepage is available which is used by the locals for drinking purposes. Electrical conductivity (EC) of groundwater samples taken from surface drains and hand pumps, from different drainage systems of Badin area, are given in Table 13. Lower values of EC are for groundwater samples taken from hand pumps used for drinking purposes.

Table-13: Electrical Conductivity of Groundwater

Sr. No.	Drainage System	EC of Groundwater dS/m	
		From	To
1.	LBOD Branch Drain	0.84	10.90
2.	Tando Bago Branch Drain	1.25	19.84
3.	Serani, 2R, Lowari, 3R, 4R and 5R of KPOD	0.66	19.32

Source: SMO (WAPDA) 2010

3.6.4 Brief Overview of Agriculture Sector in the Study Area

Agriculture sector is an important engine of growth in the study area. It directly and indirectly provides livelihood to about three fourth of the Sindh population residing in the left bank. The left bank receives almost 60% to 65% of the canal withdrawals, while its share in the total cropped area is about three fourth. Apart from wheat, the main staple, most of the main cash crops and high value crops, such as cotton, sugarcane, vegetables, condiments, and fruits (mango and banana) are grown.

Agriculture in the project area is still primitive and mainly at subsistence level. The yields of many crops are among the lowest in the world for irrigated agriculture. Several factors are responsible for this state of affairs. The physical restraints are important but the land tenure system; lack of credit facilities and lack of modern farming knowledge combine to rob the farmer of the necessary incentive to improve. As yet very little fertilizer is used and crop protection measures are totally ineffective. Farming has not developed in the way envisaged when the Sukkur Barrage system was designed. At that time cropping intensities for the Rohri and Nara canals were expected to reach 27 percent in Kharif and 54 percent in Rabi. The reason for this design was to even out the flows in the canals; it was assumed that the summer crop water requirement was twice the winter requirements and therefore with a constant water supply the summer cropped acreage would be only half that of winter. While this arrangement was desirable for canal design it rather ignored the capability of the farmer. Generally, if farmers have the capacity to cultivate certain acreage, then they tend to utilize this acreage in both winter and summer, consequently the overall winter and summer acreages are much more nearly equal than was planned.

In the project area, cotton in summer and wheat in winter, dominate the cropping pattern. Rice is important in Kotri Barrage Command but in Sukkur Barrage Command, its cultivation is restricted to reclamation purposes and special permission is required for its growth. Sugar cane is becoming increasingly important in the area. Mangoes, bananas and to a lesser extent guavas, are the main fruits grown.

About half the area that was brought under command by the Sukkur Barrage was previously uncultivated land and the new irrigation layout was arranged with conveniently rectangulated fields. The remainder of the command area was old inundation-irrigated land, where the fields still retain the original random shapes and sizes. This makes efficient irrigation and management difficult.

The subsistence type farming and a rather low population density on the land has generally limited the amount of money invested in agriculture.

<u>Cropping Pattern</u>

Sindh has two main cropping seasons, namely Kharif – summer season (mid-April through mid-October), and Rabi – winter season (mid-October through mid-April). The main Rabi crops are wheat, rape and mustard, vegetables, and fodder. The main crops grown in Kharif are cotton, sugarcane, paddy, millets, and cluster-bean, Kharif vegetables, pulses, nontraditional oilseeds, etc. In addition to this, the left bank produces different fruits such as mango, banana, dates, papaya, guava, etc. The data on area under various crops for the last three years show that the total cropped area under crops decreased from about 3 million ha in 2007/08 to about 2.8 million ha in 2009/10. This decline is attributed to decline in the canal water availability. This has also changed the share of individual crops in the total area.

The photo graphs of 2012 crops are given below:

Figure 5: Rice Crop near RD 126+720 of FGOD

Figure 6: Millet Crop at Village Bakar Mori near Shahdadpur of WNMD

Figure 7: Onion Crop near RD 128+940 of WNMD

Figure 8: Rice Crop harvesting in Badin Area

Figure 9: Mango Farm near Mirpur Khas Area

Figure 10: Banana Farm in District Shaheed Benazirabad

Figure 11: Cotton Crop near RD 465+000 of Spinal Drain

Figure 12: Sugarcane at village Bakar Mori Near Shahdadpur.

The overall cropping intensity in the Study area is estimated as 65%. It is highest in the Guddu sub-region (110%), followed by Kotri sub-region (63%), and 60% in the Sukkur region. One reason that explains high farming intensity in Guddu sub-region is rapid growth in private tubewells. Moreover, major portion of the culturable waste and area uncommandable lies in the Sukkur sub-region.

The cropping intensity mentioned above should not be seen same as command area specific cropping intensities. The estimated cropping intensity reflects cropping intensity of the Study area as a whole, which include barrage and non-barrage areas. The Figures 5 to 12 show the condition of different crops in Kharif 2012 of the project area.

3.6.5 Water Logging Trends of Study Area

The Study area as already mentioned is irrigated by the left bank canals of three barrages of lower Indus region, surveyed area in each canal command in presented in Figure 13 & 14. Within this area the water table trend is based on the available data of 30 years for two periods i.e the Pre monsoon (April) & Post monsoon (October) seasons of each year. However, some where the data is missing due to lack of funds, which were not provided at proper time to the concerned organization (SMO south) & because of that survey of the area could not be conducted within a scheduled time.

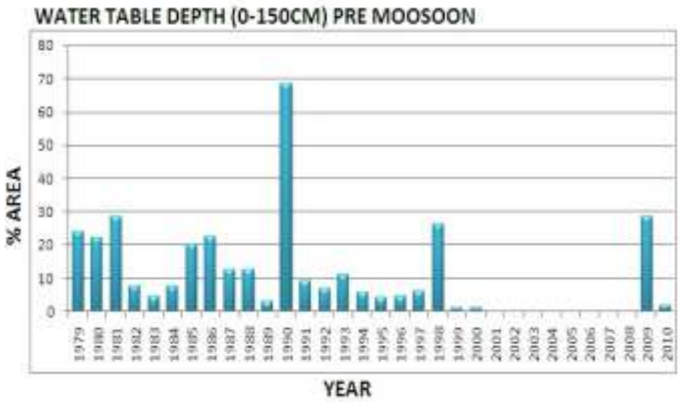
It is obvious from the two different categories of pre monsoon & post monsoon seasons for the period of 30 years (1979-2009), the water table trend remained at highest level (0-150 cm) in both seasons. In general, the high water table conditions have clearly been observed in the post-monsoon (October) as compared to the pre-monsoon (April) period. The percent wise area covered on bi-annual survey basis indicate that major part within different Canal Commands remained under 0-150cm water table depth during post monsoon season. This is because of the rainfall, flooding condition & simultaneously canals are running in full swing for supplying irrigation water during the Kharif season, and water table rises at the peak before the start of the Rabi season. After that decreasing trend of water table starts, that is why the area covered by water logging is more during the post monsoon period.

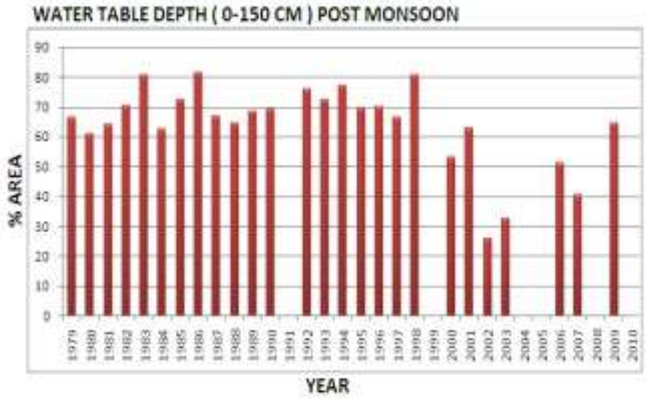
Further it is pertinent to note that during the recent past drought conditions prevailed throughout region i-e from 1999 till the end of 2009 because of this the water table depths were remarkably lowered down to a larger extent, leaving a small area within 0-150 cm depth zone in pre monsoon season, where as a decreasing trend has also been observed during post monsoon period.

Figure 13: Observed Water Table Pre Monsoon (April) and Post Monsoon (October)

GHOTKI FEEDER CANAL COMMAND

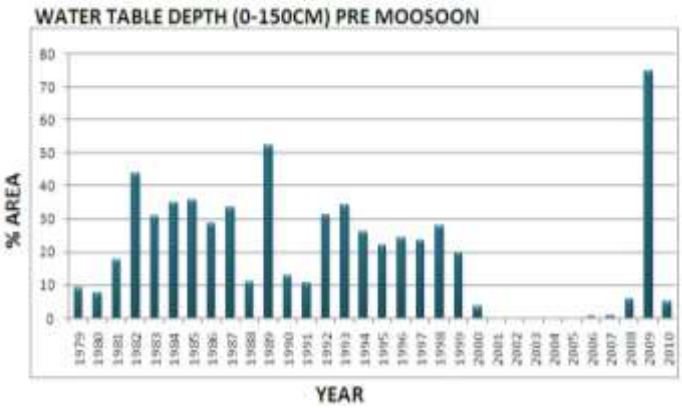
SURVEYED AREA (389000 HA)

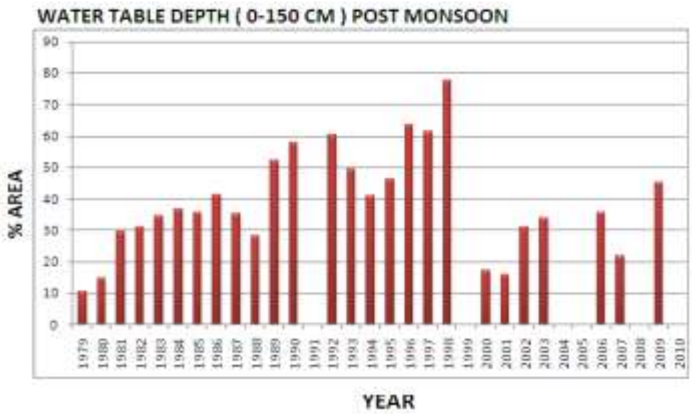




KHAIR PUR WEST CANAL COMMAND

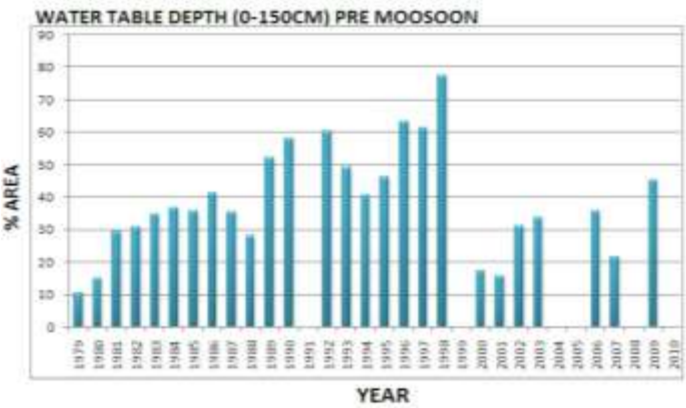
SURVEYED AREA (121000 HA)

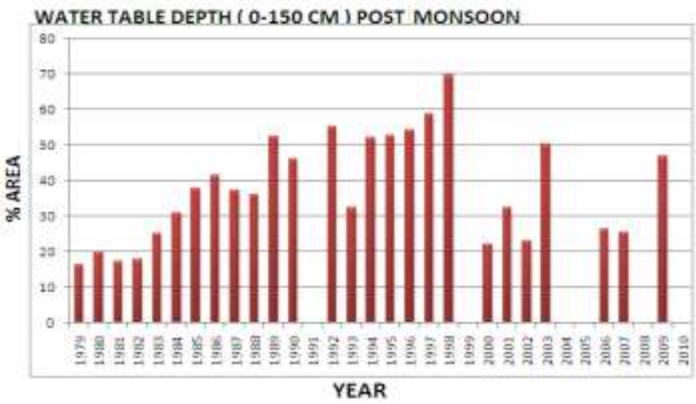




KHAIR PUR EAST CANAL COMMAND

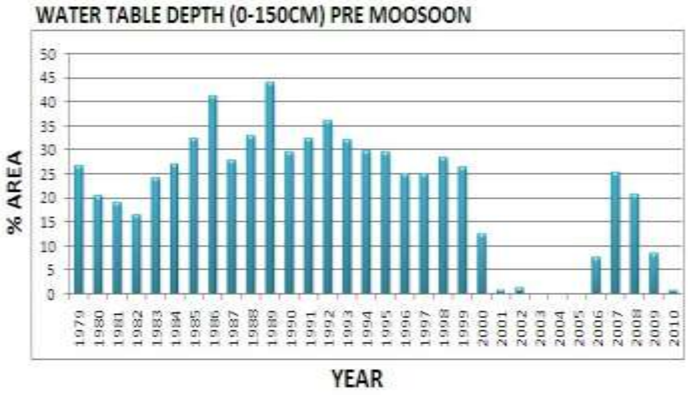
SURVEYED AREA (23100 HA)

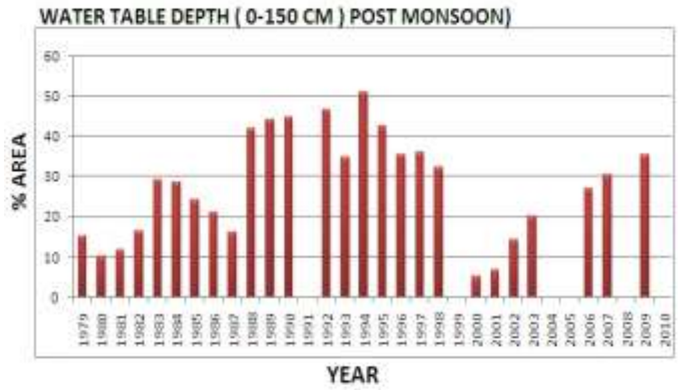




NARA CANAL COMMAND

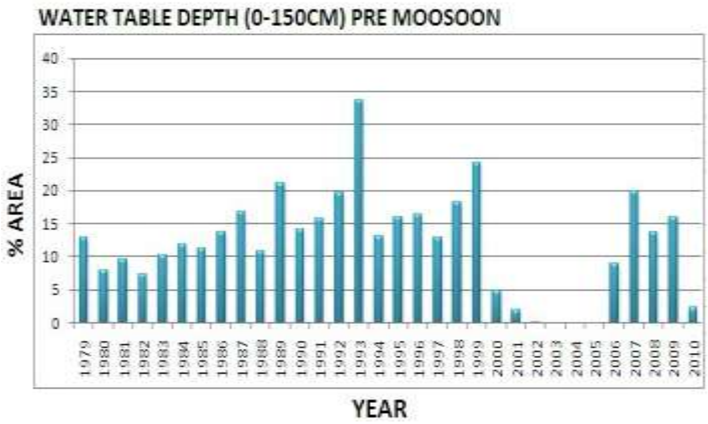
SURVEYED AREA (1017000 HA)

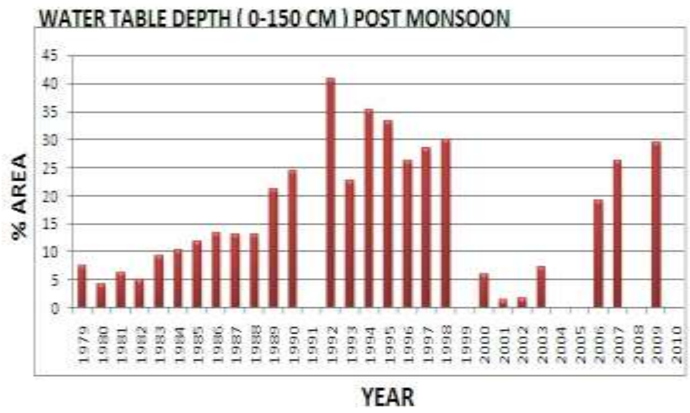




ROHRI CANAL COMMAND

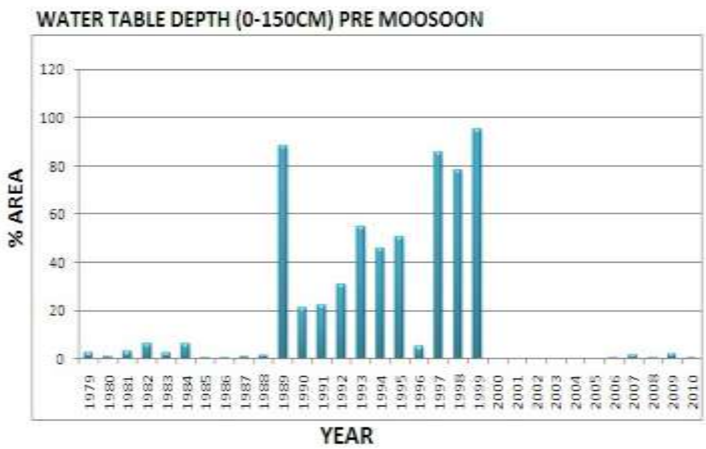
SURVEYED AREA (1195000 HA)

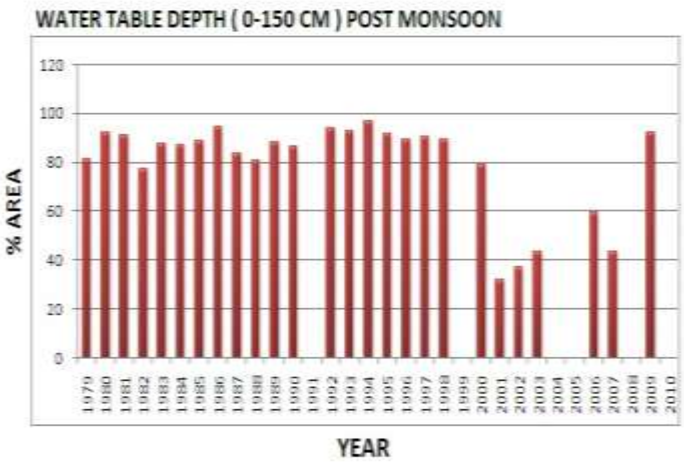




PINYARI FEEDER CANAL COMMAND

SURVEYED AREA (385000 HA)

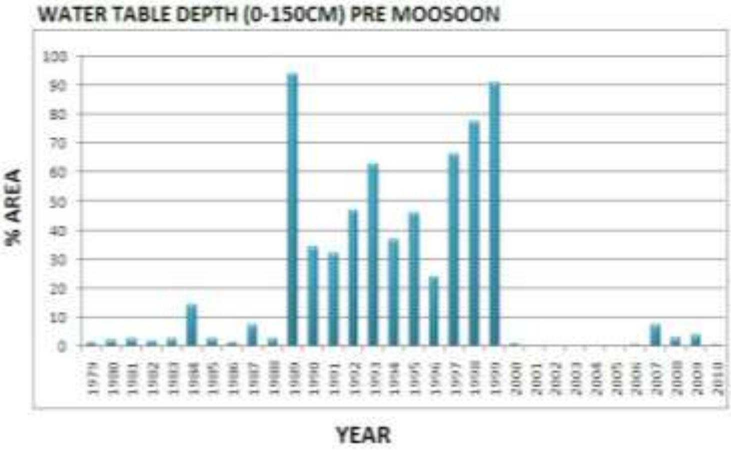


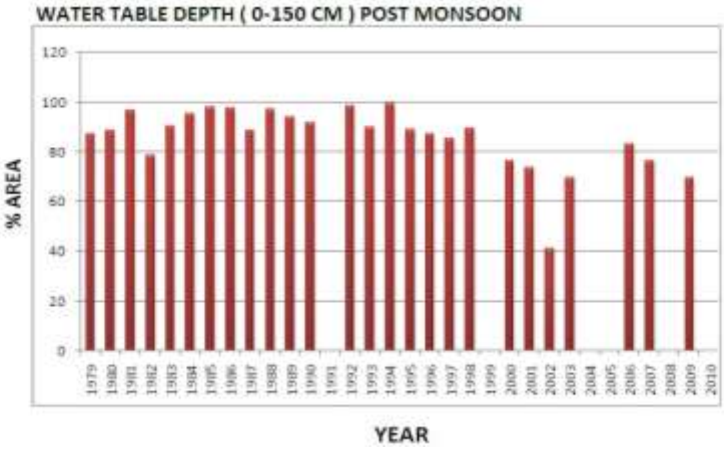


Source: SMO South WAPDA

FULELI CANAL COMMAND

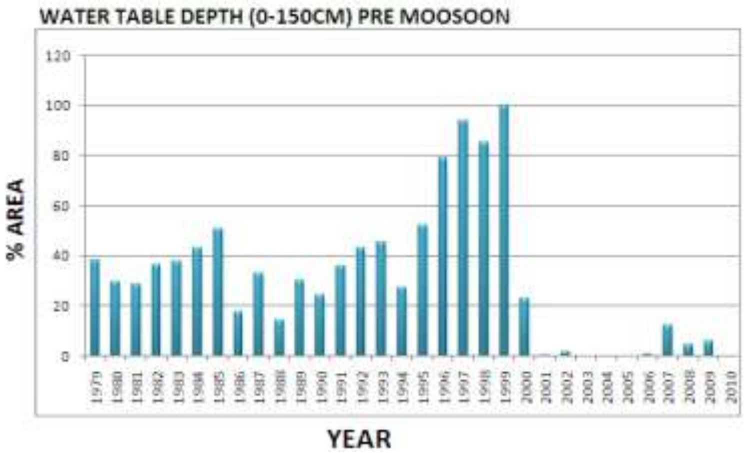
SURVEYED AREA (409000 HA)

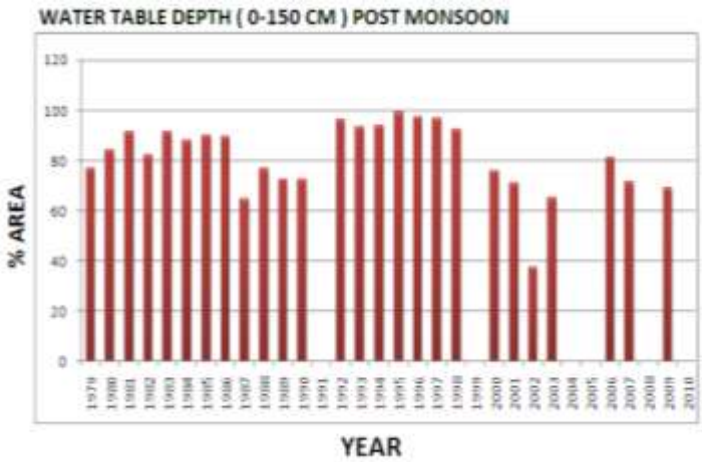




AKRAM WAH CANAL COMMAND

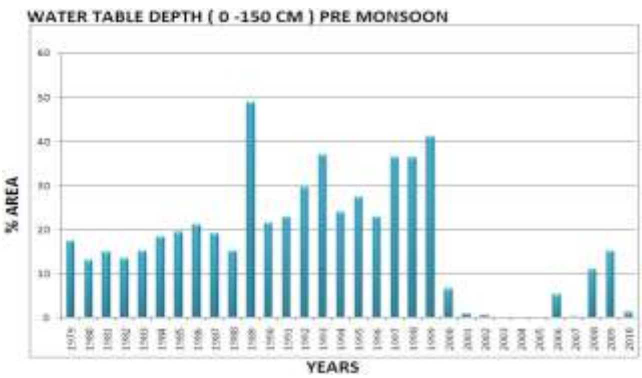
SURVEYED AREA (236000 HA)

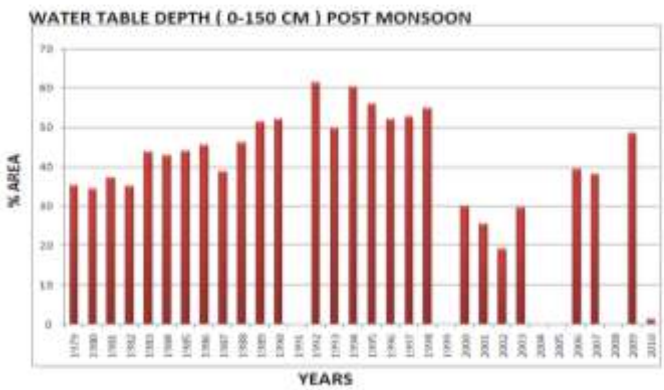




Source: SMO South WAPDA

Figure 14: Pre Monsoon (April) and Post Monsoon (October) Water Logged Area in Study Area





Source: SMO South WAPDA (2011)

3.7 Pollution Caused by Effluent of Sugar Mills

Sugar Mills: out of 33 sugar mills in Sindh, 30 are located on left bank of Indus. Three out of 33 sugar mills use the molasses to produce industrial alcohol (ethyl alcohol) a significant quantity of which is exported. Mills in Sindh have crushing capacity ranging from 4-9,000 metric tons per day. It is estimated that these mills discharge untreated effluents of about 25 million cubic meters per year in the irrigation and drainage systems (SDPI 2006). This untreated effluent have high BOD, COD and TDS levels which pollute the water and are hazardous for humans and other biotic life. The sugar mills in Sindh mostly dispose off their effluents into the LBOD drainage system that kills the fish and induce toxic chemicals in the drainage system.

The consultants have analyzed water samples from various sugar industries to estimate the physic-chemical parameters to assess the quality of the effluent. Research has indicated that the parameters such as pH, EC, TDS, DO, BOD, COD significantly exceeded the permissible limits, indicating the need of proper treatment of waste water before discharge into water bodies (Kumari et al 2006).

1997, it is mandatory upon every industry and city government to have a pre-treatment plant at their premises. There are well defined procedures and techniques being practiced all over the world for treating the industrial and municipal effluents before disposing off or using for agriculture/lawn/parks irrigation etc. These include: i) physical treatment; ii) chemical treatment; and biological treatment.

Table-14: Water Quality of Sugar Mills Effluent during the Year 2011

Sr No.	Name of Sugar Mill	D.O mg/I	BOD mg/I	COD mg/I	TSS mg/I
1.	LAR Sugar Mills at Sujawal	2.1	980	1740	1250
2.	DEEWAN Sugar Mills at Badin	1.8	840	1690	1080
3.	Army Welfare SM#01 at	2.4	390	780	800
4.	Shah Murad Sugar Mill at	2.4	1100	1800	2600
5.	PANGRIO Sugar Mill at	2.2	740	1180	1800
6.	BAWANI at Talhar	2.7	180	260	340
7.	Tando Muhammad Khan Sugar Mill at	2.6	210	300	450
8.	SINDHABAD GAR Sugar Mill at	2.5	800	1200	2400
9.	SERI Sugar Mills at	1.9	920	1490	350
10.	KHOSKI Sugar Mill at	-	330	500	300
Permissible Limits		>4	80 WHO	150 WHO	150 WHO

The water quality indicates that all the parameters tested exceed the permissible limits and SIDA and IPA of Government of Sindh should not allow untreated effluent to drainage network of LBOD. Even the treated effluent should be allowed after recovering in advance 75% of the O&M of LBOD Drainage Network including operation cost of saline tubewells from the mill owners the effluent is destroying ecosystem of the area and spreading skin diseases among local population. This needs to be checked with iron hand. Without proper cost recovery, no drainage project is going to be economically viable and timely successful.

3.8 Disaster Areas Needing Drainage Improvement

Timely preventive and regular maintenance of drainage systems is absolutely necessary for an effective performance for which they are designed and built. The importance of timely maintenance is often overlooked resulting in reduction in capacities and require additional expenditure for restoration of drain capacities. The deferred maintenance results overtopping, breaches and flooding of the adjoining areas causing damages to life and property.

The second is the Dhoro Puran Catchment, an area of 464, 000 acres CCA and 497,000 GA between the Jamrao Canal and West Branch. The area is to be served by the Dhoro Puran Branch Drain. At present, the natural drainage line of Dhoro Puran is badly impeded. The land slopes are relatively flat, and the rainfall intensities are high. This area has been one of the worst affected areas during severe storms in recent years. The rain storms of 1961, 1964, 1967 and 1970 caused heavy flooding which resulted in some loss of life and considerable damage to property and standing crops of the entire catchment this area is likely to benefit most by surface drainage.

The area north of West Branch head and up to the northern edge of the command between Jamrao and Mithrao Canals was chosen in preference to the South Rohri Branch Drain catchment. Although the area lies in a storm zone of lesser intensity, its drainage requirements are acute. With practically no natural drainage outlets, it is continuously subjected to seepage and water logging from major canals. The area measures 489,000 acres CCA and 513,000 acres GA. Its drainage is envisaged through Jamesabad Branch Drain total catchment of which is 561,000 acres gross of which 527,000 acres are CCA. It will run between Mithrao and Jamrao canals and will be one of the longest branch drains in the system. The planned surface drainage project for the above left over areas is as under: -

	Left Bank Area	G.A (Acres)
✓	Ghotki	545,129
✓	Moro	117,000
✓	South Khairpur	475,000
✓	Tando Adam	371,000
✓	Tando Muhammad Khan	569,000
✓	Digri	302,000

The feasibility of surface drainage for above area has been completed and can be further referred under feasibility study of revival of Dhoras.

CHAPTER 4: EXTENT OF LBOD SURFACE DRAINAGE NETWORK

4 Extent of LBOD Surface Drainage Network

LBOD Stage-I project area is located in Sindh, in the Lower Indus Basin. It lies between latitudes 24º 10' and 26º 40' N and Longitudes 68º 09' and 69º 26' E in the districts of Nawabshah, Sanghar and Mirpur Khas. The project is located on the Left Bank of River Indus in the command of Sukkur Barrage. Major towns of the project area are Shaheed Benazirabad, Sanghar and Mirpur Khas. All the major towns of the area are either connected by metalled roads or by railway line.

4.1 Components of LBOD Drainage Network

The project area lacks natural drainage and the few existing natural drainage lines, were severed by the network of irrigation canals built in 1932 or subsequently and also by construction of road infrastructure. The poor drainage conditions coupled with perennial irrigation supplies have resulted in the rise of water table.

In the extreme southern catchment, namely Badin area, open surface drains were constructed by Irrigation Department within Kotri Barrage Command to cater for storm water drainage and excess effluent from rice fields. The system has been provided with the outfall through Kadhan Pateji Outfall Drain (KPOD) on to the mud flats and Pateji Dhand in Runn of Kutch.

To check the rising water table and to provide relief from surface runoff generated by rainfall in Nawabshah, Sanghar and Mirpur Khas areas, extensive networks of surface drains, drainage tube wells, tile drains and interceptor drains along the major canals were constructed by WAPDA during the implementation of LBOD Stage-1 Project.

Hierarchy of the surface drainage system of LBOD Stage-1 Project comprise; Sub-drains, Branch drains, Main drains, Spinal drain, Outfall drains and Tidal link out falling into the Arabian sea. Geographical units, where this surface drainage system is located, are: -

- Nawabshah (Shaheed Benazirabad) Component;
- Sanghar Component: and
- Mirpur Khas Component
- Badin Component

The salient features of 3 units of LBOD system are: -

S. No.	Drainage System	Length	
		RDs	**Canal Miles**
1.	Nawabshah Drainage System	1968	394
2.	Sanghar Drainage System	1467	293
3.	Mirpur Khas Drainage System	1474	295
	Total	**4909**	**982**

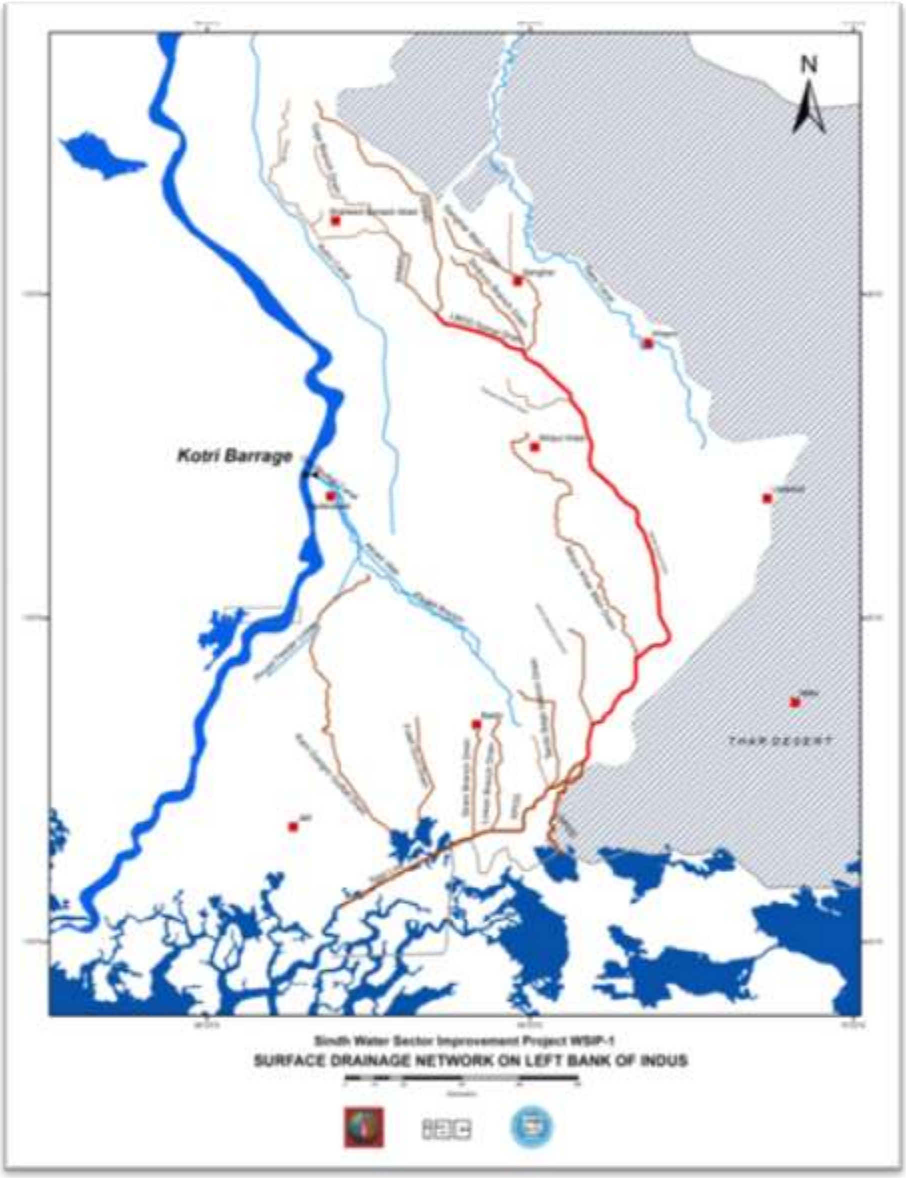


Figure 15: Map Showing LBOD Drainage System

4.1.1 Surface Drainage System of Nawabshah Component

Nawabshah Component is the northern most drainage system and drains its surface as well as sub-surface drainage effluent through two main drains i.e. West Nawabshah Main Drain (WNMD) and East Nawabshah Main Drain (ENMD). Both of these main drains outfalls into the Spinal Drain at its staring point i.e. RD 815+960. Sub-surface drainage effluent of the component, generated by 465 saline groundwater tube wells, is 421 cfs. Gross area of the component is 626,000 acres. As per adopted design criteria the storm water generated due to rainfall, within the component, is 789 cfs. Nawabshah component is drained by the following network of drains: -

Type of Drain		Length in RDs
Sub Drains		1101
Branch Drains		348
Main Drains		519
		1968

Figure 16: Inauguration By Honourable Prime Minister of Pakistan on 09-08-1995

Figure 17: Inadequate Capacity of Road Culvert Nawabshah Component

4.1.2 West Nawabshah Main Drain (WNMD)

It originates from south west of Nawabshah and east of Sakrand and Rohri canal. It's outfalls into Spinal at Shadadpur. It is designed to drain out storm water and saline tubewells effluent from the western area of Nawabshah District.

Figure 18: Illegal Cut to IP by Land lord at RD 118+336 of WNMD

Figure 19: Looking Upstream at RD 124+888 of NWMD

Figure 20: Illegal Pipe Crossing at RD 11+498 of WNMD

Figure 21: Illegal Huts near RD 36+456 of WNMD

Figure 22: RD# 125+700 WNMD

Figure 23: Illegal Pipe Crossing of WNMD 49

4.1.3 East Nawabshah Main Drain (ENMD)

It originates from north of Nawabshah, passes through Rahwari, Khadro and outfalls into spinal at Shadadpur The ENMD main drain is designed to drain storm water and saline tube wells effluent from the eastern portion of Nawabshah. The drainage system consist of 12 number of sub drains ranging from 20 to 50 cfs.

Figure 24: ENMD at RD 26+850 (Looking Upstream)

Figure 25: Relief Cut at RD 0+00 of ENMD

The Sub Drains of Nawabshah Drainage Component are described in Table 15.

Table-15: Sub Drains of Nawabshah Drainage System

S. No.	Sub Drain	Length		Design Discharge cfs
		RD	Miles	
1.	EN1L	21.825	4.125	11.05
2.	EN2L	24.400	4.612	13.15
3.	EN3L	49.100	9.280	13.23
4.	EN4L	75.520	14.273	23.74
5.	EN4LA	9.000	1.701	6.60
6.	EN5L	20.000	3.780	15.50
7.	EN6L	36.500	6.899	17.60
8.	EN7L	35.000	6.615	12.36
9.	EN8L	17.800	3.364	9.04
10.	EN9L	9.000	1.701	9.96

S. No.	Sub Drain	Length		Design Discharge cfs
		RD	Miles	
11.	EN10L	42.000	7.938	13.60
12.	EN1R	20.000	3.780	12.69
13.	EN2R	18.080	3.417	11.41
14.	WN1L	19.898	3.761	6.00
15.	WN2L	34.028	6.431	10.00
16.	WN1R	18.869	3.566	6.50
17.	WN1AR	18.680	3.531	8.00
18.	WN2R	6.415	1.212	1.70
19.	WN3R	14.666	2.772	2.40
20.	G1R	13.276	2.509	3.50
21.	G2R	10.557	1.995	4.90
22.	G3R	38.090	7.199	48.50
23.	G3RA	32.350	6.114	11.40
24.	G3RB	44.547	8.419	26.10
25.	G3RC	15.500	2.930	11.80
26.	G4R	25.080	4.740	11.80
27.	G5R	67.000	12.663	63.94
28.	G5RA	39.450	7.456	40.21
29.	D1L	19.810	3.744	5.60
30.	D2L	45.445	8.589	8.30
31.	A0L	8.600	1.625	6.60
32.	A1L	55.200	10.433	14.00
33.	A2L	40.000	7.560	20.90
34.	A3L	37.760	7.137	11.30
35.	A4L	15.816	2.989	7.80
36.	A1R	19.755	3.734	11.30
37.	A2R	37.700	7.125	4.50
38.	A3R	12.157	2.298	6.20
39.	A4R	32.670	6.175	20.20

4.2 Surface Drainage System of Sanghar Component

Sanghar Component is located in the south-east of Nawabshah Component. The surface as well as sub-surface drainage effluent of Sanghar Component is carried by Sanghar Main Drain (SMD) and Nara Valley Main Drain (NVMD) and three Branch Drains namely Sinjhoro Branch Drain (SIBD), Makhi Branch Drain (MBD) and Patoyun Branch Drain (PBD). Sub-surface drainage effluent of the component generated by 793 saline groundwater tube wells is 740 cfs. Gross area of the component is 424,000 acres. As per adopted design criteria the storm water generated due to rainfall, within the component, is 747 cfs. Sanghar component is drained by the following network of drains: -

Type of Drain		Length in RDs
Sub Drains		934
Branch Drains		306
Main Drains		227
Total		**1467**

4.3 Sanghar Main Drain

The Sanghar Main Drain is the trunk carrier for the entire command of Jamrao, Mithro Canals, Irrigation Network and Outfalls into Spinal Drain with design discharge of 390 cfs and 77 RD in length, the alignment passes through major towns of the district including Sanghar.

Figure 26: Illegal Cut at RD 44+325 of Sanghar Br Drain

Figure 27: WCA Crossing at RD 39+665 of Sanghar Br Drain

4.4 Sinjhoro Branch Drain

The design discharge is 245 cfs and 143 RD lengths, comprises 10 sub drains ranging from 10 to 60 cfs. The major towns in catchment area are Sinjhoro and Jhol.

Figure 28: Damaged VRB at RD 132+460 of Sinjhoro Br Drain

Figure 29: Lift Irrigation at RD 71+120 of Sinjhoro Br Drain

4.5 Patayon Branch Drain

The design discharge is 104 cfs and out falls into spinal at RD 95. Its length is 94 RDs. The major towns in catchment area are Nauabad, Berani and Sindhri.

Figure 30: Damaged Foot Bridge at RD 42+000 of Patoyun Br Drain

Figure 31: Damaged WCA at RD 70+069 of Patoyun Br Drain

Figure 32: Fish Catch From Patoyun Br Drain

Figure 33: Obstructions through Illegal Bridge at RD 87+007 of Patoyun Br Drain

The Sub Drains of Sanghar Drainage Component are described in Table 16.

Table-16: Sub Drain of Sanghar Drainage System

S. No.	Sub Drain	Length		Design Discharge cfs
		RD	Miles	
1.	S1L	46.746	8.872	32.80
2.	S1LA	24.936	4.733	17.10
3.	S2L	25.387	4.818	23.10
4.	S1R	36.794	6.984	43.90
5.	S2R	24.674	4.683	20.70
6.	S3R	52.980	10.056	40.00
7.	M1R	76.423	14.505	79.50
8.	M1RA	23.293	4.421	17.60
9.	S3L	72.799	13.817	64.90
10.	Si1R	32.800	6.199	18.60
11.	Si2R	9.933	1.877	5.00
12.	Si1L	13.810	2.610	13.20
13.	Si2L	12.294	2.324	19.20
14.	Si3L	46.381	8.766	70.30
15.	Si3LA	24.830	4.693	37.50
16.	Si3LA/L	5.450	1.030	4.50

S. No.	Sub Drain	Length		Design Discharge cfs
		RD	Miles	
17.	Si4L	9.468	1.789	16.20
18.	Si5L	16.017	3.027	24.40
19.	Si6L	52.290	9.883	55.90
20.	Spinal 4R	15.650	2.958	17.20
21.	Spinal 5R	27.022	5.107	24.50
22.	Spinal 6R	31.905	6.030	55.60
23.	Spinal 6RA	19.500	3.686	27.60
24.	Spinal 7L	17.253	3.261	21.20
25.	P1L	12.000	2.268	11.00
26.	P2L	36.200	6.842	25.00
27.	P1R	63.200	11.945	34.00
28.	Spinal 6L	12.000	2.268	10.00
29.	Spinal 6LA	48.800	9.223	26.00
30.	SSD	10.000	1.890	21.00
31.	SSD1L	12.600	2.381	6.00
32.	SSD1R	20.878	3.946	14.00

4.6 Surface Drainage System of Mirpur Khas Component

Mirpur Khas Component is in south of Sanghar Component. The surface as well as sub-Surface drainage effluent of Mirpur Khas Component is carried by Mirpur Khas Main Drain, which outfalls into the Spinal Drain at RD 297. Apart from the main drain a part of the component is drained by some sub-drains, which independently outfall into the Spinal Drain. Sub-surface drainage effluent of the component, generated by 719 saline groundwater tube wells and tile drainage network constructed on about 38000 acres of land, is 585 cfs. Gross area of the component is 376,000 acres. As per adopted design criteria the storm water generated due to rainfall, within the component, is 815 cfs. Mirpur Khas component is drained by the following network of drains: -

Type of Drain		Length in RDs
Sub Drains		1088
Main Drains		386
Total		**1474**

4.7 Mirpur Khas Main Drain

It is the carrier drain, the alignment bisecting the water way of natural nullah (Dhoro Puran), starts from the urban city limit of Mirpur Khas, passes through east of Tando Jan Muhammad, Digri, by passes Jhudo from western side and outfalls into Spinal at RD 297. The design capacity of the drain is 327 cfs and 386 RD in length and comprises of 29 sub drains.

Figure 34: Illegal Cut at RD 201+042 of MMD

Figure 35: Downstream View of Outfall Structure of MMD

Figure 36: Fully Damaged Saline Tubewell near RD 267+136 MMD

Figure 37: Lift Irrigation at RD 285+382 of MMD

The Sub Drains of Mirpur Khas Drainage Component are described in Table 17.

Table-17: Sub Drains of Mirpur Khas Drainage System

S. No.	Sub Drain	Length		Design Discharge cfs
		RD	Miles	
1.	M1L	22.280	4.220	45.00
2.	M2L	36.425	6.899	20.80
3.	M3L	71.224	13.489	28.70
4.	M3LA	44.600	8.447	14.50
5.	M4L	3.500	0.663	5.00
6.	M5L	16.554	3.135	10.00
7.	M6L	30.007	5.683	15.00
8.	M7L	16.000	3.030	5.00
9.	M8L	19.538	3.700	13.60
10.	M1R	64.104	12.141	75.80
11.	M1RA	47.990	9.089	21.80
12.	M1RA/R	28.060	5.314	17.90
13.	M1RB	49.422	9.360	31.50
14.	M2R	39.094	7.404	21.60
15.	M3R	96.445	18.266	73.20
16.	M3RA	15.515	2.938	14.00

S. No.	Sub Drain	Length		Design Discharge cfs
		RD	Miles	
17.	M3RB	30.432	5.764	15.30
18.	M3RC	7.288	1.380	12.60
19.	M4R	18.050	3.418	23.90
20.	M5R	21.385	4.050	17.90
21.	M6R	40.961	7.758	21.10
22.	Spinal 1L	36.906	6.990	23.10
23.	Spinal 2L	42.284	8.008	26.20
24.	Spinal 3L	98.300	18.617	70.80
25.	Spinal 4L	22.800	4.318	25.60
26.	Spinal 4LA	16.650	3.153	16.50
27.	Spinal 5L	66.225	12.542	44.40
28.	Spinal 5LA	18.196	3.446	14.50
29.	Spinal 1R	68.000	12.879	37.40

4.8 Surface Drainage System of Badin Area

Badin is the main city situated in the project area. Other major towns of the project area are Tando Bago and Talhar. Surface drainage system of Badin area comprises 54 branch and sub drains. Eighteen (18) branch or sub drains of Badin area outfall directly either into the Spinal Drain or into the KPOD at various points located between RD 203 of the Spinal Drain and RD 1+030 of the KPOD. Surface drains of Badin area falling within the present project boundaries comprise the following five sub-drainage systems: -

- Drains under LBOD Branch Drain System
- Drains under Tando Bago Branch Drain System
- Drains under East KPOD Drainage System
- Drains under Lowari Branch Drain System
- Drains under West KPOD Drainage System

Salient features of the drainage system are: -

- Number of branch or sub drains out falling into Spinal Drain is 5.
- Number of branch or sub drains out falling into KPOD is 13.
- Number of Sub Drains out falling into respective branch drains is 37.
- Total length of these drains is 1886.065 RDs.
- Gross area commanded by these sub-drainage systems is 927 sq. miles.
- Total design discharge of these drains at outfall is about 2000 cfs.

The Sub Drains of Badin Drainage Component are described in Table 18.

The rain water in Badin catchments is more than the other areas, which drain out slowly due to low lying area of Badin district and Tidal action of 3 to 4 meter high from Arabian Sea which obstruct the water flow of Tidal Link resulting in slow evacuation of storm water and causing back flow.

Figure 38: Illegal Cut at RD 73+352 of LBOD Br

Figure 39: LBOD Br 49, herd animal returning to Thar after rainfall

Table-18: Sub Drains of Badin Drainage System

S. No.	Sub Drain	Length		Design Discharge cfs
		RD	Miles	
1.	3R Sub-Drain	24.800	19.58	52
2.	4R Sub-Drain	64.500	35.63	94
3.	4RA Sub-Drain	11.800	2.55	7
4.	4RB Sub-Drain	24.560	6.00	16
5.	4RC Sub-Drain	26.350	15.55	41
6.	16L Sub-Drain	92.200	51.90	137
7.	16LA Sub-Drain	59.580	31.26	82
8.	17L Sub-Drain	29.300	8.47	22
9.	5R Sub-Drain	7.530	7.70	20
10.	18L Sub-Drain	26.000	10.86	29
11.	19L Sub-Drain	115.000	67.28	177
12.	19LA Sub-Drain	8.000	1.90	5
13.	6R Sub-Drain	12.500	8.26	22
14.	20L Sub-Drain	13.000	4.17	11
15.	7R Sub-Drain	12.500	6.32	17
16.	8R Sub-Drain	38.500	13.85	37
17.	21L Sub-Drain	8.500	1.67	4
18.	22L Sub-Drain	19.400	13.04	34
19.	Khoski Link of SBBD	22.000	8.00	25
20.	2R of SBBD	27.500	14.20	44
21.	V Bahadur of SBBD	10.000	3.18	10
22.	Gaheji Link of SBBD	12.000	3.70	11
23.	3R of SBBD	15.000	10.90	33
24.	AC Link of KPOD	10.000	6.06	19
25.	1R of KPOD	30.000	15.20	47

S. No.	Sub Drain	Length		Design Discharge cfs
		RD	Miles	
26.	Kumbharo Link of KPOD	6.000	7.00	21
27.	Panhwar Link of KPOD	5.000	7.00	21
28.	2R of TBBD	28.000	10.00	31
29.	3R of TBBD	15.000	8.65	27
30.	5R of TBBD	15.000	18.10	56
31.	6R of TBBD	40.000	27.10	83
32.	1R of Tando Bago of KPOD	66.500	19.88	61
33.	Panhwarki Link of 1R of Tando Bago	5.500	2.27	7
34.	5R of KPOD	59.230	22.80	83.6
35.	Jhanjhli Link Drain	20.000	2.70	14.12
36.	4R of KPOD	63.200	18.10	141.32
37.	1L of 4R of KPOD	10.000	4.10	16.44
38.	Kadhan Link Drain	25.000	4.30	50.35
39.	3R of KPOD	65.750	48.10	207.36
40.	1L of 3R of KPOD	10.000	1.90	7.92
41.	Behdemi Link Drain	25.425	9.90	29.36
42.	1R of LBD	21.500	10.55	27.4
43.	Kamaro	13.000	2.14	5.6
44.	2R of LBD	18.000	8.49	22.1
45.	Bukho Khadi	9.500	8.38	21.8
46.	2L of LBD	14.440	10.79	28.1
47.	3R of LBD	11.100	6.85	17.8
48.	4R of LBD	10.100	6.35	16.5
49.	2R of KPOD	54.500	22.45	65

4.9 Surface Drainage System of Kotri Barrage

Following are the main drainage system of Kotri Barrage: -

4.9.1 Fuleli Guni Outfall Drain

The construction of Fuleli Guni Drainage System was started in 1959 and completed in 1960s. The catchment area extends longitudinally from Tando Muhammad Khan to Mehro Dhand and laterally from Badin to Golarchi including Tando Muhammad Khan, Matli, Talhar, Badin and Golarchi. The system comprises of the following main and sub drains which falls into Mehro Dhand: -

Type of Drain		Length in RDs
Sub Drains		373
Main Drains		126
Total		**499**

4.9.2 Karo Ghungro Outfall Drain

Karo Ghungro Surface Drainage System was constructed in the sixties. It originates from Tando Muhammad Khan, passes through west of Golarchi, Talhar, Bulri Shah Karim and finally outfalls into Sanhro Lake, which is connected to sea through a creek without any gated regulator. The gross command area (GCA) of the system is 318,100 acres and design discharge of 1233 cfs. The system comprises of the following: -

Type of Drain	**-**	**Length in RDs**
Sub Drains	-	491
Main Drains	-	371
Total	**-**	**862**

4.10 Spinal Drain

Spinal Drain is 131.4 canal miles long main trunk drain and starts from the outfalls of East Nawabshah Main Drain (ENMD) and West Nawabshah Main Drain (WNMD) where the RD is 815+960. During its flow southwards surface drains of Sanghar and Mirpur Khas Components outfall into it. The End point of the Spinal Drain is at RD 159+000 where a bifurcation structure is provided and downstream of this structure two outfall drains i.e. Dhoro Puran Link Drain (DPOD) and Kadhan Pateji Outfall Drain (KPOD), flow in separate directions and convey the spinal drain water into Runn of Kutch and Arabian Sea. Total design base flow at this location is 1,240 cfs, while the total design storm water flow is 4,600 cfs. Base flow is defined as the saline groundwater pumped by subsurface drainage facilities of the components, while storm water is the runoff generated by rainfall. Salient design features of the Spinal Drain are: -

Length	(RD)	-	657
Discharge	(cfs)	-	1240 – 4600
Bed width	(ft)	-	85 -162
Depth	(ft)	-	8.75 -13.33
Side Slope	(-)	-	1:3
Berm width	(ft)	-	20
Longitudinal Slope	(ft/ft)	-	0.000118 - 0.00005

Figure 40: Breach of Spinal Drain at RD 204

Figure 41: Relief Cut in Spinal Drain at RD 248+00

Figure 42: Overtopping of LBOD Branch Drain at Outfall point RD 203 Spinal Drain

Figure 43: Spinal Drain RD 789

Figure 44: Sub-Drain (3R) Out falling into Spinal. (Direct Sub Drain)

Figure 45: Damaged Berm and Bank of Spinal Drain RD 578

The Figures 20 to 45 show the existing conduction of the drainage system.

Table-19: Main Branch Drainage System of LBOD

S. No.	Branch Drain	Length		Design Discharge at Outfall (cfs)
		RD	Miles	
1.	East Nawabshah Main Drain	313.000	59.157	142.56
2.	West Nawabshah Main Drain	205.600	38.858	277.50
3.	Gajrah Branch Drain	147.388	27.856	132.20
4.	Amurji Branch Drain	177.900	33.623	98.50
5.	Sanghar Main Drain	277.00	15.4	389.80
6.	Sinjhoro Branch Drain	143.121	27.050	244.50
7.	Patoyun Branch Drain	94.525	17.865	104.00
8.	Mirpur Khas Main Drain	386.400	73.180	326.60
9.	LBOD Branch Drain	144.00	28.00	936.00
10.	Shaadi Bahadur Branch Drain	58.00	11.60	70.00
11.	Tando Bago Branch Drain	96.00	19.2	123.00

Table-20: List of Infrastructure on Spinal Drain

S. No.	Description	Nos.
1	Village Road Bridges	23

S. No.	Description	Nos.
2	District Road Bridges	3
3	Water Course Crossings	44
4	Water Course Crossings With Foot Bridges	31
5	Twin Water Course Crossings	8
6	Minor Aqueducts	3
7	Feeder Water Courses	2
8	Minor Crossings	10
9	Escapes	2
10	Railway Crossing	1
11	Drain Junctions/Outfalls	26
	Total	**153**

4.11 Drainage Effluent Quality of Spinal Drain

The drainage effluent quality as observed by the Consultant during the year November 2012 is compared with the years of 2006, 2007 & 2008.

(ds/m)

Sr. No.	RD	Year 2006 (Nov)	Year 2007 (Nov)	Year 2008 (Jan)	Year 2012 (Nov)
1.	812	5.200	7.220	11.250	3.7
2.	796	5.300	7.480	11.100	3.79
3.	774	6.470	7.990	11.340	3.57
4.	722	6.600	7.930	11.370	3.59
5.	678	7.620	10.270	13.810	3.05
6.	645	7.460	10.220	15.030	3.05
7.	567	7.570	12.000	13.720	6.75
8.	456	7.210	12.140	14.000	-
9.	361	7.420	11.930	14.460	4.63
10.	305	7.600	11.950	14.380	4.63
11.	277	7.250	13.170	15.720	4.79
12.	204	7.220	12.910	16.200	1.66
13.	159	5.850	10.740	15.000	4.51

4.12 Terminal Structure of Spinal Drain

Spinal drain effluent at RD 159+000 bifurcates into two outfall drains namely Kadhan Pateji Outfall Drain (KPOD) and Dhoro Puran Outfall Drain (DPOD). The reason for bifurcation of flow into two parts is:

- To divert the saline flow into KPOD because of limitation of International territory boundary with India near the outfall of DPOD.
- To divide the excess' storm water into KPOD because of the limitations of DPOD capacity.

At the bifurcation structure, the Spinal Drain water is directed towards Dhoro Puran Link. Dhoro Puran Link is a 17 RD long link between the Spinal Drain, downstream of the bifurcation structure, and an abandoned river course called Dhoro Puran. The link drain joins the Dhoro Puran at its RD 110. Design discharge of the link drain is 2,000 cfs. Dhoro Puran Link combined with 110 RD of the Dhoro Puran makes a 127 RD long Dhoro Puran Outfall Drain, which further leads the drainage water to Shakoor Dhand (Non Tidal Lake) in Runn of Kutch.

On Dhoro Puran Link, just 1,000 feet below the bifurcation point, a cement concrete weir is constructed to control the flow of drainage water. In its original design the crest level of the weir is fixed in such a way that the entire base flow of the Spinal Drain i.e. 1,240 cfs, is diverted to KPOD and saline effluent does not finds its way into DPOD. Salient features of the weir are: -

Location of the Dhoro Puran Weir	-	RD 127
Length of Dhoro Puran Link	-	17 RDs
Location of Dhoro Puran Link Outfall in to Dhoro Puran	-	RD 110
Distance of the Weir from RD 159 of the Spinal Drain	-	1000 ft
Upstream bed level of the weir structure	-	+ 3.00 ft
Downstream bed level of the weir structure	-	+ 3.00 ft
Crest level	-	+ 10.3 ft
Design water level in approach channel	-	+15.05 ft
Berm level in approach channel	-	+16.05 ft
Wing Wall top level	-	+ 17.22ft
Length of the weir	-	138 ft
Overall length of the stilling pool	-	44 ft
Design discharge through the weir	-	2000 cfs

During flood flows design discharge of the Spinal Drain is 4600 cfs. Under this condition discharge over the weir is 2000 cfs and the balance discharge of 2600 cfs is diverted towards KPOD.

4.13 Dhoro Puran Outfall Drain (DPOD)

DPOD is a 127 RD (25.4 canal miles) long drain and it diverts the Spinal Drain water in southerly direction, more or less following the course of Dhoro Puran, the abandoned course of an old river. It outfalls into a depression called Shakoor Dhand, located in Runn of Kutch. Upper part of the Shakoor Dhand is in Pakistan territory and the lower part in India. Design storm water capacity of this drain is 2000 cfs. Shakoor Dhand is an isolated depression and receives drainage water at design water level of +6.3 feet above mean sea level (amsl). It fills up nearly in 30 days and spills at a water level of 10.3 feet amsl. At the time of spilling, DPOD water is pounded due to backwater and this effect reaches up to the bifurcation point where design water level of DPOD is 12.3 feet amsl.

Figure 46: Weir at RD 127 of DPOD

Figure 47: DPOD at RD 26 During Storm Flow of 2011

Table-21: List of Infrastructure on DPOD

Sr No.	Description	Nos.
1	Village Road Bridges	2
2	District Road Bridges	1
3	Escape	1
	Total	**4**

4.14 Remodeling of Crest Level of DPOD

The President of Pakistan during a meeting held on August 20, 2004 at Governor House, Karachi recalled that during heavy rains in 2003, people of Badin and Thatta suffered a lot because of absence of proper flood water disposal system. The Engineer-in-Chief of Pakistan Army gave the recommendation that as an immediate measure the weir on DPOD to be slashed off by 2.5 feet to level it up with maximum capacity level of Shakoor Dhand. The President approved the proposal and the weir slashing by 2.5 ft was executed by Engineers 5th Corps in year 2005 at a cost of Rs. 1.060 million provided by Government of Sindh. Now the weir crest level is only 10.30 feet amsl.

4.15 Kadhan Pateji Outfall Drain (KPOD)

The remodeled KPOD forms a continuation of the LBOD Spinal Drain which discharges into the KPOD at its head at RD 159. The KPOD was remodeled in 1990 with a design discharge of 2600 cfs, for inflow from the LBOD Spinal Drain plus 1000 cfs discharge from the existing drains of Badin area, as against the previous design discharge of 1217.5 cfs. KPOD was widened to about 170 ft. (top width) while the depth increased from 7 to 13 ft.

The length of KPOD is 36.1 canal miles [from RD 159 to RD (-) 21.4] drain and it leads the Spinal Drain water in westerly direction for about 10,000 feet along Pakistan-India border, and then towards Runn of Kutch within the Pakistan territory. Design base flow of saline groundwater for this drain is 1240 cfs, while the design storm water capacity is 3120 cfs. Pateji Dhand spills out into Runn of Kutch at +3.5 feet elevation. The water level in Pateji Dhand can rise up to +8.0 feet under severe monsoon conditions. Salient design features of the KPOD are: -

Length	(RD)	-	180.4
Bed width throughout the length	(ft)	-	92
Side Slope		-	1V:3H
Water Level at Outfall	(ft)	-	+ 5.57

Bed level at Outfall	(ft)	-	(-) 8.04
Longitudinal Slope	(ft/ft)	-	0.0000718

Before the remodeling of KPOD, the overall flow was out falling into the Pateji Dhand. It then spread over a large area towards the Runn of Kutch. The KPOD is now linked with the Arabian Sea at Shah Samando Creek through Tidal Link. During the remodeling of KPOD the existing outfall drains of Badin area were not revised.

The KPOD drainage system is a highly complex hydraulic system. Water levels within the system are dependent on the combination of several unrelated factors including flood flow conditions in the local catchments, base flow and storm water discharges from remote catchments discharging into KPOD via the Spinal Drain and tidal variations.

The Tidal variations experienced at each drain outfall into KPOD are dependent on the tidal range at the KPOD outfall into Tidal Link and the state of flow in the KPOD. At low flow the water surface within KPOD is practically a level pond and the water surface rises and falls in direct response to the variation in tidal level at the outfall. At higher flows the KPOD water surface has a hydraulic gradient. Tidal variations cause backwater and drawdown effects. The backwater effect can extend for many miles upstream of the outfall.

Table-22: List of Infrastructure on KPOD

Sr No.	Description	NOs
1	Village Road Bridges	9
2	District Road Bridges	1
3	Water Course Crossings	6
4	Twin Water Course Crossings	1
5	Minor Aqueduct	1
6	Escape	1
7	Drain Junctions/Outfall	8
	Total	27

4.16 Tidal Link

The last part of the drainage system is a channel called Tidal Link, which is 26.7 canal miles long [from RD (-) 21.400) to RD (-) 154.990] and leads the KPOD effluent to Arabian Sea via Shah Samando Creek by connecting several depressions located in Runn of Kutch. The tidal impact i.e. back water of sea was supposed to influence Shah Samando Creek all the way up the Tidal Link to KPOD, but sea water was not expected to extend farther than 12 miles upstream from the tidal creek (to RD -93), just below the Dhand. The northern side of the embankment running along Pateji and Cholri Dhand was provided with an 1,800 feet long overflow concrete- crested weir at RD (-54) called Cholri Weir. Top of the weir was fixed at +4.5 feet amsl to prevent over-drainage of the Dhand at low tide, and to allow temporary flow of canal water into the Dhand to attenuate water levels in the canal at high tide. Salient design features of the Tidal Link are: -

Length	(RD)	-	133.590
Bed width throughout the length	(ft)	-	92
Side Slope			1:3
Longitudinal Slope	(ft/ft)	-	0.000072

Figure 48: Damaged Cholri Weir at RD (-) 54 of Tidal Link

Figure 49: Eroded Banks at RD (-) 46 of Tidal Link near Cholri weir

The storm water events of 1994, 1999, 2003, 2006 and 2011 damaged the embankments of tidal link and now it is in state of beyond repairs. The result is completely changed condition at outfall points. The sea intrusion in the area is very active. It has widened and deepened the bed of the Tidal Link and now the erosion is moving upstream of KPOD and is touching RD 26 of KPOD.

4.17 Cholri Weir

Under LBOD programme, the KPOD was remodeled and connected with the sea through the construction of a 26.7 mile Tidal Link canal. The Tidal Link physically separated the four major lakes in the Sindh portion of the Runn of Kutch, called Sanjoro, Mehro, Cholri and Pateji, from the Runn of Kutch. Still the Pateji Lake was not connected with the sea as the Tidal Link was contained within high embankments. The top of embankments was fixed at 20 feet amsl to avoid overtopping from both sides since water levels in Pateji and Cholri Lakes and Runn of Kutch sometimes exceed +8.0 to +10.0 amsl. However, the flow of water between Tidal Link and Pateji Lake was made possible by constructing a side channel weir (Cholri Weir) on Tidal Link at RD (-54). Crest level of the weir was +4.5 feet amsl to prevent over drainage of the lakes at low tide and to allow temporary flow of Tidal Link canal water into the lakes to attenuate water levels in the canal at high tide. The salient data of the weir were;

Table-23: Design Data of Tidal Link

S. No	Item	Design value
1.	Length	133,590 ft
2.	Bed width throughout the length	92.0 ft
3.	Side slope	1:3
4.	Depth of cut (minimum)	10.0 ft
5.	Depth of cut (maximum)	23.4 ft
6.	Top width (minimum)	152 ft
7.	Top width (maximum)	233 ft
8.	Berm on Northern side	100 ft
9.	Berm on Southern side	350 ft
10.	Longitudinal Slope	0.0000718
11.	Bed level at start (RD -21.4)	-8.04 Feet AMSL
12.	Bed Level at the end (RD -155)	-17.66 Feet AMSL
13.	Ground level range	2 to 6.8 Feet AMSL
14.	Water level lower	0.9 to -9.18 Feet AMSL
15.	Water level upper	6.9 to 7.1 Feet AMSL
16.	Design Capacity	3118 cfs
17.	Northern embankment top elevation	9 Feet AMSL
18.	Southern embankment top elevation	14 Feet AMSL
19.	Extent of Northern embankment	RD-25toRD-125

20.	Extent of Southern embankment	RD-28toRD-153

Source: LBOD Feasibility report, WAPDA (2009).

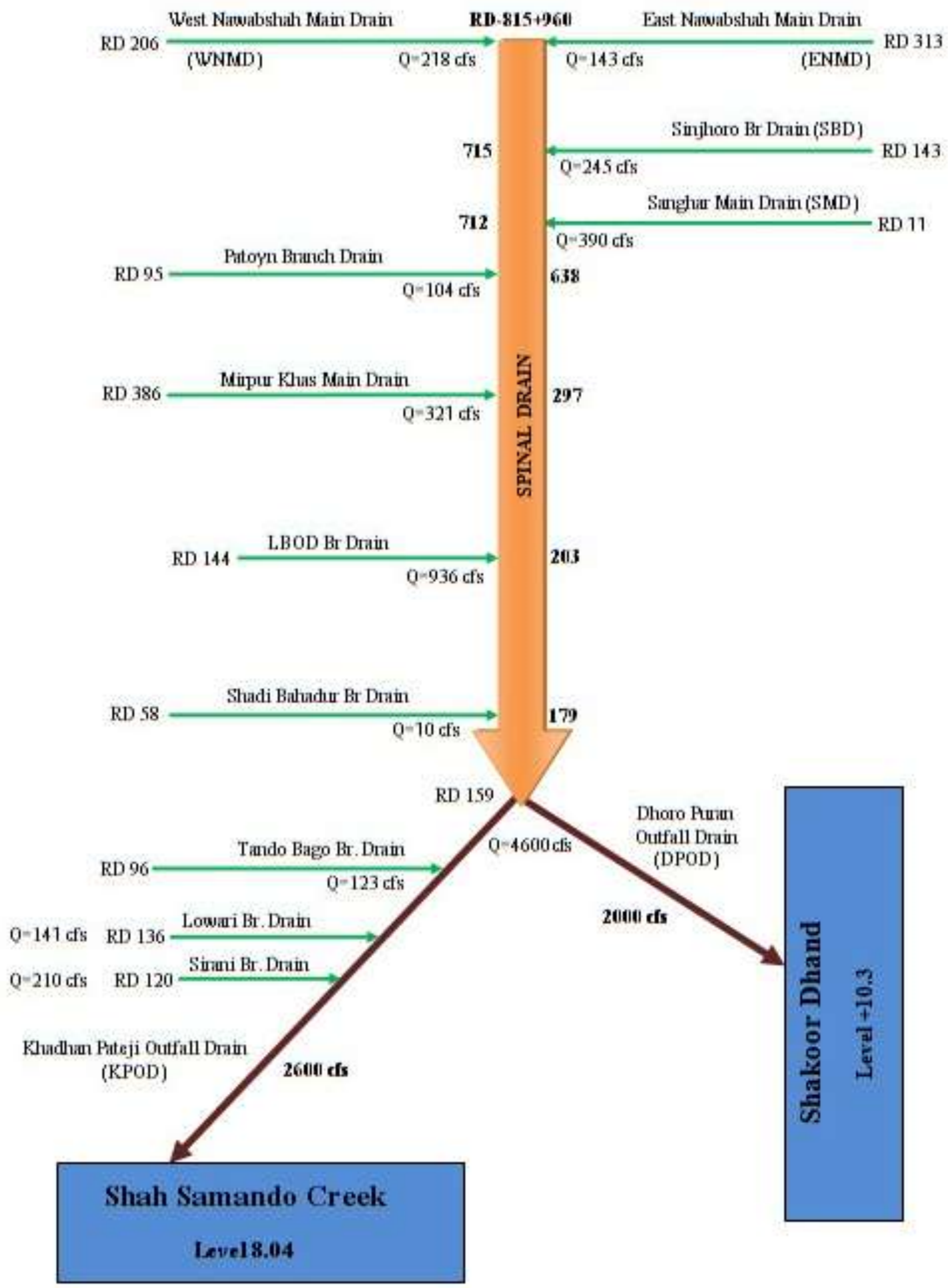
Figure 50: Eroded Banks at RD (-) 52 of Tidal Link

Figure 51: Eroded Banks at RD (-) 42 of Tidal Link

This weir was washed away during cyclone of 1999 and is non functional now.

A line diagram of the Drainage System is given in the Figure 52.

Figure 52: Line Diagram of LBOD Drainage System



4.18 Canal Escapes

Apart from the surface drains, surplus water from the following sources of irrigation system also contributes to the drain flows.

- Surplus water from irrigation watercourses;
- 500 cfs contributes to Spinal Drain by an escape .from Jamrao canal located at the crossing of Spinal Drain and Jamrao Canal;
- 200 cfs contributes to Spinal Drain by an Escape from Mithrao canal located up stream of Kot Ghulam Muhammad-Samaro road bridge on Mithrao canal;
- 130 cfs contributes to Mirpur Khas Main Drain by an escape from Jamrao canal located at Jhilori Head works of Jamrao Canal; and
- Irrigation surplus from the Left Bank of Kotri Barrage canal command.

The irrigation water from the above escapes during the rain fall period needs to be checked through good water management practices. The irrigation system in the area is to be closed at least 7 days before start of monsoon warning.

4.19 Performance of Drainage System during 2011 Flood

In Sindh it was the largest monthly rainfall ever recorded during 2011 in the catchment of LBOD. The rain fall commenced from 9th August 2011 with small intervals. The Average rainfall recorded was about 300mm within 24-48 hours about 8-10 times higher than the land drainage capacity of existing drainage system. The second spell started from 6 September and lasted for four days. While the 3rd spell commenced on 12th September and heavy showers continued till 14th September. The LBOD System attained its maximum levels due to very heavy rainfall and additional disposal of water through pumps and cuts along drains by farmers. The unprecedented rainfall seriously affected the people of Mirpur Khas, Badin, Tando Muhammad Khan, Umerkot, Thar Parkar, Tando Allahyar and other districts of lower Sindh.

4.20 Rainfall Events

The events of rain fall recorded in the months of August & September 2011 are as under: -

- Rain fall received during the months of August 2011 and September 2011 for Major cities in the project area is as under: -

August 2011

- ✓ Nawabshah 275 mm.
- ✓ Mirpur Khas 263 mm.
- ✓ Mithi 530 mm.
- ✓ Badin 331 mm.

September 2011

- ✓ Nawabshah 353 mm.
- ✓ Mirpur Khas 603 mm.
- ✓ Mithi 632 mm.
- ✓ Badin 281 mm.

The magnitude of the precipitation records in August and September is much larger than the design rainfall that the LBOD cannot cope with the drainage water.

4.21 Area Inundated During Flood

This heavy rainfall in District Badin, Mirpur Khas, Umerkot, Tando Muhammad Khan and Nawabshah & Sanghar generated runoff of about 9000 cfs discharge in LBOD system, while the LBOD system is designed for 4600 cfs. This resulted overtopping in the system at several places.

The Areas inundated as of 18 September 2011 are as under: -

Table-24: Area Inundated During Flood

S No	District	Depth Of Flood Water (feet)	Area Inundated (Sq. Kms)
1	Badin	2 to 4	3,726
2	Sanghar	1 to 3	3,322
3	Mirpur Khas	2 to 4	2,145
4	Umerkot	3 to 6	1,016
5	Nawabshah	2 to 3	782
6	Tando Allahyar	2 to 4	301
7	T.M Khan	2 to 4	289

4.22 Back Flow in Drainage System

The back flow of out falling system is given below: -

- Mirpur Khas Main Drain near Jhudo City.
- Sanghar Main Drain near Shahdadpur.
- LBOD Branch Drain Out falling at RD 204 of Spinal suffered back flow of about 17 Kms in length near Pangrio City.
- Shadi Bahadur Branch Drain Out falling into KPOD at RD 118 suffering about 3 Kms back flow.
- Lowari Branch Drain up to 10 Kms.
- Serani Branch Drain up to 14 Kms from outfall point (up to Badin - Kadhan Road).

This disaster occurred because of limited carrying capacity of LBOD System, partially chocked city drainage system, back water flow in drains due to submerged outfalls effect, encroachments along drains and waterways, construction of wide network of roads and irrigation canals, railway line and closure of natural drainage routes.

Although the irrigation canals were closed by 7 August, however, as reported by locals Nara Canal was not closed until 12 August. Later, the water from Nara Canal was let off in Spinal which resulted in over topping of Spinal Drain, contributing to inundation in the surrounding area.

The natural flow of storm water was blocked by roads, therefore, storm relief cuts were given to metalled roads in Mirpur Khas, Naukot, Badin, Jhudo, Naukot, Tando Adam, Hyderabad, Chamber, Tando Allahyar, Badin and Nindo at various locations where water was trapped along the road without culverts and causeways. Due to back flow and excessive discharges in the system a number of breaches occurred and the farmers also made cuts to drain their water quickly from their cropped area.

The list of breaches/overtopping sites (2011) of LBOD System is given in Table 25.

Table-25: Major Breaches/Relief Cuts to LBOD Drainage System During 2011

S No.	Description	Location of Breach	Type
1.	KPOD	RD-30	Relief Cut
2.	KPOD	RD-33	Relief Cut
3.	KPOD	RD-35	Relief Cut
4.	KPOD	RD -50	Relief Cut
5.	KPOD	RD -126	Relief Cut
6.	KPOD	RD -120	Relief Cut
7.	KPOD	RD -157	Relief Cut
8.	KPOD	RD -159	Relief Cut
9.	LBOD (Spinal)	RD -204	Breach
10.	LBOD	RD-235	Breach
11.	LBOD	RD-238	Breach
12.	LBOD	RD-245	Relief cut
13.	LBOD	RD-260	Breach

S No.	Description	Location of Breach	Type
14.	LBOD	RD-261	Breach
15.	LBOD	RD-270	Breach
16.	LBOD	RD-273	Breach
17.	LBOD	RD-276	Breach
18.	LBOD	RD-280	Breach
19.	LBOD	RD-311	Breach
20.	LBOD	RD-326	Breach
21.	LBOD	RD-355	Breach
22.	LBOD	RD-359	Breach
23.	LBOD	RD-371	Breach
24.	LBOD	RD-405	Breach
25.	LBOD	RD-451	Breach
26.	LBOD	RD-476	Breach
27.	LBOD	RD-477	Breach
28.	LBOD	RD-483	Breach
29.	LBOD	RD-511	Breach
30.	LBOD	RD-522	Breach
31.	LBOD	RD-523	Breach
32.	LBOD	RD-583	Breach
33.	LBOD	RD-650	Breach
34.	LBOD	RD-651	Breach
35.	LBOD	RD-653	Breach
36.	LBOD	RD-661	Breach
37.	LBOD	RD-670	Breach
38.	LBOD	RD-668	Breach
39.	LBOD	RD-665	Breach
40.	MMD	RD-365	Breach

Source: SIDA flood report 2011.

4.23 Major Problems of LBOD System during Storm Water Flood of 2011

The major problems for slow delivery of drainage system are: -

- In-efficient performance of natural drainage due to encroachments and obstructions.
- Overtopping at number of places due to in adequate capacity.
- Submergence of drains at out falls points feeding KPOD.
- Backflow in Mirpur Khas Main Drain and Drains feeding KPOD.
- Limited capacity of the entire drainage network to cope with heavy storms.
- Roads, canals, built up areas and drains have caused compartmentalization of the area blocking the natural drainage system.
- Inadequate capacity of Culverts/Bridges at crossing points of drains.
- Additional storm water entered into LBOD system from overflowing of Dhoras.

4.24 Obstruction of Natural Flow of Storm Water by Road Network

The natural flow of storm water was blocked by roads; therefore, storm relief cuts were given to metalled roads in Mirpur Khas - Naukot, Badin – Jhudo, Naukot - Jhudo, Tando Adam - Hyderabad, Chamber – Tando Allahyar, Badin – Nindo and at various locations where water was trapped along the road without culverts and causeways.

4.25 Submergence of Drains at Outfall Points

Storm rainfall on the upper catchments of Nawabshah, Sanghar and Mirpur Khas components produce maximum flow resulting in high water levels in the KPOD submerging some of the outfall drains: -

- **Drains out Falling into Spinal**
  - ✓ MMD at RD 297 of Spinal.
  - ✓ LBOD Branch Drain at RD 204 of spinal.
  - ✓ Shadi Bahadur Branch at RD 182 of spinal.
- **Drains out Falling into KPOD.**

  Submergence of the drains out falling into KPOD along with level difference is as under: -
  - ✓ Tando Bago Branch Drain - 4.54 ft.
  - ✓ 1R to Tando Bago Branch Drain - 4.54 ft.
  - ✓ 5R Sub-drain of KPOD - 0.45 ft.
  - ✓ Behdmi Link Sub-drain - 1.23 ft
  - ✓ 2R Sub-drain of KPOD - 0.3 ft.
  - ✓ Serani Branch Drain - 0.92 ft.

4.26 Bad Water Management

Following are the major draw backs of water management which have added to the storm water damages during 2011.

- ➢ Entire area is crossed by irrigation channels/canals. The water in some canals was not stopped well before rains and it added to storm water flows and caused wide spread inundation in the area.
- ➢ Breaches and Cuts by farmers in the canal network for immediate evacuation of storm water also increased the flow in the drainage system.
- ➢ The irrigation escapes continued to function during the rainfall storm.

4.27 Damage to Infra Structure

- **Damage to Main Drains**

The following main drains have over topped their banks breached at number of places and also relief cuts were given to save the cropped area and Abadies. The detail of damages is as under.

- ✓ Damages to Spinal Drain during the storm water floods of 2011 and was running, the Spinal Drain System was running in full up to banks level with the discharge range of 9000 to 10000 cfs.
- ✓ Damages were reported when Dhoro Puran was running full and parallel to DPOD and also high water level observed.
- ✓ Damages to KPOD while carrying discharge in excess of design flows approximately in the range of 7000-8000 cfs.
- ✓ DPOD damaged when was carrying about 4000-5000 cfs.
- ✓ Mirpur Khas Main Drain breached at number of places due to submergence at outfall of the Spinal Drain at RD 297.
- ✓ Damages to LBOD Branch Drain and other drains in the Badin area due to in adequate capacity.
- ✓ Damages were reported to crops, houses and road network due to flooding of the towns of Jhudo, Digri, Pangrio and Badin area from breaches of drains and canals network.

- **Damage to Bridges and Water Course Crossing Aqueducts**

  On the spinal drain and branch drains a number of bridges have been affected due to submergence and overtopping. A number of water course crossing aqueducts were completely washed away as indicated in the pictures. Damage to hydraulic structures on spinal drain and main and branch drain network is enormous.

4.28 Lessons Learnt From Storm Water Flows

The performance of drainage system in rainfall events 203 and 2006 has remained poor and it caused heavy losses to the life and property due to overtopping, breaches, flooding and damages due to direct rainfall in the command area due to in efficient performance of drainage network. People also made several cuts in the main drains, branch drain for evacuation of flooding water form fields.

The role of the beneficiaries in the management and maintenance of the drainage infrastructure should be acknowledged at all stages of a projects development.

Land acquisition and resettlement should be completed before award of the civil works contracts.

The damages have occurred due to inefficient operation, management and the surcharges of drains over and above their design capacity. The operational problems in the LBOD system are summarized as under: -

4.28.1 Problems Faced In Operation of Drains

- Storm rainfall in the project area causing flooding and overtopping of drain embankments.
- Inundation of low lying areas during heavy rains.
- Some of the branch and sub-drains outfall into KPOD under submerged conditions causing backwater effects during peak floods. It then results in delayed drainage of the area.
- Some of the branch and sub-drains outfall in KPOD under submerged conditions causing backwater effects due to high tides causing delayed drainage of the area.
- During high tides, sea water intrudes into the catchment area causing salinity problems and
- Tidal effect causes serious erosion in KPOD.

4.28.2 The Deficiencies in the System

- During heavy rains numerous cuts in the embankments of drains are made by the farmers to evacuate rain water within a short period these drain cause flooding and breaches of the drains at downstream reaches.
- Lack of management of canal water during heavy rains.
- Backwater effect in Badin area surface drains.
- High flow velocities due to Tidal effect causes erosion of sides of tidal link as well as of KPOD.
- Environmental degradation of Dhand has been caused due to sea water intrusion.

To overcome deficiencies in the system and for an efficient water collection, conveyance and safe disposal of storm water, the LBOD Re-design consultants worked out different alternatives as presented in chapter.

CHAPTER 5: IDENTIFICATION OF PROBLEMS OF LBOD DRAINAGE NETWORK AND THEIR SOLUTIONS

5 Identification of problems of LBOD Drainage Network and Their Solutions

Irrigation in the Sindh Province of Pakistan has a history of several thousand years. Without it there would be virtually no agriculture and productivity.

A major program of improvement and construction of new inundation canals was undertaken in the latter half of the nineteenth century but it was not until 1932 that barrage commanded irrigation was introduced with the construction of the Sukkur Barrage system commanding a gross area of some eight million acres on the left and right banks of the River Indus. Later two other barrages, Kotri (1955) and Guddu (1962) completed the system as it is today.

It is the left bank of the Sukkur Barrage with which the Left Bank Outfall Drain Project is concerned. Virtually all this command is supplied with perennial water and this supports a summer (Kharif) crop which is mainly Cotton, Rice, Sugarcane, Mango Orchards, Banana and a winter (Rabi) crop which is largely wheat and sunflower. It was known in 1932 that the command would eventually require drainage but with the deep water tables prevailing at that time it was not initially needed and not provided.

By 1959 the position had become serious and Consultants were engaged to study the position in Khairpur the most northerly area of the Left Bank Command. This study was completed and a drainage project undertaken with World Bank assistance. The study area was extended to eventually cover the whole of Sindh in what became known as the Lower Indus Project (LIP). The Left Bank Outfall Drain was first proposed in the LIP report in 1966. Broadly the study proposed that the drain should be aligned from the Runn of Kutch and taken north through the command area as far as the Khairpur Project, which was then under construction and was proposing to discharge saline drainage water to the Rohri canal. It was suggested that the drain could if necessary be extended up to the Guddu command.

Various reports followed from 1969 until 1981. The 1969 report was the first full feasibility study and subsequent reports presented more detail, updated costs and benefits. Technically they were mainly concerned with capacity and alignment variations.

5.1 Major Issues of Drainage

- The LBOD/KPOD outfall infrastructure was not designed properly and has caused miseries to the communities in lower reaches due to its faulty design i.e Cholri Weir failure.
- Stake holders are apprehensive of any reconstruction or extension of LBOD and/or KPOD and construction of any major drainage water in Coastal area.
- A need is felt to extend the drainage network in the upper and middle parts of the left bank area.
- Drainage effluent intrusion from southern Punjab in Ghotki area is degrading productive lands.
- There is inadequate infrastructure to safely dispose off and conserve storm water in case of in extreme event of monsoon rainfall, of like storm water events of year 1994, 2003, 2006 and 2011.
- Inadequate and poor O&M of the drainage network, including sub drains and sub surface drainage.
- Wide spread fishing by installing permanent fishing nets by locals in throughout LBOD drainage network is destroying the capacity of the drains and so far has gone un-checked.
- A significant proportion of SCARP tube wells are non operational as vertical drainage.
- The continued and unabated environmental degradation due to seawater intrusion.
- The pollution level in the river, irrigation canals, and drains is increasing significantly, due to Sugar Mills and Chemical Industry and no one can touch the mill owners.
- Deforestation of riverside forest is being done by influential land lords and District Administration.
- Very bad Disaster Management and Preparedness during monsoon specifically role of respective DCOs/Deputy Commissioner in their district is highly objectionable and painful

during rainfall storms in relation to treatment with displaced persons of villages. They derive pleasure in serving the members of parliament only.

Majors Problems of LBOD Drainage Network

Following are the major draw-backs and constraints of the LBOD drainage network to perform during heavy rain storm flows of 2003, 2006 and 2011.

- The existing drainage network is unable to drain the catchment areas of all three sub components of LBOD Project within a period of 3 to 5 days to minimize damage to standing crops, mostly cotton.
- The inadequate F.B resulted in breaches at weak sections of Spinal Drain and over flowing at bridges and other structures.
- Inundation of low lying areas and towns due to breaches in irrigation and drainage network.
- There was submergence of main drains due to less working head like Mirpur Khas Main Drain, LBOD Branch drain and other direct drains out falling at their point of confluence with the Spinal drain.
- The rain-fall pattern in lower Sindh has been modified due to climate change phenomena with the result that the extreme events of rain fall have been recorded and those causing wide spread inundation in the cropped areas and these would continue to do so in future also.
- Due to weak sections and breaches the number of structures like Water Course- Crossings, Inlets and Bridges were completely washed away.
- Increased Sea intrusion and entry of salt water at control points of Outfall Drains.
- Absence of Control Structure to check Tidal effect.
- The irrigation water of escapes and breaches of the irrigation distribution network when added with the storm water played havoc with the neighboring Towns and Villages and Abadies and damaged infra structure in the area i.e. road network and protections bunds.

Absence of On-Farm Drainage in Nawabshah Component

There is a zero on farm drainage being adopted during October 2012 rainfall in Nawabshah area along Nawabshah West Main Drain. The damage to cotton fields not drained at the end portion of cotton plot ranges from 20-30% of production and when integrated to total cotton area of district, it becomes a national loss in production. No one in Agriculture Department of SIDA is prepared to appreciate is problem which is a crime on the part of the farming community of the area. No proposed drainage solution is going to work if the farming community is callous in attitude.

Figure 53: Damaged Cotton Crop at village Kalri Near Shahdadpur

Figure 54: Damaged Cotton Crop near RD 12+554 of WNMD

Permanent Fishing Nets All Along LBOD Drainage Network

The local fisher men along LBOD drainage network have been installed permanent fishing nets in the bed of the drains and have completely chocked up the entire prism of the drain depositing sediment heaps and creation of bed bars at the side of the fishing nets. This has reduced the flow velocity of the system, thereby reducing the discharge capacity of the drainage system. On continues bases supply of canal water is arranged by the fisher men and has become an industry and never checked by the field staff. The **Figures 55 to Figures 64** are showing the true picture of the fishing nets existing all along the LBOD Drainage Network. This need to be checked and all such obstruction begot removed with the help of the police of the area.

 **Figure 55:** 2L Sub Drain at RD 104+282 of FGOD	 **Figure 56:** Fish Nets at RD 199+000 of Spinal Drain
 **Figure 57:** Fish Nets at RD 220 of Spinal Drain	 **Figure 58:** Fish Nets at RD 230 of Spinal Drain
 **Figure 59:** Fish Nets at RD 231+220 of Spinal Drain	 **Figure 60:** Fish Nets at RD 251+250 of Spinal Drain

Figure 61: Fishing Net at WCA Crossing RD 202+022 of Spinal Drain

Figure 62: Fishnets at RD 211+995 of Spinal Drain

Figure 63: LBOD Branch Drain RD 0+00 of Spinal Drain

Figure 64: Fish Nets at RD 1+166 of WNMD

5.2 Suggested Solutions for LBOD

Following are the suggested structural measures: -

- ✓ Redesign the Sub Drains, Main and Branch Drains and Spinal Drain for a return period of 20 years with actual rain fall intensity recorded during flood of 2011.
- ✓ Raising and strengthening banks of drainage network to provide F.B to water levels of 2011 to avoid over flow and breaches to the system.
- ✓ Re-activation of Dhoro Puran, the old natural river course to restore natural drainage.
- ✓ Off loading of Spinal Drain with the minimum discharge of 3000 cfs by constructing 03 side weirs.
- ✓ Provide inlets at the sites of relief cuts made by the farmers for early evacuation of storm water.
- ✓ Construct siphons at outfall points of MMD and LBOD Branch Drains to divert storm water flows into Old Dhoro Puran natural drainage course.
- ✓ Construct additional Inlets on Sub Drains to support On –Farm Drainage.
- ✓ Construct additional new Bridges as per need of the area.
- ✓ Construct a Tidal Control Structural at RD 22 of KPOD to cut off entry of sea water into the LBOD system and to protect ecosystem of adjoining areas.
- ✓ Contract a Gated Structure at RD 52 of KPOD for to offload 1000 cfs from KPOD to Runn of Kutch.
- ✓ Increase the design capacity of DPOD to 6000 cfs for diverting maximum storm water of Spinal Drain for the benefit of locals.
- ✓ Increase the design capacity of KPOD to 7000 cfs for diverting maximum storm water of Spinal Drain for the benefit of locals.

- ✓ Provide Mobile pumping stations for drainage of low lying areas of Badin.
- ✓ Provide Permanent pumping station at RD 792 of Spinal Drain to pump 1000 cfs into Jamarao Canal.

As a result of consultant work on the performance of the existing drainage system of LBOD network and previous work of other Consultants to redesign the LBOD system after floods of 1999, 2003 and 2006, short term and long term measures are suggested below. This would improve the performance of LBOD Drainage system and also would minimize the damages to life property and standing crops in command of LBOD drainage network.

Help was obtained through Hydraulic Modeling using HEC-RAS Model to assess the hydraulic functioning of drainage system and to judge possible structural improvements. The model was supported through actual measurement of the discharges on the main drainage system. The simulation was done for different water storm events and the distribution of the discharges and water levels were calculated from the model. The location of three weirs for offloading 3000 cfs from spinal drain was also optimized. The interventions verified on hydraulic model have been given the shape of long term structural measures and the same are reported as under.

5.3 Proposed Interventions for LBOD Drainage Network

Structures on existing LBOD drainage system would be rehabilitated as per following criteria: -

- ✓ Metal Road proposed on IP of Spinal Drain from RD 159+000 to RD 815+822.
- ✓ All watercourse crossing aqueducts are to be replaced with pipe crossing in reach RD 159 to RD 297 of Spinal Drain.
- ✓ All submerged bridges are to be raised minimum 2 ft from the existing deck level in above reach of spinal drain.
- ✓ All Bridges Crossings of District metal roads with LBOD Drainage network to be reconstructed with full water way and zero fluming and minimum 2 ft free board is to be provided.
- ✓ Inlets to be provided on all sub drains at interval of 2 RDs on either side.
- ✓ All structure of LBOD Branch Drain (Badin) to be newly constructed.
- ✓ All outfall structure of main drain out falling in to spinal drain to be newly constructed with full water width and with 10 ft raised both banks to allow for surcharge storage.
- ✓ On Spinal Drain all structures shall be provided with stone pitching of 200 ft upstream and 300 ft downstream and adequate water way upstream of structure will be ensured.
- ✓ A discharge of 3000 cfs will be offloaded at RD 211, RD 335 and RD 578 of Spinal Drain.
- ✓ All natural depressions/vacant lands/barren lands would be connected to drainage network through appropriate structures and artificial lakes/storages would be created for temporary detention of storm water and to cause delay in contribution to main system.
- ✓ A Gated Tidal Control Structure to be manually operated would be constructed at RD 26 of KPOD and connected with the Tidal Link through properly stone pitch outfall drain with bank width of 50 ft on either site.
- ✓ Provide mobile pumping stations in four units of LBOD drainage network.
- ✓ Construct discharge measuring sites on LBOD drainage network.
- ✓ Rising plantation along banks of Drainage Network.
- ✓ Providing raised plate form along LBOD Drainage Network.

All drainage culverts at crossing points of metal roads be provided with full water way of crossing drains with minimum 2.0 feet Free Board and also to provide 5 feet high flood embankments in the LBOD command area with 10 feet top width at sites inundated during storm flows of 2011 (two be executed by highway department of Sindh).

5.4 Provision of Escape at RD 792 of Spinal Drain to Indus River near Manjhu

It is proposed to offload 1,000 cfs from Spinal Drain (Major flows of Nawabshah component to River Indus through construction of a 35 miles escape channel). The difference of bed level of spinal and River Indus is 17 ft and technically it is feasible proposal but not supported by the stakeholders as the escape channel would pass through highly fertile agriculture lands. As such this proposal was dropped but it is recommended passage of time the local population may support it and then it can be taken up for a detailed study. As one alternative to this a permanent pumping station has been recommended at RD 792 of the Spinal Drain.

5.5 Construction of On Farm Drainage

The need to improve water use efficiency is generally recognized, but on-farm drainage has not yet been clearly incorporated into the concept of integrate water resources management of Left Bank Area of Indus River and there is to establish organizations for managing agricultural on-farm drainage, water logging, and salinity control. The main benefits of on farm drainage are given below: -

- ✓ Drainage not only removes surplus rainfall and irrigation water but protects soils which are the ultimate natural resource required for crop production.
- ✓ Saline and waterlogged conditions severely limit crop choice, diversification, and intensification, adversely affect crop germination and yields, and can make soils difficult to work.
- ✓ Drainage sustains and increases yields and farmers incomes.
- ✓ Drainage contributes to improve health conditions of plants and human beings.
- ✓ Drainage allows control of surface and groundwater quality.
- ✓ It is financially more attractive to prevent land from becoming salinised than the high costs of reclamation of saline and waterlogged soils or the development of new land.
- ✓ Drainage protects irrigation investments.
- ✓ Farm-level drainage is a well-established and elaborated engineering technique.

The main purpose of a detention basins is to store runoff and reduce peak discharge by allowing flow to be discharged later at a controlled rate and within a reasonable downstream capacity (regional and local facilities) or on a limit on the increase in flows over predevelopment conditions (local facilities only).

Storm water storage reservoir types are numerous, but they essentially fit into one of two categories: detention or retention. The words "pond" and "basin" are used in retention reservoirs. A detention basin or pond detains water temporarily, releasing water through a pipe or channel by means of a wire, orifice, or pump. Because of storage required for a given storm event is reduced. Another advantage of the detention basin is the positive means of outflow, resulting in fewer problems with long any initial release during inflow. Once the storm event is over pond drainage may occur due to evaporation and percolation into the soil.

Soil and water conservation are an integral component of agriculture production in particular and environment protection program in general. Himachal Pradesh is a hilly terrain with rolling topography and sloppy lands. The rain fall is high in rainy season which add the problems of soil and water conservation, where water scarcity is experienced in other seasons. Keeping in view, the importance of soil and water conservation, the Department of Agriculture is implementing rain water harvesting, soil conservation and soil erosion control schemes including individual, community based tank and Head weirs etc. under various schemes run by the department to increase the agriculture production. The detail of various measures adopted for soil and water conservation programme are as under: -

Objectives

- ✓ To reduce splash erosion by moderating the impact of rain drops.
- ✓ To reduce runoff velocity and increase infiltration opportunity time.

Types of Biological Measures

- ✓ Vegetative Barriers
- ✓ Inter Cropping
- ✓ Strip Cropping
- ✓ Contour Farming
- ✓ Land Configuration
- ✓ Tillage
- ✓ Mulching
- ✓ Residue Management

The selection and suitability of engineering control measures to be adopted under different locations depend on soil depth, rainfall, land slope and crops to be raised.

Mechanical Measures

- ✓ Bedding
- ✓ Terracing
- ✓ Leveling
- ✓ Diversion Drains
- ✓ Contour Trenches
- ✓ Stone Walls
- ✓ Retaining walls

Rainwater Harvesting Techniques

In situ Rainwater Harvesting

- ✓ Bedding And Terracing
- ✓ Vegetative Contour Barriers
- ✓ Land Leveling
- ✓ Contour Ditching
- ✓ Grades Border Strips
- ✓ Contour Farming
- ✓ Cover Crops and Mulching
- ✓ Conservation Tillage and Deep Plugging
- ✓ Contour Trenching

Basic Objectives of Scheme

- ✓ Recharging of Ground Water
- ✓ Reduction in Soil Loss
- ✓ Production of Fish Culture
- ✓ Reduction in Flush Floods
- ✓ Mitigation of Draught
- ✓ Better Environment Conditions in the Catchment
- ✓ Reduction in Drainage Density
- ✓ Higher Availability of Water for Drinking and Other Domestic Needs
- ✓ Higher Availability of Other Needs like Fuel and Fodder

The further details of On-Farm Drainage techniques to be implemented by the community are described in detail in Annexure I.

5.6 Development of Regional Lakes (Dhoras)

The main purpose of regional lakes is to store runoff and reduce peak discharge b allowing flow to be discharged later at a controlled rate, and within a reasonable downstream capacity (regional and local facilities) or on a limit on the increase in flows over predevelopment conditions (local facilities only). A case study was developed by the Consultants along Matli to Digri Road for mapping of the existing lakes in the LBOD area and it is concluded that with proper regulation IE lowering the water level in the regional lakes. Prior to issue of the warning for extreme rainfall events is going to be highly beneficial for quick evacuation of storm water from the cropper area. Map of the case study is shown in Figure 65. The similar regional lakes are numerous in district Badin but need systematic regulation and control to support surface drainage of the area.

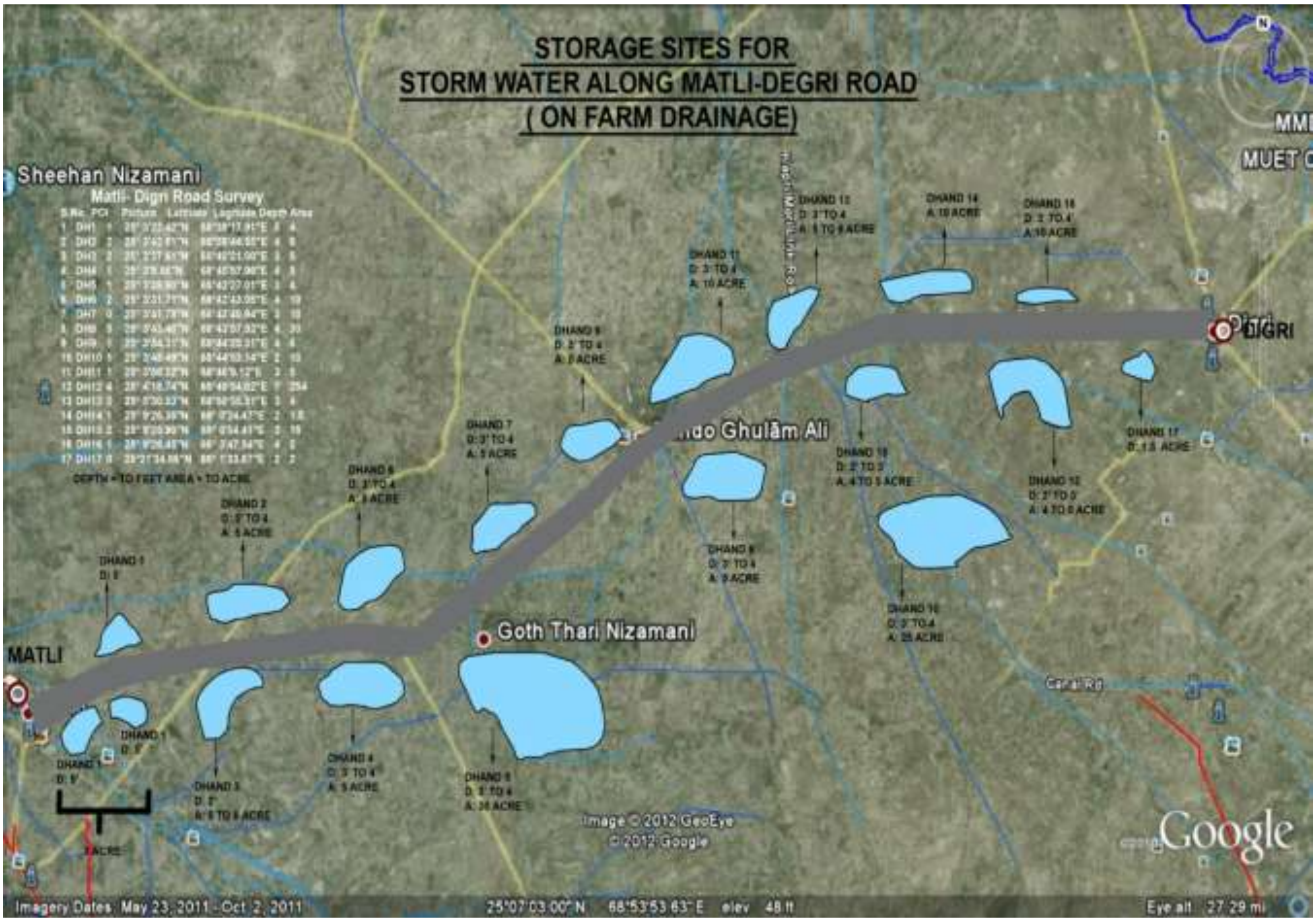


Figure 65: Regional Lakes in Matli to Digri Area

CHAPTER 6: HYDROLOGICAL STUDIES AND DESIGN DISCHARGES

6 Hydrological Studies and Design Discharges

6.1 Hydrological Estimates

The rainfall frequency and drainage coefficient are updated for a larger set of data and keeping in view functioning of the drainage network during the mega storm flows of 2011. A step-wise estimation is carried out for the gross rain water runoff, total drainable flows and drainage coefficients required. Simulated design values are compared with the existing capacities. Drainage flows are routed through the catchments to compare the response behavior of the physical network of LBOD. The hydrological model HEC-RAS used for hydrological analysis and drainage coefficient estimates.

The analysis and assessments carried out in the following sections include: -

- Estimation of the rainfall frequency and return periods using a longer data set
- Estimation of rain runoff and drainage surplus using Soil Conservation Services (SCS) Curves Number (CN) for 10 year and 20 year return periods.
- Estimation of drainage coefficients and evacuation periods under capacity implications.

6.2 Storm Flow Runoff Pattern

- The monsoon rains in the region are spread over the months of July to September; however, historical data shows that heavy rains causing floods normally occur in August and September.
- The monsoon wind direction is normally from South-East to North-West. It causes first monsoon spells in Badin district while clouds move inland. A less often inland monsoon path could be enhanced by other factors like the local depression in the coastal region.
- The rains causing runoff above the local capacity for two or more successive days have been most detrimental. Because of limited local cushions (surface water ways, groundwater storage potential) and way outs for water, it starts accumulating in low lying areas, locally moving around and causing infrastructure and crop damages.
- Continuous rains of lower than the design intensity of the network can cause capacity problems, especially affecting downstream systems and areas.

6.3 Estimation of Runoff Volume and Drainage Rate

The estimation of flood quantities is a generic challenge for any large basin having limited field measurements and intensive water use practices. All methods for storm flows estimation use empirical coefficients, which needs to be calibrated at different levels and condition, soil types and their actual hydrological functioning, land use pattern, climatic variables like evapotranspiration and topographic characteristics of the basin such as size of the low lying areas and depth of trapped storm water.

While, all processes mentioned above are difficult to quantify, empirical relations are adjusted (or calibrated for a given set of conditions) using few reliable measurements. Two measurable quantities in rainwater hydrology are: i) precipitation and ii) actual drainage flows in constructed and natural channels.

For the Left Bank Area, runoff and drainage requirements were first calculated in 1967 by the LIP study. This study used a step wise approach to calculate different drainage components. Another hydrology study was carried out in 1980 by WAPDA consultants (Left Bank Outfall Drain, Annex 4 Hydrology, MMP & Hunting Technical Services). Two reported objectives of the study were: “to provide estimates of the key storm water runoff for the sizing of surface drainage system and size of the sub-surface drainage system required.”

6.4 Frequency Analysis

Three commonly used methods to estimate recurrence frequency of rainfall, Gumble, Normal and Log Pears III were compared and log Pears III method selected. Return periods are estimated using daily maximum of 35 years. For the consistency, the same period is used for different stations. Results of return period for three meteorological stations in LBOD catchments are shown in Table-26.

Table-26: Rainfall Frequency Analysis - Using Log Pearson III

Probability of Occurrence	Return Period (Years)	Rainfall (mm)		
		Badin	Chhor	Nawabshah
Latitude (N)	-	24° 38'	25° 31'	26° 15'
Longitude (E)	-	68° 54'	69° 47'	26° 15'
0.1	1000	339.78	489.14	325.24
0.2	500	313.68	425.2	283.86
0.5	200	278.01	348.17	233.17
1	100	250.12	295.19	197.76
2	50	221.39	246.44	164.77
5	20	181.96	187.94	124.7
10	10	150.79	147.68	96.86
20	5	117.99	110.25	70.89
50	2	69.75	62.966	38.25
99	1	10.76	13.287	6.06

Source: Appendix VII of Regional Plan Report (2012)

6.5 Estimating Runoff Volume

The rainfall runoff is estimated using the method adopted for the design and earlier planning studies. Calculation for 10 and 20 year return periods are given in tables 8 and 9. Area based reduction factors remain the same in both sets of computation. Similarly, curve numbers are kept the same for runoff estimation.

The Table 27 summarizes different reduction factors.

- ✓ The Areal Reduction factor from 85% to 92% for four sub-catchments contributing to the runoff.
- ✓ The SCS Curve Numbers (CN) is kept as proposed by the NESPAK (2008). The soil classifications and cropping patterns are explained in the above mentioned report. More than 70% of the LBOD command is agriculture land, main determinant of the curve numbers.
- ✓ 10 to 15 percent of the catchment area is considered impervious, i.e. no reduction is applied.
- ✓ Daily reference evapotranspiration is taken as 5 mm/day in January to 9.4 mm/day during 2 hottest months. These values are based on the climatic normal published by the MET departments.
- ✓ The drainage effluent from irrigation is estimated as 10 percent of the total water allowance to each catchment area. The water allowance varies from 5 cfs to 14 cfs for perennial and non-perennial areas.

Table-27: Hydrology Parameters

Component	LBOD Service Area		Area Reduction Factor	SCN
	Acres	sq.miles		
Nawabshah	626,000	978	0.85	70.5
Sanghar	424,000	663	0.89	70.0
Mirpur Khas	376,000	587	0.89	67.8
Badin LBOD	280832	439	0.92	69.6
Badin KPOD	312462	488	0.92	69.6

Source: Appendix --------------- of Regional Plan Report (2012)

The estimated runoff and discharge coefficients for 10 and 20 years return periods are given in Tables 28 and Table 28. The evacuation period is taken 5 days and a uniform outflow is considered over this period. These coefficients are substantially high compared to the original design values.

Table-28: Runoff and Discharge Coefficients

10 Year Return Period – 5 Day Evacuation Period

Drain	Catchment Area	Volume of Flow	Runoff	Runoff	Drainage Coefficients	Capacity (20% margin)
	sq mile	cfs	inches	acre-foot	cfs/sq.mile	cfs/sq.mile
West Nawabshah	660	6989.2	0.82	28886.8	2.1	2.5
East Nawabshah	318	2923.2	0.71	12096.9	1.8	2.2
Sanghar	660	7361	0.86	30408.9	2.2	2.6
Mirpur Khas	587	9352	1.23	38644.7	3.2	3.8
LBOD Branch	439	8553.7	1.51	35273.8	3.9	4.5

Source: Appendix VII of Regional Plan Report (2012)

However, existing capacity of the spinal drain can accommodate storm flows of 10-year return period with limited capacity improvements. The main and branch drains will need well planned capacity enhancement measures, while taking care of the topographic levels, local cushions and evacuation periods. Current floods have shown that the middle level of the drainage system (main and branch drains) is pressurized from both sides. Physical capacity at the secondary and primary level is a key limitation in responding to the drainage inflows. While, additional factors like submergence and backwater flows in the system hamper evacuation efficiency of the network.

Table-29: Runoff and Discharge Coefficient

20 Year Return Period – 5 Day Evacuation Period

	Catchment Area	Volume of Flow	Runoff	Runoff	Drainage Coefficients	Capacity (20% margin)
	Sq. mile	cfs	inches	acre-foot	cfs/sq.mile	cfs/sq.mile
West Nawabshah	660	9122.6	1.07	37664	2.76	3.0
East Nawabshah	318	4271.6	1.04	36608	2.69	2.9
Sanghar	660	9514.9	1.11	39072	2.90	3.2
Mirpur Khas	587	16501.3	2.17	76384	5.62	6.1
LBOD Branch	439	16588.8	2.92	102784	6.55	7.0

Source: Appendix VII of Regional Plan Report (2012)

Table-30: Required Drainage Coefficients

Sr. No.	Drainage Component	Design Drainage Coefficient cfs/sq.mile	Required Drainage Coefficient (cfs/sq.mile)	
			10 Years	20 Years
1.	Nawabshah	0.72	2.4	3.0
2.	Sanghar	1.53	2.6	2.9
3.	Mirpur Khas	0.93	3.8	6.1
4.	Badin	2 – 3	4.5	7.0

Source: Appendix VII of Regional Plan Report (2012)

6.6 Drainage Coefficients and Capacity Constraints

It is not expected that the existing capacity will be enhanced three to four times. Other than physical constraints, like outfall limitation, there will be economic constraints. The cost of such measures will be prohibitive. It must also be considered that the capacity of existing system is much higher than the original design. To address the capacity constraints off-loading option of 3000 cfs from spinal will provide the desired relief.

For further hydraulic analysis, the capacity of LBOD at RD 159 is proposed 9000 cfs to accommodate drainage flows from existing four sub catchments areas. For 20-years return period, this capacity should be more than 9000 cfs, hence about 3000 cfs flows are offloaded. The next chapter on Hydraulics simulates different options to rehabilitate and remodel LBOD Spinal with minimum possible changes in the infrastructure. The drainage coefficients indicate major changes in the expected flows routed through the sub and branch drains. However, actual capacity at the catchment level has already increased. The direct inlets are allowed at all levels. The farmers have connected their farms and watercourses to the main and branch drains where ever it was possible. The actual drainage network has expanded in size. During floods storm water enter into the system not only through control inlets but also as sheet flow in some of areas.

CHAPTER 7: HYDRAULIC ASPECTS OF LBOD DRAINAGE NETWORK

7 Hydraulic Aspects of LBOD Drainage Network

7.1 Hydraulic Model of the LBOD System

The basic data required to build a model in HEC-RAS includes geometric data of drainage network and structures, water distribution principles for the full discharge range and boundary conditions or hydraulic properties at all critical nodes and junctions of network. Many sets of physical parameters can be defined representing changes in cross-sections or other geometric parameters. The LBOD Spinal Drain (RD 815 to RD 159), KPOD, DPOD and all out-falling secondary drains have been described in HAC-RAS with following details.

- Elevation of the drain bed, berms, banks and inspection paths (IPs).
- Data of longitudinal sections of LBOD Spinal, KPOD, DPOD and branch drains including reach wise lengths, slopes and confluence sections at outfall point.
- All existing weir structures – on the branch drains and DPOD (below bifurcation point).
- Design cross sections and elevations of each branch and main drain at the outfall locations. Actual length and design slope for each branch and main drain are used. However, water distribution and sections of these drains in upstream sections represent the average conditions.
- Water distribution for range of discharges, base flow, design discharge, runoff at 10 and 20 years return periods.

A typical section of LBOD Spinal is given in Figure-42. Starting bed-width of the section is 30.2 ft (labeled as "b"). Bed-width is increased to "3b" (60.6 ft) at the elevation increases by 2.2ft. For a typical design section, berms were provided one feet(1ft) higher than the maximum water surface level and inspection path two feet (2 ft) higher than the berm level. The KPOD was remodeled in 1990 by widening to 92 ft (from 80 feet), while the design depth was increased from 7.0 ft to 13.0 ft. Latest design discharge capacity of KPOD is 3120 cfs which includes 2120 cfs inflow from the LBOD Spinal Drain and 1000 cfs discharge from Badin drains.

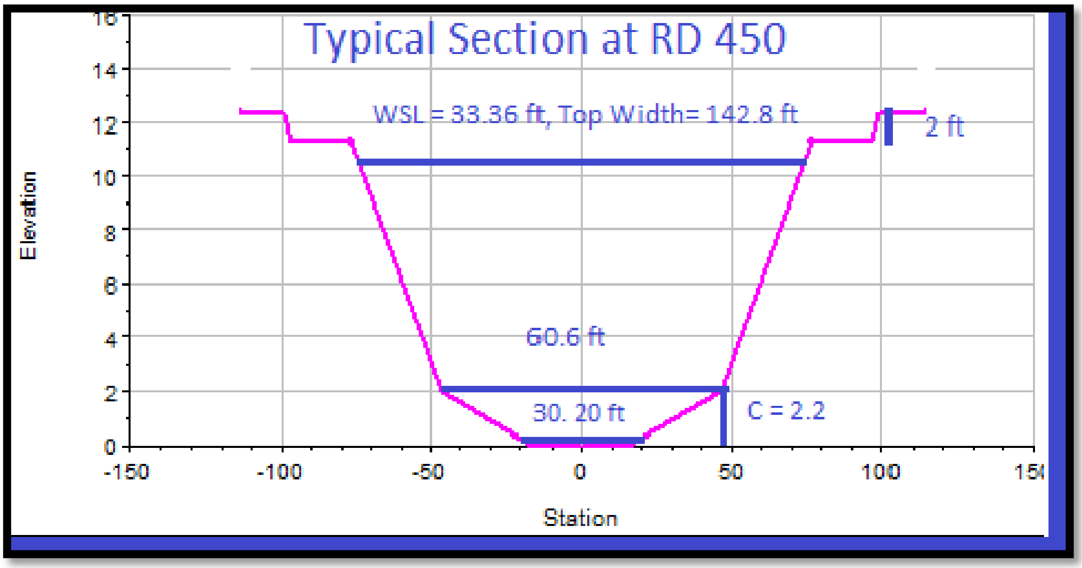
The original design data of LBOD is given in Table 31. Similar datasets were used for KPOD and DPOD.

Table 31: Last Design Parameters of LBOD

Design Data of LBOD Spinal Drain

Sr. No.	RD	Design Discharge	Bottom Bed Width	Width at Height "C"	Design Velocity	Top Width at Design Q	Depth of Flow	Bed Level	Water Level	Berm Level
	1000 ft	cfs	ft	ft	ft/sec	ft	ft	ft	ft	ft
1	816	2000	28.33	85	2.23	133	8.75	60.38	69.13	70.13
2	722.5	2500	30.67	92	2.20	148	10.25	47.88	58.13	59.13
3	638	2500	30.67	92	2.10	148	10.25	40.35	50.60	51.60
4	545	2500	30.67	92.	2.06	148	10.25	31.75	42.00	43.00
5	468	2500	30.24	90.6	2.05	148	10.25	24.94	35.19	36.19
6	450	2500	30.2	90.6	2.03	152	10.90	22.46	33.36	34.36
7	375	2500	30.2	90.6	2.00	152	10.90	16.91	27.81	28.81
8	305	2500	30.2	90.6	2.00	206	10.9	11.73	22.63	23.63
9	295.8	3000	32.1	96.3	2.00	212	12.25	9.70	21.95	22.95
10	203.2	4212	47.0	141	1.99	222	13.33	2.83	16.16	17.16
11	178.55	4412	51.0	153	1.98	222	13.33	1.60	14.93	15.93
12	164.2	4513	52.5	157.5	1.97	232	13.33	0.88	14.21	15.21
13	160.8	4609	54.0	162	1.93	232	13.33	0.71	14.04	15.04

Source: Appendix VII Draft Regional Report (2012)



Elevation = feet, width = feet

Figure 66: A Typical Section or Design Template of LBOD at RD 450

7.2 Design Drainage Rate

Figure-43 shows sub-component wise distribution of drainage flows and capacities, considered at the design stage. The bars indicate percent contribution from each sub-component for; i) estimated capacity of the sub-component drains, ii) capacity of LBOD in the corresponding section, iii) base flow, and, iv) storm runoff,

- The design capacity of local drainage system (sub-drains) is almost equal for three upper sub-catchments, jointly making 65%. While, Badin component of LBOD is 35% of the total. The largest share of base-flow, about 40%, was expected from Sanghar followed by Mirpur Khas and Nawabshah.
- On five year return period, largest share of storm runoff was expected from Sanghar, followed by Badin and Nawabshah. A small contribution was expected from Mirpur Khas, less than half of the other components (about 400 cfs).
- The LBOD spinal starts from Nawabshah with relatively higher capacity double of the local capacity of Nawabshah branch drains. There is about 10% increased for the Sanghar inflow and again 10% for Mirpur Khas inflow at RD 295 followed by 28% increase below RD 203 for Badin inflows.

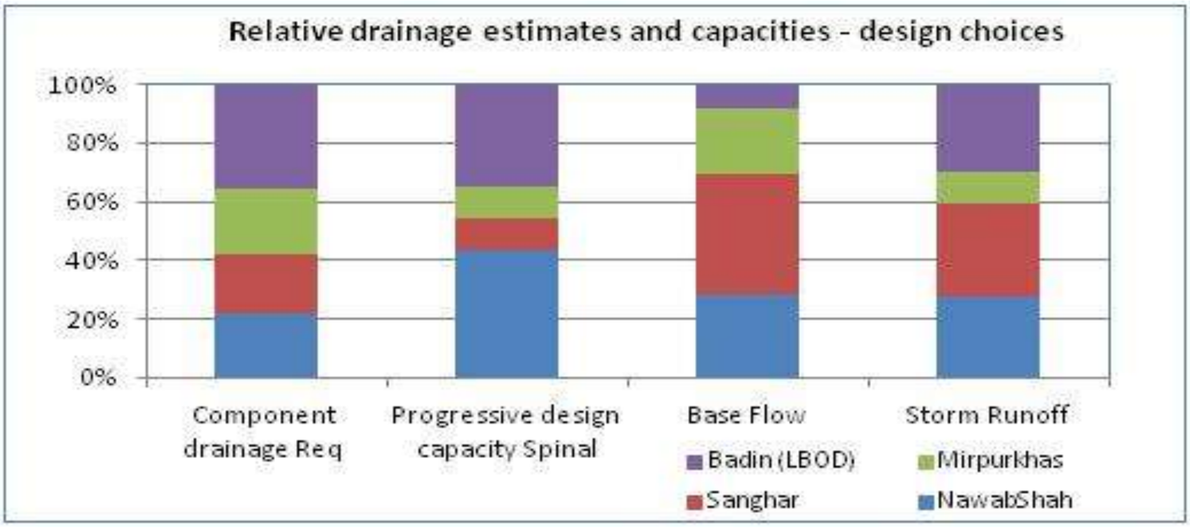


Figure 67: Relative Distribution of Design Capacities

The distribution of estimated drainage effluent and capacities indicate capacity limitations of the middle section of LBOD. While the first and last sections have sufficient capacity margins. The sections having outfalls from Sanghar and Mirpur Khas are expected to face capacity constraints.

7.3 Principal Discharge Ranges for LBOD

The full discharge range considered for LBOD main network is from 1300 cfs to 9000 cfs (ref: chapter on hydrology), Table 32:

i. Base flow of 1300 cfs - despite changes in pump capacity, this range is kept as the minimum winter flow in Spinal drain.
ii. Original design discharge of 4400 cfs, which is a vital reference for comparisons and estimation of proposed changes.
iii. Estimated runoff of 7000 cfs for from existing service area of Spinal drain with partial offloading of storm runoff.
iv. Estimated runoff of 9000 cfs through LBOD Spinal with 3000 cfs evacuation through side weirs.

Table 32: Discharge Simulation for Strom Flows

Drainage System	Catchment Area	Base Flow	Design Discharge	Discharge of 7000 cfs at Terminal Point RD 159	Discharge of 9000 cfs at Terminal Point RD 159
	Sq. miles	**cfs**	**cfs**	**cfs**	**cfs**
East Nawabshah Main Drain	318	-	143	601	833
West Nawabshah Main Drain	660	-	277	1247	1729
Nawabshah Sub Component	978	352	420	1848	2562
Sanjoro Branch Drain	158	-	245	341	471
Sanghar Main Drain	223	-	389	482	665
Patoyun Branch Drain	110	-	104	238	328
Sanghar Additional Drains	171	-	146	369	510
Sanghar Component	662	507	884	1430	1973
Mirpur Khas Main Drain	413	-	327	1152	1479
Mirpur Khas Additional Drains	174	-	-	485	623
Mirpur Khas Sub Component	587	203	-	1638	2101
LBOD Branch Drain	409.8	-	935	1983	2385
Shadi Bahadur Branch Drain	29	-	150	140	169
Badin Sub Component	438.8	-	1308	2124	2554

Source: Appendix ______ Draft Regional Report (2012).

7.4 Capacity Margins of Design Sections

Four discharge ranges selected in the previous section are simulated using the design model of LBOD. The results are summarized as under.

- Simulated levels for the base flow are shown in Figure-44. The figure shows elevations for the bed, water surface and bank levels. The design bed of LBOD was provided with three drops of one foot each at RDs 722, 295 and 203. Drain sections also widen at these locations. About 26% capacity is consumed by the base flow. While hydraulic depth is 40% to 60% of the design depth.

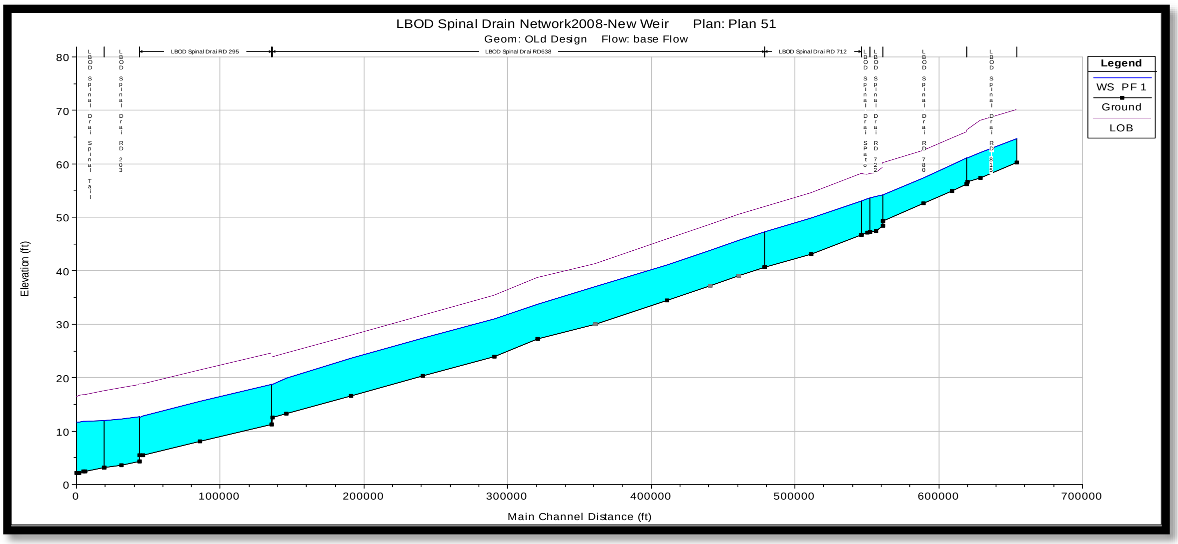


Figure 68: Bed, Water Surface and Bank Elevations at the Base Flow of 1300 cfs

- The elevations at the design discharge are shown in Figure 18. The spinal drain can take design discharge in all of its sections. However, middle section has minimum free-board, less than 1 foot.
- As the discharge increase beyond 5000 cfs, it starts encroaching the banks. At 7000 cfs water levels raise one to two feet higher the design level in many reaches. However, first reach still has free-board available (Annexure 1). At 9000 cfs water levels in the design sections become two to five feet higher than the design water levels.
- The rise of water levels in a cross section is shown in Figure 19. At RD 295 downstream, water surface varies from 12ft (msl) to 25 ft (msl) when flow varies from 700 cfs to 7300 cfs in the reach.

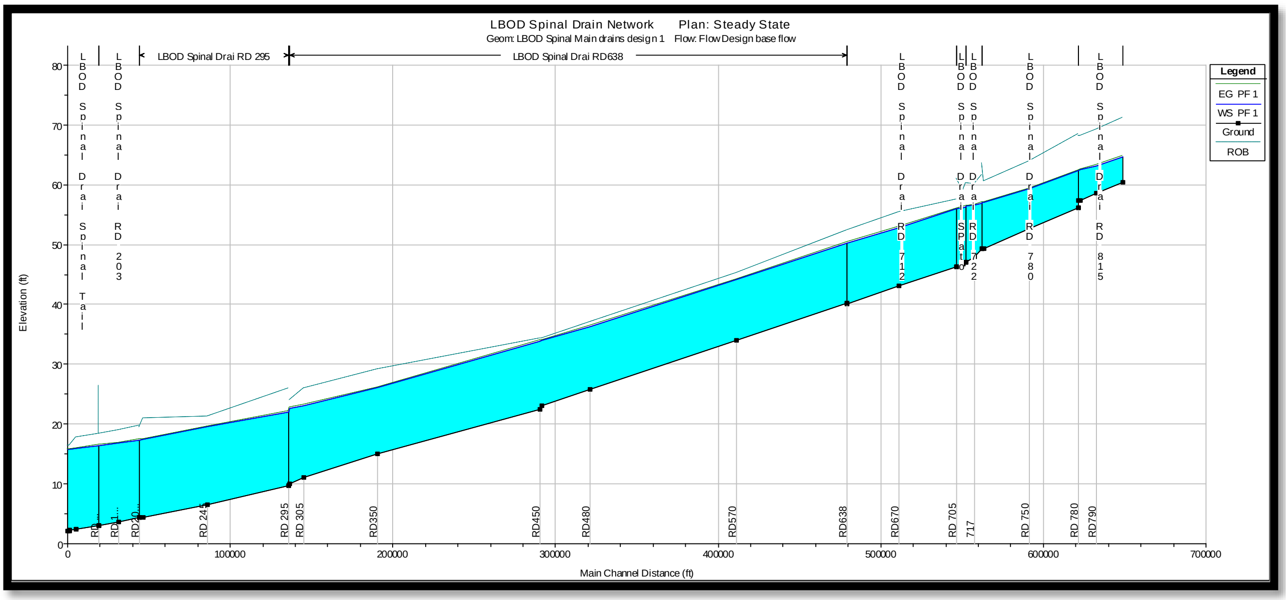


Figure 69: Elevations at the Design Flow of 4400 cfs

7.4.1 Existing Capacity of Spinal Drain

Proposed LBOD Cross-Sections for 9000 cfs

Based on the analysis of design and actual physical parameters of LBOD, optimal cross-sections are proposed to carry 9000 cfs flow in the outfall reach of spinal. The templates are defined in HAC-RAS to create new sections of Spinal with minimum changes in the observed sections. The original design criteria are followed and most of the assumptions are kept in-tact.

- Shape of the lower section and increase in bed-width during first 3 feet elevation is maintained.
- The side slopes are kept as 3H: 1V.
- Changes in the cross-sections and top-widths are not uniform relative to the design sections.
- Net capacity increase of the Spinal reaches depends upon runoff estimations for four sub-catchments.
- The last section is not de-silted to the original design level, which was lower than the bed of KPOD. The proposed sections maintain the same bed levels for the outfall reach of LBOD and the head reach of KPOD.
- No filling of the sections is recommended.

7.5 Hydraulic Assessment of New Sections

The four water scenarios (1300, 4400, 7000, 9000 cfs) are simulated using new geometry of the Spinal Drain. Results are given in Annexure -III. Impacts on water levels are illustrated for the tail RD 164 of LBOD.

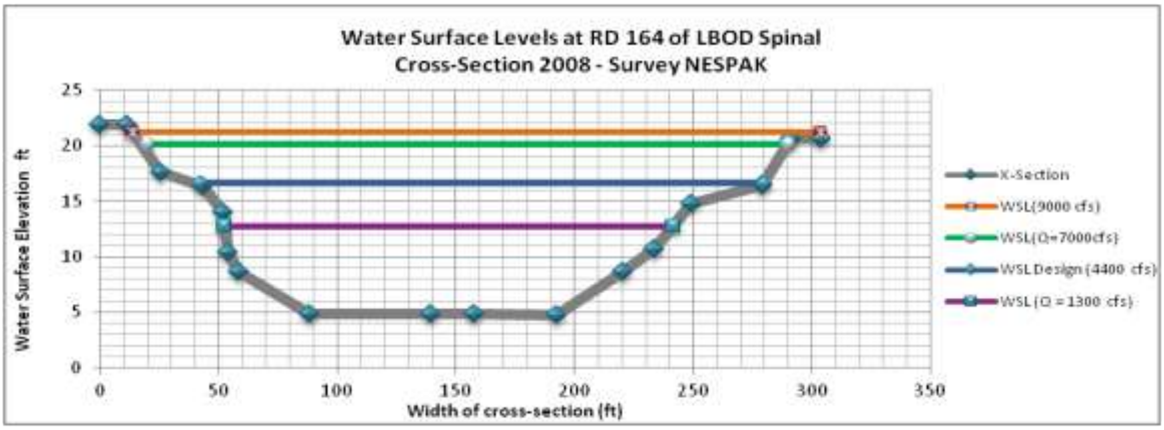


Figure 70: Water Surface Elevations Actual Cross-Section

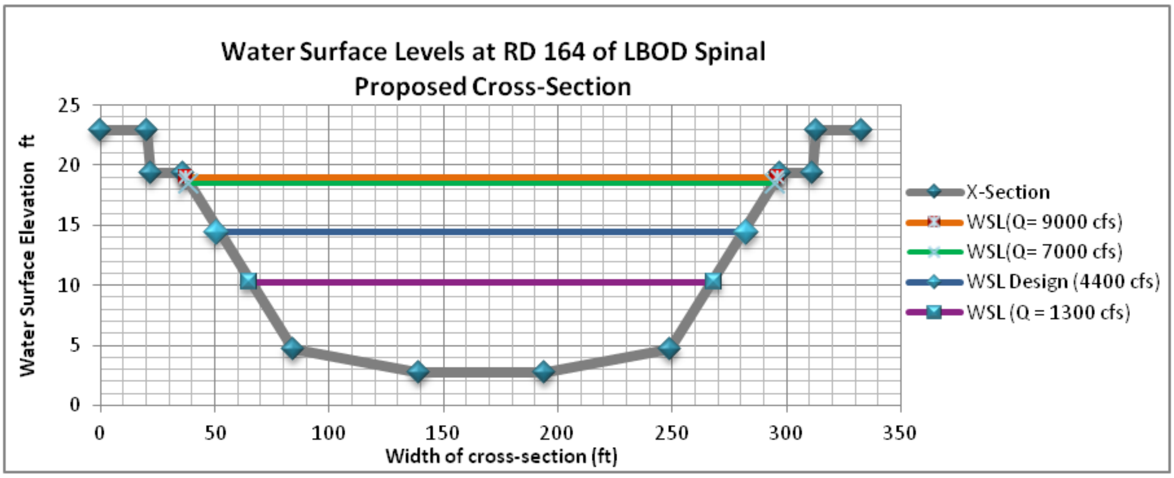


Figure 71: Water Surface Elevations Proposed Section

Summarizing changes proposed by this scenario:

1. Simulated water profiles in a cross-section are shown in Figure 29. With proposed modifications in bed and lower banks, Spinal drain will be able to convey 7000 cfs discharge with 1.0 ft to 3ft free-board (Table 7). For 9000 cfs with no free-board will be available and submergence of berms in some reaches will occur (Figures 29 & 30).
2. Existing banks are not extended in this option, hence their width will reduce by 3 to 8 feet on both sides, which has already happened in most of the reaches. The minimum bank will be 12ft in the middle and tail reaches as compared to the design width of 20 feet.
3. In case of floods, water will flow over the berms, especially in the sections closer to the outfalls.
4. For safe operations of LBOD at 9000 cusec, off-loading of discharge is proposed. Three weirs proposed by the design engineers are simulated to quantify their impact on water levels.

Table 33: Hydraulic Parameters of Spinal Drain - At 9000 cfs Bank full Storm Flows

RD	Flow Area	Water Surface Elevation	Discharge in Reach of Spinal Drain	Top Surface Width Required	Flow Depth	Flow Velocity
	sq.ft	**ft**	**cfs**	**ft**	**ft**	**ft/sec**
815	925.12	69.81	2200	126.6	9.43	2.38
780	923.66	66.07	2200	126.54	9.42	2.38
722	1363.22	60.89	2700	163.82	11.39	1.98
638	1724.23	53.61	4330	208.68	13.11	2.52
295	2237.21	26.29	6128	212.86	15.69	2.76
203	3261.58	21.42	8120	240.25	16.72	2.5
164	3395.9	18.73	9000	263.79	16.68	2.77

Source: Appendix VII Draft Regional Report (2012)

The details of simulation of hydraulic parameter can be seen in Appendix ____ of Draft Regional Plan Main Report (2012). The above determined hydraulic parameters through model simulation of HEC-RAS have been mostly adopted for Redesign of LBOD Drainage Network with a little practical and professional adjustment. The above simulations have been used as guide line for redesign of LBOD drainage network.

The reader is referred to Appendix--- of Main Report of Master Plan for in depth study.

CHAPTER 8: ENGINEERING DESIGN

8 Engineering Design

8.1 Redesign of LBOD Drainage Network

The past experience of storm water flows 1994, 2003, 2006 and 2011 indicates that the capacity of the drainage system is inadequate to drain storm water flows with a desired evacuation period of 10 to 15 days for a monsoon extreme rainfall event like 2011. There is a need to design the system for enhancement of drainage capacity of LBOD existing network along with integration of natural water ways of "Dhoras" the suggested design criteria is as under : -

8.1.1 Hydrological Design Criteria

Chapter 5 of the Draft Feasibility Report describes in detail the hydrological analysis based on critical rainfall storms. The required Drainage Coefficients for providing adequate drainage to the area are given in Table 34.

Table 34: Required Drainage Coefficients

Sr. No.	Drainage Component	Last Design Drainage Coefficient cfs/sq.mile	Required Drainage Coefficient (cfs/sq.mile)	
			10 Years	20 Years
1.	Nawabshah	0.72	2.4	3.0
2.	Sanghar	1.53	2.6	2.9
3.	Mirpur Khas	0.93	3.8	6.1
4.	Badin	2	4.5	7.0

Source: Appendix VII of Regional Plan Report (2012)

The suggested **alternatives** for design of the system are as under: -

- Drainage coefficients based on 10 years return period.
- Drainage coefficients based on 20 years return period.

The required discharges in the system of LBOD were simulated and it indicated that for a return period of return period with the critical values of rainfall level of 2011 a discharge of 7000 cfs would be generated at RD 159, terminal point of spinal drain and for a return period of 20 years with same critical value, a discharge of 9000 cfs would be generated at the terminal point of spinal drain and the catchment area would be vacated in a period of 10 to 15 days. A lengthy discussion was held with the SIDA and finally agreed that the system be designed with a return period of 20 years with the rainfall intensity of 2011 storm level and with possible evacuation period of 10 to 15 days as such the drainage coefficient have been adopted for the redesign of system based on practical values, taking above values as guide line.

8.1.2 Hydraulic Design Criteria of LBOD Network

In the LIP and the LBOD reports it was accepted in principle that the control of water logging and salinity can only be achieved by provision of proper disposal system to remove saline drainable surplus from the area. The disposal system if planned carefully can also cater for storm water runoff. The capacity of the drainage system can be optimized by controlling inlets during peak storm flows and switching off temporarily the drainable surplus. The entire system was routed through hydraulic modeling to determine actual flows in the drains at various points. From actual simulations it was deduced that for storm events of 175 mm or more intensity, the controlling factor for the capacity of drains is the storm runoff contribution, whereas for storm zones of 125 mm and 150 mm intensity drainable surplus dictates the capacities. The detailed designed criteria adopted for redesign of LBOD drainage network are given as Appendix----------.

Hydraulic Design of Spinal Drain

The HEC-RAS model through simulations have indicated the following design values for the Spinal Drain to pass a discharge of 9000 cfs at the terminal point, RD 159. The suggested hydraulic parameters for the redesign of the Spinal Drain are as under: -

Table 35: Hydraulic Parameters of Spinal Drain

At 9000 cfs at Bankful Storm Flows

RD	Flow Area	Water Surface Elevation	Discharge in Reach of Spinal Drain	Top Surface Width Required	Flow Depth	Flow Velocity
	sq.ft	**ft**	**cfs**	**ft**	**ft**	**ft/sec**
815	925.12	69.81	2200	126.6	9.43	2.38
780	923.66	66.07	2200	126.54	9.42	2.38
722	1363.22	60.89	2700	163.82	11.39	1.98
638	1724.23	53.61	4330	208.68	13.11	2.52
295	2237.21	26.29	6128	212.86	15.69	2.76
203	3261.58	21.42	8120	240.25	16.72	2.5
164	3395.9	18.73	9000	263.79	16.68	2.77

Source: Appendix VII Draft Regional Report (2012)

During redesign the efforts have been made to provide the suggested parameters within practical limits keeping in view professional experience and financial constraints

Berm width adopted for Spinal Drain ranges from 30 to 20 feet with IP width of 50 to 30 feet and to ensure a minimum to FB of 2.0 feet from observed High Water Levels of 2011.

Redesign of the Main and Branch Drains

The simulated result on the model HEC-RAS for the redesign of the existing Main Drains and Branch Drains of LBOD drainage network is given in Table 36.

Table 36: Discharge Simulation for Different Flow Discharges

Drainage System	Catchment Area	Base Flow	Last Design Discharge	Discharge of 7000 cfs at Terminal Point	Discharge of 9000 cfs at Terminal Point
	sq. miles	**cfs**	**cfs**	**Cfs**	**cfs**
East Nawabshah Main Drain	318	-	143	601	833
West Nawabshah Main Drain	660	-	277	1247	1729
Nawabshah Sub Component	978	352	420	1848	2562
Sanjoro Branch Drain	158	-	245	341	471
Sanghar Main Drain	223	-	389	482	665
Patoyun Branch Drain	110	-	104	238	328
Sanghar Additional Drains	171	-	146	369	510
Sanghar Component	662	507	884	1430	1973
Mirpur Khas Main Drain	413	-	327	1152	1479
Mirpur Khas Additional Drains	174	-	-	485	623

Drainage System	Catchment Area	Base Flow	Last Design Discharge	Discharge of 7000 cfs at Terminal Point	Discharge of 9000 cfs at Terminal Point
	sq. miles	cfs	cfs	Cfs	cfs
Mirpur Khas Sub Component	587	203	-	1638	2101
LBOD Branch Drain	409.8	-	935	1983	2385
Shadi Bahadur Branch Drain	29	-	150	140	169
Badin Sub Component	438.8	-	1308	2124	2554

Source: Appendix VII Draft Regional Report (2012)

A minimum berm width of 25 has been adopted for design of Main and Branch Drains with IP width ranging from 30 to 20 feet on both banks of the drains and also a minimum FB of 2 feet has been adopted for computing the dimensions of the above network. A value of manning roughness coefficient of 0.025 has been used for determining the design capacity of the proposed Cross-Sections of above drains.

Design of Sub Drains of LBOD Area

The sub-drains have been designed with the required drainage coefficient and with clear berm width of 15 feet on either side and the width of the IP as 20 feet through out. The sub-drains would be provided with drainage inlets to facilitate the on farm drainage after every second RD along the length of sub drain.

Re-Design of KPOD of LBOD Area

It is proposed to redesign the KPOD with a outfall discharge of 7000 cfs and with berm width of 30 feet on either side and with IP width of 50 feet on both the banks and also a minimum FB of 2 feet has been provided for 2011 water levels. In order to check the tidal effect into KPOD a gated tide control structure is purpose is RD 22 of KPOD with complete protection works to its point of outfall with Tidal Link and with proper protection against bank erosion.

Re-Design of DPOD of LBOD Area

It is proposed to re-design the DPOD link RD 127+000 to RD 110+000 with a outfall discharge of 6000 cfs. The berm width provided is 30 feet on either side and with IP width of 30 feet. The balance reach of the DPOD is covered under Draft Feasibility Study of Revival of Dhoras.

8.1.3 Topographic Field Survey LBOD Drainage Network

Survey and Investigation work was got done by utilizing services of Country Survey and Mapping Services Lahore. The cross-section survey of selected drains with plan and profile was obtained from the firm for tentative earth work cost estimates and detailing would be done under Phase IV of the Study. The survey firm has also prepared the contour plans and site maps for major hydraulic structures proposed in the feasibility study. The scope of the field survey of LBOD Drainage Network is as under: -

- Topographic survey of proposed structures at selected locations of LBOD Drainage Network (500 ft x 1300 ft area of each with contouring), including one cross section at each structure site, with reference to survey of Pakistan Datum with Dual Frequency GPS.
- Observation of Cross Section of Spinal Drain at selected locations with reference to Survey of Pakistan datum with Dual Frequency GPS.
- Observation of cross sections of main, branch and sub drains of LBOD at selected locations with reference to survey of Pakistan datum with Dual Frequency GPS.
- Topographic survey of Spinal, Main, Branch and Sub-Drains with Total Station.

8.1.4 Conditions Survey of LBOD Drainage Network

The cost estimates of improvements to existing structures of LBOD drainage network are based on condition survey of Spinal, Main, Branch and Sub Drain was carried out by a team of Consultants deputed for Feasibility Study of LBOD Project. Details of conditions survey for different components of LBOD drainage Network can be seen in Volume III - Drawings of the Draft Feasibility Report of LBOD.

The rehabilitation works are of the following categories: -

CATEGORIZATION OF REHABILITATION WORKS

Rank	Concept	General Criteria
Rank A	Reconstruction/ Replacement	➢ Structural stability is not secured. ➢ Hydraulic function is not working well. ➢ Canal flow capacity is not sufficient for present water requirement. ➢ Size or structure is not met to present social requirement.
Rank B	Partial Repair	➢ Fundamental functions are secured. ➢ Minor defects are observed.
Rank C	No Rehabilitation	➢ Required functions are fully secured.

WATER COURSE AQUEDUCTS

Rank A	Reconstruction/ Replacement	➢ Leakage or seepage from trough. ➢ Big cracks (crack width is more than 1.0 mm). ➢ Exposure of reinforce bars (at the bottom of side wall).
Rank B	Partial Repair	➢ Loss of trough concrete. ➢ Leakage and seepage from abutment. ➢ Cracks of abutment.
Rank C	No Rehabilitation	➢ No damage, and also Water flow capacity is sufficient

BRIDGES

Rank A	Reconstruction/ Replacement	➢ Unstable structure (wooden food pass, aged deterioration). ➢ Insufficient width for tractor or vehicle passing. ➢ Insufficient free board.
Rank B	Partial Repair	➢ Loss of parapet masonry. ➢ Cracks of abutment.
Rank C	No Rehabilitation	➢ No damage. ➢ New Road Bridge and Foot Bridge.

8.1.5 Geotechnical Investigations of LBOD Drainage Network

The preliminary Geotechnical Investigation Report has been publish by the Geotechnical Expert of the Consultant team and can be referred as appendix I of Draft Regional Plan Main Report (Volume I). The existing structures do not need any further detailed foundation investigations. The Tidal Control Gated Structure proposed at RD 22 of KPOD will be tasted for SPT and all laboratories testing and boring logs. The above detailed report shall be available under Phase-IV of the study.

8.1.6 Structural Design Criteria

The type of existing structures on the drains can be put under three main headings, communications, drainage and irrigation. Communication structures are the Road and Railway Bridges which must have adequate waterway to maintain lines of communications across the drains. Drainage structures comprise Inlets and Falls at Drain Junctions. Irrigation structures are Siphons and Aqueducts needed to keep the irrigation system open at places where drains cross Irrigation canals and Water-Courses.

Because of the uncertainty of drainage flow estimates it is necessary to design cross structures such as culverts, bridges and fall structures in such a manner that the maximum flexibility of flow acceptance with minimum afflux at the structure can be obtained. It is recommended therefore, that wherever possible culverts should not be rebuilt at site of damaged bridges but new bridges should be provided instead of damaged culverts. The reason for this is that culverts if required to flow at greater value of discharge than design, it causes a greater afflux when compared with bridges because there is no room vertically for the water level to rise. All hydraulic structures have been designed in reinforced or mass concrete and it is recommended that sulphate resisting cement should be used for all concrete work in contact with the saline soils.

Proposed Structural Design for Hydraulic Structures of LBOD

Bridges

Three types of bridges are provided. District Road bridges are designed for class AA loading and have a carriage way width of 24 feet. Village Road Bridges have a carriage way width of 18 feet and are designed to carry class "A" loading on the sub-drains and branch drains where there is no bridge within 4 miles then a 12 Foot Bridge has been provided to give access to farmers for both banks.

Fluming at New Bridges

The present design involves no expenditure or protection of bed and side slopes against scour, and while fluming would reduce the cost of the structure itself, the apparent saving would be more than offset by the additional pitching and abutment works which would be required. The fluming at new bridges is not recommended.

Water-Course Aqueducts

The existing water-course aqueducts on spinal drains in outfall reach caused all breaches and over flows of spinal drain and inundation of adjoining villages during storm flow of 2011 as such from RD 297 to RD 159, the Terminal Point. The existing Box type water course aqueducts have been replaced with pipe type and this should be done at dangerous point of LBOD network.. A typical design is shown in the accompanying Drawings.

The foundations of aqueducts are similar to those for bridges. At sites where the soffit of an aqueduct structure is below maximum water level in the drain, inverted siphons will be used. Pipe siphons are preferred to cast-in-situ and most suitable for sub drains.

Drain Junctions

Drain junction structures are provided in order to prevent damage to the larger drain, when it is empty, by water flowing into it from smaller drain and also to provide a continuous access road along the drain. At sub-drain junctions a pipe structure and outlet boxes are employed, Stone pitching is provided around the inlets and outlets. For larger junctions a box culvert is recommended.

Drain Inlet

A structure of considerable interest is the drainage inlet which serves to pass the storm run-off through the drain bund into the drain. For this a simple pipe inlet is suggested. The diameter of the pipe is chosen by considerations of (i) the difference of head between water pounded behind the bund and that in the drain, (ii) the run-off in cfs per square mile and, (iii) the catchment area which drains to the particular inlet. Each inlet can be designed on this consideration. It is recommended that a drainage inlet is provided at each low point on the drain and in any case at the rate of one for every 2000 feet to 3000 feet of sub drain on each bank.

The whole catchment should be divided into parts based on different irrigation system boundaries and the boundaries of the minor catchments. It is recommended that farmers should not be allowed to construct inlets of their own and no one should be permitted to cut banks of drainage network for immediate evacuation of rain water from their cropped area. The big landlords be particularly asked to stay away from drainage network. In case of repeated cutting of banks of drains, the drains in their area shall not be maintained. Design criteria for rehabilitation of LBOD drainage network is given in Annexure-II.

8.2 Provision of Mobile Pumping Station for Badin Area

During the heavy monsoon rains of 2003, 2006 and 2011 storm water caused flooding and overtopping of drain embankments. As a result vast areas of Nawabshah, Sanghar, Mirpur Khas and Badin components were submerged with storm water. This was due to the fact that the discharge generated by the rains was more than the maximum capacity of drains and the situation was further aggravated by obstructions constructed by the locals, over a period of time, within the waterway of LBOD Branch Drain and Mirpur Khas Main Drain and other drains.

In order to drain out trapped water pumps are to be procured and water channels to be excavated. To exercise economy effort put in should be consolidated. However, pumps should be switched over to solar energy to guard against pilferage of fuel/electricity.

8.3 Improvements to Outfall Conditions of LBOD/KPOD

During the designing/planning stage it was expected that Seawater would penetrate up to 19 km from its outlet upstream into the Tidal Link, to an area about 11 km downstream of the Cholri Weir. Whereas it is evident from the NIO Karachi, observations, that erosion and intrusion of seawater in the Tidal Link commenced just after its completion. Later on storms in 1998 and in 1999 ‘Cyclone 2A’ further worsen the situation. The storm, in July 2003, was the final blow and destroyed the already deteriorating Tidal Link now it is turned to be tidal creek rather an outflow of drain. During the post storm inspection (GOS Technical Review Committee) 56 breaches were recorded, it was the almost complete disaster of the outlet system of the LBOD. A Tidal Control Gated structure has been proposed at RD 22 of KPOD.

8.4 Environmental Impact Assessment of LBOD Project

The proposed intervention will address the issue of drainage in the project area by disposing flood/drainage water into sea. It is environment friendly and supportive in reducing water accumulation thereby helping to address the water logging issue. It has positive effect on environment of the area.

The proposed intervention will also address the issue of overloading of the drainage infrastructure and will divert appreciable quantity of the drainage effluent (mostly storm water) to the thirsty Thar area where it will be utilized for recharging the underground aquifers and also for growing agriculture. Efforts will be made to give passage to water flow through natural water ways under gravity. If unavoidable, the displaced persons of the locality will be compensated by providing alternate livelihood and space provisions by appropriate re-settlement procedures. However, the overall impact of the intervention will be environment friendly.

Positive Impacts:

a. Drainage effluent from the project area will find its way to the sea through enhanced drainage system
b. The storm water will be evacuated within a time frame of 3-7 days in most places this will save the crops from inundation and failure as experienced in the previous design.
c. Agriculture production will increase due to control of water logging and salinity on one hand and threat to the crop damage due to pounding of storm water would be reduced.
d. Overall environment of the area will improve.
e. Tidal Control Structure will minimize sea intrusion to cropped areas as well as stop backflow of sub-drains out falling in to KPOD.

Negative Impacts:

a. More water from the project area will enter the LBOD system. The O&M activities are not if taken on regular basis will result the erosion of the banks of the drains and will make the system vulnerable and unstable.
b. The process of erosion of Tidal Link banks and bed yet continues and may extend with the passage of time. Until the system becomes stable, there is always risk of extended flooding in the inland areas.
c. Under heavy rains as of the intensity of 2011 rains the system may not handle the storm water resulting in damage to crops, people and the property.
d. Many isolated pockets exist in various areas of the left bank. Such pockets need to be connected to the drainage infrastructure for drainage disposal otherwise; depressions may hold storm water for months as observed in 2011 rains.
e. Irrigation system in the event of heavy rains if not closed at least one week before rains, may add to the grievances of the people as in 201 rains and again a big disaster for area.

Culverts of suitable cross section if not provided at places of inadequate discharge may create pounding of water in isolated pockets/depressions.

The reader may like to refer the detailed Environmental Impact Study done by the Consultants at Appendix VII of Main Draft Report of Regional Plan of Left Bank Area.

8.5 Establishment of Drainage Research Institute at Badin

Pakistan has 38.4 Million acres under canal irrigation of which 12.4 Million acres are provided drainage and another 16 Million acres are under different stages of project preparation. The area provided with sub-surface pipe drainage is 45000 acres and area for which sub-surface pipe drainage is under different stages of planning, design and execution is 632,700 acres.

Around 78% of the area in Sindh Province is underlain by saline groundwater which is unsuitable for irrigation and other uses. Surface and sub-surface drainage systems are inadequate, resulting in much of the drainage effluent being either retained in the basin or disposed of into rivers, canals, and through a drainage network. There are 13 existing surface drainage systems in Sindh, which serve a total area of over 6.2 million acres (2.5 million hectares) and have an aggregate length of about 3.8 thousand miles (about 6.1 thousand Kms). In addition, there are two sub-surface drainage systems, which serve an area of 0.10 million acres (0.04 million ha).

During the last three decades, particularly in 1994, 2003, 2006, and 2011, the left bank of Indus experienced repeated extreme rainfall events that caused colossal damage to human lives, agriculture, particularly standing crops, livestock, stored grains, private and public properties, productive and physical infrastructures. A large segment of population was marooned and or displaced constraining their access to social services, and livelihoods, till the return of normality. It is anticipated that due to climatic changes coming decades will witness occurrence of such extreme weather conditions more frequently. The situation is further exasperated by damage to tidal link and collapse of Cholri Weir, causing sea encroachment during high tides, degrading large tracts of productive land and depressing its productivity potential, and salinizing the fresh water bodies diminishing their fish production potential. This has led to loss of livelihood of considerable populace.

Due to an inadequate drainage network and the flat topography of the basin, nearly one-fifth of the canal command area is affected by water logging and salinity – widely referred to as the twin problems or twin menace.

To solve the related problems and to suggest remedial measures, Drainage Research Institute (DRI) is proposed to be established at Badin for solving drainage problem of Lower Sindh. This institute will be helpful to give scientific recommendations for the solution of drainage problems.

Objectives

- To study and prepare critical plans for re-use of drainage water for irrigation purpose.
- To conduct research and give recommendation for development of sub- surface drainage system to control water logging and salinity.

- Study the physical and economic effect of drainage water on soil properties and different crop yields.
- Determination of salt water balance in the drainage areas and its relationship to surface water management.
- Introduction of necessary modification in the design of drainage net works according to modern theories and practices.

Justification

Country as a whole and the Sindh in particular is going to face major challenges relating to drainage sector so there is need to establish Drainage Research Institute to keep watch and handle the drainage issues according to modern scientific methods and the research based solutions.

Location

The Institute will be established at Badin, as this place is central to the problem areas.

Organizational Set Up

Director	(BPS-19)	01-No
Deputy Director/SRO	(BPS-18)	04-Nos
Assistant Director/JRO	(BPS-17)	10-Nos

04- Nos. Deputy Director/SRO will be entrusted assignments as under:-

DD/SRO (Surface Drainage)	1-No
DD/SRO (Sub Surface drainage)	1-No
DD/SRO (Experiment & Lab. Testing)	1-No
DD/SRO (Dissemination)	1-No

Additional Staff

Sub Engineers	(BPS-16)	02-Nos
Silt Analysts	(BPS-16)	04-Nos
Silt Observers	(BPS-14)	04 Nos
Steno/PA	(BPS-16)	01 No
Computer Operators	(BPS-14)	05 Nos
Lab. Attendants	(BPS-14)	16 Nos
Chowkidars	(BPS-4)	04 Nos
Coolies	(BPS-4)	08 Nos
Sweepers	(BPS-4)	02 Nos

Efforts are to be made to transfer to existing staff from the irrigation department and deputed to run the institute. New building for the Institute is proposed at Badin Canal Colony as Government Land is available in abundance.

CHAPTER 9: IMPROVEMENTS TO OUTFALL CONDITIONS OF LBOD

9 Improvements to Outfall Conditions of LBOD

The Development of Irrigation system in Sindh commenced in 1932 and continued till 1962. This irrigation system comprises three barrages i.e. Sukkur (1932), Kotri (1955) and Guddu (1962) and various canals and sub canal to irrigate an area of about 13 million acres 10. Before the advent of the irrigation system, though it was realized that water table in the command area of these braggers would raise and would eventually require drainage system. Initially it was not needed, however, due to the progressive raising of water table the situation during 1950s became serious. During 1960s, the Kotri Basin drains lie west of the LBOD (Left Bank outfall Drain) basin, were built to discharge saline water into the Dhands. Later on studies and ground work continued to expand drainage system to combat the water logging problems subsequently LBOD stage 1 was commissioned in December 1997 10. Tidal Link is a about 42 Km channel the seaward component of the LBOD that carries LBOD effluent to discharge it in the sea.

Tidal Link, a 42-km link was constructed from the Pateji Dhand (at the downstream end of KPOD) to the Shah Samando tidal creek. The channel would operate independently of the Pateji Dhand and the Runn of Kutch, and the channel berm would isolate the channel from high water levels in the Runn of Kutch. The channel would have a bed width of 40 m and, at its outfall to the creek; the width would be gradually increased to 114 m to avoid critical velocities during periods of low tide. Channel design would provide the most efficient hydraulic gradient for the outfall. Under design conditions, intrusion of sea water would occur up to 19 km inland; however, such intrusion would be of short duration and the drain would operate mostly at outfall levels below water levels in the Runn of Kutch.

An 1800 ft weir, called the Cholri Weir, was built on the right bank of the tidal link, where it passes through Cholri Dhand in order to attenuate high water levels in the Tidal Link Canal during high tide by allowing water to flow into the Dhands during this period, and to protect the Dhands from excessive drainage during low tide when the water would flow back into the Tidal Link Canal. Since sea water was not expected to come closer than about 11 km downstream of the weir, the negative effects of the intrusion of the much more saline sea water would also be minimized. The outlet works of LBOD thus consist of the DPOD, which discharges through the Dhoro Puran natural channel into Shakoor Dhand, the enlarged KPOD drain, the Tidal Link Canal connected directly to the sea, and the Cholri Weir.

No tidal gate was placed at the terminus of the Tidal Link, so uncontrolled tidal currents moving rough the Tidal Link resulted in erosion of the Tidal Link channel once it was opened to the sea in 1995.The Cholri Weir experienced almost immediate major damages, perhaps due to undermining of the scour protections and unsuitable foundation material. A cyclone in 1999 resulted in more severe erosion, with nearly complete destruction of Cholri Weir, and breaches in the embankments paralleling and protecting the tidal link from the influence of high tides. To this day the breaches continue to widen as tidal creeks develop through them, resulting in daily inundation of the Dhands by high tides. The influence of tides and intrusion of saltwater is also extending beyond the Tidal Link and affecting the downstream end of KPOD up to RD 100 and smaller branch drains that discharge directly into the lower end of KPOD (John, 2011).

Plans have been developed to remedy the bank erosion, halt further advance of the saltwater intrusion, and restore a more brackish water environment to the Dhands that were altered by construction of the Tidal Link (NESPAK, 2009). A geomorphologic review of these plans was conducted to better understand why the initial problems with the Tidal Link occurred, better anticipate how the proposed remediation will behave in the dynamic tidal environment, and provide recommendations for remedial actions that will have the greatest chance for long-term success.

9.1 International Policy Guide Lines and Practices for Coastal Erosion Management

The developed nations have formulated their own policy guide lines to protect their valuable assets from the unwanted impacts of ocean forces.

The specific principles that guide this coastal Protection Policy are to:

- ✓ Minimise the need to interfere with natural coastal processes;
- ✓ Undertake coastal protection works only if the benefits outweigh the cost;
- ✓ Ensure that the direct beneficiaries of coastal development carry all consequential costs;

- ✓ Ensure that the coast continues to be available for the benefit of the whole community;
- ✓ Ensure that local coastal managers receive proper guidance and assistance to solve their coastal protection problems;
- ✓ Establish that coastal protection is a partnership between the state and local coastal managers, with the lead taken by the local coastal managers; and
- ✓ Ensure that the most appropriate coastal protection technologies are considered.

The review of international practices was done to check sea erosion for preparing the plans for shore management and protection of coastal structures. The major concepts are the followings:

- ➢ Work with the dynamic nature of the coastal environment rather than fighting the forces of the sea
- ➢ Use "soft" engineering measures like beach nourishment where applicable
- ➢ Make more environmentally friendly designs of "hard" engineering works like breakwaters (e.g. minimize the length, lower the crest elevation, make it submerged where appropriate)
- ➢ Apply the concept of "retreat" management
- ➢ Apply the concept of "do-nothing" option
- ➢ Introduce a detailed monitoring program to observe the coastal changes near the sea structures

There are three famous types of managerial options in response to coastal erosion (Van der Weide, de Veroeg & Sanyang (2001). These are:

- ❖ Retreat
- ❖ Accommodate for the present
- ❖ Defend

The "retreat" option indicates the acceptance on the shoreline erosion as a long-term phenomenon, and movement of development to inland locations that are sufficiently far away for not being affected from the ongoing erosion within a reasonable timeframe. This option is especially meaningful for undeveloped (rural) coasts where not many people suffer critically from the ongoing erosion process.

Accommodate for present option could be the rational choice when an important infrastructure (such as a highway) can be modified with a reasonable budget so that it can be used for an additional period after the eroding shoreline more or less hits a length of the structure. This option merges with the "retreat" option in the long run.

The "defend" option is the undisputed choice for an eroding urban coast. It indicates the use of one or more types of structural or non-structural measures to stabilize the length of the eroding coast facing the urban areas. The "defend" option may also benefit from improved watershed management practices.

The shoreline management options should pay due attention to the climate change and the anticipated sea level rise.

9.2 Existing Conditions at Outfall Point

A gated structure was not constructed at the terminus of the Tidal Link, because hydraulic and physical modeling prior to construction indicated deposition, not erosion, would occur as a result of storm water flows and tidal forces acting in the link canal. However, erosion of both the bed and the banks of the Tidal Link began almost immediately after its opening on June 6, 1995 (NESPAK, 2009). The Tidal Link had nearly consistent dimensions along its 25.3 miles length (from RD -21+.400 to -154+.990) at the time of completion with a bed width of 92 ft, a top width ranging from 152-233 ft, and side slopes of 3:1. While the ground surface in the area ranges from 2.0-6.8 ft amsl, the bed elevation at the upstream end was - 8.0 ft amsl and - 17.7 ft amsl at the terminus resulting in a constant bed slope of 0.000072 (1 in 13888). The topographical surveys of the Tidal Link reveal that the bed elevation as of 2007 was over 52 ft deep in places due to bed scour. Although this represents a depth below an uncertain water elevation, even the most conservative estimate (that assumes the water level was at its maximum design elevation of 7.1 ft amsl and the original bed elevation was - 17.7 ft amsl) indicates more than 27 ft of scour has occurred in some locations since construction. Erosion of the banks has been similarly dramatic.

The topographic cross sections at various points along KPOD and the Tidal Link reveal limited erosion in KPOD and the upstream end of the Tidal Link, but much more extensive bank recession at the downstream end. The widest section of the Tidal Link documented in a June 2009 survey was over 3,000 ft (NESPAK, 2009), which was consistent with measurements from 2009 satellite images . Recent photographs of the Tidal Link illustrate the impact of this severe bank erosion on the ground. The areas of most extensive erosion are near the downstream end of the Tidal Link, but not necessarily at the terminus, with the cross section at RD-80, near the midpoint, recording the greatest erosion (Photographs of Tidal Link Figure-3).

Narrow embankments were constructed from local silts and sands on the left and right bank of the Tidal Link in an effort to prevent not only flows within the canal from spilling onto the tidal flats and adjacent Dhands, but also to keep tides from moving into the Tidal link from anywhere other than its mouth. The top elevation of the northern or right bank, embankment was set at 9 ft amsl while the southern, or left bank, embankment was set 14 ft amsl. The southern embankment on the seaward side was built higher to better protect the Tidal Link from daily sea waves and high spring tides. The southern embankment is a minimum of 7.2 ft above the natural ground level that ranges from 2 to 6.8' ft amsl, but only 6.9 ft above the designed upper water surface of 7.1 ft amsl. The freeboard on the northern embankment was less than 2 ft at the design maximum water stage. In addition to its height, the northern and southern embankments were setback 100 and 350 ft, respectively, from the original banks of the Tidal Link. The southern embankment was built along almost the entire length of the Tidal Link from RD -28 to RD -153, but the northern embankment extends from only RD -25 to RD -125. A stone armoring was built on the flanks of the embankments facing the Tidal Link along at least portions of their length.

The unexpected erosion of the Tidal Link has led to seawater intruding further upstream than was anticipated during the design of the canal. Tidal fluctuations according to the modeling were supposed to move through the Tidal Link from Shah Samando Creek and reach KPOD, but seawater was expected to extend only 12 miles upstream from the Tidal Creek to RD -93, still downstream of the Dhands and Cholri Weir (NESPAK, 2009). There is now open connection between Dhands and the Tidal Link, exposing the Dhands to large tidal fluctuation, sea water intrusion, sedimentation and excessive drainage during low tide. Salinity has much increased in the Dhands. The salinity level of Tidal Link as of 2012 is given in Table-2 influence in KPOD now extends upstream of RD 100 where a 2-2.5 ft difference in water elevation is observed between low and high tide. However, the influence of tides becomes negligible further upstream with no Tidal influence observed at RD 159. Seawater now moves into KPOD twice daily with the tides as far upstream as RD -12, more than 20 miles further upstream than model predictions. As tides move further upstream, the added flow velocities and water level fluctuations result in increased bank erosion (NESPAK, 2009), but erosion in KPOD is now nearly as severe as along the Tidal Link. Side drains that enter KPOD downstream of RD 100 experience daily tidal fluctuations and downstream of RD -12 also experience seawater intrusion. As a result, high tides can slow runoff down the drainage canals during the monsoon season and agricultural lands can be destroyed by salt accumulations where seawater intrudes.

The widening and deepening of the Tidal Link has allowed tides and seawater to influence areas far further upstream than predicted by the modeling results of design stage. In addition, breaches in and erosion of the embankments allow the tides and seawater to enter the Tidal Link at multiple points along its length and over a much broader area than the canal's terminus as was the case when it was first opened in 1995. As the Tidal Link continues to enlarge and the delta front continues to recede due to the absence of freshwater and sediment inputs to the Arabian Sea, tides and seawater should be expected to move further upstream over time. The destruction of the embankments along the Tidal Link also means cyclones, even smaller than that of May 1999 with a storm surge of up to 10 ft, can move further inland than before. A storm surge at high tide that might have been blocked by intact embankments can now move inland for several miles without encountering any obstructions over the very flat terrain. In addition to the direct threat to lives and property, damages to agricultural areas inundated by storm surges can persist for years because of the resulting salinization of the soils and rendered these barren lands.

Construction of the Tidal Link cutoff the exchange of waters between the Dhands to the north and south such that those from the south no longer had significant freshwater inputs. The collapse of Cholri Weir, the widening of the breaches through the embankments, and the growth of tidal channels into the Dhands has led to a twice-daily tidal fluctuation into Pateji Dhand. The resulting changes towards a more marine environment have had a dramatic impact on fish production and the livelihoods of 300 local fishermen. As the tidal channels grow further into the Dhands, both to the north and south of the Tidal Link, the brackish water lakes are increasingly exposed to large tidal fluctuations, sea water intrusion, sedimentation, and excessive drainage during low tide. In addition to the impacts the Tidal Link has had on the Dhands, Dhand degradation had already begun before 1995, because freshwater inputs from the Indus River had been severely curtailed by the completion of the Kotri Barrage. While some freshwater continues to reach the northern Dhands through the drainage canals, sugar factories and other sources often pollute this water, further degrading water quality of drainage inflows. Te water quality of Tidal Link as observed by the consultant during 2012 is given in table 37.

Table 37: Water Quality of Tidal Link -2012

Location	Coordinates	Water Depth feet	Altitude feet	TDS ppm	pH value	Salinity EC (mS/cm)
At Cholri Weir	24 15.5478 N 68 40.4230 E	37.0	3.25	41216	8.3	64.4
Main Creek in Dhand Area	24 16.0502 N 68 37.1513 E	26.0	4.93	44352	8.4	69.3
Main Creek near Zero Point	24 15.3603 N 68 40.7705 E	18.0	10.22	44800	8.3	70.0
Tidal link near RD minus 53	24 15.3640 N 68 40.7542 E	20.5	9.02	41336	8.3	65.0

9.3 Failure of Tidal Link

During the designing/planning stage it was expected that Seawater would penetrate up to 19 km from its outlet upstream into the Tidal Link, to an area about 11 km downstream of the Cholri Weir. Whereas it is evident from the above mentioned NIO observations, that erosion and intrusion of seawater in the Tidal Link commenced just after its completion. Later on storms in 1998 and in 1999 'Cyclone 2A' further worsen the situation. The storm, in July 2003, was the final blow and destroyed the already deteriorating Tidal Link now it is turned to be tidal creek rather an outflow of drain. During the post storm inspection (GOS Technical Review Committee) 56 breaches were recorded9, it was the almost complete disaster of the outlet system of the LBOD.

9.4 Probable Causes of Failure of Tidal Link and Cholri Weir

The consultants presented the following possible causes for the failure:

1. The design capacity of the Tidal Link was 2400 cfs and a maximum carrying capacity of 4440 cfs corresponding to a 125 mm rainfall of 5 days duration, which would result in flood duration of 5 days, leaving a freeboard of 2 feet. As a result of the Cyclone July 2003, Badin districted experienced ever recorded highest rainfall, 218 mm that led to pass about 10000 cfs floodwater through KPOD and the Tidal Link and quantity of outflow was more than the twice the maximum designed capacity of Tidal Link.
2. July 2003 resulted in the largest monthly rainfall recorded at Badin station in 67 years. It was assumed in the design of LBOD canals that the channel system would not be allowed to carry base flow during heavy rainfall, but it was not the case during the 2003 storms. Not only base flow was present in the system but irrigation water refusals were also diverted directly to the drain system and additional inlets were provided by farmers breaching the embankments.
3. Soon after completion some of the banks and weir structures in the Tidal Link failed mainly because of the silty loam material of the soil in the area used in the construction which is highly sensitive to flow velocity which scoured the bed and breached the embankments.
4. Probably during designing stage the effect of the flow velocity on the material of bed and the embankments was not seriously considered. Both measured data and computer

simulations suggest that maximum observed velocities in the Tidal Link were around 1.2 m/s (Tables 3 and 4). This velocity is greater than the permissible velocity of the loam material forming the channel, which should be less than 0.9 m/s for silt loam. Velocities caused by ebb flows were even greater than when the Tidal Link was recently built. Therefore, the channel cross sections and longitudinal profile are continuously changing, due both to erosion produced by the above mentioned high velocities and the relatively high load of sediments brought from upstream sections. Erosion is especially intense at the outlet of the channel to the Shah Samando Creek. It is likely that these high velocity flows were the primary cause of the Cholri Weir failure in 1998.

5. Probably no hydrographic survey such as bathymetric survey at Shah Samando Creek, such as coastling (HW Line), long term tidal observation, (at least for one month), Current observations, was not conducted before designing/planning of the Tidal Link, as it is not mentioned in the reports/studies, which have been reviewed. All the estimation regarding level, particularly sea water intrusion would be made with reference to the HW (spring) level. Though it was expected that high water would reach up to 19 Km4 from the terminus of Tidal Link, that was done without taking observed HW (spring) level into account. Moreover, demarcation of HW line might provide valuable data to indicate exact extent of seawater intrusion and would lead to design an appropriate and a stable Tidal Link.
6. The design of the embankment was based upon insufficient geotechnical data.
7. The level of Outflow of the drain water could not be maintained as per the designed to obstruct seawater intrusion at RD -93, it should be 19 feet from the bed and 7.5 feet from the MSL, as it is evident from its design and various observations such as Tidal, current and salinity observation. As a result high ebb velocity eroded bed and the banks of the Tidal Link.
8. Even if the level of outflow of drain water would have been maintained at 7.5 feet AMSL at RD-93, it would achieve high velocity with descending tides particularly during Spring Tides. According to design and at required water level, massive quantity of water would had to pass at this location even more than the capacity of the tidal link. Discharge at various velocities is described below:

Discharge at various velocities	
1 ft/sec	2840 cfs
1 ft/sec	5680 cfs
3 ft/sec	8520 cfs
4 ft/sec	11360 cfs

Some mechanism should be in place to at the mouth of the Tidal link to control seawater intrusion and control the flow velocity.

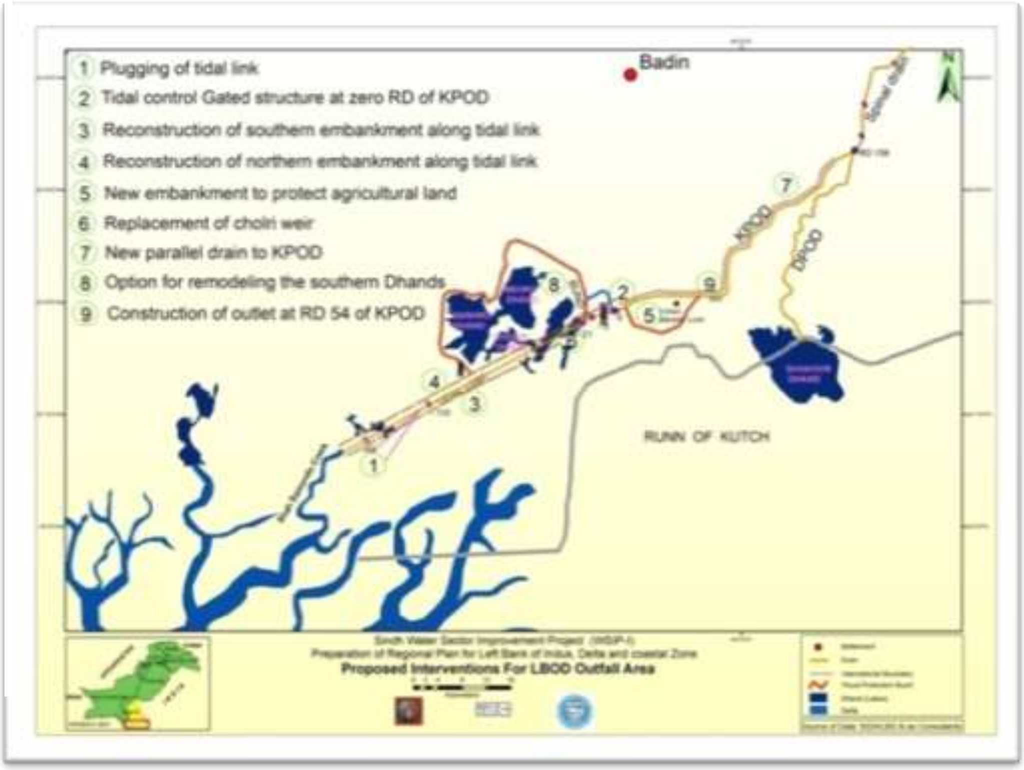
9.5 Previous Suggested Remedial Measures

With the failure of Cholri Weir during 1998 and cyclone of 1999, the active erosion started throughout the tidal link and resulting in degradation of Dhands and obstructing the flows of drainage system at outfall points. To prevent these, eventualities from occurring, a number of possible solutions were proposed by NESPAK (2009) and others. The suggested remedial measures were:

1. Plugging of the Tidal Link.
2. Tidal control gated structure at zero RD of KPOD.
3. Reconstruction of southern embankment along Tidal Link.
4. Reconstruction of northern embankment along Tidal Link.

5. New embankments to protect agricultural land.
6. Replacement of Cholri Weir.
7. New parallel drain to KPOD.
8. Options for remediating the southern Dhands.
9. Construction of outlet at RD 54 of KPOD.

Figure 72: Major Suggested Structural Measure



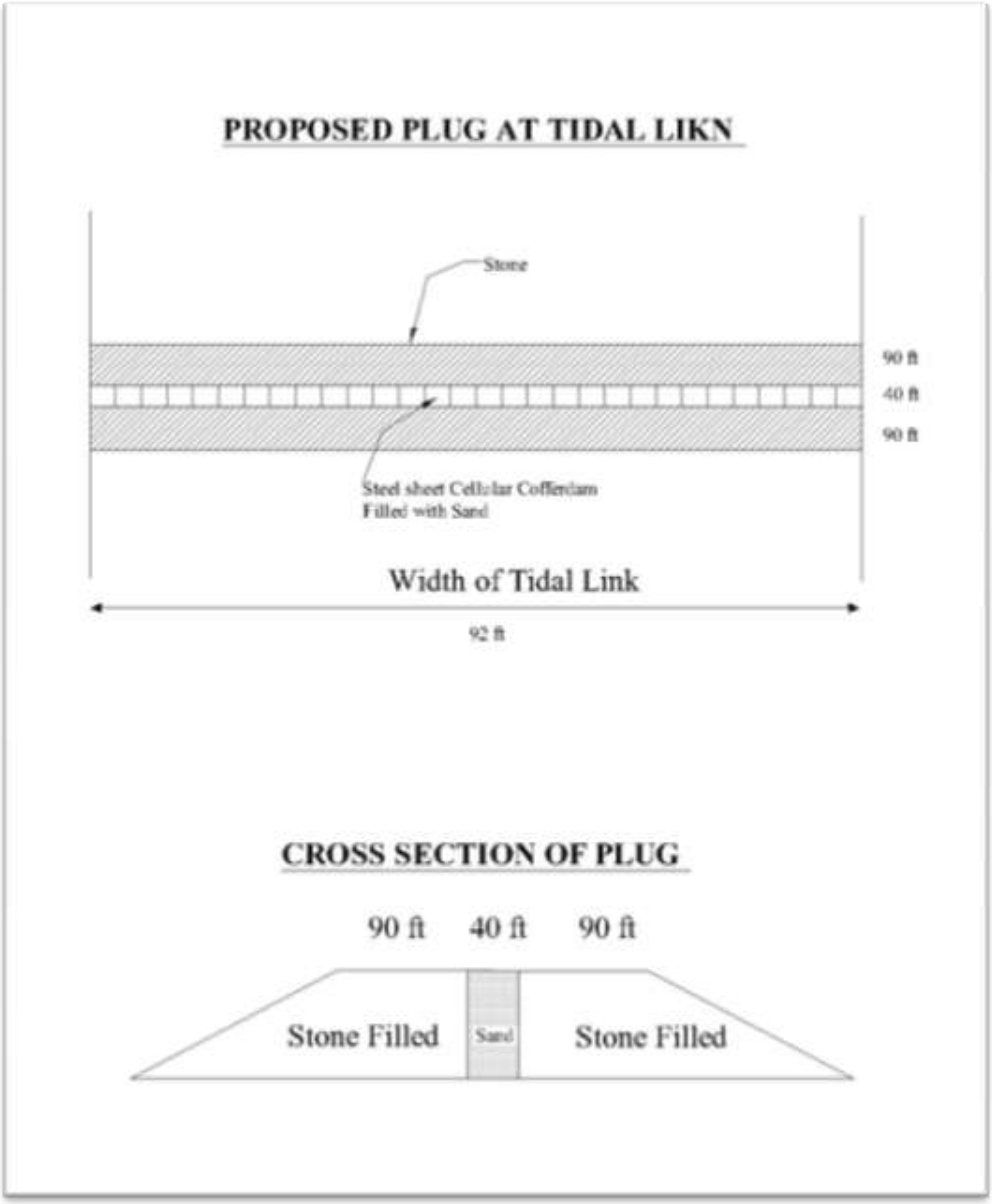
9.6 Plugging of Tidal Link

During Model study of Tidal Link at design stage it was not found suitable to provide a gated structure at the terminus point of tidal due to model predictions that the tides would extend upstream significant distances or create velocities sufficient to cause erosion in the tidal link and upstream. Given the erosion that has occurred now and the continuing upstream migration of tides, a plug near the terminus of the Tidal Link was suggested to be essential to prevent further erosion and saltwater intrusion.

NES PAK study proposed constructing two plugs separated by 1,000 ft near RD -110 with a top elevation of 0 ft amsl. The Tidal Link was 1,200 ft wide at this location in 2009 and widen to 3000 ft in 2012. The second plug is recommended to provide a backup in case one of the structures fails. The intent of the plugs is to check erosion of the Tidal Link by preventing extreme tidal velocities from being generated in the canal. The top elevation is set at 0 ft amsl, so saline effluent at low flow and freshwater runoff at high flow can still be discharged from LBOD in concert with a gated structure proposed for KPOD at RD -13. The tidal plugs are envisioned to be sand-filled steel sheet pile cellular cofferdams 40 ft wide, driven to a depth 60 ft below the top elevation of 0 ft amsl, and flanked by stone aprons on both sides to provide added support and scour protection. The stone aprons will be piled 30 ft high from the bed elevation with a width of 165 ft at the base and 90 ft at the top. In addition to the plugs, an access road will be built on top of an embankment that will run from the tidal plug north for a distance sufficient to prevent seawater intrusion from entering the Dhands during high tides, essentially serving the role of the now largely destroyed northern embankment.

While the proposed plugs in the Tidal Link provide a potential solution to the erosion problems, the final design must be substantially more robust than presented in NESPAK (2009) to adequately protect against liquefaction, ongoing bank erosion and bed scour, cyclones, and relative sea level rise, processes that could lead to the collapse of both plugs in this very remote and difficult to access region. Failure of the plugs could occur by either undermining or lateral outflanking. Gridded sheet pile to a 60 ft depth below the structure's top elevation of 0 ft amsl will be only 45.6 ft below the design bed elevation of-14.4 ft amsl at RD -110. This depth is inadequate for two reasons. First, scour depths of over 60 ft (2012) have been observed in the Tidal Link, a hardened structure as proposed would encourage even greater scour than occurs in unobstructed areas, and the current bed elevation is likely already below the design elevation of 14.4 ft amsl. Although scour depths of 50ft do not appear to have been experienced, to date, at the site of the proposed plugs, the structures must be designed to account for this potentiality. Second, the risk of liquefaction decreases due to soil compaction only at depths greater than 50ft, so the structure founded to a depth of only 47 ft would be at risk of failure due to liquefaction and side erosion that can cause outflanking of the plugs and is not recommended.

Figure 73: Typical Cross Section of Propose Tidal Plug



9.7 Gated Tidal Control Structure in KPOD

The tidal plug will prevent strong erosive tidal currents from moving in and out of the Tidal Link. However, seawater will still move up the Tidal Link to RD-13 .To prevent further upstream migration of seawater, a gated structure with flap gates was proposed by NESPAK 2009 for RD -13 that will be closed at high tide to prevent seawater intrusion but opened at low tide to allow for freshwater or saline effluent runoff. The congruence of high tide with high flows during the monsoons will invariably create backwatering upstream in KPOD and the lower end of some branch drains, but this effect already occurs without a gated structure. While bank erosion in KPOD is also as severe as at the downstream end of the Tidal Link, the gated structure will help reduce erosion further upstream. However, the gated structure itself will increase local scour, so adequate protection will be needed to prevent undermining and outflanking of the structure.

The structure is to be built by driving sheet pile; the sheet pile will need to be driven to a depth greater than 70 ft to reduce the risk of liquefaction. Since scour in the area is not nearly as severe as further downstream, a concrete structure founded several feet below the expected scour depth may be more feasible with a launching apron added around its flanks to provide an extra factor of safety. Bank protection around the structure, perhaps using dolos and deflectors will also be incorporated into the structure's design to prevent outflanking. The proposed tidal control structure will be manually operated on the pattern of Right Bank Outfall drainage system of Kotri Barrage, which is working satisfactory.

9.8 Reconstruction of Southern Embankment

Functioning of the Tidal Link to its full potential and without significant seawater intrusion, the NES PAK study (2009) suggested that the southern embankment needs to be rebuilt to prevent continued growth of the tidal creeks through the breaches. If active tidal creeks are entering and exiting the Tidal Link upstream of the proposed tidal plugs, such plugs will not serve their intended purpose. With a proposed top elevation of 14 ft amsl, the reconstructed southern embankment will have the same height as the former embankment. The embankment also has a proposed top width of 40 ft and will be setback 400 to 500 ft from the current bank of the Tidal Link. The base of the embankment, which is typically under water at high tide, is to be constructed with sand rather than the local materials. Where the embankment has been breached, the tidal creeks that have developed through them will be filled with stones until reaching the surrounding ground level with the stones encased in gabion baskets at the base of deep tidal creeks. The stone plugs will have a width of 200 ft at the ground surface.

The situation of 2012 indicates very severe erosion with no chance of satiability in near future as such this proposal not supported

9.9 Embankments to Protect Agricultural Lands

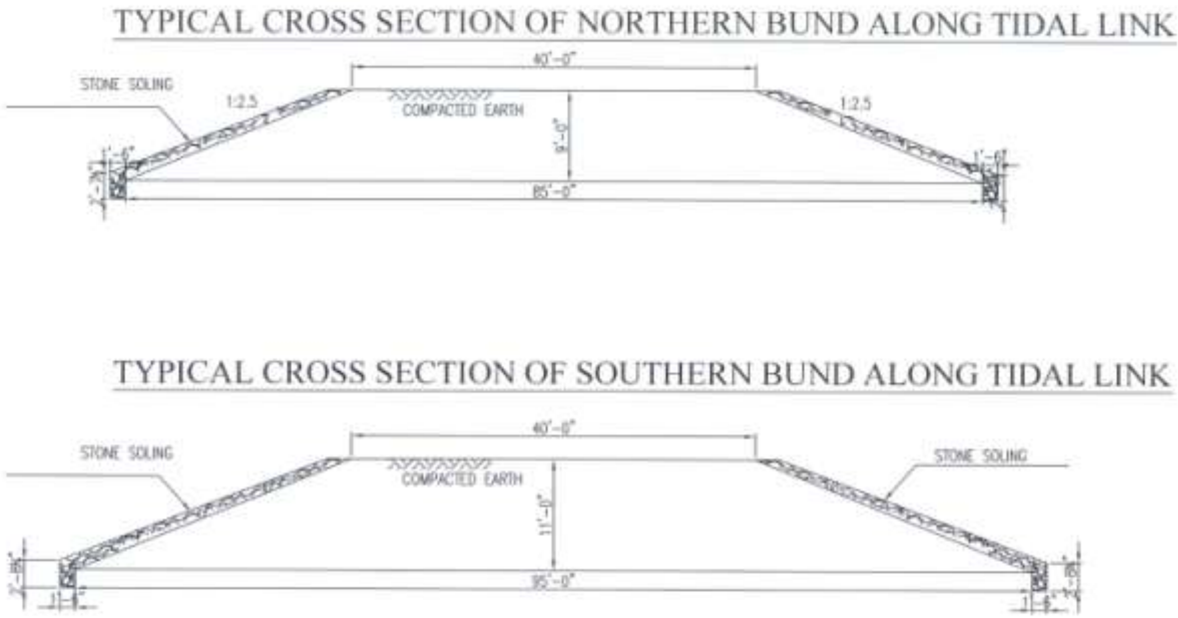
Several embankments are proposed to protect agricultural lands from continued seawater intrusion and in some cases villages on the lower delta (NESPAK, 2009). The embankments will be of particular value during cyclones when storm surges can overspread areas several kilometers inland. Given the great distance of the embankments from the Tidal Link, robust bank protection measures are likely not necessary, but some armoring of the structures is probably warranted to prevent erosion of the structures by waves or overtopping tidal surges. While the top elevation of 15 ft amsl will likely be sufficient to contain most tidal surges, the 1999 cyclone had a storm surge up to 10 ft with high waves superimposed that would have presumably overtopped the proposed berms. Consequently, consideration should be given to raising the 15 ft amsl elevation of the proposed berms in places. For those embankments built far from the LBOD system and are several kilometers inland, the proposed height and materials of the embankments are probably sufficient to contain most high tides and storm surges, but those portions of the embankments closer to the Tidal Link and the sea are more likely to need further reinforcement. The embankment around Khan Bahadur Lund village is recommended for implementation.

9.10 Reconstruction of the Northern Embankment

It has also been suggested by NES PAK (2009) to construct northern embankment. Without reconstructing the northern embankment, tidal channels that have formed through breaches in the existing embankment will continue to interact with the Dhands on a twice-daily basis and sustain the more saline environment that has developed since the opening of the Tidal Link in 1995. If the brackish water ecosystems are to be restored, then the northern embankment must be reconstructed in some form. The access road leading to the proposed tidal plugs will be built on top of an embankment that will block tidal flows from entering the northern Dhands directly from the sea, but tides above 0 ft amsl will continue to move up the tidal Link and into the northern Dhands. Therefore, the primary purpose of the reconstructed northern embankment would be to prevent all but the highest tides from entering the brackish water ecosystems.

The existing situation (2012) indicates that now Dhands have become part of open sea with the average values of depth of water exceeding 30 feet. As such the construction of northern bund is not supported.

Figure 74: Typical Cross Section of Propose Embankments



9.11 Replacement of Cholri Weir

Currently, the tidal creeks developed through breaches in the northern embankment allow tides to move in and out of the Dhands on a twice-daily basis. The Cholri Weir, at an elevation of 4.5 ft amsl was designed to prevent complete drainage of the Dhands at low tide, while still allowing freshwater to flow in from the Tidal Link during high flow periods. The proposed replacement as suggested by some Consultants is that a weir will be set at a similar elevation but at a new location setback 1,000 ft from the Tidal Link and connected to it through a short channel. Additional precautions should be taken to avoid the collapse of the new weir such as setting the sheet pile to a much greater depth to avoid liquefaction and undermining. But due to current situation of tidal link as a part of open sea the replacement of Cholri Weir is not recommended and is not considered for execution.

9.12 New Drain Parallel To KPOD

A new 7.6 mile long drain parallel to KPOD as proposed in Alternative 2B of NES PAK Report is recommended that will capture runoff from three branch drains and discharge the flow directly into Pateji Dhand and shall also solve problem of submergence at outfall conditions. Assuming the water quality in these drains is better than those that currently drain directly into the Dhands, the proposed new canal should help increase freshwater inputs into the Dhands. The new drain should be built far enough upstream on the branch drains such that backwatering from KPOD during high tides or high water levels will not disrupt the passage of freshwater runoff to Pateji Dhand. This proposal was not supported by the stakeholders and is not recommended.

9.13 Options for Remediating Southern Dhands

The components of the LBOD redesign described above have the potential, if implemented together, to remedy seawater intrusion and bank erosion in the Tidal Link and KPOD while restoring brackish water conditions in the northern Dhands. However, degradation of the southern Dhands, cutoff from the northern Dhands and freshwater inputs from LBOD or the Indus River, remains unaddressed by any of the proposed redesign alternatives presented by NESPAK (2009). Two options as suggested by NES Pak for addressing this issue are described below that will need further investigation to determine their feasibility: 1) construction of a bridge or tunnel connecting the northern and southern Dhands and 2) construction of a drain south of the Tidal Link connecting KPOD to the southern Dhands. A bridge over the Tidal Link has the potential to reconnect the northern and southern Dhand systems and would need to be much wider, but in many respects similar, to canals that flow on bridges crossing over KPOD. A possible remedy for this could be to construct a Bridge on Tidal Link to allow a connection between the Dhands on both sides. This bridge later on can also be used for plugging of tidal link as conditions permit and is recommended for construction. But due to unstable morphological conditions heavy risk is involved for construction of the embankments. So as to start with the plantation of Mangroves on large scale is recommended.

9.14 Construction of Outlet at Rd 54 KPOD with Connection to Kandri Dhoro

It is proposed to construct an outlet at RD 54 of KPOD and a link drain to offload discharge from the KPOD. The link would offload into Kandri Dhoro and can provide further link to the sea creeks. It would also provide storm water of good quality every year for fishing and other uses the Kandri Dhoro has a well defined channel exceeding 20 feet in depth and has a regular connection to the creeks The Dhoro has no regular source of recharge but receives storm water from its catchment during rainy season. During extra ordinary periods of rain fall the storm water can be easily diverted to Kandri Dhoro. The construction of outlet is recommended at RD 54 of KPOD, being demanded by the locals.

9.15 Cost Estimates of Suggested Structural Measures by NESPAK Study (2009)

The cost estimates of the above structural measures are given below: -

S. NO.	Type of Interventions	Rough Cost Estimated (Rs Million)
1	Plugging of Existing Tidal Link at Two Sites (RD -110 & -112)	4,785.235
2	Bridge at Tidal Link (3000 ft Length at RD -80 of Tidal Link)	900.000
3	Construction of Tidal Regulator at (RD 00 of KPOD)	2,800.000
4	Construction of Southern Bund along Tidal Link including Protection works	5,841.666
5	Construction of Northern Bund along Tidal Link including Protection works	2,877.000
6	Protection Embankments for Dhands & Villages	1,166.000
7	Construction of New Drain Parellel to KPOD	400.000
8	Construction of Outlet at RD 54 of KPOD	250.000
	TOTAL (Rs. Millions)	**19,019.900**

9.16 Recommended Action Plan for Outfall of LBOD

Outfall conditions of LBOD are affected by cyclones and tidal waves and their compounding affects. The area has suffered from sea based storms in varying degrees. The devastating cyclone types of 1999 and the periodic storm surges are the most destructive natural forces of the area and causing large scale erosion of coast line and the KPOD outfall drainage system. A field team of Consultant visited the Tidal Link and the trip report is attached as Annexure -1, which very clearly mentions that no Tidal Link is a past history and this costly mistake shall not be repeated.

The possible remedy is to distribute outfall system into several portions so that it can be discharged through more one location. It is planned to discharge 3000-4000 cfs of storm flow into old Dhoro Puran Dhora system through 03 weirs to be located at RD 576, RD 318 and RD 214 of spinal drain. DPOD is to be designed for a discharge of 6000 cfs. The gates are to be provided at RD 127 of DPOD and at RD 159 of KPOD. A tidal control structures to be constructed at RD 0.00 of KPOD with full sea protection works. In order to protect the ecosystem of Dhoras a tide control barrier is be constructed downstream of Dhoras to cutoff the movement of saline system into lakes of Dhora and the proposed Bridge across tidal link can be converted into a tidal control barrier at later stage and its construction would also help in checking the fast erosion of banks of tidal link and subsequently can serve the purpose of a permanent barrier for cyclones and sea surges The major works proposed to improve the outfall conditions and to check sea erosion are as below: -

- Offloading the Spinal Drain with discharge of 3000 cfs
- Providing a Gated Tidal Structure at RD 22 of KPOD at RD Zero
- Redesign DPOD for a discharge of 6000 cfs
- Redesign KPOD for a discharge of 7000 cfs
- Construction of Outlet at RD 52 KPOD

9.17 Short Oceanographic Desk Study of Tidal Link Drain, LBOD by NIO, Karachi.

The study was interested by the Consultant to National Institute of Oceanography (NIO) at Karachi. Their main recommendation is *"A number of non-structural natural measures that might attenuate the influence of the Tidal Link on the dhands and in particular slow or stop its progression beyond Cho lri Dhand. A belt of mangroves generally along in the alignment where Cholri Dhand joins Sanhro Dhand has been suggested as a way of trapping sediment and attenuating any tidal pulses or effects that might enter Sanhro Dhand. However, past attempts to establish extensive mangrove belts or forests in this area of the coastal zone have not been successful probably because of the soils (they are reported to be flourishing in the area of Shah Samando Creek though over harvested by local people). A third possibility is to try to establish appropriate specie of reeds and other grasses that are well adapted to the prevailing salinities in the shallow silted area between Cholri and Sanhro Dhands. Such a reed and grass belt would behave much like a constructed wetland filtering sediments, pollutants and nutrients moving from Cholri Dhand to Sanhro Dhand".*

The detailed study done by NIO is attached as Annexure III of the Feasibility Study of LBOD

CHAPTER 10: ESTIMATION OF PROJECT COSTS

10 Estimation of Project Costs

10.1 Cost of Civil Works

The cost estimates of most civil works are based on quantities computed from the feasibility level drawings of various components. The drawings of small structures have been prepared on the basis of approved typical drawings of LBOD Project Phase-I obtained from WAPDA, Hyderabad. However in spite of best efforts the in built drawings of Spinal Drain from RD 159 to RD 815 were not made available either by WAPDA or SIDA. Under Phase-IV of study another attempt would be made to search for above drawings. Some of the Feasibility level drawings were prepared from similar drawings of RBOD Project I, II and III and cost estimates prepared accordingly. The rates of completed projects in SIDA have also been used for guideline. The detailed cost estimation is attached as Annexure IV of Volume II of Draft Feasibility Report.

For all scheduled items the item unit rates have been taken from Sindh Government Composite Schedule of Rates (CSR) 2012. Non Schedule items have been estimated as market price of 2012. The cost estimates have been prepared in Pak Rupee and thereafter, converted into US$s for seeking funding from International Donors.

10.2 Land Acquisition Costs

No new land is required for the project land there is a sufficient land available along existing network of drains for purpose of widening within established ROW but for borrow pit areas the contractors have to arrange earth from private lands and the cost of compensation is built up in the unit rate.

10.3 Environment and Compensation Costs

No costs are involved as no significant negative impacts are anticipated.

10.4 Buildings, Vehicles and Equipment

No provision has been made for construction of any new permanent office, residential and other buildings. But the existing buildings need improvement and so provision has been made accordingly. The criteria laid down by SIDA for other project have been followed. Similarly provision for procurement of vehicles has been kept to cater for the transport requirement of the field staff deputed for the execution of the project. Provision has also been made for procurement of equipments and furniture for the offices as per approved criteria and local prices.

10.5 Miscellaneous

Provision for insurance, performance bonds etc. has been made @ 0.5% of total cost of works which is comparable with other projects.

10.6 Physical Contingences

Physical contingencies are included in the project to cover unforeseen items during execution of work, subject to site conditions. A provision of 3.0% of base cost has been made as physical contingence. The percentage is compatible with other projects of similar nature such as Nara remodeling works and RBOD.

10.7 Engineering and Administration

The project also provides for the cost of Consultants to assume certain responsibilities in respect to project execution and to provide professional services for all aspects of investigations, detailed engineering design, contract administration, construction supervision and commissioning of completed sections of work. A provision of 5.0% of the base cost has been made for Engineering and Admin.

10.8 Price Escalation

Composite schedule of rates 2012 of Sindh Government In order to bring the price to market level GDP deflator of 35% has been applied.

10.9 O&M Cost during Construction Period

A provision of 1.0% of the cost of civil works has been made in the project estimate for O&M of the completed works.

10.10 Total Project Cost

The Total Project Cost of the Project including provision discussed above is estimated as PKR 195,156 million.

10.11 Estimation of capital coast of the Project

CAPITAL COST ESTIMATES

A. Baseline Costs		**(Rs. Millions)**
1.	Drainage Infrastructure	12,583.93
2.	Drainage Management	800
3.	Project management Unit	900
	Total Baseline Costs	14,283.93
B. Contingencies		
	Physical Contingencies	1027.50
	Price Contingencies	4795.00
C. Total Costs to be Financed		19522.50
D. Financing Charges during Implementation		1952.25
	Total Project Coast	**21474.75**
	Say Rs. **US$ (Million)**	**21475** **224**

The projected annual expenditure on the basis of implementation plan is as under: -

Year	**I**	**II**	**III**	**IV**	**V**	**VI**	**Total**
	5%	**15%**	**30%**	**30%**	**15%**	**5%**	
Total Project Cost (Rs. Millions)	976.20	2928.4	5856.6	5856.7	2928.4	976.20	19522.50

10.12 Scope of Works of LBOD Project

COST ESTIMATES OF CIVIL WORKS

Sr. No.	**Components of LBOD Project**	**Estimated Cost (Million Rs.)**
1	Spinal Drain	3,997
2	KPOD / DPOD Link	1,728.93
3	Nawabshah Component	914.816
4	Sanghar Component	1,683.9
5	Mirpur Khas Component	1,197.026
6	Badin Component	1,716.6

7	Kotri Surface Drainage System	621.403
	Total	**11,859.675**

The detail of estimation of project costs is given in Annexure IV.

CHAPTER 11. ECONOMIC AND FINANCIAL ANALYSIS

11 To be provided by Syed A. Hussani Sahib

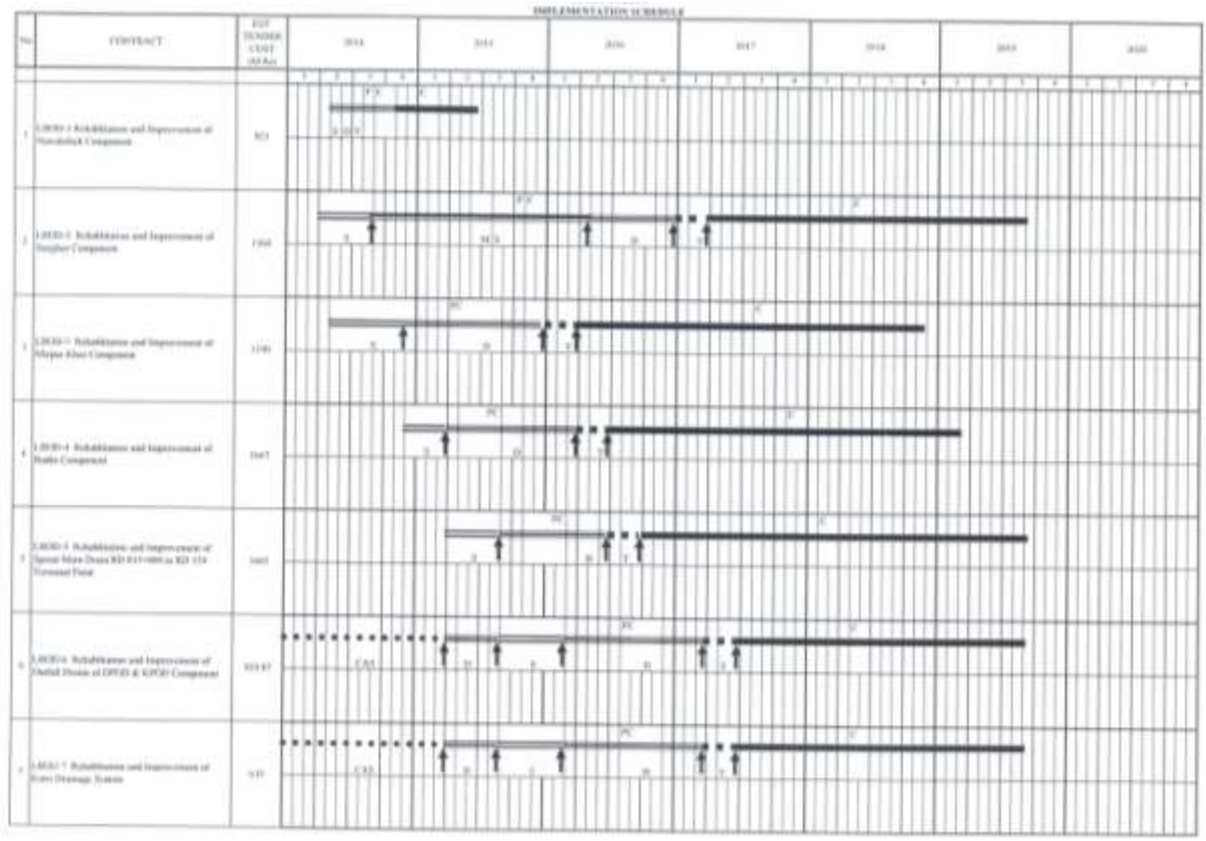
CHAPTER 12: IMPLEMENTATION PLAN

12 Implementation Plan

12.1 Implementation Period and Arrangement

It is planned to implement the suggested long term measures starting from July 2014 and it will be completed by June 2020 the entire project for the purpose of biding has been divided in 07 packages for implementation and is to be executed through international and national bidding in a competitive manner insuring full transparency the construction work are to be supervised for quantity and quality through renowned International and National Consultants of repute. The size of package varies from Rs. 500 million to 2000 million. The schedule of activities is given in below: -

Figure 75: LBOD Project – Implementation Schedule



PC- Pre-Construction Activities including survey, design, tendering and award.
D- Design, C-Construction, S-Strip Survey, T-Tendering, MS-Model Studies, CAS-Command Area Survey

12.2 Management Structure and Manpower Requirements

12.2.1 Administrative Arrangement

Executing/Implementing Agencies

Government of Sindh, Irrigation and Power Department (SIPD) and Sindh Irrigation and Drainage Authority (SIDA) are the executing agencies.

Steering Committee

Project Steering Committee (PSC) headed by Additional Chief Secretary P&D Department, GOS will be established for the implementation of the project. The committee will include representatives from Irrigation Department, Agriculture Department, Finance Department and other agencies as deemed necessary by the Chairman P&D Board.

Project Management Unit

A Project Management Unit (PMU) will be established to oversee implementation of all the activities of the LBOD Project. The PMU will be established within SIPD headquarter at Hyderabad. The PMU will be headed by Project Management Unit (PMU) of the rank of Chief Engineer (BPS20). The PD will be supported by the following team members:

i. Deputy Director
ii. Project Finance Manager
iii. Technical Specialists

The Deputy Director (BPS-19) will assist and coordinate for; (i) Reviewing all the engineering design and construction activities under the Project - related to improvements of the distributaries and minors and other civil works, (ii) To monitor Groundwater Management, (iii) Environmental studies and safeguards, (iv) Institutional strengthening and capacity building, (v) Procurement for civil works and Consultant Services. The Project Finance Manager will: (i) Coordinate the overall financial management and procurement aspects of the Project; (ii) Consolidate financial reporting from all activities financed under the project and prepared annual summary financial statements for presentation at the annual review meetings of the LBOD Project. The Head PMU, Deputy Director, Project Finance Manager and Technical Specialists will be selected and appointed in accordance with the transparent and competitive procedures. Each will serve on a full time basis and assisted by adequate professional and support staff. The other major responsibilities of PMU will include:

(i) Recruitment of Consultants; (ii) Coordination and supervision of the work of the design and construction supervision consultants for R&U works of the distributaries minors and process progress and other payments on contracts for these works upon receiving certification from the engineer; (iii) Coordinate and monitor the civil works; (iv) Ensure that project works are implemented in accordance with the provisions of both the approved environmental impact assessment and resettlement issues; (vi) Maintain full and constructive liaison with Sindh Irrigation and Power Department ensuring that progress related to institutional reform keeps pace with the civil works; (vii) Coordinate and supervise the groundwater management, (viii) Undertake financial accounting and management ensuring that funds are allocated and made available to all operating units to ensure expeditious project implementation. (ix) Coordination of capacity building and training activity.

The implementation arrangements for various project components would be as follows:

Project Management Support: Besides the administrative, technical and financial management support provided to PMU, AWB and FOs the Project provides for support by Consultants. Consulting services required to support the Sindh Irrigation and Power Department/SIDA in implementing the Project including design and construction supervision of civil works. Recruitment of the consultants will be in accordance with the Guide Lines Evaluation Procedure for Procurement of Consultant from Donors.

12.3 Manpower Requirement

Most of the manpower during design and construction phase will be provided by the consultants and contractors. The staff of SIDA will maintain the Project after completion. Additional staff will be recruited by the SIDA for the PMU from the market where as existing staff of IPD will also be eligible to compete.

12.4 Machinery Requirement

The following types of machinery would be needed for execution of the project: -

Concrete batching plants	Transit mixers
Concrete pumps	Vibrators
Pile diving machines	Dumpers
Loaders	Graders
Dozers	Road rollers
Excavators	Pneumatic hammers

Cranes	Low bed Trailers
Water bowzers	Low bed Trailers
Generators	Cranes

12.5 Water Pricing/Abiana

The Government of Sindh will cause SIPD to establish adequate procedures for assessing and auditing the collection of abiana and assume responsibility for the collection of the water charge/price. The Government of Sindh will ensure that: (i) transfer from assessment of crops to a flat rate; (ii) develop a commercial flat rate for economic production whilst maintaining a lower, affordable rate for poorer farmers; (iii) move towards volumetric pricing, initially as an option with a commercial flat rate set at a level for full cost recovery; and (iv) assess and, if appropriate, implementation of remote sensing and cadastral mapping as the basis for a transparent and objective determination of due water charges.

12.6 Communication Participation and Monitoring

The primary function of Phase I of LBOD is the control of storm water which causes havoc frequently. The control of drain flows during storms will be the most important function of the operating authority. Canal escape flows will have to be controlled to minimise breaches while keeping drain flows within the peak capacity. The success of such a storm control system will be dependent very largely on a rapid and efficient communication system. The drain monitoring office will have to be in close contact with its field staff, the local drainage operating staff, the Irrigation Department and as many meteorological stations as possible. Thus in addition to normal communications, a telephonic link would be provided along the entire length of the outfall drain, main drain and branch drains to connect local drainage offices to the Central Monitoring Office of SIDA.

Flow measurement at various points along the main channel and branch drains will be necessary. Gauging stations should be established at important points and gauge observers posted.

However it is pointed out that the correct model of participatory irrigation management has miserable failed and the Government of Sindh may give second thought to functioning of SIDA.

12.7 Maintenance Works

The maintenance works required on the drains will be of three kinds: earthworks, weed control and structures. All these works will be carried out by the operating authority. A regular programme of maintenance must be established and improved during the early years of operation.

Structures, if properly constructed, will require minimal maintenance. The likely maintenance problems are downstream erosion of banks and bed, and deterioration of concrete in contact with sulphate bearing water. While both of these problems are least likely to arise if the work has been executed properly, but in practice they do occur. Consequently regular inspections should be carried out so that remedial measures can be taken at an early stage. An allowance of 1 percent of basic capital cost of structures has been made for the annual cost of maintenance. The earthwork would include desalting of drains and general maintenance of embankment s inspection paths and spoil banks. The minor works can be done by manual labour and an allowance of one labourer for every three m i Le s of drain has been made in the estimates. De-silting works will have to be done by machines in the case of outfall, main and branch drains, whereas sub drains could be cleaned by hand labour. An allowance has been made of three inches of the drain bed to be removed annually. In the early years the drains beds will regrade themselves to regime conditions. Some slumping of the banks may occur in places, but in time the amount of material to be removed will be reduced considerably.

The third maintenance item is weed control. The desalting of the bed of the drain will retard but not stop entirely the growth of weeds. Growth on the upper side slopes of the drain can be removed by hand and this manned clearance cost is provided in the maintenance costs. Kadhan Pateji Outfall Drain in Kotri Barrage has not so far shown serious weed growth problems. This suggests that weed growth may not be a serious in the drains. This problem is discussed in greater detail in Annexure V.

12.8 Monitoring and Evaluation of LBOD Project

It is essential that the monitoring of the performance of drainage system is carried out on continuous basis with the help of staff gages installed at control points and the arrating tables established by the consultants of the study to be updated after every flood season the permant gages will be installed at outfall point of Shakoor Dhand and Shah Samando Creek the water table depth through of the left bank area w monitored for the period of pre monsoon and post monsoon with help of the SMO WAPDA as they have installed an extensive network of piezometers and tube wells a number of sugar mills are operating in the command area of drainage network and is to be monitored for the pollutions these are causing and ensure no untreated effluent we discharge into the drainage network. In addition to this environmental monitoring will be done during construction and after completion of the project on regular bases through and environmental monitoring cell to be established in the SIDA office the maintenance of the infra structure be monitored for its discharge capacity and safety of structure. A part from changes in the ground water level it is also purpose to monitor the water quality parameters and to develop a data base for monitoring the quality of the ground water and reused of drainage water.

The Consultants have proposed discharge measuring sites on LBOD network and have calibrated the gauge sites for flow discharges. The data of discharges measured and the calibration curves are attached in Annexure IV. The Field Engineers are to measures the discharges of LBOD network for better regulation of the storm flows. The water quality samples shall also be collected simultaneously.

12.9 Due Diligence

All the storm water drainage systems of the Left Bank are unregulated, and so not subject to management during the passage of floods. Management roles during such events should be:

- ✓ Ensuring canal supplies to the region are stopped as early as possible
- ✓ Making sure the sub-surface drainage effluent pumping ceases – to allow the full drain capacity to be used for storm water drainage
- ✓ Checking on water levels in the drainage system, especially in the main and spinal drains, to allow banks to be strengthened and raised if water levels are threatening to inundate valuable land areas, such as towns
- ✓ Patrolling the drains to try and regulate the cutting of embankments by farmers, and to minimize the levels of damage done, and
- ✓ Inspecting drains after the passage of the flood, to ensure all urgent remedial work is completed before the resumption of sub-surface drainage pumping.

The degree to which such tasks are carried out will obviously depend upon the resources to be made available to the operating agency, but the budgets to be allocated for operating the drainage system must take the requirements of storm water drainage management into account. It is especially important the better information is made available to the Irrigation Department to allow the reduction of canal supplies in times of forecast rain (once the reliability of these forecasts is established), and that information systems within the Irrigation Department are improved.

Flooding induced by extreme storm events is a major concerned in lower Sindh with inundation of low line area and because of very flute slope their frequent poundage in the felids it is essential that the detention ponds/recharge, percolation tanks and storm water retention basins are must for the on farm drainage and without provision of the same the collector system of LBOD cannot evacuate the storm water of 2011 level.

12.10 Social Safeguards

Environmental social impact have been studied by the consultants in detail by conducting interviews with the farming community and other people living in the vicinity of the project specially in command areas of Nara and Rohri Canal the irrigation and drainage system existing in the area is under sustainable condition and with the anticipated improvement at outfall conditions and increased capacity of drainage network will have major positive impacts no major adverse environmental impact are anticipated in respect of habitat, wild life are cultural hesitate. The proper effluent disposal would increase crop area and damages to crop and also will provide sufficient employment opportunities to locals.

No social and environmental adverse impact are visualized but project viability depends upon government enforcing existing loss and regulations to control canal water coming to drainage system and also no fishing actives to be allow in sub drain branch drain main drain spinal drain and outfall drains of KPOD and DPOD under any circumstances the water rate recovered should also include O&M drainage cost and full recovery to be insured and made available to SIDA for adequate maintenance the sugar factories owners to ensure pre treatment of the effluent and also contribute major share to improvement of LBOD drainage network. In case the above recoveries are not enforced the project would be nonviable.

CHAPTER 13: MAJOR RECOMMENDATIONS AND FINDINGS OF THE STUDY

13 Major Recommendations and Findings of the Study

Following are the major recommendations and findings of the feasibility study for improvement of infrastructure of LBOD drainage network.

1. Major focus of Feasibility study of LBOD is as under: -
   - Enhancing performance efficiency of the existing drainage Network through different structural and non-structural measures agreed by the stakeholders.
   - Identifying and evaluating technical options to optimize flood management capacity of the existing physical network.
   - Operational guidelines for conjunctive operations of the Drainage and Irrigation network during storm water flows.
   - Enhancing overall evacuation capacity of the system during floods of different intensities by providing off-loading options to LBOD and its branches.

   No major remodeling is recommended for LBOD but rehabilitation for strengthening of banks and their raising to safely pass storm water flows of 2011 level is supported.

2. The performance of LBOD drainage network has not been satisfactory during the storm water flows of 1994, 2003, 2006 and 2011. This is partly due to inadequate maintenance and operation of the drainage network. There has been a substantial contribution of irrigation flows from escapes to drainage network ranging from 1500 to 2000 cfs on the average.
3. Climate change vulnerability index indicates that Pakistan lies in the threatened zone and therefore the changed pattern of rainfalls and frequent disasters. The experience of 2003, 2006 and 2010 storm water flow emphasis on the significance of natural drainage systems and the urgent requirement of integrating manmade and natural drainage systems. The extreme events of rainfall during monsoon are reporting in Lower Sindh after and an interval of 3 to 4 years combined with drought cycle of 2 to 3 years.
4. There is need to immediately rehabilitate the infrastructure of LBOD drainage network for enhanced storm water flow corresponding to the 20 years return period and with an evacuation period of 10 to 15 days for an extreme rainfall event like 2011.There should be adequate capacity of drainage network to carry storm water flows.
5. The revised drainage coefficients for all the four components of the LBOD drainage network are as below: -
   - ✓ Nawabshah Component - 3.0 cfs/sq.mile
   - ✓ Sanghar Component - 2.9 cfs/sq.mile
   - ✓ Mirpur Khas Component - 6.1 cfs/sq.mile
   - ✓ Badin Component - 7.0 cfs/sq.mile

   The existing capacity of Kotri Drainage Network of Karo Ghungro Outfall Drain and Fuleli Guni Outfall Drain is sufficient to cater for extreme rainfall events similar to 2011.

6. The simulation results by using Hydraulic Model of HEC-RAS indicates for 20 years critical rainfall events generate 9000 cfs of storm water flows at RD 159, the terminal point of Spinal Drain. Therefore the system has to be accommodate the above rate of flow by providing minimum 2 feet free board above simulated and observed water levels of 2011. During the rehabilitation process the drainage coefficient have been adjusted on the basis technical judgment, professional experience and the economic consideration. So the drainage coefficients required under Para5 above have been modified in relation to measured flows of 2011 by a team of Consultants.
7. It have been experienced that during the extra ordinary monsoon rainfall events of 2003, 2006 and 2011 that the number of braches/over flows occurred due to obstruction caused by water course aqueducts particularly in the reach RD 159 to RD 203 of Spinal Drain and these have been now changed to pipe type crossings and estimated accordingly.
   a. The following works were agreed by the stakeholders:

- ✓ Discharge most of the Spinal drain effluent into Shakoor Dhand.
- ✓ Increase the discharge carrying capacity of DPOD.
- ✓ Remove the obstacles from Achh, Sainhri and Addah Dhands so that water from Shakoor Dhand can easily flow towards these Dhands.
- ✓ Provide flood protection embankment for villages and cropped areas in the north direction of Achh, Sainhri and Addah Dhands.
- ✓ Provide flood protection embankment for village located at RD 28 of KPOD.
- ✓ Provide flood protection embankment between KPOD and tail of Mirwah Minor and then extend up to the outfall of Fuleli Guni Drain.
- ✓ Provide a terminal structure near RD+5 of KPOD.
- ✓ Check sea water intrusion and tidal effects into Dhands and irrigated areas of Badin by providing a terminal structure on Tidal Link.

b. The stakeholders did not approve the following interventions:

- ✓ Remodeling of Spinal drain shall not be carried out, rather it shall only be rehabilitated and banks shall be raised and strengthened.
- ✓ There shall be no gated structure at RD 159 of KPOD.
- ✓ Remodeling of KPOD shall not be carried out rather it shall only be rehabilitated.
- ✓ New parallel drains shall not be constructed.
- ✓ Outlet at RD 211 of Spinal Drain shall not be provided.
- ✓ No drain shall be excavated in Achh, Sainhri and Adah Dhands.

8. The followings are the suggested structural measures to be implemented for rehabilitation of the LBOD Network.

- ✓ Metal Road proposed on IP of Spinal Drain from RD 159+000 to RD 815+822.
- ✓ All watercourse crossing aqueducts are to be replaced with pipe crossing in reached RD 159 to RD 297 of Spinal Drain.
- ✓ All submerged bridges are to be raised minimum 2 ft from the existing deck level in above reach of spinal drain.
- ✓ All Bridges Crossings of District metal roads with LBOD Drainage network to be reconstructed with full water way and zero fluming and minimum 2 ft free board is to be provided.
- ✓ Inlets to be provided on all sub-drains at interval of 2 RDs on either side.
- ✓ All damaged structures of LBOD Branch Drain (Badin) to be newly constructed.
- ✓ All outfall structure of main drain out falling in to spinal drain to be newly constructed with full water width and with 10 ft raised both banks to allow for surcharge storage.
- ✓ On Spinal Drain all structures shall be provided with stone pitching of 200 ft upstream and 300 ft downstream and adequate water way upstream of structure will be ensured.
- ✓ A discharge of 3000 cfs will be offloaded at RD 211, RD 335 and RD 578 of Spinal Drain.
- ✓ All natural depressions/vacant lands/barren lands would be connected to drainage network through appropriate structures and artificial lakes/storages would be created for temporary detention of storm water and to cause delay in its to contribution to main drainage system.
- ✓ A Gated Tidal Control Structure to be manually operated would be constructed at RD 22 of KPOD and connected with the Tidal Link through properly stone pitch outfall drain with bank width of 50 ft on either site.
- ✓ Provide mobile pumping stations in four units of LBOD drainage network.
- ✓ Construct discharge measuring sites on LBOD drainage network.
- ✓ Provide a fixed pumping station at RD 792 of Spinal Drain to provide immediate relief to Nawabshah Component against heavy rainfall and to save famous cotton belt of Lower Sindh

The capital cost work out for the above suggested structural measures is about 20500 million.

9. It is very essential that the following non-structural measures be implemented in later and sprit otherwise all the above suggested structural measures if executed would go waste.
- ✓ No Fishing should be allowed under any circumstances in the entire network of LBOD Network. The existing fishing nets permanently installed in the system have destroyed the prism and the storm carrying capacity of the drains.
- ✓ Ensuring that the canal supplies to the region are stopped as early as possible once warning for extra ordinary event of rainfall is issued
- ✓ Making sure the sub-surface drainage effluent pumping ceases – to allow the full drain capacity to be used for storm water drainage
- ✓ Checking on water levels in the drainage system, especially in the main and spinal drains, to allow banks to be strengthened and raised if water levels are threatening to inundate valuable land areas, such as towns
- ✓ Patrolling the drains to try and regulate the cutting of embankments by farmers, and to minimize the levels of damage done, and
- ✓ Inspecting drains after the passage of the flood, to ensure all urgent remedial work is completed before the resumption of sub-surface drainage pumping.
- ✓ The saline tubewells of fore drainage components are to be operated to 100% efficiency before start of monsoon so as to create enough space for percolation of storm water.
- ✓ Use Movable Steel Planks for diverting storm water to adjoining stretch of vacant /barren lands available all along drainage network. With careful planning of above intervention drainage system can be saved from breaches/over flowing and damage to hydraulic structures is saved.

10. The water logging and salinity in the Left Bank Area can only be checked through adequate functioning of the surface and sub surface drainage and also very important is provision of on farm drainage in the project area. The major component of sub surface drainage is through vertical drainage by installation of tube wells. About 90 percent tube wells in the project area are non-functional, there rehabilitation is must to control the water table in also this would increase the ability of soil to return more storm water.

11. No Agency/Local Government/Highway Department or other National Building Departments of Sindh Government/Federal Government be issued NOC to construct cross drainage works of their own but always the proposed crossings be treated as a deposit work to be executed by Executive Engineer in charge of respective drainage division of LBOD Network.

12. No remedial work on Cholri Weir / Tidal Link is recommended. The main fact findings of World Bank Mission-2001 are supported which states as, *"the repair and replacement of the Cholri Weir is meaningless because Tidal and drainage water will continue to enter and leave the Dhands freely through the gaps in the breached sections and is very difficult to constructed maintain any infrastructure there"* . It is established the consultants that the flower of the Cholri Weir and debacle of Tidal Link is the design flower. As such the International and National Firms responsible for the designing work of tidal link are taken to task.

It is suggested that mangroves plantation be raised around Dhands and Tidal Link for control of Tidal effects and sea water intrusion under Phase-I (fully described under other feasibility of wet lands completed by the Consultants). The structural measures can be taken up once the morphology of Tidal Link has stabilized.

13. The sustainable agriculture need a reliable drainage system and with adequate maintenance and monsoon preparedness. The damages of 2003, 2006 and 2011 to LBOD fairly indicates that the O&M of the LBOD drainage Network system due to paucity of O&M funds was not regular, systematic and not proper and it is recommended that the entire O&M cost of LBOD including pay of establishment may be fully recovered from the land

owners of the project area. The sugar mills of LBOD area to contribute 1oo % towards special repairs budget needed every year for allowing their treated effluent to LBOD drainage network

14. Most modern flood forecasting and early morning systems are established in the office of the PD LBOD of drainage network.

The foregoing technical feasibility and economic analysis clearly indicate that the project is technically and economically viable with EIRR exceeding _________% (will be provided by Mr. Syed A. Hussani) and is recommended for execution.

Annexure – I

ON-FARM DRAINAGE

A. Drainage Benefits of On Farm Drainage

Drainage affects both plant growth and overall farm management. The major benefits of good drainage area:

- ✓ Drainage promotes earlier warming and drying of soil in the spring. Seed can be planted earlier (better trafficability) and can germinate earlier (higher temperature). This is very important in areas wi1h shod growing seasons and where early harvests may bring higher prices.
- ✓ Drainage removes the excess (gravitational) water from the root zone leaving only the capillary water which is required for plant growth.
- ✓ The removal of excess water is also essential to maintain a continuous supply of oxygen to the root zone. A lack of oxygen discourages the growth of beneficial soil microorganisms and the formation of useable forms of plant nutrients. Fertilizer applied to a poorly drained soil may only be partially used by the plant due to the lack of oxygen.
- ✓ Plant roots will penetrate more deeply into a drained soil, thus enlarging the supply of plant food which produces healthier, more vigorous growth (Figure 4). Deeper roots also help the plant to withstand drought and strong winds. Most plant root systems will not penetrate into a water table. In poorly drained soils, the plant root system will be shallow and more susceptible to disease.
- ✓ Drainage promotes conditions that maintain soil structure and workability while reduclog compaction. Well drained soils are essential to efficient field operations throughout the season. Poorly drained soils adversely affect planting, cultivating, and harvesting operations.
- ✓ Drainage can increase infiltration and reduce surface runoff. On fields susceptible to sol I erosion, subsurface drainage can help to control soil loss caused by the runoff of surface water. Also, surface drainage techniques such as diversion ditches and grassed waterways can control runoff and reduce soil erosion.
- ✓ Less soil heaving and root damage will occur during winter on drained land.
- ✓ Drainage enhances farm productivity and net returns by adding productive areas without extending farm boundaries, and by increasing the yield and quality of crops. Increased crop yields of 10 - 25% or greater can be expected, depending on the initial drainage status of the land.
- ✓ Good drainage provides the farm manager with a wider range of crop choices and an increased scope for crop, production planning.

B. Types of Drainage Systems

The following discussion outlines a variety of techniques that are used to drain the most common mineral soils in Atlantic Canada. If drainage of peat soils is being considered, variations or different techniques may be required. Professional assistance should always be requested before commencing drainage projects.

Surface Drainage

Surface drainage is the removal of excess water from the land surface through improved natural channels, constructed open ditches or shaping of the soil surface.

1. Open Ditching

Open ditches are the most widely used form of surface drainage in the region. Open ditches generally provide an economic solution to conveying large volumes of water. They act as field perimeter drains, cut-off drains (collecting water from an upslope wooded or other area) and outlets for other drainage systems. Open ditches also have disadvantages. They may take some land out of production and they require considerable maintenance. Field ditches may also interfere with farm equipment operations. These considerations notwithstanding, it should be realized that, few drainage systems can be constructed without some form of open ditching to provide an outlet.

When planning an open ditch system there are a number of items which should be considered:

a. volume of water to be drained.
b. topography.
c. type of soil.
d. depth requirements.

The volume of water to be drained by an open ditch is a function of the size, length, slope, vegetation. soil type and hydrologic condition of the affected watershed.

The slope of a ditch is determined by the area's topography. Slopes as little as 0.05% or 0.5 m 1000 m (0.5 ft. 1000 ft.) may be used. In situations where open ditches are required to transport large volumes of water on steep slopes, they should be carefully planned to avoid ditch bottom and side slope erosion. If high water velocities are expected I the open ditch should be rock lined or water control structures installed to prevent erosion.

Open ditches require adequate side slopes to prevent eroding and sloughing of ditch banks. Table 1 indicates the recommended side slopes for various soil types. A typical open ditch cross-section is shown in Figure 5. Note that the minimum ditch bottom width for soils susceptible to erosion is 1.0 m (3.3 ft.).

Table-1: Recommended Open Ditch Side Slopes [Horizontal [x]: Vertical]

Soil	Shallow Channels < 1.2 m [4ft.]	Deep Channels >1.2m [4ft.]
Peat and Muck	Vertical	0.25:1
Heavy Clay	0.5:1	1:1
Clay or Silt Loam	1:1	1,5:1
Sandy Loam	1,5:1	2:1
Loose Sandy	2:1	3:1

An open ditch should be planned in conjunction with the other drainage systems- discharging into it. For example, if an open ditch is to serve as an outlet for a subsurface drainage system, the ditch depth should be 0.3 m (1.0 ft.) greater than the outlet depth of the subsurface system. Perimeter cut-off ditches should have a depth of 1.0 m (3.3 ft.). Other ditches should have sufficient depth to provide an adequate outlet for all field drainage systems to be constructed.

The ditch banks should be seeded with a recommended grass mixture as soon as possible after construction. This will help stabilize the ditch bank and prevent bank erosion. Also, sediment control structures such as settling ponds and check dams may be required to prevent sedimentation of downstream water- courses. Watercourse Alteration Permits are required before constructing ditches that discharge into brooks; streams and other watercourses.

2. <u>Land Leveling</u>

The purpose of land leveling is to grade or level the surface of a field to eliminate areas where surface water may pond. Land leveling is commonly used to drain dyke land fields where it is generally referred to as land forming (see Dyke land Drainage). But the technique may also be used to improve surface drainage on upland fields.

Perennial forage crops and fall seeded cereals may not survive winter as a result of ponded water. Crops may also be negatively affected during the growing season when Ponding occurs after heavy rains. Thus, eliminating areas subject to ponding can improve crop production.

To level upland fields, where top soil is, often shallow, the topsoil should be removed and piled both from the higher field areas and from the lower ponding areas with earth moving equipment. The ponding areas are then filled with sub soil and the topsoil replaced. This extra movement of topsoil is expensive but necessary to provide the best conditions for crop production.

3. <u>Land Smoothing</u>

Land smoothing is the process of eliminating minor surface irregularities or the finishing operation in land leveling. Smoothing is usually performed by farm tractor powered land levelers after the bulk of the soil has been moved by larger equipment.

4. <u>Grassed Waterways</u>

Grassed waterways are broad, shallow vegetated channels designed and constructed to carry natural concentrations of surface water runoff or the discharge from terrace systems, diversion channels or farm pond emergency spillways. Grassed waterways help to prevent gully erosion and are normally constructed in depressions where water can collect and flow to an outlet.

Grassed waterways should not be used for continuous flows, such as may discharge from subsurface drains, since prolonged wetness in the water way will result in poor vegetative cover. If they must be used under these circumstance special supplemental treatment should be considered such as grade control structures, stone centers or subsurface drainage.

Grassed waterways should be designed to transport peak runoff volumes at low velocities. Figure 6 shows a typical grassed waterway cross-section. The shape and dimensions of a waterway are dependent upon the design peak flow the type of vegetative cover or channel bottom material required, and the waterway slope, the cross-section should be designed to permit crossing of equipment where necessary and to allow for easy mowing and maintenance of the waterway.

Grassed waterways usually discharge into a ditch or stream and it is important to construct non-erodable outlets at these points, A rock chute spillway or a drop inlet-structure may be used. Subsurface drainage should be offset from the centerline of a waterway by at least 25% of the total waterway width.

5. <u>Dyke Land Drainage</u>

For many years, difficulties have been encountered in farming dyke land soils due to their poor drainage condition. In the past, numerous shallow ditches were excavated resulting in small field sizes and little drainage improvement. To overcome this problem many farmers have successfully used the surface drainage method of land forming to improve drainage and to make larger fields.

Two principle methods of dyke land forming have been developed.

- ✓ Forming with open ditches -In this method an area between shallow open ditches is crowned or formed so that the cross-section midpoint slopes from 1 to 2% to the ditches. This sloping of the land causes more rapid movement of surface water from the field to the ditches. The distance between these ditches is normally 35 - 60 m (115 - 200 ft.), the actual distance depending on depth to subsoil and the length and size of the field to be formed. Since the ditches between the crowns cannot be easily crossed with farm equipment, each crowned area is farmed separately.
- ✓ Forming with "runs" – This method is similar to (a) above, except that water drains from the crown to a "run" or low area formed between the crowns rather than a shallow ditch. A run usually has a gradient of 0.1 - 0.4% to an open collector ditch. The advantage of this system is that much larger areas can be worked as one field Since the runs, when dry, may be crossed with farm equipment. The disadvantage is that more earth movement may be required to grade the runs to a collector ditch. To reduce earth movement, run lengths are usually less than 150 m (500 ft.).

Forming has been widely accepted by the farming community and in some dyke land areas all of the fields are drained by this method. Installations of subsurface drainage in combination with land leveling also may tie an effective method of dyke land drainage and could be considered prior to draining some areas.

<u>Subsurface Drainage</u>

Subsurface drainage, commonly called tile drainage, is the removal of excess water below the ground surface. Subsurface drainage lowers high water tables caused by precipitation, irrigation water and seepage from higher lands and ground water under artesian pressure.

As previously mentioned, a high water table damages most crops to varying degrees. The optimum depth of the water table is not constant for all areas, but varies with son texture, depth of soil and subsoil layers and crops grown. Table 2 indicates the recommended minimum water table depths for various crops (deeper water tables are preferable).

Table-2: Minimum Water Table Depths for Various: Crops Water Table Dept m (ft)

0 – 0.30 (0 – 1.0)	0.30 – 0.40 (1.0 – 1.3)	0.40 - 0.5 (1.3 – 1.6)	0.5+ (1.6+)
Tolerant Species	**Shallow Rooted**	**Medium Rooted**	**Deep Rooted**
Rushes	Cranberries	Strawberries	Alfalfa
Sedges	Forage Grasses	Blueberries	Raspberries
Reed Canary	Red Top	Black Currants	Red Currants
Grass	Ladino Clover	Nursery Crops	Nuts
Water Fox	White Clover	Red Clover	Tree Fruit
Tail	Vegetable Leaf Crops	Alsike Clover	Asparagus
	Spinach	Vegetable Root Crops	Corn
	Lettuce	Carrots	Grapes
	Cabbage	Parsnips	
		Potatoes	
		Beets	
		Bulbs	

With subsurface drainage, excess water moves through the soil, and enters drainage pipe through perforations spaced around the pipe. The water then flows along the pipe by gravity and is discharged into an open ditch, watercourse, or other low point in or near the field.

1. <u>Types of Subsurface Drainage</u>

Subsurface drainage systems generally are of the random or systematic types (Figure 7). The topography, slope, and drainage condition of the field determine the type of system that should be installed.

Random

A random system is used to drain isolated wet spots caused by springs or pending. Although this approach works well for the wet spots, as a rule it does not benefit the other areas of the field. Since many of our soils in Atlantic Canada are not naturally well drained, random drainage may only provide a partial answer to the total problem. Quite often fields drained with a random system will be re-drained several years later in a systematic fashion.

Systematic - Gridiron and Herringbone

A systematic system results when drainage lines are planned and installed to control excess subsurface water over the entire field.

The gridiron system is used to drain fields with uniform slopes in one direction. The main collector line is installed along one side of the field and lateral lines are connected perpendicular to it. A herringbone system is used to drain fields in which '8 narrow depression is near the centre of the field. The main is installed in the depression with angled laterals connecting on both sides.

2. <u>The Interceptor Principle</u>

Wet spots on a hillside may appear as a line of seepage along the upper surface of a clay or compact layer. To correct this situation, the water must be intercepted by a subsurface drain installed across the slope above the seepage area (Figure 8), Since Atlantic Canada has many rolling fields, this interceptor principle should be recognized when designing a subsurface drainage system.

3. Design of Subsurface, Drainage Systems

To design an effective drainage system, a field investigation is necessary. Information on excess water problems and crop production plans, in combination with soil and topographical survey data is required.

A soil investigation is important to determine the hydraulic conductivity (rate of water movement through the soil), texture of the soil (clay, silt, and sand content), soil profile characteristics, and the location of impermeable layers. These factors affect the depth and spacing of drains. Generally, the lower the hydraulic conductivity the closer the required drain spacing. A topographic survey is required to determine outlet locations and drain sizes, depths and gradients. These investigations contribute to the final design and preparation of plans for the proposed drainage system. Proper Investigation and planning will help to ensure the optimum performance of the system.

Whatever the combination of drain depth and spacing, subsurface drainage systems should remove gravitational water to a depth of 0.3 m (1 ft.) below the soil surface at a point midway between the laterals within 24 hours after a heavy rain. This is a general recommendation for a wide range of crops.

The following important points should be considered when planning a subsurface drain age system:

Depth of Drains

Drain depth is controlled by soil hydraulic conductivity, depth to the impermeable layer, depth of the outlet and machine limitations. Subsurface drains should have at least 0.6 m (2.0 ft.) of soil cover to protect them from damage by equipment travelling over the field. Generally, subsurface drains are installed at a depth of 1.0 m (3.3 ft.) which may vary depending on the topography and soil, where impermeable subsoil layers exist, the pipe should be placed on or above the impermeable layer if possible.

Spacing of Drains

Drain spacing is determined by soil hydraulic conductivity, type of crop, drain depth, the extent of surface drainage and depth to impermeable layer. Generally, the narrower the spacing, the better the control of the water table (Figure 9). However, selection of the most economic system calls for determination of the maximum drain spacing which can be tolerated by the crops to be grown. In Atlantic Canada, most subsurface drainage laterals are spaced at 9 - 18 m (30 - 60 ft.)

Grade

Subsurface drains are normally placed on uniform grades and as close to uniform depth as topography permits. Usually a grade of at least 0.3% is desired on the laterals. Where sufficient slope is not available, the grade should not be less than the minimum, unless special precautions are taken during construction to prevent reverse-grade conditions.

Table-3: Minimum Grades for Subsurface Drains

Pipe Diameter mm (in)	Minimum Grade %
75 (3)	0.2
100 (4)	0.1
150 (6)	0.05

Maximum grades are limiting only when drains are designed for near maximum capacity or are embedded in unstable soil. The maximum grade 01 lateral drains should not exceed 2%.

Outlets

The most important part of a drainage system is the outlet. The outlet must be deep enough to provide free flow of water from subsurface drains. The outlet should have adequate flow capacity to accept and safely dispose of all the water delivered by the drainage system. The two main types of outlets for subsurface drains are gravity and pumped (Figure 10). The type of outlet used for a particular area depends on the existing conditions.

Gravity outlets, which are the most common, are usually natural channels (brooks) or constructed waterways and open ditches.

An outlet pipe of corrugated metal or other rigid pipe, about 3 m (10 ft) long and extending into the bank, is recommended. The bottom of the outlet pipe (pipe invert) should be above the high water mark where possible, and at least 0.3 m (1.0 ft.) above the normal water level in the ditch. Submergence for an extended period of time could cause silting in the pipe.

Pumped subsurface drainage outlets are required when the normal water level at the outlet location is higher than the bottom of the outlet pipe, resulting in the system being unable to adequately drain the field only by gravity flow of water. Pump installations should have facilities for storing water, such as a sump or an open ditch, to reduce the frequency of pump starts and stops.

Filter Requirements

Filters for subsurface drains are permeable materials placed around the drains for the purpose of preventing fine grained materials in the surrounding soil from being carded into the drain by groundwater. The commonly used tilter material is a factory ore-wrapped synthetic envelope. A filtered pipe should be used in uniform soils where most of the particle size is from 0.01 - 0.25 mm (fine sands - silty soils). A soil may be sandy but have a wide range of particle size, with the larger acting as filters for the smaller sizes. In these cases, a filter is not required. Also, filters may not be required if grades are great enough to create water velocities that with flush sediment out of the drain lines.

Surface Inlets

Surface inlets may be used to collect and drain excess surface water when other surface drainage methods are not practical. A surface inlet is a structure used to divert surface water into an open ditch or a tile line. They may be constructed from concrete, metal, or prefabricated plastic materials (Figure 22, page 15). The size arid or type of inlet required depends on the flow volume and whether or not suspended sediment will be allowed to pass through it Trash racks or screened inlets should be used to prevent debris from entering the inlet structure. Surface inlets should be inspected several times each year to ensure performance during heavy rainfall and spring runoff periods.

4. Sub-soiling

Sub-soiling is applicable to soils in which the hydraulic conductivity in the entire root zone, or of layers within the profile, is very low. There are soil types in Atlantic Canada with the above conditions; sub-soiling may be required to improve response to subsurface drainage by loosening and shattering the compacted soil. Sub-soiling without subsurface drainage may create a "bath tub" with the excess water readily sinking into the loosened soil but being unable to drain away. Sub-soiling should normally be performed perpendicular to the drainage laterals to improve water movement to the drains. Also, the response to sub-soiling is improved If performed when the soil is dry (Figure 20, page 14).

5. Mole Drains

Mole drains are unlined cylindrical channels artificially produced in the subsoil by a moling plow without excavating a trench from the surface. The moling plow has a long blade-like coulter to which is attached a cylindrical bullet-nose plug, known as the mole (Figure 11). As the plow is drawn, through the soil; the mole forms a cavity at a set depth, .0.4 - 0.6 m (1.3 - 2.0 ft.) below the ground surface. Mole-channels usually range in diameter from 50 - 100 mm (2 - 4 in.) and are spaced 2.5 - 3 m (8 - 10 ft.).

Heaving and fracturing of soil by the mole provides drainage pathways for water trapped at or near the soil surface. Moling is normally employed on heavy clay land. The optimum ranges of clay content and soil moisture which produce stable, long-lasting mole channels are still being investigated.

Mole drains should be on grade and have a suitable outlet. In areas of the world where mole drains are commonly used, they are generally pulled across and over subsurface drains. These sub-drains have a permeable gravel backfill which provides an outlet for the intersecting mole drains. The frequency of remoling is dictated by the drainage response and maybe from one to five years. Mole drainage is not a common practice in Atlantic Canada.

C. Drainage Equipment and Materials

This section presents a brief outline of the specialized equipment and materials commonly used for agricultural land drainage in the Atlantic Provinces. Since these items are available through drainage services provided by land improvement contractors, farmers do not need to be greatly concerned with their operation, handling, and or installation.

Drainage Equipment

1. Draglines

Cable operated, crawler mounted shovels or draglines are often used to construct large open ditches and main outlet drain systems (Figure 12). Draglines are also used for dyke construction because of their long reach and deep excavating capabilities.

2. Excavators

Hydraulically operated, crawler or wheel mounted excavators (Figure 13) have gained wide acceptance for construction of farm ditches. Excavators have good reach, speed and trafficability and can efficiently construct ditches ranging from shallow field perimeter drains to main outlet drains, Specialize "V" ditch and side ditching bucket attachments improve the efficiency of excavators used for open ditching.

3. Backhoes

Industrial loader backhoe combination machines are commonly used for secondary open ditch construction, placement of culverts, and installation of subsurface drainage tubing, with the advent of specialized drainage installation equipment, the backhoe alone is rarely used to excavate trenches for placement of drainage tubing. Rather, it is used for excavating outlet ditches and making connections between main and lateral drainage lines while the drainage machine performs the tubing installation work.

4. Crawler Tractors

Shallow ditch excavation, leveling of spoil material from ditches, and land leveling are the most common drainage jobs performed by crawler tractors. On the dyk lands, crawler tractors of 75 kw (100 hp) or greater, perform most of the land forming / surface drainage construction work (Figure 14). Large crawler tractors may also be used to pull drainage plow attachments for installing Sub-surface drainage tubing.

5. Rotary Ditchers

Powered by farm tractors of 30 kw (40 hp) or more, rotary ditchers have gained acceptance for constructing small field ditches, primarily on the dyka lands (Figure 15). Rotary ditchers can excavate several kilometers of ditches in one day while spreading the spoil at the same time. Rotary ditchers are used in rock-free soil where surface drainage improvement is the primary concern.

6. **Subsurface Drainage Trenchers**

Trenchers are used to install sub-surface drainage tubing or clay tile (Figure 16). Basically, the trencher's digging wheel excavates a rectangular ditch or trench with a groove in the center of the trench bottom. The trencher then places the tubing or tile in this groove and covers it with several centimeters of topsoil. In good conditions, light trenchers of 60 - 90 kw (80 - 120 hp) can install drains at depths to 2.0 m (6.5 ft.) at speeds of 200 - 300 meters per hour (650 - 1000 feet per hour). Grade control may be achieved by using an engineer's level and stakes (manual system) or a laser grade system.

7. Subsurface Drainage Plows

In agricultural areas where the annual installation rate of sub-surface drainage is high, trench less drainage plows have become popular drainage machines, Available in self propelled or crawler-mounted models, the trenchless plow does not excavate a trench; rather, a large blade or tine is pulled through the soil and the drainage tubing is placed in a hollow chute at the back of the blade. As the plow moves, the tubing is drawn through the chute into the soil at the bottom of the blade (Figure 17). Connections between drainage laterals and mains are made using a backhoe. No backfilling of drains is required except at lateral connections; Trenchless plows have the potential to work 2 - 3 times faster than trenchers and are more suited to installing drains in stony soils. The most common drainage plows have approximately 150 kw

(200 hp), a maximum installation depth of 1.6 - 2.0 m (5.2 - 6.5 ft.) and are equipped with a laser grade control system.

Both the trencher and trenchless plow can perform quality drain installations over a range of soil conditions when properly maintained and skillfully operated.

8. Laser Grade Control Systems

Laser equipment is used with most subsurface drainage machines to automatically control installation depth and grade. Variations of subsurface drainage laser equipment may also be used for aiding excavator operation or for performing field level surveys.

The subsurface drainage machine laser system consists of an emitter and a receiver. The emitter (Figure 18) is usually located in the field about midway between the main collector and the ends of the lateral drainage lines.

It establishes a pre-determined sloping reference plane over the field by means of a rotating laser ray. The receiver, located on the machine (Figure 17), detects this plane of reference and transmits a signal to the machines hydraulic system. The drain depth in relation to the reference plane is monitored five or more times per second, allowing drains to be installed with great accuracy. The machine operator can adjust the drain slope using a control panel in the cab or, by changing the emitter settings.

9. Land Levelers

These machines are pulled by farm tractors of greater than 35 kw (47 hp) and vary in size from the smaller single, blade levelers (Figure 19) to large multi-blade levelers up 12 m (40 ft) in, length. Land levelers are designed to smooth and plane the soil surface to eliminate minor surface irregularities without changing the general contours of the land. Levelers are normally used as part of the finish operation in a land leveling or forming project. They may also be used to smooth the land after land clearing or subsurface drainage installation.

10. Sub-soilers

These are specialized machines with one or several tines pulled through the soil to cause lifting, shattering and loosening in compacted soil layers (Figure 20).

For shallow sub-soiling, 4 or 5 tines spaced 50 cm (20 in.) apart may be used. For soli loosening at a depth of 60 - 80 cm (24 - 30 in.), 2 - 3 tines spaced about 80 cm (30 in.) apart may be used. An effective sub-soiler tine should be rather robust and its foot or tip should have an inclination of not less than 25 - 300 to produce good lifting and loosening of the soil. Proper side wing attachments to the foot of the sub-soiler tine will increase the area of soil loosening. Generally, power requirements for sub-soiling are considerable, depending on the soil condition, the desired sub-soiling depth, and the spacing and configuration of the sub-soiler tines.

Drainage Materials

1. Culvert Pipes

Culverts are used for the construction of road and other crossings over ditches and for transporting drainage water in areas where open ditches or waterways are not practical or feasible. Most culverts are constructed of corrugated steel pipe but concrete and corrugated plastic pipes are also used. 150 - 1500 mm (6 - 60 in.) diameter culvert pipes, 6 - 18 m (20- 60 ft.) In length, are used for most agricultural applications. Culvert pipe should be sized and installed properly to ensure adequate discharge of peak water flows.

2. Subsurface Drainage Tubing

Perforated, corrugated polyethylene or polyvinyl chloride plastic tubing has become the most commonly used subsurface drainage material because of its light weight, ease of handling, bearing strength, cost, and availability. Normally, lateral drains are 100 mm (4 in.) and main collector drains are 100 - 150 mm (4 - 6 in.) tubing. Larger or smaller sizes are also available but are not commonly used. Tubing connections are easily made using manufactured plastic fittings (Figure 21). Also, tubing is available covered with filter material to prevent drain plugging in fine sandy loam and some silty soils (Figure 17, page 13).

3. Subsurface Drainage Outlets

Subsurface drainage outlets should be protected by a 3 m (10 ft.) length of continuous, rigid non-perforated corrugated steel or plastic pipe (Figure 21). A hinged rodent grate or flap is attached to the outlet pipe to prevent rodents from entering and I or .causing damage to the drainage tubing. The inside diameter of the outlet pipe should not exceed the outside diameter of the drain pipe by more than 50 mm (2 in.)

4. Surface Inlets

Manufactured plastic surface inlet riser pipes (Figure 22), are used occasionally to provide entry of excess surface water into a subsurface drainage pipe. Surface Inlets should be equipped with screens or trash racks, or manufactured with smaller diameter inlet holes to prevent debris entry into the drainage system. The drainage system capacity should be large enough to allow entry of the excess surface water. Manufactured plastic inlets may vary in diameter from 150·250 mm (6 - 10 in.) with 25 mm (1 in.) inlet holes or slots. They may be adjusted to pond the water before entering the inlet causing the silt to deposit, or to allow free flow of water into the subsurface drainage system.

D. Successful Farm Drainage

Planning and Construction

Agricultural land drainage is a significant investment and should be properly planned, constructed, and maintained if optimum value for the drainage dollar is, to be achieved.

Before commencing drainage work, careful consideration should be given to assessing drainage priorities and alternatives on the farm. For example, drainage improvements generally should be made on the higher quality land where the major limitation to crop production is wetness. Poorer quality land with a variety of other limitations such as stoniness, steep slopes, poor soil structure, etc. may not give an acceptable economic return on the drainage investment.

Once the area to be drained has been chosen, proper planning and scheduling of the work is necessary. It is always advisable to contact the local Department of Agriculture drainage engineer to obtain assistance in planning drainage projects as outlined in Section III of this booklet. The following general outline should be followed when draining a typical farm field in Atlantic Canada:

- ✓ Open ditches should be constructed first. This would include perimeter and cut-off ditches and outlet ditches for subsurface drainage. Open ditches should be constructed before September 1, if ditch bank seeding is required to prevent erosion and sedimentation.
- ✓ Land forming or leveling should be performed in conjunction with or after open ditch and or surface water way construction. Excess spoil can be used to fill low areas or blended with other forming work. The ditches and waterways will also provide some topographic relief to facilitate land forming.
- ✓ Subsurface drainage normally should be installed after open ditch and or other surface water control structures are in place. This eliminates damage to drainage lines which could occur if ditching and other excavation work is performed after sub- surface drainage installation.
- ✓ Where subsurface drains are to be installed on fields which are susceptible to soil erosion (row crops, steep slopes, etc.) planning should encompass both drainage and erosion control measures. For example, if grassed waterways and for diversion terraces are required, subsurface drainage should be planned in conjunction with these erosion control structures. It may be necessary to locate main collector lines and outlets to one side of waterway locations and/or to install subsurface drains after soil erosion controls are constructed. Drainage lateral locations should also be adjusted to the location of diversion terraces.
- ✓ Sub-soiling may be performed on compacted soil after subsurface drainage installation if it is determined that additional crop production improvements will result. If required, sub-soiling may also be performed prior to subsurface drainage installation provided field conditions are sufficiently dry.

- ✓ Mole drainage, if used, should be performed after the subsurface drainage tubing is installed so that an-outlet is available for the mole drains.
- ✓ To eliminate minor field surface irregularities remaining after the drainage work and to provide an even seed bed, the final drainage operation should be land smoothing.

Drainage construction should not be under taken when the field is excessively wet or frozen. Working in wet soil leads to compaction and reduces construction efficiency. Working in frozen soil is usually not practical as the soil shears in large chunks which are difficult to form or shape.

Drainage construction should be performed by experienced land improvement contractors with the proper equipment and trained operators. For large drainage projects, requiring several weeks of construction, it is wise to leave the field fallow and have the work done during the summer months when conditions are drier and contractors may be more available than during the early spring or late fall.

When drainage projects are planned that will alter water courses, it is necessary to check with Provincial Environment authorities before proceeding with construction, Every precaution should be taken to control erosion of soil from ditch banks and fields that may result in sedimentation damage to a watercourse. Also, open ditches should be properly located to serve the maximum possible area to be drained, thereby reducing the number and length of ditches required.

Field Management after Drainage

Generally, it is difficult to immediately grow a valuable cash crop on recently drained land that has a history of poor productivity; this land may have a shallow rooting zone, poor pH and or low natural fertility. The soil fertility and pH should be monitored and amended. Also, it may be advisable to grow a grain or hay crop for several years following initial drainage. This will help improve the soil structure: which/in turn improves soil drainage and aeration. The performance of the drainage system should improve over time as the crop rooting zone extends deeper into the soil profile.

A good crop rotation, including grains and forages, will benefit .the long term performance of the drainage system. High value cash crops generally require more intensive machinery use leading to an increased risk of soil compaction. Continuous row crops may lead to a degraded soil structure adversely affecting downward mobility of water and reducing the effectiveness of the drainage. The field should not be worked too early in the spring or immediately following a rainfall. The soil should be allowed time to dry and strengthen to avoid soil compaction problems. Drainage reduces the time required for this but some evaporation of water from the field's surface is still necessary.

Contact the local Department of Agriculture Soil and Crop Specialist for advice on soli management and crop production.

Inspection and Maintenance

Properly planned and constructed drainage systems normally require very little maintenance. Any deficiencies will usually appear in the first two years after construction. If minor repairs are promptly carried out, future major and costly damage can be avoided.

It is important to preserve good plans of the drainage system if proper maintenance is to be provided. These plans should be revised and updated as repairs and extensions are made. "As-built" drainage plans should indicate the field area; the locations of field boundaries roads, open ditches, waterways, subsurface drains and outlets; and the size and length of subsurface drainage lines.

Inspections of the drainage system should be made in the spring, fall, and after heavy rainfall events. Debris and other obstructions should be removed from open ditches, waterways, and culverts to maintain their capacity. Grassed waterways and open ditch banks should be mowed at least once annually. Adequate side slopes should be maintained to prevent ban~ erosion. Grass buffer strips approximately 3 m (10ft.) wide should be maintained on both sides of a ditch to minimize siltation.

Water holding depressions in land formed fields caused by settlement or machine operation should be filled in and leveled immediately to ensure long-term successful operation of the system.

If soils are compacted or have poor permeability in the area of a subsurface drain line, but surface water does eventually disappear, a closer drain spacing or more permeable backfill may be required in this area. However, if water remains on the surface for extended periods while the rest of the field has dried, a drainage line may be damaged or a connection may have separated during installation. The drain should be exposed at the seepage-area and checked for blockage with a plumber's "snake". When the damaged section of pipe is found, it should be repaired as soon as possible with pipe of equal diameter.

Blockage of subsurface drains can be caused by a number of factors including roots, sedimentation, ochre formation, or as a result of organic wastes entering drains. Consider the following points when inspecting a drainage system:

1. Tree Roots

Water loving trees, such as willows, elms and poplar, growing near drains may extend their root system to the drain in search of water during dry periods. Roots can enter the drains via the perforations in the drain side wall reducing the effectiveness of the drains in conveying water. The area upstream of the blockage may experience ponding and remain wet for extended periods of time. If blockage by root growth is confirmed, the trees should be removed within a distance of·30 m (100 ft.) from the drain and the section of blocked pipe replaced. If the tree Is considered valuable and is to be retained, the affected section of pipe should be replaced with a continuous length of non-perforated pipe or moved to another location.

2. Sedimentation

Soils with a high content of fine sand and silt can pose a hazard to subsurface drainage systems. The fine soil particles can flow into the drains and cause blockage. Drainage blockage by sedimentation can be detected by initially checking at the outlet. If there appears to be a significant accumulation of fine sand or silt and the drainage system had performed satisfactorily for a period of time after installation, a portion of the system may be blocked. Exposing the main line at lateral connections where the drainage system's performance seems to be impeded will indicate whether the main or a lateral is blocked. If blockage is detected, It may be possible to flush out the drains with a high pressure water jet, but It may be more desirable and less expensive to replace the blocked pipe with a new filtered pipe of equal diameter.

3. Iron Ochre

Iron ochre is a tan to red-colored, gelatinous deposit containing extensive amounts of iron in association with bacterial slimes. It is formed by an oxidation reaction involving iron laden groundwater and bacteria. Ochre deposits can block perforations in drains and or drain filters, eventually leading to reduced flow rates and in severe cases, complete blockage. Only isolated cases have been reported in the Region. The exact conditions under which ochre formations occur are complex and it is difficult to predict whether ochre will be a problem in any particular field prior to drainage. The presence of ochre can be detected by checking for a reddish deposit at the outlet. If a neighbor has experienced problems with ochre and a large subsurface drainage system is being planned on a similar soil type, it may be advisable to install a few check tines through the field that could later be incorporated Into a complete system: If after a couple of years no problem is evident, it should be safe to complete the job.

If a field has a severe ochre problem, it is debatable whether subsurface drainage is practical. Flushing of problem lines with high pressure water, acid treatments, liming of trenches to increase pH and a number of filter treatments have been tried without long lasting success. Judicious use, of surface drainage techniques may provide a workable alternative.

4. Organic Wastes

A household or barn waste disposal system should never be connected to a subsurface drainage system. Waste water solids may settle out and the nutrients in the waste may encourage the growth of organisms which can cause blockage and deterioration of drains very quickly. Manure, if spread on the field in extremely high concentrations; can also create organic growths in drains.

5. Blowouts

Water may be present on the soil surface over a drainage line as the result of a blowout. Blowouts most commonly occur with lines flowing at high capacity on steep grades. Failures usually occur at drain connections or at a change in grade to a more moderate slope. Relief wells can be used to relieve the pressure in a drain which might cause a blowout. The relief well, consisting of a vertical riser to the surface, should be located at points where the drain may become over loaded for brief periods of time such as where the grade changes from steep to flat. Where possible, relief.' wells should be located at fence or property boundaries.

6. Erosion over Drainage Lines

The backfill over drain lines should also be inspected, especially after Installation and following the first winter. Deep holes in the backfill may indicate that a drain is broken and that surface water is entering the drain at this point. The drain should be dug up and repaired immediately before too much silt enters the subsurface drainage system. If the backfill has settled below the original grade, additional backfilling is required; all drains should be checked for this condition prior to winter. If there is any surface flow through the winter months, the water could travel down the inadequately backfilled trench causing severe' erosion problems over the drainage lines, If drainage is installed with a trencher or backhoe, the backfilled grade over the trench should be higher than the surrounding grade to allow for settling. In severe cases of trench washout, the drainage lines may be partially or totally exposed and or washed out. If severe washout has occurred, repairs should take place in a relatively dry period. Debris should be .cleaned from the trench, and exposed pipe examined and discarded if damaged. New pipe of equal diameter should then be placed on firm footing at the bottom of the trench at an adequate grade and backfilled.

Drainage pipe should never be installed in a natural watercourse without' adequate erosion protection.

7. Outlets

The outlet is the single most important aspect of the subsurface drainage system. The location of the outlet should be clearly marked with a stake so that it can be easi.ly located. All outlets should be protected with a 3 m (10ft.) length of corrugated metal or rigid plastic pipe at the end of the drain line where it discharges into the ditch.

The stability of the ditch bottom and banks at the outlet should be regularly inspected. If erosion is occurring, stone tip-rap underlain by a suitable filter mat should be placed on the ditch side s lope and bottom.

Surface water should not be permitted to enter a ditch at a subsurface drainage outlet. If water tends to flow into a ditch at this point, a small dam or berm should be constructed on the ditch bank such that surface water is diverted into the ditch at some other location.

If the color of water flowing from an outlet is cloudy, it may indicate that surface water is directly entering the drain. Surface water should only enter a drain by seepage through the soil or through a properly designed surface inlet.

Any debris or silt that is present at an outlet should be removed so that the outlet is kept flowing freely.

For further information on agricultural land drainage, contact the Provincial Department of Agriculture or your local drainage contractor.

Annexure - II

DESIGN CRITERIA FOR REHABILITATION OF LBOD DRAINAGE NETWORK

Design criteria are generally established partly on the basis of sound scientific theory and analysis and partly on the basis of experience. The role of prior experience is reflected mainly in the use of (semi-)empirical formulae and engineering rules of thumb. Also, the design of a new system in an area usually relies heavily on experience obtained on similar work in the area or under comparable conditions elsewhere. All this should be judiciously applied, especially when the conditions to which the experiences apply are not well defined.

Often locally tested criteria will be unavailable, while results from test plots and/ or pilot projects can often not be waited for (easily takes three to five years). In such cases estimated criteria may have to be used, at least four preliminary planning/ early implementation. When a testing/ monitoring programme is started early on in parallel with the progress of the work, preliminary adopted criteria may be verified and/ or revised as work proceeds. However, by a judicious combination of theory, analysis and relevant experience, reasonable estimates can in fact be made in most cases.

The planner should of course be cost-conscious throughout the planning and design process. This applies specially to the selection of the design discharges which largely determine the required canal dimensions, pump capacities, etc, making it a main cost-determining factor. Other design parameters/ criteria, however, also have a considerable influence on drainage costs, both on investments and on operational costs. With respect to construction, the local availability of skills and materials should always be an important consideration. It should also be stressed that design criteria should be established with a view to the future operation of the project. The future functioning of the project should be thoroughly analysed and defined prior to and alongside the design and the planner should make sure that the technical aspects of the drainage system and its envisaged operation are manually compatible. Operational considerations should play an important and fully integrated role in the planning and design of a drainage project.

A. Rainfall Runn-Off Analysis Used for Determination of Drainage Coefficient

The rainfall quantities measured over one and two days periods during five floods events of moderate to strong intensity are shown in table-1. The daily rainfall data of these meteorological stations is plotted in Figure-1 to Figure-4. The daily maximum precipitation data are traditionally considered equal to 24 hour maximum. However, both of these data could be different. The floods of 2011 were the most severe followed by 1994, 2003 and 2006. Moderately wet year of 2010 was within management limits of the system. The rainfall patterns determine intensity and spread of floods, evacuation period and longer response of the command area. Understanding of this behavior is important for operation of the systems (drainage as well as irrigation systems) for better flood management.

Table 1: Precipitation (mm) During Historical Storms Causing Floods and Damages to

MET Station	1994 (Aug, Sep)		2003 (July, Aug)		2006 (Aug)		2010 (Jul, Aug)		2011 (Aug, Sep)	
	1 day (24 hr)	2 day (48 hr)	1 day (24 hr)	2 day (48 hr)	1 day (24 hr)	2 day (48 hr)	1 day (24 hr)	2 day (48 hr)	1 day (24 hr)	2 day (48 hr)
Badin	176.5	247	150	218	58	63	102	109	148	295
Nawabshah	143	189	61	96	72	72	70	72	108	125
Hyderabad	76.7	82	45	68	43	71	38	39	153	153
Mirpurkhas									190	288
Chhor	81.3		137	198	141	168	55	74	129	270

Table 2: Rainfall Frequency (Return Period) for Daily Maximum Rainfall (mm) Using Log Pearson III

	Badin	Chhor	Nwabshah	Hyderabad	Padidan	Jacobabad	Mohenjodaro	Karachi	Rohri
Latitude (N)	24° 38'	25° 31'	26° 15'	25° 23'	26° 51'	28° 18'	27° 22'	24° 54'	27° 42'
Longitude (E)	68° 54'	69° 47'	26° 15'	25° 23'	68° 08'	68° 28'	68° 06'	67° 08'	68° 54'
Daily maximum records (years)	70	44	44	44	30	25	19	42	35
500	234.4	183.8	168.1	243.9	192.0	461.0	269.0	475	292
200	222.0	177.7	161.8	213.5	182.0	353.6	213.6	389	265
150	217.5	175.2	159.1	203.5	167.9	323.4	197.6	363	255
100	210.4	171.0	154.6	189.3	157.8	283.6	176.1	328	239
75	204.9	167.5	150.9	179.0	143.7	257.2	161.6	303	227
50	196.4	161.8	144.7	164.1	119.6	222.6	142.2	270	209
25	179.5	149.4	131.2	138.1	111.8	169.7	111.7	215	173
20	173.4	144.6	126.0	129.6	101.9	154.3	102.6	199	161
15	164.8	137.7	118.6	118.4	87.9	135.5	91.3	178	145
10	151.5	126.5	106.5	102.5	64.1	111.1	76.3	149	120
5	124.5	102.3	81.3	74.7	0.0	74.3	53.0	103	77

Table 3: Rainfall Frequency (Return Period) for 24 hours Maximum Rainfall (mm)

Return Period	Badin	Chhor	Nawabshah	Hyderabad	Padidan	Jacobabad	Mohenjodaro	Karachi	Rohri
Years	**(mm)**	**mm**	**mm**	**Mm**	**mm**	**mm**	**Mm**	**mm**	**mm**
500	265	208	190	276	217	521	304	536	330
200	251	201	183	241	206	400	241	440	299
150	246	198	180	230	190	365	223	411	288
100	238	193	175	214	178	320	199	371	270
75	232	189	170	202	162	291	183	343	257
50	222	183	163	185	135	251	161	305	236
25	203	169	148	156	126	192	126	243	196
20	196	163	142	146	115	174	116	224	182
15	186	156	134	134	99	153	103	201	163
10	171	143	120	116	72	126	86	168	136
5	141	116	92	84	0	84	60	116	88

Table 4: Drainage Coefficient for Catchment or Sub-Drains Level - cusec/square mile

	Design Coefficient	**Based on proposed Return Period**	
		10 Years	**20 Years**
Nawabshah	0.72	1.89	2.62
Sanghar	1.53	2.16	2.98
Mirpur Khas	0.93	2.79	3.58

Badin	2 – 3	4.84	5.82

Runoff and Drainage Computations

Table 5: Estimation of Runoff and Drainage Quantities for Existing LBOD System for 10 Year Return Period

	Area	Rain	CN	Reduced Rain	Total Runoff		Runoff /Day	Runoff Flow	Irrig.R.F	Tot. Drainage Flow	Adjustment	Adjusted Flow	Drainage surplus
	acres	mm		mm	(mm)	Acre-ft	Acre-ft	cfs	cfs	Cfs	Factor	Cfs	cfs/ sq.mile
Nawabshah	626,000	106.5	70.5	90.5	27.3	56134	11227	5653	313	5966	0.310	1851	1.89
Sanghar	424,000	106.5	70	94.8	29.3	40775	8155	4106	212	4318	0.331	1431	2.16
Mirpur Khas	376,000	126.5	67.8	112.6	37.4	46166	9233	4649	188	4837	0.338	1636	2.79
Badin LBOD	280832	151.5	69.6	139.4	60.2	55467	11093	5586	393	5979	0.355	2125	4.84
Total LBOD	-	-	-	-	-	-	39708	-	-	21100	-	7043	-
Badin KPOD	312462	151.5	69.6	139.4	60.2	61714	12343	6215	437	6652	0.349	2322	4.76

Table 6: Estimation of Runoff and Drainage Quantities for Existing LBOD System for 20 Year Return Period

	Area	Rain	CN	Reduced Rain	Total Runoff		Runoff /Day	Runoff Flow	Irrig.R.F	Total drainage	Adjustment	Adjusted Flow	Drainage surplus
	Acres	mm		mm	(mm)	Acre-ft	Acre-ft	cfs	cfs	Cfs	Factor	Cfs	cfs/ sq.mile
Nawabshah	626000	126	70.5	107.1	38.36	78774	15755	7933	313	8246	0.31	2558	2.62
Sanghar	424000	126	70	112.1	40.99	57022	11404	5742	212	5954	0.33	1973	2.98
Mirpur Khas	376000	144.6	67.8	128.7	48.55	59897	11979	6032	188	6220	0.34	2104	3.58
Badin LBOD	280832	173.4	69.6	156.1	73.20	67448	13490	6792	393	7186	0.36	2554	5.82
Total LBOD	-	-	-	-	-	-	52628	-	-	-	-	9190	-
Badin KPOD	312462	173.4	69.6	156.1	73.20	75045	15009	7557	437	7995	0.35	2791	5.72

B. Design of Surface Drains

Alignment

Alignment of storm water drainage and a storm-cum-seepage drain ordinarily should follow the line of depression except where it is desirable to short-circuit loops or to improve outfall by a short cut. In short-circuiting loops the latter serve as Branch Drains. Drain alignment should not go too near. Swamps and ponds for practical reasons as excavations through marshy land is extremely difficult and can only be done by excavators and in spite of expensive precautions, the danger of excavator getting bogged is always there. Similarly the maintenance of such reaches is almost impossible. Swamps and ponds should, however, be connected by branch drains to the main drain.

Storm water drains- The capacity of these drains depends on a number of factors, i.e., rainfall characteristics, type, slope and area of catchment and its surface characteristics. The drain is expected to remove from the natural surface all accumulations of water, due to design precipitation of a specified return period, within a period of three to six days, depending upon the type of land and farming practices. This is based on the idea that most crops are not damaged to any appreciable extent if the flooding is removed within this period.

Capacities for open drains should be sufficient to carry normal flow of ground water seepage, irrigation surface waste or surplus, estimated storm flow, and the quantities delivered to the open drains by surface drains.

Drain capacities will be calculated by using the parameters for runoff mentioned in the preceding section. The area to be drained by the drainage system will be subdivided and the channel capacity varied accordingly. The required capacity of the drain in various reaches will be computed using following equation:

$$Q = C * M^{5/6}$$

Where; Q: Design Discharge, ft^3/s
C: Drainage Coefficient, ft^3/s per sq. mile
M: Catchment Area, sq.mile

Since not all the catchment contributes uniformly to runoff at a specific point, i.e., as the catchment increases the resulting runoff per square mile decreases, an adjustment has to be made. To account for this phenomena actual catchment area is reduced by the power 5/6.

Sizing of Drains

The size of drainage channel will be calculated using the Manning Equation:

$$V = 1.486 / n \times R^{2/3} \times S^{1/2}$$

Where; V: Flow velocity (ft/s)
R: Hydraulic Mean Radius (ft)
S: Hydraulic Gradient, usually longitudinal slope of channel bed/water surface in open channel flow
n: Roughness coefficient of channel

Velocity

Flow velocity in drains should be low enough to avoid scouring and high enough to minimise sedimentation. Since flows in most drains are intermittent, flow velocities will fluctuate. Drains will be designed using selected maximum allowable velocity. The table below indicates recommended maximum velocities at design flow depth for various soils above which scour and erosion may take place. Desirable minimum design velocities will be kept at least 1.0 ft/s to minimise sedimentation.

Table 7: Maximum Recommended Velocity

Soil Texture	Max. Velocity (ft/s)
Fine Sand	1.5
Sandy Loam	2.5
Silty Loam	3.0
Stiff Clay	5.0

Source: Surface Drainage Manual for Pakistan (1993).

Coefficient of Roughness

The value of "n" depends on a number of factors, such as, roughness of the channel bed and sides, thickness and stem length of vegetation, irregularity of alignment, and hydraulic radius of the channel. For a man-made trapezoidal shaped channel and reasonably well maintained canal, "n" values are related to the hydraulic radius and the value of "n" decreases as the hydraulic radius increases. The recommended "n" values for different sizes of drainage channels are as follows:-

Table 8: Value of Manning "n" for Drains

Hydraulic Radius (ft)	Manning "n"
Less than 2.5	0.040- 0.045
2.5 to 4.0	0.035- 0.040
4.0 to 5.0	0.030- 0.035
More than 5	0.025- 0.030

Bed Width to Depth Ratio

The relationship between the drain bed width and drain depth becomes or approaches the most economical cross section when its shape approaches that of a semi circle, but this s an inconvenient shape for construction so a trapezoidal section will be adopted. As a general rule a deep narrow drain will carry more water than a wide shallow drain of the same cross sectional area. An excessively wide shallow drain tends to develop sand or silt oars which causes meandering and bank under cutting & erosion. A deep narrow drain tends to increase the flow velocities and to reduce meandering and siltation. From experience in the hydraulic performance of trapezoidal channels it has been found that the c d ratio should not be less than 2 and should increase linearly as the channel capacity increases upto a value of 6 at a discharge of530 ft^3/s. This range of b/d ratio will be adopted for the design of drains, except where the outfall conditions are such that it becomes necessary to deviate from these ratios.

Drain Side Slope

Drain side slopes are determined primarily by the stability of soils through which the drain is constructed and by the maintenance methods to be used. The steepest side slopes (horizontal: vertical) recommended for four generalised soil types are as under: -

Table 9: Recommended Side Slopes

Soil	Side Slopes
Sand	3:1
Loam	2:1
Clay	1.5:1
Peat	1:1

Berms

Berms would be provided in order to:

- Provide room for movement of the maintenance equipment;
- Provide for work areas and to facilitate spoil spreading;
- Prevent excavated material from washing back into the drains during rain storms; and,
- Prevent sloughing of banks caused by placing heavy loads too near the edge of the drain.

The suggested width of the berm is given is Table 10.

Table 10: Suggested Berm width

Drains	Recommended Berm Width

	ft
Spinal Drain	30 – 20
Main Drain	20 – 20
Branch Drain	20 – 50
Sub-Drain	12 – 12

Design of Banks

Banks are designed and constructed along open drains to control water flows within or from outside the designated land width of the drain. The recommended top width of the banks and freeboard according to the Surface Drainage Manual for Pakistan are given in Table 11. The recommended values depend on the type of drain and whether or not the bank is to be used as an inspection road. The freeboard is specified above the designed water level DWL or above the natural ground surface level, whichever is higher. A minimum additional construction height is provided to allow for settlement of one inch per foot of height.

Table 11: Minimum Top Width and Free Board for Banks

(ft)

Drains	Top Width		
	Used as Inspection Path (IP) (ft)	Not used as Inspection Path (NIP) (ft)	Free Board (ft)
Spinal Drain	30-50	30-50	6
Main Drain	30	30	4
Branch Drain	30	30	4
Sub-Drain	20	20	3

Right of Way (ROW)

The Right of Way (ROW) is needed along the banks of the drain to permit the disposal of spoil during subsequent maintenance operations. The ROW is generally narrower on the inspection road bank since spoil obtained from manual labour is disposed on this side. All spoil from subsequent mechanical excavation should be placed on the opposite side of the drain.

LBOD drainage network has sufficient ROW available and is recommended to be consumed, so that there is no chance of encroachment in future. The field engineers can adjust width of berms and IPs of main drainage system to fully occupy the acquired lands of LBOD project.

C. Hydraulic Stability Design Criteria

General

Whenever a hydraulic structure is founded on alluvial soil foundations, it is subjected to seepage water beneath the structure. The water seeping below the body of the hydraulic structure may endanger the stability of the structure and cause its failure either by piping or by direct uplift, as explained below:

Failure by Piping or Undermining

When the seepage water attains sufficient residual head at the emerging downstream end of the structure, it may lift up the soil particle at the exit. This leads to increased porosity of the soil by progressive removal of the soil from beneath the foundations, and the structure may fail due to formation of voids under the foundations. In order that the soil particles at exit remain stable, the upward pressure at exit should be safe. The limit of exit gradient depends on soil texture and its permeability. The exit gradient generally ranges from 1/5 to 1/7 for a structure to be safe.

The depth of the downstream end cut-off or pile line which controls the exit gradient, which is worked out with Khosla's Exit Gradient Equation:

$$GE = \frac{H}{d}\frac{1}{\pi\sqrt{\lambda}}$$

Where

$$\lambda = \frac{1+\sqrt{1+a^2}}{2}$$

H = Total head across the structure under worst conditions, in feet.
a = b/d
b = Total length of pacca floor in feet.
D = Depth of downstream cut-off / sheet pile line, in feet.

For a structure with open pit foundation in the form of base slab and toe walls, the exit gradient will be checked with Lane's weighted creep ratio as given below:

Soil Texture	Ratio
Very fine sand or silt	8.5
Fine sand	7
Medium sand	6
Coarse sand	5.7
Shingle	4
Soft clay	3
Medium clay-Hard clay	2

Lane's weighted creep ratio is given by the formula:

C = L/H

Where

C = Weighted creep ratio
H = Head across the structure under worst conditions, in feet.
L = Creep length (with the weightage factor as below).

The weightage factors are as follows:

Horizontal creep = 1/3
Vertical creep = 1.0

The sloping surfaces of 45° or steeper are taken as vertical, while surfaces flatter than 45° are treated as horizontal.

Failure by Direct Uplift

The water seeping below the structure exerts an uplift pressure on the floor of the structure. If the pressure is not counter-balanced by the weight of concrete or masonry floor or by the moment of resistance of concrete section in case of RCC floors, the structure will fail by rupture of a part of the floor. To reduce uplift pressure, cut-off of sufficient depth will be needed both on upstream and downstream of the hydraulic structure.

The hydraulic structures are designed against the uplift pressure. The uplift pressure can be calculated by a number of methods, e.g, from the flow nets (exponential lines) established in Khosla's theory for design of weirs on permeable foundations.

The uplift pressures can also be determined by Khosla's method of Independent Variables. These values should be corrected for the thickness of floor, slope of the floor and for mutual interference of plies.

Failure by Uplift Due to Formation of Jump on Downstream Apron

The failure due to the uplift pressure also occurs in the region of the trough of the hydraulic jump formed at downstream. This causes damage in two ways; firstly by raking out the joints of the masonry floor and then lifting the top layer; and secondly by lifting the floor from below the bottom profile of the glacis. The thickness of floor as determined by standing wave considerations will also be checked, where considered necessary.

Excessive hydrostatic head across a regulating structure develops seepage of water through the underlying sub-soil. The seepage water causes uplift pressures underneath the structure.

A factor of safety of 1.10 against uplift will be provided. Similarly, the buoyancy for each element of the floor will be checked.

The uplift pressure under a structure will be determined under steady seepage by Khosla's Theory (Ref: 2.10). The percentage pressure of key points can be computed using Kholsa's curves reproduced in Figure 2.2. The percentage pressures given by Khosla's curves are valid for a simple profile of the structure i.e. for a straight horizontal floor of negligible thickness with a cutoff on the upstream end or downstream end. For complex profile of the structure, the following corrections to percentage pressures are applied:

i. Correction for floor thickness: the pressures are corrected by assuming linear pressure distribution.

ii. Correction for mutual interference of piles:

$C= 19 (D/b') ½ [(d+D)/b]$

Where:

C = correction in percent and is positive for points in the rear or backward direction and negative for points forward in the direction of flow

D = depth of pile, the influence of which is to be determined on the neighboring pile depth (d). The "D" is to be measured below the level at which interference is desired (ft)

D = depth of pile on which effect is considered (ft)

b' = distance between the two considered piles (ft)

b = total length of floor between two end piles (ft)

iii. Floor slope correction: is taken as positive for the down slopes and negative for up slopes relative to the direction of flow. Correction curve is used for calculation.

D. Stone Pitching Protection

The slope protection will consist of hammer dressed stone pitching underlain with transition layer of well graded rock spawl and filter layer of well graded gravel or crushed stone, up to the crest level. Typical details of stone pitching protection on embankment slope are shown in figure 2.10.

a) Stone Pitching Layer

All stones shall be contained within the thickness of stone pitching layer to provide maximum resistance against erosive forces. The larger stones should not protrude above the general surface of the stone pitching. As normal requirement the minimum thickness of stone pitching layer will be kept as 1.5 feet (0.45 m) for containing the larger stone. Minimum thickness of stone pitching layer $=1.5D_{50} \geq 1.5$ ft (0.45m)

b) Rock Spawl Transition Layer

It is recommended to provide standard six (6) inches (150 mm) thick rock spawl transition layer between the stone pitching layer and filter layer. The spawl layer will be well graded from two (2) to four (4) inches (50 mm). Not more than fifteen (15) percent shall be lager than four (4) inches (100 mm) and not more than five (5) percent shall be smaller than two (2) inches (50 mm).

c) Filter Layer

To prevent infiltration of the material susceptible to draining into the filter, the following requirement will be met:

D15 percent size of filter material ≤ 5 (stability)

D85 percent size of material being drained

D50 percent size of filter material ≤ 25 (segregation)

D50 percent size of material being drained

Where:

D15, D85, D50 = material size for which 15%, 85%, 50% respectively are finer than

To assure that the filter material is much more permeable than the material being drained the following requirement will be met:

Permeability:

D_{15} percent size of filter material ≥ 5 (permeability)

D_{15} percent size of material being drained

The permeability of a soil is approximately proportional to the square of its D_{15} percent size. Therefore, the criterion given by above equation assures that the filter material is at least twenty five (25) times more permeable than the material being drained.

The maximum six (6) inches (150 mm) thick filter layer of gravel or crushed stone will be well graded from two (2) inches (50 mm) down. Not more than fifteen (15) percent shall be larger than two (2) inches (50 mm) and not more than ten (10) percent shall be smaller than one sixteenth (1/16) of an inch (1.5 mm).

E. Structural Design

General

These design criteria shall be used in the design of all structures. The supplemental design criteria applicable to specific structures will be established for any particular requirements/ conditions.

Design for concrete structures will be based on design methods as set out in applicable Codes of the American Concrete Institute (ACI) or British Standards (BS) where ACI Codes do not carry pertinent information.

Design Loading

All structural members will be designed to withstand dead and live loads expected to be imposed. These loads will include the self-weight of the structure, imposed load including earthquake forces, wind loads, internal and external hydrostatic (uplift) and hydrodynamics (flow) loads, construction loads, impact loads and earth pressures. Where elements would be precast lifting forces shall be considered.

Dead Loads

The dead loads on structures will be computed from the following unit weights of the materials:

Material Type	**Unit Weight**	
	(lb/ft^3)	**(kg/m^3)**
RCC	150	2403
PCC (1:2:4)	144	2306
Massive concrete (1 :4:8)	140	2243
Rubble masonry	140	2243
Brick masonry	120	1922
Dry earth	100	1602
Compacted earth1	115	1842
Saturated earth	135	2163

1Subject to the results obtained from laboratory testing.

Bridge Live Loads

The bridges will be designed or evaluated for the following live loading:

Bridge Classification	Live Load
AR. Bridge	Class AA loading
	Class A loading
	NLC loading
D.R. Bridge	Class AA loading
	Class A loading
	NLC loading
V.R. Bridge	Class A loading
Foot Bridge	100 lb/ft2 (488 kg/m2)

Class AA Loading: This is 70 ton (69 tonne) Army tank. The nose to tail distance between two successive tanks will not be less than three hundred (300) feet (92 m) and no other live load shall cover any part of the roadway of the bridge when tank is crossing.

NLC loading: This has a maximum twin wheel loading of 20 x 10-inch (50.8 x 25.4 cm). The nose to tail distance between successive truck trailer units shall not be less than sixty (60) feet (18 m).

Class A loading: is a train of one truck plus two trailers. The nose to tail distance between successive truck units shall not be less than 60 feet (18 m).

Live load stresses shall be increased for impact effect as below:

Class AA loading (tracked loading)

Live load impact - Deck = 25%
Live load impact - Girder = 10%

NLC and Class A loading (wheeled loading)

$$I = \frac{50}{L + 125}$$

Where:
I= Impact factor
L= Length of span (ft)

Wind Loads

Wind pressure will be applied to the exposed area of all structures in accordance with Building Code of Pakistan, for a maximum wind velocity of hundred (100) mph (161 kmph) acting horizontally in any direction.

Earthquake Load

The earthquake loading will be selected according to the established earthquake zones of Pakistan.

Flow Pressure

The effect of the flow on piers will be calculated by the formula:

P=KV2

Where:
P= Pressure (lbs/ft2)
V= Velocity of flow (ft./sec)
K= Constant (0.66 for circular nose piers)

Uplift Pressure

Uplift pressure will be assumed to correspond to full head across. Uplift will be assumed to act on hundred (100) percent of the base area.

Earth Pressure

Lateral earth pressures due to backfill under static conditions will be computed by the Rankine Method, taking into account the effects of any soil saturation or submergence.

A surcharge of two hundred (200) Ib/ft2 (975 kg/m2) will be added for computing earth pressure.

Loading Combinations

The loads listed above will be divided into two main groups:

Group-I Loads:

- ✓ Dead and imposed loads.
- ✓ Live loads including impact.
- ✓ Earth pressure.
- ✓ Hydrostatic pressure corresponding to head across.
- ✓ Uplift pressure.

Group-II Loads:

- ✓ Wind loads.
- ✓ Earthquake load.

The following three different loading combinations will be considered for the design of structures:

- ✓ Normal Loading Condition: will result from the combination of Group-I loads only.
- ✓ Exceptional Loading Condition: will arise from the combination of anyone load from Group-II with the Group-I loads.

- ✓ Extreme Loading Condition: will occur when two loads from Group-II loads are combined with Group-I loads.

Stability Criteria

Stability analysis will be carried out for structures for most severe conditions of horizontal and vertical forces. Stability criteria are aimed at ensuring the overall safety of structure against overturning and sliding.

Overturning

Allowable limits under different loading conditions will be a follows:

- Normal Loading

Resultant of all forces acting on structures will fall within the middle sixth of the base (Le. no tension allowed between concrete and foundation) and the allowable foundation pressure will not be exceeded.

- Exceptional Loading

Resultant of all forces acting on the structure will remain within the middle third of the base and allowable design foundation pressure (20% higher than for Normal loading case) will not be exceeded.

- Extreme Loading

Resultant of all forces acting on the structure will remain within the middle half of the base provided that a minimum of 75% of the base area is subject to compression and the maximum base pressure will not exceed the allowable design foundation pressure (33% higher than for Normal loading case).

Sliding

Friction factor of safety = **μ (Normal Forces)**
(Forces in sliding plans)

Where:

μ= coefficient of friction at rough interface of foundation base

The minimum factor safety will be as follows:

Loading Condition	Factor of Safety
Normal loading	1.50
Exceptional loading	1.25
Extreme loading	1.00

Floatation

Minimum factor of safety against flotation in different conditions will be as follows:

Normal loading = 1.25
Exceptional loading = 1.15
Extreme loading = 1.05

Allowable Stresses

The following allowable stresses will be followed in the design of the members of various structures:

Reinforced Concrete (RCC, 1:2:4)

Description	**Allowable Stress (psi)**

Modulus of elasticity ratio "n" =Es/Ec $=29{,}000{,}000/57{,}000\sqrt{f_c'}$ For concrete strength of fc' =3,000 psi "n" =9	
CONCRETE	
• Flexure: Stress in compression (fc) - Normal	0.35 fc'
- Exceptional	0.40 fc'
- Extreme	0.45 fc'
Tension in plain concrete footings and walls	$1.6\sqrt{f_c'}$
• Shear: Beams with no web reinforcement - Normal	$1.10\sqrt{f_c'}$
- Exceptional	$1.15\sqrt{f_c'}$
- Extreme	$1.20\sqrt{f_c'}$
Joists with no web reinforcement	$1.20\sqrt{f_c'}$
Members with web reinforcement	$5.0\sqrt{f_c'}$
Slabs and footings	$2.0\sqrt{f_c'}$
• Bond	
Main Bars	$2.4\sqrt{f_c'}$
Top Bars	$1.7\sqrt{f_c'}$
• Bearing	
On full area	0.25 fc'
On one third area or less	0.375 fc'
REINFORCEMENT	
- Normal	0.375 fy
- Exceptional	0.450 fy
- Extreme	0.500 fy

Where:
fc'= compressive strength of concrete cylinder in 28 days (psi)
= 3,000 psi (211 kg/cm2) (cube strength = 3, 750 psi) (264 kg/cm2)
fy= yield strength of reinforcement (psi)
= 40,000 psi (2812 kg/cm2) (Grade 40 reinforcement in conformity with ASTM A615)
d= bar diameter (in.)

ii. Plain Concrete (PCC)

The PCC will have a 28 days compressive strength as below:

PCC (1:2:4) - Cylinder = 3,000 psi (211 kg/cm2)
- Cube = 3,750 psi (264 kg/cm2)

PCC (1:3:6) - Cylinder = 2,500 psi (176 kg/cm2)
- Cube = 3000 psi (211 kg/cm2)

iii. Lean Concrete

The lean concrete (or blinding concrete) will have 28 days compressive strength of:

Cylinder = 2,000 psi (141 kg/cm2)
Cube = 2,400 psi (169 kg/cm2)

iv. Bricks

The bricks will have a minimum crushing strength of 2,000 psi, (141 kg/cm2) when tested flat.

Minimum Reinforcement (Or Temperature Reinforcement)

A minimum area of reinforcement is required to control the cracking, which occurs in the concrete due to temperature, shrinkage and creep. It enables cracking to be uniformly distributed and therefore minimizes individual crack width.

The following criteria will be used to determine the cross-section area of temperature or minimum reinforcement required in hydraulic structures. The percentages indicated are based on the gross cross-sectional area of the concrete to be reinforced. Where the thickness of the section exceeds fifteen (15) inches (380 rnrn), a thickness of fifteen (15) inches (380 mm) should be used in determining the temperature or minimum reinforcement.

Concrete Member/Face	Minimum Reinforcement Percentaae
SINGLE LAYER REINFORCEMENT	
Slabs not exposed to direct sun - joints spacing < 30 ft (9 m).	0.25 %
Slabs exposed to direct sun - joints spacing < 30 ft (9 m).	0.30%
Slabs not exposed to direct sun - joints spacing >30 ft (9 m).	0.35 %
Slabs exposed to direct sun - joints spacing >30 ft (9 m).	0.40 %
DOUBLE LAYER REINFORCEMENT (EACH FACE)	
Face adjacent to earth - joints spacing < 30 ft (9 m),	0.10 %
Face not adjacent to earth nor exposed to direct sun - joints spacing < 30 ft (9 rn).	0.15 %
Face not adjacent to earth but exposed to direct sun - joints spacing < 30 ft (9 m).	0.20 %
If member exceeds 30ft (9m) in any direction parallel to reinforcement, add to the above reinforcement requirement in that direction because of the increased length.	+0.05 %

The temperature reinforcement shall not be less than ½ inch (13 mm) at nine (9) inch (230 mm) centre to centre. All concrete stilling basins, glacis and floors and all concrete aprons of regulators and similar structures (with slab thickness> 15 inch (380 mm)) shall be reinforced in the exposed (top) face with % inch (19 mm) bars at twelve (12) inch (300 mm) centre to centre, both ways, placed three (3) inch (75 mm) clear from concrete face, unless otherwise designed.

Nominal reinforcement of concrete chute blocks, baffle blocks and sills for stilling basins, aprons and other portion of regulators, falls and similar structures shall consist of % inch (19 mm) bars at twelve (12) inch (300 mm) centre to centre, both

Minimum Concrete Cover for Reinforcement

The following minimum concrete cover shall be provided for the nearest reinforcement.

Concrete Element	Minimum Concrete Cover	
	(in)	(mm)
Face in contact with earth	3	75
Face exposed to weather and flowing water	3	75

Beam, girder, column and wall - dry condition	1.5	40
Beam, girder, column and pier - exposed to water and weather	2	30
Slabs - not exposed (dry condition)	1.5	40

<u>Concrete Joints</u>

There are three (3) types of joints generally used in concrete construction. These are:

- Construction Joints
- Contraction Joints
- Expansion Joints

One joint may be combination of the two or more of these types. The joints for the structures which are subjected to internal and external hydrostatic (uplift) pressure, shall be provided with rubber or polyvinyl chloride (PVC) water stop of suitable sizes.

i. Construction Joints

These shall be provided where necessary for the practical placing of concrete. The reinforcement steel shall be continued across the construction joint. Unless required to resist heavy shear caused by lateral loads, keys shall not be placed in construction joints. Where necessary to ensure water tightness in construction joint, water stop shall be provided.

ii. Contraction Joint

These shall be used to relieve tensile stresses induced in the concrete by shrinkage. They differ from construction joints wherein means are used to prevent bond between the joint faces, and the reinforcement does not cross the joint face. Concrete on one side of the joint is cast first, and after the form is removed from the joint face, the joint is painted with sealing compound to prevent bond with the concrete placed against it. Water stop shall be placed in contraction joints to provide water tightness, where necessary. Contraction joints may also serve as construction joints.

iii. Expansion Joints

These are used to eliminate or reduce compressive stresses that would otherwise result from thermal expansion, creep, or settlement of the concrete. Water stop shall be placed in expansion joints to provide water tightness, where necessary. Expansion joints may also serve as construction joints.

<u>Pre-Stress Concrete</u>

AASHTO Maximum Permissible Stresses in Concrete and Reinforcement

a) Concrete Stresses before Creep and Shrinkage

<u>Compression</u>

Pre-tensioned members 0.06 f'_{cl}

Post-tensioned members 0.55 f'_{cl}

<u>Tension</u>

Pre-compressed tensile zone No. temporary, allowable stresses are specified

b) Concrete Stresses at Services Load after Losses

Compression 0.40 f'_{c}

Tension in the pre-compressed tensile zone

- For members with bonded reinforcement 6

For severe corrosive exposure conditions, such as

Coastal areas	3
• For members without bonded reinforcement	

c) Cracking Stresses

Modulus of rupture from tests or if not available

• For normal –weight concrete	7.5
• For sand –lightweight concrete	6.3
• For all other lightweight concrete	5.5

d) Anchorage-bearing stress

Post-tensioned anchorage at service load (but not to exceed 0.9 f'_{ci})	3,000 psi

e) Pre-stressing Steel Stresses

• Due to tendon jacking for	$0.94\, f_{py} \leq 0.80\, f_{pu}$
• Immediately after pre-stress transfer	$0.82\, f_{py} \leq 0.75\, f_{pu}$
• Post-tensioning tendons at anchorage, immediately After tendon anchorage	$0.70\, f_{pu}$

$f_{pu} \sim 0.85\, f_{pu}$ (for low-relaxation, $f_{pu} = 0.90\, f_{pu}$)

F. Geotechnical Design

General

A detailed knowledge of subsurface condition would be required for safe and economical design of foundations of various components of LBOD Drainage Network. The detailed STP testing would be required for at the sites of siphons, side weirs, and Gated Tidal Control Structural at RD 22 of KPOD.

Ground Exploration

The main objectives in making the ground explorations would be:

- ✓ to assess the general suitability of the site.
- ✓ to prepare an adequate and economic design.

Drilling will be undertaken keeping in view the site conditions at each Barrage location. Drilling in water shall be done from a barge or an assembly of pontoon units adequately tied up and anchored. Generally the following testing and sampling procedures will be followed.

Standard penetration tests will be carried out in the boreholes, generally at a depth interval of 1 m. The number of blows for penetrating the last 30cm of sampler will be recorded. Cone penetration tests (CPTs) will also be performed at various selected locations. The results from these tests will be used for direct as well as indirect determination of strength and deformation characteristics using empirical correlations.

The undisturbed samples will also be taken at appropriate depths in various subsurface strata if found necessary. Piston/Shelby samples will be used at shallow depths in softer conditions. For alluvial sands Pitcher sampler will be used while for cohesive soils Denison sampler will be used. The samples recovered shall be carefully cleaned, waxed, labelled and stored at site with a minimum of delay after sampling, before being transported to the laboratory. Special care would be exercised during transportation so as to avoid any disturbance due to vibration and shock.

Permeability tests in boreholes will be performed at selected locations either with the flush bottom or lifted casing cases if considered necessary. Any difference between the results of the two tests is an indication of a difference between the vertical and horizontal permeabilities due to thin stratification. However, if the two tests are entirely within one stratum, similar permeabilities will be obtained even if on a larger scale, horizontal permeability is higher than vertical permeability. The permeability data will be analysed and a ratio of horizontal to vertical permeability will be established.

In-situ density will be determined through tests carried out in the test pits by sand Replacement Method and CPT carried out in boreholes.

The initial description of soils will be done on site. An experienced geotechnical engineer/engineering geologist will be at site in the early stages to see that the site staff is on the right lines. For quality control and sporadic check intermittent visits by senior personnel will be made.

Geophysical Explorations

The Electrical Resistivity (horizontal profiling), gravity and shallow Refraction surveys will be carried out to delineate the voids and probable channels below concrete mass and also to demarcate the shape and size of the voids and channels.

Laboratory Testing

Depending on the ground conditions some or all of the following tests will be carried out on selected soil/water samples transported to the laboratory:

- ✓ Grain size Analysis
- ✓ Atterberg Limits
- ✓ Maximum/minimum densities
- ✓ Unconfined compression
- ✓ Direct Shear
- ✓ Triaxial Compression (CU)
- ✓ Consolidation
- ✓ Permeability of soil
- ✓ Chemical analysis of soil/ water

In general both BS and ASTM would be followed for the field and laboratory testing. However ASTM would be given more weight age.

Data Evaluation and Analyses

The results obtained through ground explorations and laboratory testing will be studied in conjunction with each other and judicious engineering judgment to evolve design parameters. Where ever possible more than one method would be adopted in evaluating the design parameters.

The results of the geotechnical investigations will be used for the design of specific structures.

Foundation Design Criteria

Generally following two criteria will be considered and satisfied separately:

- There must be an adequate factor of safety against local and general shear failure in soil.
- The settlements and particularly the differential settlements must be kept within the tolerable limits imposed by functional and structural design requirements.

Estimation of Foundation Stresses

For evaluation of ultimate bearing capacity as well as settlement calculation, estimation of stress transferred by the foundation to soil layers at different depths is required. For estimation of increase in vertical stress beneath the centre of uniformly loaded flexible rectangular or circular foundation, chart given by Janbu, Bjerrum and Kajernsli will be used. For estimating stresses beneath foundations of other shapes chart given by Newmark will be used.

Shear Based Design

In this approach ultimate bearing capacity of soils shall be evaluated using the following Meyerhofs (Ref.4.1) bearing capacity equation. A factor of safety (FOS) of 3 shall be used to calculate the allowable foundation pressures from the calculated values.

$$q_{ult} = cN_c S_c d_c + \overline{q} N_q S_q d_q + 0.5\gamma B N_\gamma S_\gamma d_\gamma$$

Where,

qult= Ultimate bearing capacity
γ= effective unit weight of the bearing stratum
C= cohesion
$\overline{q}$= effective overburden pressure at the foundation level
B= footing width
N_c, N_q, N_γ= bearing capacity factors, a function of angle of internal friction
S_c, S_q, S_γ= shape factors
dc,dq,dy= depth factors
$N_q = e^{\pi \tan\phi}\, tan^2\left(45 + \frac{\phi}{2}\right)$
$N_c = \left(N_q - 1\right) Cot\phi$
$N_\gamma = \left(N_q - 1\right) tan(1.4\phi)$
$S_c = 1 + 0.2\, K_P\, \frac{B}{L}$
$S_q = S_\gamma = 1 + 0.1 K_P\, \frac{B}{L}$
$d_c = 1 + 0.2\sqrt{K_P}\, \frac{D}{B}$
$d_q = d_\gamma = 1 + 0.1\sqrt{K_P}\, \frac{D}{B}$
$K_P = tan^2\left(45 + \frac{\phi}{2}\right)$

For granular soils of high permeability drained soil strength parameters will be used.

Cone Penetration Test (CPT) results from the field shall be used to determine a notional value of angle of shearing resistance. (Ref.4.2) Fig. 4.1 shows Meyerhofs correlation between static cone penetration resistance and angle of shearing resistance of sand. This value shall be judiciously used to determine the ultimate bearing capacity using the Meyerhofs approach.

Settlement Based Design

The prevalent subsurface conditions at the three barrage sites indicate that, the allowable pressure which may be applied to the barrage foundation will be governed by consideration of settlement, rather than of the shear strength of the soil. Therefore accurate prediction of the settlement of the structures founded on sands is very important. The settlement based design will be carried out using the following approaches:

i. Using SPT 'N' values
ii. Using CPT 'Cr' values

SPT 'N' Value

The Meyerhofs relationship as modified by Bowles (Ref.4.1) shall be used for determining net allowable foundation pressures 'qa'for 1 inch total settlement. The equations are as follows:

$$q_a = \frac{N}{F_1} K_d$$

B <F4

$$q_q = \frac{N}{F_2}\left(\frac{B+F_3}{B}\right)^2 K_d$$

B ≥F4

$$q_a = \frac{N}{F_2}$$

for rafts

N= field standard penetration test values

Kd= $1 + 0.33\frac{D_f}{B}$ ≤ 1.33

Df= depth of footing

Factors in ft

F1= 2.5
F2=4
F3=1
F4=4

CPT 'C' value

The cone penetrometer has proved to be a reliable tool for predicting settlements on shallow as well as deep foundations. Safe prediction of strength and relative density has also been made through this test.

Cone penetration tests shall be carried out at the selected locations as per ASTM 03441, BS 5930. The test is performed by pushing the standard cone (with a 600 point and base diameter of 36 mm with cross-sectional area of 10 cm2) into the ground at a rate of 10 to 20 mm/sec. Data collected is the static cone resistance (Cr or qc), which shall be used for estimation of relative density and angle of internal friction using correlations developed by Schmertmann (1978) and Robertson and Campanella (1983), (Ref.4.1) Fig. 4.2 and Fig. 4.3.

Schmertmann's relationship given below shall be used for determining the settlement. (Ref.4.2)

$$\delta = C_1 - C_2\,\Delta p \sum_{0}^{2B}\left(\frac{I_z}{E}\right)\Delta z$$

Where:

Δp= increase in effective overburden pressure at foundation level
Δz= thickness of layer under consideration
C1= depth embedment factor
C_1=1-0.5 $\left[\frac{p_0^{'}}{\Delta p}\right]$
$p_0^{'}$=initial effective overburden pressure at foundation level
I_z= strain influence factor (Fig. 4.4)
C2= empirical creep factor
$C_2 = 1 + 0.2\log_{10}\left[\frac{t}{0.1}\right]$
t= Period in years for which settlement is to be calculated
E= deformation modulus depending on the US ratio (Fig.4.4)
Cr=static cone point resistance in ton/ft2 or kg/cm2

Soil parameters shall be evolved from laboratory tests on "undisturbed "samples but more likely from SPT or CPT data obtained in the field.

The results of the above-mentioned field tests shall be judiciously used for predicting the ultimate bearing capacity of either shallow or deep foundations with much greater accuracy than using the results of routine laboratory tests only.

Curves selecting minimum of the above criterion will be developed for half of an inch, one inch and two inches total settlements, giving allowable foundation pressures Vs foundation sizes.

Deep Foundations

Wells/caissons shall be used as deep foundations so as to provide greater upward, downward and lateral bearing capacity as compared to piles because of their larger diameter. The following equations shall be applicable to the design of caissons in sands:

$$Q = Q_S + Q_b$$

$$Q_S = \sum \Delta L \, f_S \, A_S$$

$$Q_b = q_b A_b$$

Where

Q, QS and Qb are the ultimate loads for axial, skin and end bearing.
fs = friction between caisson and adjacent sand
As = circumferential area of the shaft
qb = unit ultimate end bearing
Ab = area of the base of the caisson

QS Shall be calculated by using the fs given by Reese (Ref.4.3) in the following form:

$$f_S = \alpha_S \sigma_V' \tan \emptyset$$

Where

α_S=a reduction factor for sand
σ_V=effective vertical stress
φ= soil friction angle

For caissons penetrating more than 7.6m but less than 12.2m as of 0.6 shall be used.

The ultimate shaft resistance shall also be estimated directly from field penetration tests. Following Meyerhofs expressions with an upper limit of 50 kPa shall be used.

$$f_s = \ddot{N}$$

$$f_s = f_c$$

$\ddot{N}$= average standard penetration blow count within the caisson embedment length corrected to an effective overburden pressure and

f_c= unit resistance of the friction sleeve for the cone penetrometer

The ultimate end bearing shall be estimated from bearing capacity factors and effective overburden pressure.

$$q_b = N_q \sigma_V'$$

Where following table shall be used for determination of Nq by Peck.(Ref.4.4)

Standard penetration Blow Count 'N'	**Friction angle φ**	**Nq**
10	30	18
32	33	26
30	36	37
40	39	55
50	41	72

The ultimate base resistance shall also be estimated from correlations given by Meyerhof.

qb= 120N

qb= qc

The ultimate lateral load resistance of intermediate fixed-headed caissons, for (1 <ηL <2) where l is the caisson length and

$$\eta = \left(\frac{\eta h}{EI}\right)^{0.2}$$

E= modulus of elasticity of caisson material

I= moment of inertia of caisson section

ηh= coefficient of horizontal subgrade reaction

Typical values of ηh as recommended by Terzaghi (Ref) are given in the following table:

kN/m³	ηh	
	Dry or moist	Submerged
Loose sand	940	1250
Medium sand	6590	4390
Dense sand	17560	10660

Shall be calculated using the expression:

$$P_{ult} = \frac{2M_P}{e+0.54\left(\frac{P_{ult}}{\gamma DK_P}\right)} ½$$

$Pult$= ultimate lateral load applied at a distance e above ground level
M= ultimate moment capacity of the caisson section
L= caisson length
D= caisson diameter
Y= unit weight of the soil
K_P= $tan^2 \left(45 + {}^{\phi}/_{2}\right)$
φ= the angle of internal friction of soil

A factor of safety of 3.0 shall be used for design.

G. Mechanical Design

General

The barrages under study are aged structures with ages ranging from 47 to 112 years, and so are their mechanical and regulation systems. The barrages and the main off-taking canal regulators are installed with vertical lift gates, radial gates or a combination of gates and drop shutters. The vertical gates are supported either through Fixed Wheel System or Roller Train System. Gates are designed to move vertically on the track fixed within the groove of the pier.

The gates' and hoisting mechanisms are in general badly deteriorated and will have to be rehabilitated/and replaced where beyond repairs. The Consultants will identify the defects and assess the present conditions/capabilities of the regulating gates system in detail and establish the needs for rehabilitation, remodeling or replacement of the systems or parts thereof including the most appropriate level of automation compatible with the needs, structure acceptability and maintainable operatability.

Type and Description

General

Radial type gates being used successfully for the various recently constructed barrages have been considered appropriate for new structures. Number of gates and their dimensions will be fixed during detailed design stage of the Project. The barrage gates will be in lowered position in order to retain the pond upstream and will be raised only at time of flood. The gates of the under sluices will be opened more frequently for removing the silt.

Operation

The gates will be raised and lowered by means of wire rope hoists. The machinery will be located at the top of the piers downstream of the bridge of the Barrage and Canal Regulator gates. For pond control, the gates shall be moved from the fully closed position to the fully open position with the low point of steel of the gate at Elevation to be fixed later. Matching gate stops shall be provided in the piers to prevent over travel of the gates, in the event of failure of the electrical controls to stop the gate.

Each gate will have its own electric motor and Raise-Lower contactor gear and in addition to the push button control sited at the contactor gear, arrangements will be made whereby contactors can operated by remote-control from one of the abutments, and extent of the gate opening also be known automatically. As a stand-by precaution, all gates will be fitted with hand operated gear.

Gate Features

In the case new structures to be installed with radial gates, the gates will be of all welded construction, except the gate arms, which will be site-bolted to the horizontal girders and trunnion assemblies. The arms of the end frames will frame into a trunnion hub assembly, which will transmit the gate loads through trunnion pin into yoke mounted on a concrete trunnion girder. The site thrust of the gate reaction resulting from inclination of the end frames will be transmitted directly to the concrete piers. Provisions will be made for setting and adjusting the trunnion shoes so that the axis of the trunnion hub assemblies when seated shall be brought to a true and common horizontal line. The side seal will be in contact with side seal steel plates embedded in the face of the concrete pier. The bottom seal will be fastened to the lower edge of the gate and will contact a steel sill beam embedded in the face of the Barrage or Canal Regulator crest. The side seals shall be set to a slight initial compression to ensure positive contact with the side seal plates. The bottom seal shall be compressed, as the bottom edge of the gate comes to rest on the sill.

Hoist Features

All the hoists would be identical for Barrage and Regulator gates. They will be wire rope hoists having two drums, each. There will be one motor per hoist. Each motor will be located over a pier, so that power is transmitted to one drum by a drive shaft. The drive shaft will be supported throughout its length by bearing pedestals located on a catwalk. Each drum will wind required number of corrosion resisting wire ropes spirally, thus minimizing the drum lengths. There will be a drum gear and pinion, with the remainder of speed reduction accomplished by a triple reduction gear speed reducer and a right angle worm gear unit. Limit or position sensor switches will be provided as required to implement the desired operation control for the gates.

CODES

AGMA American Gear Manufacturer's Association,
1330 Massachusetts Avenue, N.W.
Washington D.C., U.S.A.

AISC American Institute of Steel Construction, Inc.
400 N. Michigan Avenue,
Chicago, IL 60611, U.S.A.

ASTM American Society for Testing and Materials
1916 Race Street,
Philidelphia, PA 19103, U.S.A.

ASME American Society for Mechanical Engineers
345 East 47th Street,
New York, NY 10017, U.S.A.

Design Loads

The gate equipment shall be designed for the applicable loads described hereunder:

i. Dead Load

The dead load includes the weight of the components, machinery elements, equipment, protective devices and contained fluids. Eccentricity of loading shall be taken into account when the actual loading conditions are asymmetrical.

ii. Hydrostatic Load

Hydrostatic loads shall be calculated with a specific weight of 62.5 Ib/ft3 (1000 kg/m3) for fresh water. Components of gate subjected to water pressure will be designed for hydrostatic loads corresponding to the maximum differential pressure expected during the life of the Project.

iii. Buoyancy

The nominal buoyancy shall be calculated using the volume of the gate including any other equipment mounted thereon.

iv. Friction Forces

The friction forces considered in the design will be based on the applicable coefficients of friction taken from the following table:

	Maximum	Minimum

Corrosion-resisting steel on carbon steel, non-lubricated	0.50	0.10
Corrosion-resisting steel on carbon steel, lubricated	0.18	0.08
Rubber on steel	1.00	0.30
Fluoro-carbon on corrosion-resistant steel	0.15	0.05
Bronze on corrosion-resistant steel	0.50	0.15

v. Wind Load

Horizontal wind load of 30 Ibs/sq.ft., acting in any direction on the projected area of affected components, will be considered in the design.

vi. Seismic Loads

Seismic effect shall be calculated by applying a horizontal force resulting from the specified earthquake acceleration on all masses in any direction and adding the dynamic water loads to the static water loads acting on the gates.

vii. Live Loads

Walkway flooring shall be designed for a uniformly distributed load (UDL) of 100 Ibslft2 plus a superimposed concentrated load of the heaviest piece of hoisting equipment or sub- assembly. Stair treads and their fastenings shall be designed for a concentrated live load of 1000 Ibs. The catwalk shall be 3 ft. clear width and shall be designed for a UDL of 50 Ibs/ft2 plus a single movable concentrated load of 1000 Ibs.

viii. Thermal Loads

The thermal forces will be considered in the design of the components when temperature fluctuations relative to an assumed erection temperature would exceed 100 C.

A temperature variation of 50 C to 550 C shall be used for design of the components located periodically exposed and submerged respectively.

ix. Miscellaneous Loads

Loads due to changes in conditions of support, lifting and raising forces as well as impact will also be considered in the design of components thus affected.

Load Combinations And Conditions

The detailed design of equipment will be based on the following most critical loading condition applicable to major components.

i. Erection Conditions

Normal Loading

Equipment in any stage of erection subjected to applicable dead and live loads plus forces resulting from the erection procedures.

Exceptional Loading

Normal loading plus wind/earthquake effects.

ii. Operation Conditions

Normal Loading

Gates closed. Effects of the following loads shall be combined:

- Water load.
- Dead weight.

Gates being raised or lowered, at any point of travel. Effects of the following loads shall be combined:

- Water load.
- Dead weight.
- Rated hoist pull.
- All force components caused by friction, and other effects.
- Additional friction and/or blocking forces originating in the guiding devices and at the seals in contact, and having the magnitude required to match the rated hoist capacity.

Exceptional Loading

Exceptional loading conditions shall be obtained by combining each one of the normal loading conditions with the effect of one exceptional force component. The following exceptional combinations shall be considered:

- Water load.
- Earthquake effect.
- Exceptional operating forces, including maximum hoist pull, combined with any normal loading condition.
- Wind effect.

Working Stresses

i. Factor of Safety - Mechanical Components

A factor of safety not less than 5, based on the ultimate strength of material, will be used under normal loading conditions.

ii. Allowable Stresses

The allowable stresses for structural steel under normal loading conditions shall be those given in the AISC "Specifications for the Design, Fabrication and Erection of Structural Steel for Buildings" but shall not exceed the following:

Fy = Yield stress

Fu = Ultimate stress

Fa = Allowable stress

Type of Stress	Load Cases	
	Normal	Exceptional
STRUCTURAL MEMBER		
Bendino	0.60 Fy	0.80 Fy
Shear	0.40 Fy	0.50 Fy
Tension	0.45 Fy	0.50 Fy
Bearina pressure (machined surfaces)	0.80 Fy	0.85 Fy
Combined stresses	0.75 Fy	0.95 Fy
Bucklinq		
- AISC value	1.00 Fa	1.30 Fa
- Hertzian stresses Kg/mm2	0.55 BHN	0.60 BHN
MECHANICAL COMPONENTS		
For all mechanical components	0.33 Fy or 0.20 Fu	0.67 Fy or 0.40 Fu

	whichever are minimum

Gate Design

Gate Leaves

Gate leaves shall be designed by considering a vertical unit width of skin plate as a continuous beam with supporting haunches and modified end cantilevers. The flanges of the horizontal beams are the supporting haunches and shall be considered to have an effective width equal to the actual flange width for welded construction. The portions of the skin plate above the top beam and below the bottom beam are cantilevered sections supported laterally at frequent intervals by brackets welded to the horizontal beams. Those portions of the skin plate shall be designed as a series of rectangular plates with edges supported at the brackets, fixed at the horizontal beam bending. The skin plate is subjected to biaxial stresses resulting from skin plate bending and from horizontal beam bending. The combined stress shall be evaluated by means of Westergaard's criteria of failure for ductile material subjected to two-dimensional stress and shall be limited to the value given for combined stress under allowable stresses.

The horizontal beams shall be designed to resist the moment produced by the hydrostatic load on the continuous skin plate. Since the skin plate is attached to the horizontal beams, it adds to the. moment of inertia of the beam. The width of skin plate effective in resisting bending as a part of the horizontal beam area shall be considered as equal to 30 times the thickness of the skin plate.

Wheels and Tracks

In case of the design of vertical gates with wheels, adequate number of wheels shall be provided to take up the hydrostatic load and they should be symmetrically positioned about the vertical central axis of the gate.

The tracks shall be slightly crowned in order that the point of contact remains in the central portion of the track even though the side beams have rotated slightly due to the bending of the main beams. Hence the stresses should be analysed for point contact.

The wheel pins shall be designed for bearing, bending and shear. They may be supported at both ends within the gate frame or cantilevered out from a box.

The pin supports shall be designed for bearing and shearing forces.

Gate Hoists

Loads

The loads used in hoist design will include the following:

Suspended weight of gate including weight of hoist rope and fittings, trunnion friction, and side seal friction.

Rope tension due to hoist motor maximum torque. Maximum motor torque used for design purposes shall be the maximum torque which the motor can develop over its speed range with an impressed voltage equal to 112 percent of its rated voltage.

Suspended weight of the counter balance boxes in case of the design of vertical gates.

i. Efficiencies

Efficiencies of hoisting machinery components shall be assumed as no greater than the following:

Speed reducer with worm gear	90 per cent
Speed reducer (triple reduction)	95 per cent
Drum gear and pinion	95 per cent
Drum bearings	96 per cent
Wire rope efficiency at drums	92.5 per cent

ii. Operating Speed

The speed at the rope attachment will be approximately one foot per minute when half the amount of rope, from closed to normal full open position, is wound on the drums.

Gate and Hoist Loading Condition:

i Case 1: Normal Operating Condition:

Gate in lowered position either resting on sill or being lifted off pond at maximum Elevation. This case is considered a normal loading condition.

ii. Case 2: Earthquake Condition:

Gate in lowered position either resting on sill or being lifted off pond at maximum Elevation, earthquake forces acting downstream. This case is considered an exceptional loading condition.

iii. Case 3: Exceptional Operating Condition:

Gate in fully raised position, lower edge of gate clearing maximum water in pond. Wind load acting in either the upstream or downstream direction, whichever is critical. This case is considered an exceptional loading condition.

iv. Case 4: Jammed Condition:

Gate jammed at both sides. Pool at maximum Elevation. Rope tension caused by maximum motor torque, load divided equally between rope attachments. This is considered an exceptional loading condition.

v. Case 5: Emergency Condition:

A uniformly distributed live load of 100 pounds per square foot plus a superimposed concentrated load of the heaviest piece of hoist equipment of subassembly will be used to design the hoist machinery platform. Deformation of the hoist platforms will be limited to the amount which will limit the maximum gear misalignment to that permitted by AGMA (American Gear Manufacturers Association) Standards.

Working Stresses

Working stresses for the foregoing loading conditions will be as follows:

i. Structural Working Stresses:

Allowable working stresses for the design of the gate and its component members for the various loading conditions will be the percentages of the yield stress of the respective material used as shown in Table 5.1 below.

Table 5.1

Allowable working stresses

Allowable Working Stress	Percentage of Yield Stress		
	Loading conditions		
	Normal	Exceptional	Extreme
Tension (on net section)	50	67	75
Bending (tension and compression on extreme fibers of unsymmetrical members)	50	67	75
Bending (tension and compression on extreme fibers of symmetrical members).	55	73	75
Shear (on gross section of beam and plate girder webs)	33	45	50

Working stress values for welds and bolts may be obtained by multiplying comparable values in the AISC Specifications for the Design, Fabrication and Erection of Structural Steel for Buildings, 1967, by a factor of 83 per cent, to obtain allowable stress to be used for normal loading conditions. AISC values should be multiplied by 111 percent to obtain allowable stresses for exceptional loading conditions, and by 125 percent to obtain allowable stresses for extreme loading conditions. Combined stresses, where existent, shall be computed on the basis of the Hencky von Mises formula and will be limited to 75 percent of the yield stress of the material for any loading condition.

ii. Mechanical Working Stresses and Safety Factors

Mechanical parts will be designed for the loads described above using a factor of safety of 5, based on the ultimate strength of the materials used. The unit stress at momentary overload due to maximum torque of the motor will not exceed 85 percent of the yield point stress of the materials used except that rope tension at maximum motor torque will not exceed 70 percent of the bearing strength. All rope fittings and attachment of the rope will develop the full strength of the rope.

Machinery Design

Shafting

Shafting will be designed in accordance with Sub-Clause 1.1f (2) Mechanical Working Stresses and Safety Factors. A shock or fatigue factor of 1.25 will be used for shafting, except for speed reducers.

Anti-friction Bearings

Anti-friction bearings will be of standard design most suitable for the applications and shall have both inner and outer races. The bearing manufacturer's published ratings will be used in determining the bearing capacity. They will have a 8-10 life of 5000 hours, which is the number of hours (at a given constant speed and load) that 90 percent of a group of tested bearings will exceed before the first evidence of fatigue develops.

Gears

Gear design shall be in accordance with applicable AGMA standards.

Drums

The minimum diameter of the drum for winding the first turn of rope will be not less than 30 times the nominal rope diameter. The outside diameter of the drum flanges or spacers will be not less than the outside diameter of the final spiral wrap with gate fully raised, plus four rope diameters. With gate resting on the sill, there will be at least two complete wraps per rope on each drum.

Walkways and Catwalks

Walkway flooring will be designed for a uniformly distributed live load of 100 pounds per square foot plus a superimposed concentrated load of the heaviest piece of hoist equipment or sub-assembly. Stair treads and their fastening will be designed for a concentrated live load of 1000 pounds. The catwalk will be 36 inches clear width and will be designed for a uniform live load of 150 pounds per linear foot plus a single movable concentrated load of 1000 pounds. The catwalk structure will be sufficiently rigid to deflect no more than X inch under the above maximum live load conditions.

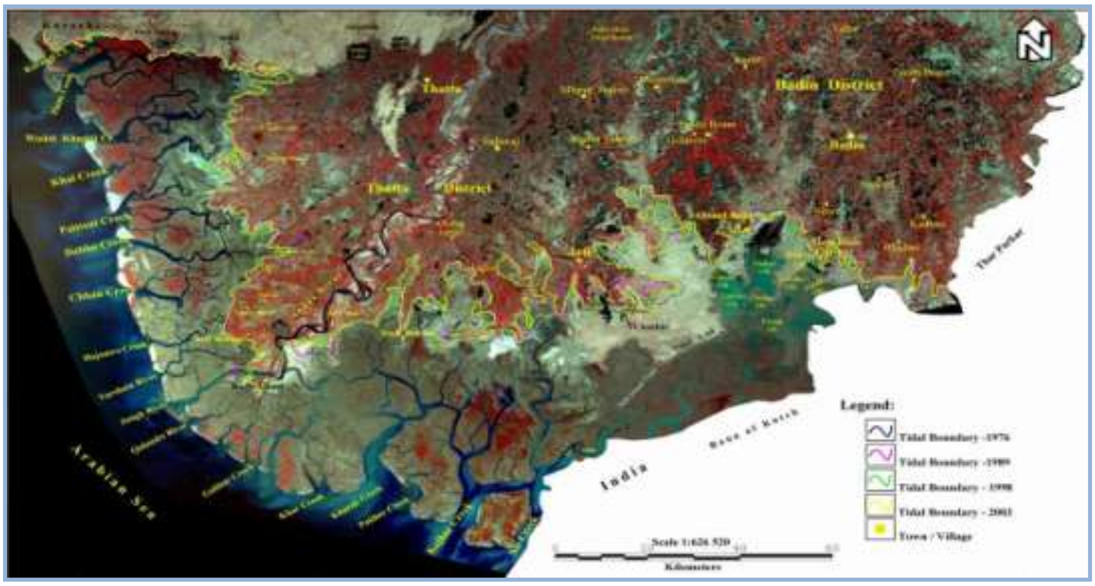
Hoist Platforms

The hoist platforms and catwalks shall be designed to suit the proposed equipment layout. All mechanical components will be supported directly on the structural members of the hoist platform. The hoist platform and catwalk gratings will be all welded construction and will be fastened to the steel supports by clips or fasteners. Hoist platforms will be tied down to pier concrete by means of anchor bolts designed to resist all possible loading casers. Hoist platforms will be designed to carry the specified live loads, dead loads, machinery loads, catwalk loads, and normal gate hoisting loads at the specified basic stress, including the effect of one gate fully opened and the adjacent gate resting on the sill. The platform will also be designed to resist the loads resulting from stall torque of the hoist motors together with dead and machinery loads. Deformation of the hoist platforms will be limited to the amount, which will limit the maximum gear misalignment to that permitted by AGMA Standards.

Annexure - III

SHORT OCEANOGRAPHIC DESK STUDY OF TIDAL LINK DRAIN, LBOD

NOVEMBER 2012



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EXECUTIVE SUMMARY

LBOD Stage I project was executed during 1984-1997 to relieve water logging and salinity of 1.27 million acres land in the area of Mirpurkhas, Sanghar, and Nawabshah Districts. The problem of water logging and salinity in the agriculture lands of Sindh is being addressed through adequate drainage and pumping of ground water by WAPDA. The area affected by water logging and salinity in Sindh include irrigated agricultural land of Sukkur and Kotri Command Area. Thus a main drain on the Left Bank of Indus River was constructed as a big national drainage project known as "Left Bank Out-fall Drain (LBOD). The lowering of water tables by the pumping of saline ground water to surface drains is only the first stage in removing the salt threat. As most of the drainage water is saline and cannot be reused for irrigation and has to be disposed away from cropped areas. The LBOD carries the waste / saline water flows into the Tidal Link Drain for final disposal to the Arabian Sea. The Left Bank Out-fall Drain (LBOD) project is serving an area of about 1.27 million acres of agricultural lands for providing drainage facilities for saline water.

The construction work on the Tidal Link Drain of LBOD was started during June 1995 and was formally commissioned in January 1996 carrying the saline drain waters from cropped lands to the sea (Sir Creek through Shah Samando Creek) through 41 km long inter-tidal open drain working on natural gravity gradient. It is a coastal engineering work which has virtually changed the direction of the natural flow of the drainage water in *Dhands* through Tidal Link Drain leading to the sea instead of its natural flow direction to Rann of Kutch. Seawater intrusion and high erosion / sedimentation has been noticed at the Tidal Link and adjacent areas due to changes in the hydraulic regime in the area. Further due to ravages of the recent tropical cyclone May (1999), the Tidal Link Drain and its adjacent areas experienced drastic morphological changes including re-opening of the old and natural drainage passage from *Dhands* to Rann of Kutch in South and South-westerly direction across the embankments of Tidal Link Drain.

This short desk study report describes the study on the following topics:

1. History of the Outfall System
2. Present Status of Tidal Link Drain (LBOD) & Dhands Areas by Using SRS & GIS Techniques
3. Cyclones in the Area
4. Review of Available Data

National Institute of Oceanography carried out the Hydraulic monitoring of Tidal Link Drain and its adjacent area including brackish water bodies called Dhands areas from 1992 to 2008.

- ✓ Metrological observations
- ✓ Tidal levels measurements in the Tidal Link Drain
- ✓ Tidal water currents measurements (Spring and Neap tide) to cover one tidal cycle, Flood and Ebb tide at different location in the Tidal Link Drain.
- ✓ Bathymetric survey of Tidal Link Drain and dhands.
- ✓ Continuous salinity monitoring in the Tidal Link Drain and dhands.
- ✓ Sedimentological study of Tidal Link Drain and its adjacent areas including dhands.

5. Recommendations for the Improvement of Eco-System of the Dhands

After construction of LBOD, it was not expected that the sea water will be penetrated more than 19 km from its outlet upstream into the Tidal Link and to an area about 11 km downstream of the Cholri Weir. But after Cyclone 2A in 1999 there is now an open connection between the dhands and the Tidal Link, exposing the dhands to tidal fluctuations, sea water intrusion, sedimentation, and excessive drainage during low tide. A small tidal creek type system of drainage channels has now developed in Cholri Dhand, which is closest to the Tidal Link. No tidal fluctuations are evident in Sanhro and Mehro Dhands.

During the July 2003 storm, Badin received 218 mm of rain and Nawabshah in the upper part of the LBOD basin received 191 mm. LBOD canals were overtopped and numerous breaches occurred, in part because farmers in the upper LBOD basin cutting the banks of the drains to hasten the drainage of rain water from their fields. Equally important, the discharge into KPOD and the Tidal Link Canal were more than twice the design discharge, resulting in severe scour of the Tidal Link Canal as well as breaches in both its right and left embankments. As a result local people have felt the LBOD outfall scheme increase the vulnerability of their already fragile livelihood system.

The present conditions of the outfall system do not provide the hydrological, environmental and social functions that were originally considered at the design phase. The LBOD can now be described as a **"New River"**(Moazzam, 2007 NIO) that is forming an estuary and is an integral part of creek formation into the coastal area. The Tidal Link has invited the sea to approach the land and now the tidal fluctuations are visible. This process will continue, and its progress is difficult to predict. Adapting to this new process requires continuous hydraulic and environmental monitoring in learning by doing approach.

The main problem concerning the LBOD Outfall is the "hydraulic gradient". The LBOD runs parallel to and at a lower level than the Indus River and has to discharge the saline water to the same level (sea level) in an active tidal creek area (i.e. Shah Samando Creek). As the level of discharge flow in the Tidal Link depends on the level of the water in the creek, which continuously varies with the stage of tide and other environmental factors. Therefore, the hydraulic performance of the Tidal Link Drain varies under the influence of prevailing environmental conditions such as the variations in tidal heights (water levels), tidal streams (tidal currents), sedimentation and Meteorological conditions, etc.

On the basis of the hydraulic monitoring carried out by National Institute of Oceanography on the Tidal Link Drain the following conclusions can be drawn:

- ✓ As the Tidal Link Drain has been severely damaged by the cyclone in May 1999 creating more than a dozen breaches in the embankment of the Tidal Link Drain have been formed. At many places the embankments have been completely washed away.
- ✓ There is now a free water exchange between the Tidal Link Drain, adjacent dhands and the Rann of Kutch due to creation of about two dozen breaches in the embankments of Tidal Link Drain between RD -38 to RD –93.
- ✓ The Tropical Cyclone (Cyclone “2A”, May 1999) has caused some drastic morphological changes in the area:
  - Creation of more than a dozen breaches in the Tidal Link Drain between RD -30 and RD –125. These breaches (openings) allow free exchange of water between the Tidal Link Drain, dhands and the Rann of Kutch.
  - The man made Cholri Weir at RD -55 has been washed away by the cyclone.
  - Re-opening of the natural passage (through several breaches in the Tidal Link Drain embankments) between dhands in the area and Rann of Kutch which was earlier blocked by the Tidal Link Drain.
  - Unification of all major (brackish water) dhands in to one large seawater body during High Waters particularly during May to August period.

- ✓ The present situation has altered the hydraulic regime at the Tidal Link Drain and adjacent inter-tidal area such as:
  - The present study shows on increased risk of seawater flooding into the KPOD via the Tidal Link Drain during high tides and for future cyclonic events. This situation has increased the influence of seawater in KPOD and hence slightly increased the risk of seawater inflow into KPOD up to RD +2.
  - The water flows and water exchange now more frequent between dhands, Tidal Link Drain and the adjacent Rann of Kutch.
  - Due to extensive damage the seawater influence has increased many folds within the Tidal Link Drain and Dhands. The marked seawater influence can now be traced up to RD +2 and beyond instead of RD -50 / RD –55 within the Tidal Link Drain during pre-cyclone period.
  - **The effective length of the Tidal Link Drain for discharges from LBOD has now been reduced to RD -38 due to several breaches in the embankments during most part of the year particularly during Southwest monsoon.** Most of the drain water discharges from LBOD through KPOD into the Tidal Link Drain at RD -38 does not reach its at the end of Sir Creek (i.e. RD –155).
  - The presence of a number of breaches in the Tidal Link Drain has resulted in complex and slightly abnormal behavior of the Tidal currents in the area particularly during southwest monsoon period.
- ✓ During the winter season (November through February) the LBOD is still functioning to carry the saline drain waters to the end of Tidal Link Drain (RD –93 and RD –125) for final disposal to the Arabian Sea. This is due to the reduced hydraulic pressures/resistance from Tidal inflows during the winter season (i.e. November through February period).
- ✓ During Southwest Monsoon (Mid April to June) there is overall residual water inflow to dhands and to KPOD instead of the residual flow to sea. However, the normal situation is restored back to normal during most part of the year with natural flow towards the creeks with the arrival of run-off from the land in the rainy season (July-August).
- ✓ During most of the year except winter the water discharges from LBOD are now restricted to the low waters only and the drain also carries water discharges from dhands in the area.
- ✓ The breaches in the embankments of the Tidal Link Drain and a marked increase in seawater influence in the drain are likely to hinder the smooth drainage of agriculture saline water from LBOD to the Arabian Sea.
- ✓ Between RD -55 and RD -95 the embankments of the drain were found breached at a number of points at both sides of the Tidal Link Drain. The water was seen flowing out of the embankments through these breaches. The depths within the Tidal Link Drain have changed drastically. Huge quantity of silt and mud appear to have been deposited at many places within the drain due to accretion along with erosion at different nearby points. This situation has changed the entire depth profile of the Tidal Link Drain, which now stands altered drastically with reference to its designed depth. The comparison of the depth. The data shows the depth before cyclone -2A 1998 and the present situation of the Tidal Link Drain from RD -154 to RD-100 a huge quality of siltation. In the middle of the Drain a rapid erosion and again siltation. This situation shows a connection between that Dhands and the Tidal Link Drain in the middle of the Drain.
- ✓ The observations on the water currents at RD –22, RD 30 and RD –38 demonstrate the drastic increase in influence of seawater build up during stronger Ebb and Flood tides at these sites. This situation is likely to increase erosion tendencies in the Tidal Link leading

to breaches and new hydraulic regimes in the area particularly during July – September period, which is the period of strong, summer monsoon (South-west monsoon) in this region.

- ✓ The observations on the water currents at RD –93 indicate the expected increase in influence of seawater build up during stronger Ebb and Flood tides at this site. The situation is likely to increase erosion tendencies in the Tidal Link and adjacent areas particularly during the period of strong summer monsoon (Southwest monsoon) in this area. The results are comparing from 1993 to 2007 in SW-Monsoon (June/July) and NE-Monsoon (December/January) at different RD's. The result shows the SW-Monsoon current velocity at RD -125 are very much stable as compare to RD# -93 the current velocity are continuously increasing because due to the erosion factor as indicated above.
- ✓ The influence of seawater has increased and it could be traced up to RD –22, RD +2 and beyond. The situation has increased the erosion of embankments and at the bed of the Tidal Link and adjacent areas particularly during the period of strong summer monsoon (Southwest monsoon) in this area.
- ✓ Visual observations in the field indicates creation of several breaches in the right and left banks of the Tidal Link Drain down RD -38 which provide extensive water exchange between the Tidal Link Drain Dhands and Rann of Kutch.
- ✓ The yearly average salinity variation at Shah-Samendo creek, RD-125, RD-55, RD 0 and RD+26 are documented for the period 1993 to 2007 and the result show that the salinity values are going back to its normal values before cyclone 2A. The increasing trends only look in the year 2000 to 2003 the fall started after 2004. The changes of bathymetry in the Tidal Link Drain have further promoted the influence of seawater in the Tidal Link Drain. The salinity profile in the Tidal Link Drain is compare from 1999 to 2007. The NE and SW monsoon variation are also presented graphically. The SW-monsoon values are on higher side as compare with NE-monsoon period.
- ✓ The high saline sea water from Shah Samando Creek which previously had direct access up to RD -125 and RD -95 has now extended its direct access up to RD -38 and beyond.
- ✓ The high water salinity in the Tidal Link Drain in December 2001 is most probably due excessive evaporation in dry period. In addition it is due to the increased water exchange between high salinity waters in the creeks, and adjacent Dhands. As the embankments of the Tidal Link Drain have been washed away at several places, this situation has allowed free exchange of water with the adjacent Dhands, and with the high salinity waters at Rann of Kutch during high tides. As a consequence the high saline seawater from Shah Samando Creek that previously had direct access up to RD -125 and RD -95 appears to be extended up to RD –22.
- ✓ These erosion and accretion observed at the Tidal Link Drain demonstrate that there is different water in flow and out flow points, which have resulted in complex current patterns and were flows. While the weaker water currents caused accretion due to a mix up of water in flows and out flows from a number of breaches in Tidal Link Drain of the 'Cyclone 2A'.
- ✓ The present study on the Ebb and Flood currents and water level variations suggests that the extent of Tidal influence in the Tidal Link Drain is noticeable significantly all along the length of the Tidal Drain. However, RD -21 site exhibit the minimum tidal fluctuations. The influence is noticeable up to RD +2. At RD -22 and beyond the tidal fluctuations are prominent.

- ✓ There is a net outflow of about 20 m3/Sec of drain waters from KPOD to the Tidal Drain and on its way collects drain waters from Serani Drain it reaches 55 m3/Sec at RD -30. By the time it reaches to at RD -38 it is already under hydraulic resistance for downward flow because of the two Flood Tide water's per day. On the other hand the two Ebb waters per day accelerate the downward flow of drain waters in the Tidal link Drain. Therefore, the resultant flow of water is dependent on the speed of water currents during Flood and Ebb Tides in the Tidal Link Drain. As the Ebb Tidal Currents are stronger, therefore there is a net flow out to the sea.
- ✓ As an impact of cyclone the intensity of water flows as well as, water exchange rate have been altered and also influenced the water discharges from the LBOD in the area. The water discharges at RD –22, RD –30 and RD –38 now represent the true picture of discharges from LBOD while the observations recorded from other points (i.e. RD –93 and RD –125, RD –155) do not represent the water discharges from LBOD as the water exchanges occur with adjacent dhands and creek waters due to the several breaches in the Tidal Link embankments. At present, the observations at RD –22 represent the discharge values of LBOD as the chances of water inflow during High Water from the Breached Tidal Link are minimized at this point.
- ✓ There is a clear indication that breaches in the embankments of the Tidal Link Drain due to the impact of Cyclone "2A" have restored the old gravity gradient and a complex hydraulic regime in the area. This has resulted in increased hydraulic pressures in the Tidal Link Drain leading to hindrances in the discharges of the Agriculture Saline Drain waters from the LBOD / KPOD to the Tidal Link at RD -22.
- ✓ The average net discharge of 54.05 m3/s was observed at RD –00, 174.00 m3/s at RD–38 and 369.59 to 993.11 m3/s at RD –93. As there are several breaches at Tidal Link after RD –38 therefore any assessment of water discharge at the Tidal Link beyond RD –38 does not reflect the true Discharge from LBOD. Considering the fact that water discharge at RD –38 is largely influenced by the seawater tidal flux the actual discharge of water from the tidal link is assessed to be 54.05 m3/sec as recorded at RD 0.
- ✓ The effective length of the Tidal Link has been reduced up to the point at the first breach in its embankments (RD –38) and it is still functioning up to that point. Beyond RD –38 there is an exchange of water over a Tidal Cycle between various dhands, water from KPOD and seawater from Shah Samando Creek and also from Rann of Kutch. This complex water exchange at RD –93 and patterns is partially reflected in the high net discharge of water at RD –93. At this point the discharge from KPOD gets thoroughly mixed up with the water from adjacent dhands and water from Rann of Kutch at RD –93 and does not represent the discharge from LBOD at this point. Therefore water discharge values at RD –00, RD –22 and RD –38 represent the actual situation.
- ✓ The discharge of salts from the Tidal Link Drain is assessed to vary between 13-42 ppt at RD 0, 22-42 ppt at RD –38 and 42-53 ppt at RD –93 during the report period. The values at RD 0, represent the true discharge of salts from KPOD. The discharge of suspended solids from the Tidal Link Drain was 470 ppm at RD –00, 850 ppm at RD –38 and 666-2521 ppm at RD –93 during the report period. The gradual increase in suspended solids down the Tidal Link Drain represents contribution of suspended solids from the creeks and adjacent areas.
- ✓ Sources is the Rann of Kutch, and it seems quite likely that water from the Rann of Kutch passing through the Tidal Link into the dhands, in the absence of large freshwater flows into the dhands, is a major influence on the very high levels of salinity observed between

1999 and 2007 in both the Tidal Link (above that of seawater) and the dhands. Satellite imagery often shows the northwestern portion of the Rann of Kutch to be without water in the dry season, but recent imagery shows that there are many points along the length of the Tidal Link where hyper-saline water from the Rann of Kutch and Sir Creek can enter the Tidal Link.

- ✓ During most of the year, particularly during Southwest monsoon, the effective length of the Tidal Link Drain for discharges from LBOD has now been reduced to about 4 km - from KPOD downstream to a point where the first large breach in the Tidal Link occurs adjacent to Pateji Dhand. Most of the LBOD discharge into KPOD and then into the Tidal Link Drain does not reach its intended end at the coast in Shah Somando Creek.
- ✓ The influence of higher salinity water including seawater and water from the Rann of Kutch has increased within the Tidal Link. The marked influence of high salinity in the Tidal Link can now be traced several km upstream within KPOD to a point above where the Serani Drain joins KPOD, instead of a point close to but below Cholri Dhand before the cyclone.
- ✓ Over most of its length, the Tidal Link has become a large mixing bowl, including where it passes through the dhands, with water moving upstream in the Tidal Link during flood tide and mixing freely with the water of the Rann of Kutch, KPOD and the dhands.
- ✓ The natural passage between dhands and the Rann of Kutch, previously blocked by the embankments of Tidal Link Drain, is now reopened.
- ✓ With the destruction of the Cholri Weir and the opening of many large breaches, water flows and water exchanges are now more frequent between dhands, Tidal Link Drain and the adjacent Rann of Kutch.
- ✓ The natural drainage pattern from Badin through the dhands to the Rann of Kutch has now been re-established. The difference is that seawater moving in the system at flood tide is now a part of the mix, but this does not appear to be the dominant influence on salinity in the dhands.
- ✓ Drainage from the dhands to the tidal link at ebb tide is strong, and a visible drainage network (having the appearance of a typical tidal creek) has formed in Cholri Dhand and to a lesser extent in Pateji Dhand.
- ✓ One of the most important indicators of the status of the dhands is the level of salinity. While a number of factors such as pH, temperature, conductivity, dissolved oxygen, turbidity and pollution, influence may strongly influence on ecosystem, it is salinity or the range of salinity that largely determines types of flora and fauna that can survive and hence the type of ecosystems that may exist and the types of functions the dhands could support. The period over which monitoring data is available present a picture of extraordinary variability.
- ✓ In 1997 the average salinity was brackish but at levels that would support species adapted to these significant but low salinities such as one finds in an estuary. The upper limits of the range of salinity in Cholri and Pateji Dhands were closer to levels more favorable for marine species. The very high salinities in Pateji Dhand reflect the cut-off of drains that once flowed into this dhand (Serani and KPOD), low circulation because there is only a weak connection to Cholri Dhand, and high evaporation.
- ✓ After the cyclone in May, 1999 as noted above, the dhands were openly connected through numerous breaches in the Tidal Link embankments to the Tidal Link which had become more strongly saline, and to Rann of Kutch where salinity was typically greater than that of sea water (which averages about 33 ppt along the Sindh coast). The salinity of the

dhands became elevated to levels above seawater, at least in the dry season when observations were made, and remained so from 2001 to 2003.

- ✓ The marked increase in salinity shown in the Tidal Link profiles and in the dhands cannot attributed to seawater since the salinity of the Arabian Sea near Shah Somando Creek averages about 33 ppt. No studies have been carried out to estimate the proportions of different sources of water that presently from the mixture in the Tidal Link near Cholri and Pateji Dhand, most saline water.
- ✓ The average salt discharge from the Tidal Link Drain (with seawater influence) was calculated to be an average of about 1600-ppm (400-2200 ppm) at RD -93. The average value of Suspended load at RD -22 was about 58 ppm (22 - 95 ppm). It is very clear that the discharge of suspended matter from the KPOD to the Tidal Link Drain is negligible in comparison to the suspended matter reaching the Tidal Link Drain from dhands and run-off from land which enters the Tidal Link Drain from a number of openings (breaches) created by the Cyclone "2A".
- ✓ It is therefore concluded on the basis of the available data that the hydraulic performance of the Tidal Link Drain has been reduced considerably and its effective length to carry Agriculture Saline Discharges to Shah Samando Creek have reduced upto RD –22 and RD -38 instead of RD –125 and RD -155 as per original design.

1 History of the Outfall System

1.1 The LBOD Stage-I Project

The area served by Left Bank Outfall Drain (LBOD) was proposed by the Government of Pakistan because of the acute problems of salinity and water logging which was severely affected the productivity, income and livelihood of the population living in this area. The Badin District in the lower LBOD basin consists of extremely flat land that is traditionally exposed to extensive inundation during heavy rain because of low infiltration rates and slow runoff (this condition prevails to a somewhat lesser degree in many areas of the upper basin as well). The natural drainage is also impeded in the monsoon season by the high tides and extensive flooding of the coastal zone, which is the natural outlet for this slow and shallow overland flow. The upper basin of LBOD, Nawabshah, Sanghar and Mirpurkhas Districts in central Sindh Province receives irrigation water from the Indus River by means of the Sukkur Barrage and the Nara and Rohri canals.

The purpose of the LBOD scheme was to relieve water logging by lowering the water table and to remove saline water from this irrigated area. The LBOD Stage- I project provided drainage tube wells and tile drains to lower the water table and collect saline water as well as new and remodeled surface drains to collect and transfer this saline water to a spinal drain. The accumulated discharge of the spinal drain was connected downstream to two older drains Kadhan Pateji Outfall Drain (KPOD) (a drain built to collect saline discharge from numerous small drains in the Kotri basin of eastern Badin District and to carry this drainage discharge into Pateji Dhand and the Rann of Kutch); and the Dhoro Puran Outfall Drain (DPOD) (an old natural channel thought to be a remnant of an ancient Indus River channel that flowed into Shakoor Dhand near the Rann of Kutch). This brought the brackish and in some cases saline agricultural drainage water of

LBOD Stage-I Project to the edge of the coastal zone – a wide, flat plain consisting of mud and partly salt encrusted flats, shallow depressions some of which are lakes perennially filled with brackish to hyper-saline water, and a zone of active tidal creeks that connect this plain to the sea. Shakoor Dhand and the Rann of Kutch lie at the Indian-Pakistan border. The Sindh dhands (lakes) lie entirely in Pakistan and are generally connected to the Rann of Kutch especially at high tide.

Since the 1960s, when the Kotri Basin drains (which lie west of the LBOD basin) were built to discharge into the dhands they have become an important local fishery, and a waterfowl habitat of international importance. Portions of two of the Sindh dhands (Sanhro and Mehro) have been declared Ramsar sites, and the Rann of Kutch, which also contains a large Ramsar site partly in Pakistan, is included on the WWF list of the 200 globally most important biodiversity hot-spots. The natural pattern of surface drainage and overland flow, especially of storm runoff, from this coastal and near-coastal zone in Badin District is south and southeastward towards the Rann of Kutch.

To avoid discharging LBOD through KPOD directly into this environmentally sensitive wetland, a TIDAL LINK DRAIN was built 42 km southwestward across the dhands and the Rann of Kutch from KPOD to the nearest active tidal creek, Shah Samado Creek. The Tidal Link Canal was isolated from the Rann of Kutch and the dhands by high embankments. An 1800 ft weir, called the Cholri Weir, was built where the TIDAL LINK DRAIN passes through Cholri Dhand in order to attenuate high water levels in the TIDAL LINK DRAIN during high tide by allowing water to flow into the dhands during this period, and to protect the Dhands from excessive drainage during low tide when the water would flow back into the TIDAL LINK DRAIN.

Since sea water was not expected to come closer than about 11 km downstream of the weir, the negative effects of the intrusion of the much more saline sea water would also be minimized. The outlet works of LBOD thus consist of the Dhoro Puran Outfall Drain (DPOD), which discharges through the Dhoro Puran natural channel into Shakoor Dhand, the enlarged KPOD drain, the TIDAL LINK DRAIN connected directly to the sea, and the Cholri Weir. The LBOD and DPOD are shown in Figure.1.

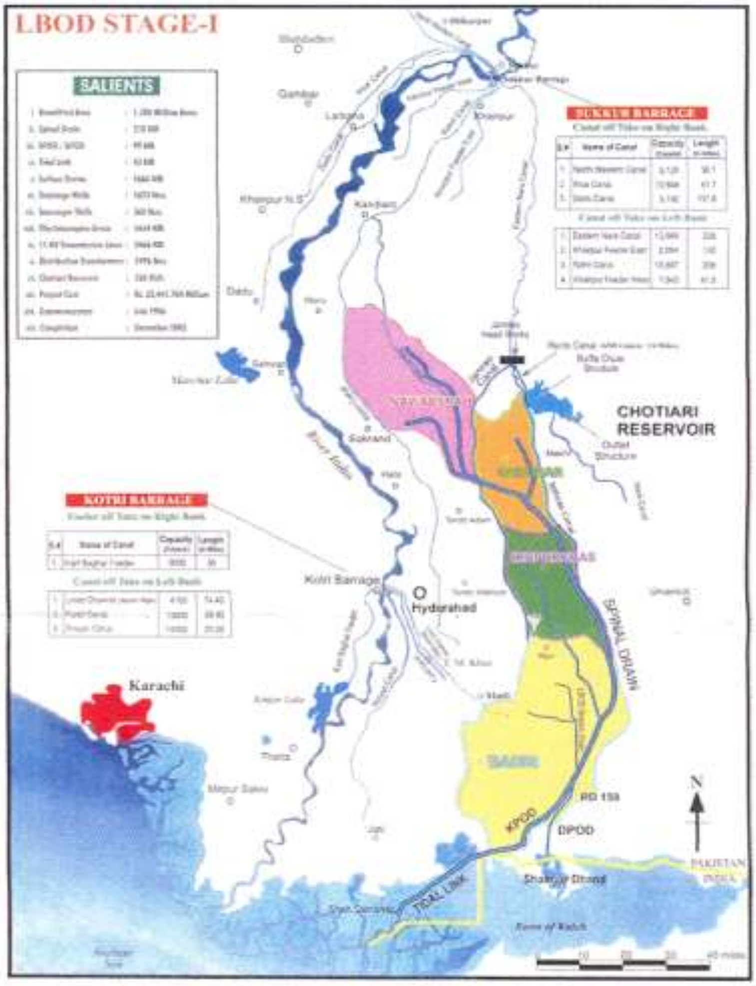


Figure 1: LBOD, DPOD and Tidal Link Drain Discharge System

1.2 The National Drainage Program

The National Drainage Program (NDP) was launched in 1998 to improve the efficiency of the irrigation and drainage system in Pakistan. NDP was deliberately “frontloaded” with institutional and policy reforms and "backloaded" with an investment program. NDP represented a major change in the water resources development strategy in Pakistan by shifting the priority from physical interventions to emphasize the need to improve management of the existing infrastructure. NDP financed the completion of irrigation improvement works including the remodeling of the Nara and Jamrao irrigation canals, and water course improvements including lining and precision land leveling. Numerous existing drains and drainage structures in the LBOD and Kotri basins were rehabilitated to take care of the deferred maintenance, and operation of the drainage tube wells. At the request of the Government the Bank organized a Panel of Experts to provide recommendations for the implementation of the Plan. At sub-project level Environmental Scoping and Screening Procedure was developed and applied to all NDP investments. This Procedure played a major role in steering NDP investments away from environmental sensitive areas and costly land acquisition problems. Although the World Bank components of NDP have been completed, the (JBIC) and Asian Development Bank (ADB) components have been extended. In particular, with ADB assistance the long delayed implementation of the LBOD Environmental Management and Monitoring Plan (EMMP) is about to be implemented. Substantial progress was made under NDP to increase the participation of farmers in the operation and maintenance of the irrigation and drainage system.

LBOD drain passes through the eastern part of Badin District and discharges to the KPOD and DPOD spinal drains. The eastern portion of Badin District, which encompasses the coastal zone – namely the *Talukhas* of Badin, S.F. Rahu and Tango Bago – suffered prolonged flooding and extensive damage during the July 2003 storms.

The Cholri Weir was constructed in the right bank of the Tidal Link Canal where it crossed the dhands to prevent damage to this area that could be cause by tidal fluctuations. Within months of the completion of the weir, erosion around the structure became evident. Despite attempts to repair this damage, monsoon storms in 1998 and 1999 led to the complete destruction of the weir due mainly to scour of its foundation and erosion of its abutments.

Upstream, LBOD's canals were designed to carry the relatively modest quantities of agricultural subsurface drainage with about 4 ft of freeboard. Design criteria assumed that these drainage sources would be cut off (tubewells and tile drain sump pumps would be turned off) so that the canals would be free to carry runoff from rainfall. However, the design criteria provided an available capacity to drain 125 mm rainfall of 5 days duration. During the storm of the July, 2003, Badin received 218 mm of rain and Nawabshah in the upper part of the LBOD basin received 191 mm. LBOD canals were overtopped and numerous breaches occurred. It was also observed that the farmers in the upper LBOD basin were cutting the banks of the drains to hasten the drainage of rain water from their fields. During the same period, the discharge into KPOD and the Tidal Link Canal were more than twice the design discharge, resulting in severe scour of the Tidal Link Canal as well as breaches in both its right and left embankments.

1.3 Study Area

The Tidal Link drain, is a man made drain which will deliver the drainage water across Pateji Dhand and Cholri into the Arabian Sea via Shah Samando Creek. The Tidal Link is 41km long from its point of juncture with KPOD in the North-east upto the Shah Samando Creek in the South-west. The vertical tidal range in the area is about 5 m. The Tidal Link is designed to carry about 3,118 Cusecs of drainage waters. The tidal Link alignment passes across Pateji and Cholri Dhands which are interconnected with Mehro and Sanhro Dhands filled with brackish / saline water and support a diverse ecosystem, fisheries and sanctuary of migratory birds. The excess water from these Dhands has historically drained into the Rann of Kutch which is now blocked by the Tidal Link.

The earthwork on the construction of Tidal Link Drain was completed by WAPDA during 1995 and the Tidal Link was finally commissioned in January 1996. With the operation of the Tidal Link Drain a number of issues concerning the water movements, flow rates of saline water and its impact on Dhands and on the adjacent coastal wet lands and sea areas are being raised by different quarters. The Tidal Link Drain does not pass through any agricultural lands the issues concerning water movements relate to the discharge quantities, net water discharges, changes in tidal behaviour, extent of the influence of sea water upstream of Tidal Link Drain, erosion of embankments, changes in water salinity profiles of Dhands and Shah Samando Creek, contribution of Cholri weir in maintenance of a water balance and water quality in Dhands.Study area is show in the Figure 2.

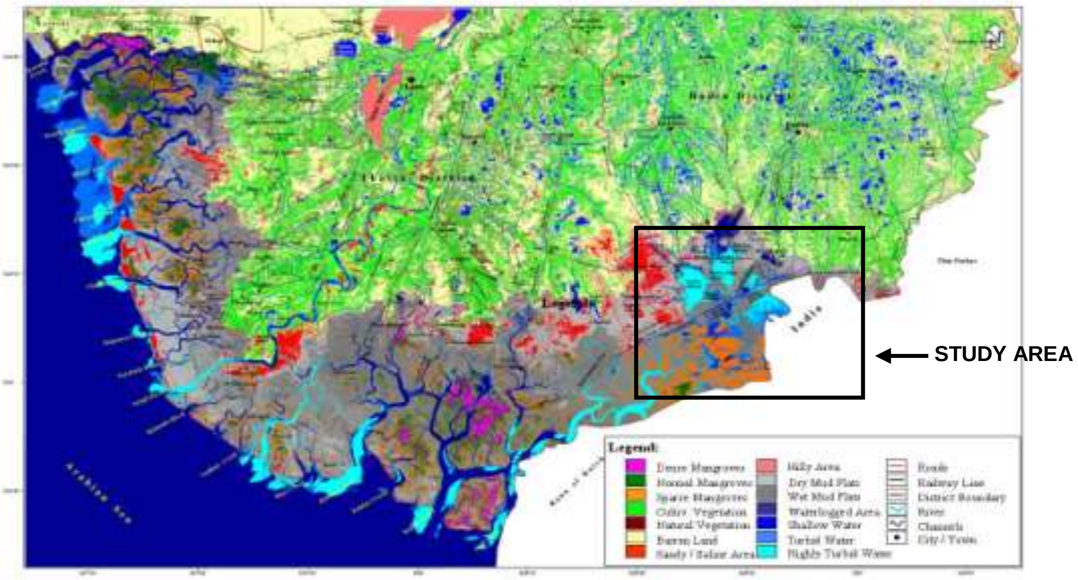


Figure 2: Location Map of The Study Area

2 Present Status of Tidal Link Drain (LBOD) & Dhands Areas by Using SRS & GIS Techniques

(JOINT RESEARCH STUDY CARRIED OUT BY NIO AND SUPARCO SCIENTIEST)

The present conditions of the outfall area are quite different from the ones observed when LBOD outfall system was in the stage of preparation and before it started operations. The area, key changes are now recognized in the topography, bathymetry and cross sections of the Tidal Link and the KPOD. There are also important deviations from the original project estimations of the salinities, velocities and water levels at several places. It is noted that the upstream LBOD's canal system is badly damage due to heavy rain in the area. There is now an open connection between the dhands and the Tidal Link, exposing the dhands to large tidal fluctuations, sea water intrusion, sedimentation, and excessive drainage during low tide. A small tidal creek type system of drainage channels has now developed in Cholri Dhand, which is closest to the Tidal Link. The Tidal Link Canal bed and banks were constructed with the soil obtained from the canal excavation and consisted mainly of silty loam in which scour and erosion processes are highly sensitive to flow velocity. These analyses determined that tidal fluctuations would be felt all the way up to the Tidal Link Canal from Shah Samando Creek to a point somewhere near the terminus of KPOD, but sea water was not expected to penetrate more than 22 km upstream to an area about 5 km downstream of the Cholri Weir, the main connection between the Tidal Link and the dhands.

Satellite Remote Sensing (SRS) data due to its repetitive and synoptic nature has proved to be extremely useful in providing information on various components of the coastal environment, viz., coastal landforms, mangrove forests, shoreline changes, tidal boundaries, brackish water areas, suspended sediments, etc. Use of SRS data, in conjunction with GIS enables such changes to be monitored, mapped and analyzed in a timely and accurate manner, and has found to be extremely useful in providing information on marine/ coastal environment. Landuse / landcover thematic maps of the study area based on multi-temporal SRS data have been prepared. The multi-temporal SRS data acquired in different time frames from 1989 to 2005, have been analyzed for monitoring the geomorphological changes, the coastal processes, and intrusion of seawater in the Indus Delta Creek System and its impact on land area, as well as on Tidal Link drain and on Dhands areas.

2.1 Landsat TM Image of 21st October 1989

Landsat TM image of 21st October 1989, prior to construction of Tidal Link, is shown in Figure 3. From this image, it is observed that most of the area is covered with cultivated or permanent vegetation. Patches of waterlogged areas in upper part of study area are very prominent and clearly indicate poor drainage system existing in the area. Some of the irrigation canals / drains feed the dhands lying in the area. Almost, all of the dhands namely: Talwar, Jhim, Kajari, Gadap, Baghari, Narahi, Mehro, Sanhro, Sandho, Pateji, Bakradi, Bakrar, Sinatry and Shakoor Dhands are clearly visible and identifiable in this image with their spatial extent. These dhands are very prominent features of the coastal belt of Sindh. Some dhands, though covered with thick vegetal cover (with brownish red colour) are identified by the presence of water underneath. At the location of Tidal Link, the area is marshy and covered with huge inter-connected waterbody comprising Mehro, Sanhro, Sanhro-Mehro, Cholri, Pateji and Khadi Dhands. Landsat TM image of October 1989 has been classified into different landuse / landcover categories. The Landuse / landcover thematic map of Tidal Link and dhands areas based on Landsat TM data of October 1989, with networks of irrigation canal / drainage and road; and boundaries of creeks and towns / villages exists in the study area is shown in Figure 3.

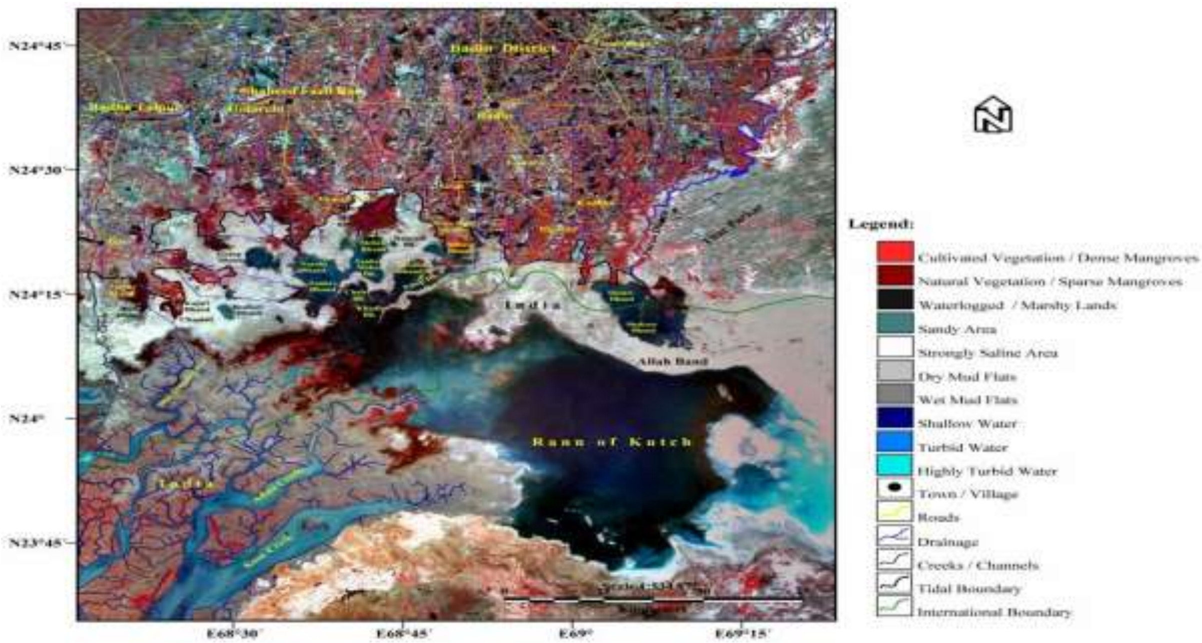


Figure 3: Satellite image of Badin district, based on Landsat TM data 21st October 1989- Prior of construction of Tidal Link.

2.2 Landsat TM Image of 30th October 1998

The Landsat TM image of 30th October 1998, after completion of Tidal Link, is shown in Figure 4. Tidal Link is a very well pronounced linear feature in this image, passing through the Mehro, Sanhro, Sandho, Cholri, Khadi and Pateji inter-connected dhands. After three years of completion of Tidal Link, a significant change has been observed in the lower Indus plain. The total vegetal cover in the land area has been increased, when compared with the Landsat TM image of October 1989, i.e. after a span of 9 years. The LBOD Project demonstrates the effective role in tackling waterlogging and salinity in Badin District, as compared with October 1989 image. It has increased the cultivable areas, as well as increased the crop productions. Additionally, some decrease in waterlogged / stagnant water area is also observed in 1998 image. The extent of dhands areas appear to have decreased in 1998 compared with 1989 image, especially in Baghari, Gadap and Bakrar Dhands. A significant reduction in the extent of water in Sinatry and Shakoor Dhands has taken place, mainly due to reduction in supply of water from Dhoro Puran. Growth of natural vegetation in the upper part of Narahi and Mehro Dhands is seen in 1998 image. After three years of completion, the Tidal link has experienced a breach at the southeastern part of Cholri Dhand, shown in Figure 4.

Figure 4: First breach occurred just after the construction of the Tidal Link Drain

The natural vegetation / swamps as seen at the location of the Tidal Link in 1989 image have been disappeared in 1998 image. A huge water body in the southern part of Cholri, Kadhan and Pateji Dhands has shrunk as compared with the 1998 image. After the construction of Tidal Link drain, the water coming from irrigation canals / drains to Cholri and Pateji Dhands to Kadhan Dhand and then to southern part has been stopped due to Tidal Link, and appears as wet mud flats. The Landuse / landcover thematic map of Tidal Link area with GIS layers based on Landsat TM data of October 1998, is shown in Figure 5.

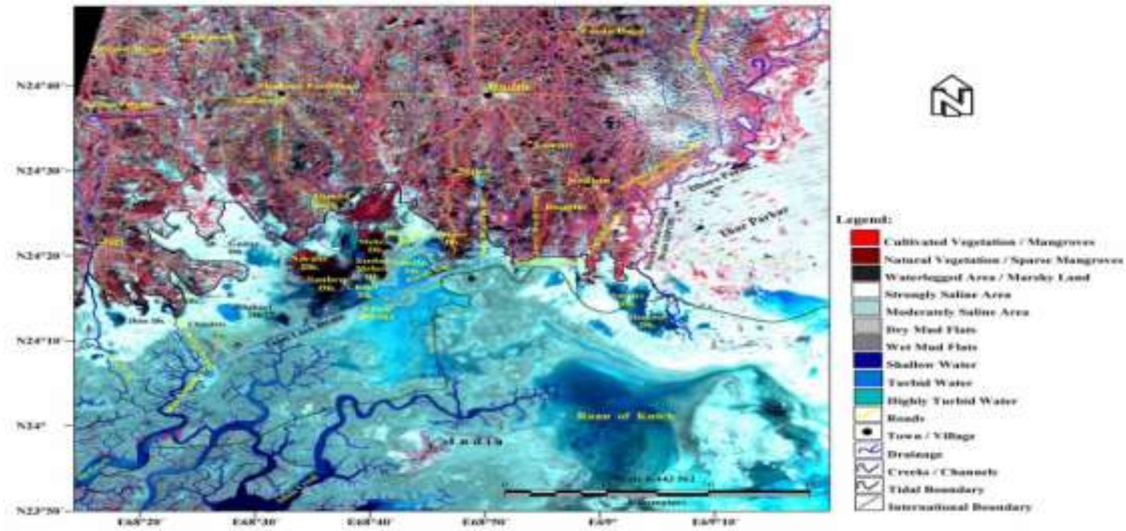


Figure 5: Satellite image map of Tidal Link – LBOD area (District Badin), based on Landsat TM data of 30th October 1989.

2.3 Landsat TM Image of 3rd February 1999

Landsat TM image of 3rd February 1999 represents the satellite image prior to Cyclone TC – 02A (which occurred on 20th May 1999), is shown in Figure 6. In this image some reduction in biomass is observed in landward areas, when compared with Landsat TM images of October 1989 and 1998, which may be due to different cropping season. The February 1999 image pertains to Rabi season and Rabi-wheat crop is prominent in this image. Since the Badin District is a paddy growing area and the area is good for cultivation of rice, sugar cane and other fruit crop like Banana, which required more water. The waterlogged area has been reduced and only permanent waterlogged and saline / barren areas still exist. The extent and number of dhands appear to have remains same as appear in 1998 image, but reduced as compared with image of 1989**.**

Extent of water in Sinatry and Shakoor Dhands is almost same as during October1998 image. Water in the Cholri Dhand has reduced and at the south-eastern part of Cholri Dhand, disintegration in the northern embankment of Tidal Link has been seen in this image. No other significant change has been observed in / around the Tidal Link area. The huge water body in the southern part of Cholri and Pateji Dhands has been recharged. The salinity around the Tidal Link from southern part of Cholri Dhand to Shah Samado Creek has been observed in Feb. 1999 image, which may be due to over topping of seawater during high tides from the tidal link, which inundates the adjacent areas, the water evaporated and salt remains on both sides of the Tidal Link, and appears prominent with white color in Figure 6. The Landuse / landcover thematic map, showing different landcover categories with GIS layers based on Landsat TM data of February 1999, is shown in Figure 6.

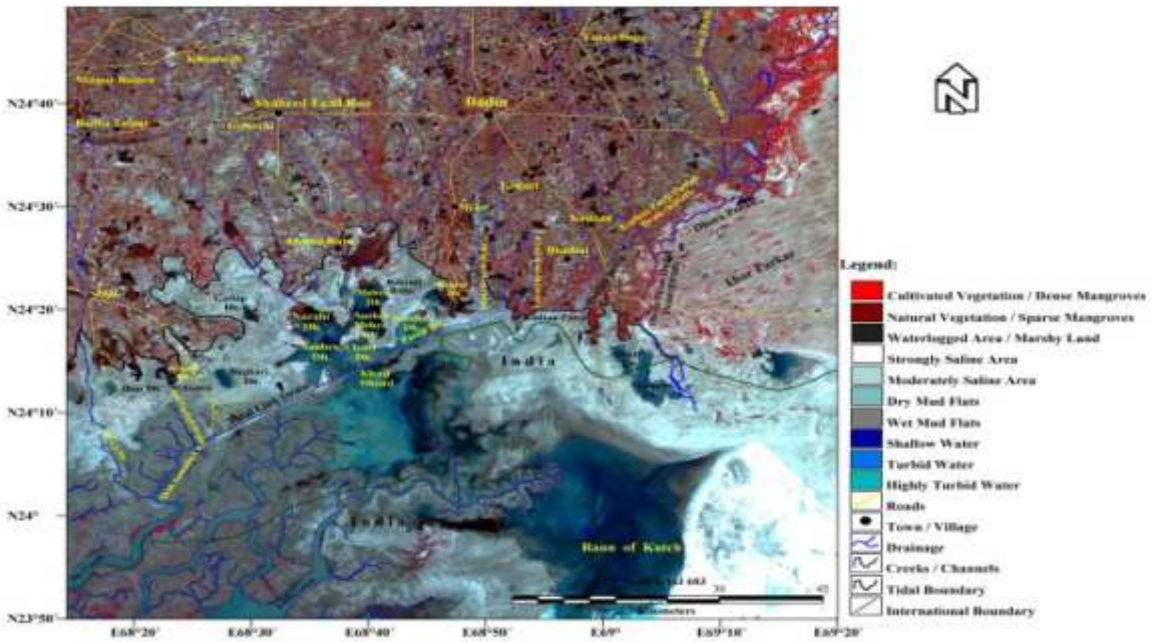


Figure 6: Satellite image map of Tidal Link – LBOD area (District Badin), based on Landsat TM data of 3rdFebruary 1999

2.4 Landsat ETM Image of 26 November 1999

Landsat ETM image of 26th November 1999, shown in Figure 7, represents the satellite image of post cyclone period. The increase in biomass is seen in this image, when compared with image of February 1999, because of the seasonal difference. As described above, the Badin District is a paddy growing area and in Kharif season most of the cultivated land is under rice paddy crop. Sugarcane and banana are also cultivated in Kharif season, because of that most of the area is under cultivated crop. The permanent waterlogged / saline and barren areas have been observed at almost the same locations as seen in the image of October 1989. Extent of water in Sinatry and Shakoor Dhands is almost the same as observed in February 1999 image. Some of the dhands like, Gadap and Baghari Dhands have dried up.

The Cyclone – TC 02A, which hit the south-eastern coast of Sindh on 20th May 1999, devastated the coastal areas of Thatta & Badin Districts and the catastrophic effect of this cyclone resulted in severe damage to Tidal Link drain. The embankments on both of the sides of Tidal Link drain were washed out and about 56 breaches occurred in several locations, particularly at Cholri, Khadi and Pateji Dhands. The sweet to saline water of dhands were turned to saline due to intrusion of seawater through Shah Samado Creek and from breaches Most of the dhands become polluted due to inclusion of contaminated water containing pesticides and other harmful chemicals (like Arsenic, etc) coming from LBOD to Tidal Link and degraded the dhands environment and the adjoining agriculture lands and destroyed the wildlife. Over topping of water is obvious in the vicinity of two drains connected directly to the Tidal Link downstream near Shah Samado Creek. No significant change in the extent of water in Cholri Dhand has been observed.

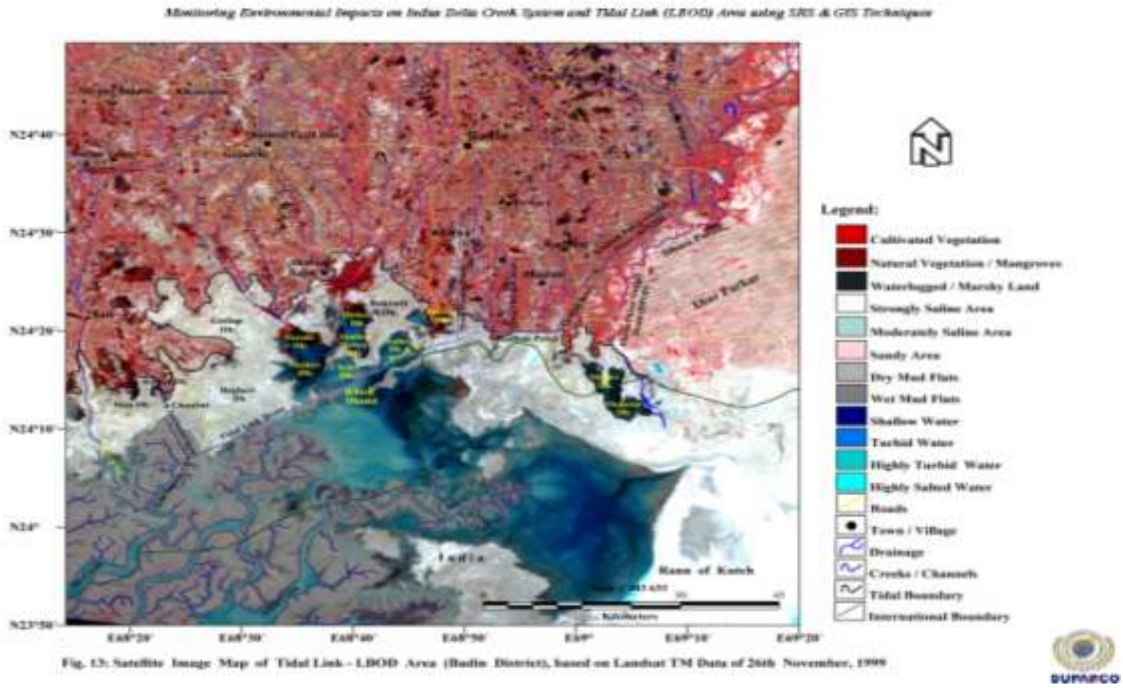


Figure 7: Satellite image map of Tidal Link – LBOD area (District Badin), based on Landsat TM data of 26th November, 1999

2.5 Landsat ETM Image of 21st November 2003

The Landsat ETM image of 21st November, 2003, is shown in Figure 8. This image shows some significant difference when compared with previous satellite images. The total vegetal cover has reduced and saline / barren land has been increased, as compared with the image of November 1999. The high moisture condition in the upper part of image is attributed to the heavy rains of August 2003, due to which the number of standing water ponds and extent of waterlogged areas have increased. The extent of water in interconnected Dhands: Mehro, Sanhro, Sandho, Khadi and Sanhro–Mehro Dhands, however, seem to have reduced. The Shakoor and Sinatry Dhands are filled with water. Tidal Link has experienced additional breaches near Pateji, Cholri and Khadi Dhands. The breaches previously seen in Nov. 1999 image are more prominent in the Nov. 2003 image. It appears that these breaches become wide and have taken the form of channels or creek system, through formation of trunk and its branches. Water in Cholri, Pateji, Bakrar and Khadi Dhands has been reduced. An unknown dhand connected with the Mehro Dhand from north-western direction, covered with thick vegetation in the previous images has almost dry up and has very little vegetation in 2003 image. The tidal zone, comprising creeks and mudflats reflects drastic changes. The surface salts appear prominent in the southern part of study area, mainly due to dryness in the deltaic region. The heavy rains falls in August 2003, did not affect the eastern part of the delta.

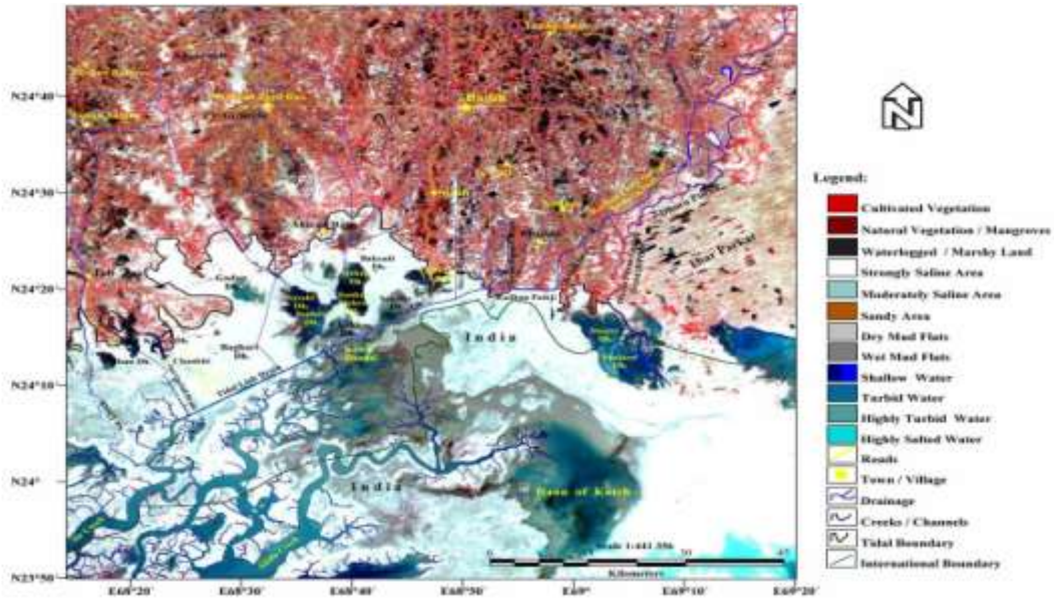


Figure 8: Satellite image map of Tidal Link – LBOD area (District Badin), based on Landsat ETM data of 21st November 2003.

2.6 SPOT–5 Image of 5th December 2005

The high resolution (2.5m) SPOT–5 color image acquired on 5th December, 2005, shown in Figure 9 cover the middle part of the study area and pertains to dry-winter season. Landuse / landcover thematic map based on SPOT data of 2005. Great significant changes have been observed in SPOT image, when compared with the previous Landsat TM and ETM images of 1989 to 2004. Further reductions in biomass, waterbodies and in waterlogged areas in landward areas have been observed, which indicate setting up of a consistent trend of degradation in vegetal cover and increase in saline area or barren land. A marked reduction of water in Mehro, Sanhro-Mehro, Sandho and Pateji Dhands is seen. Cholri and Khadi Dhands are dried up and the channels formed in Cholri Dhands appear prominent and connected with Sanhro Dhand. Sanhro and Narahi Dhands (inter-connected dhands) are under shallow water, which may be due to supply of water through Karo Gungro Outfall Drain. The polluted water coming from LBOD to Tidal Link drain is also approaching to Sanhro Dhand through these channels and because of that these dhands are under shallow water. The Baghari, Gadap and Bakrar Dhands are completely disappeared and look like strongly saline patches. The unknown dhand connected with the Mehro Dhand has some sparse vegetation. Moreover, appearance of some channels approaching towards Tidal Link in the south of Sandho and Pateji Dhands can be seen, and which are very prominent due to high resolution (2.5m) SPOT data, as compared to low resolution (30m) Landsat TM and ETM data. The salinity reaches its maximum in the dry-winter season, and appears very prominent on the mudflats along the creeks / channels and also on inland areas of Badin.

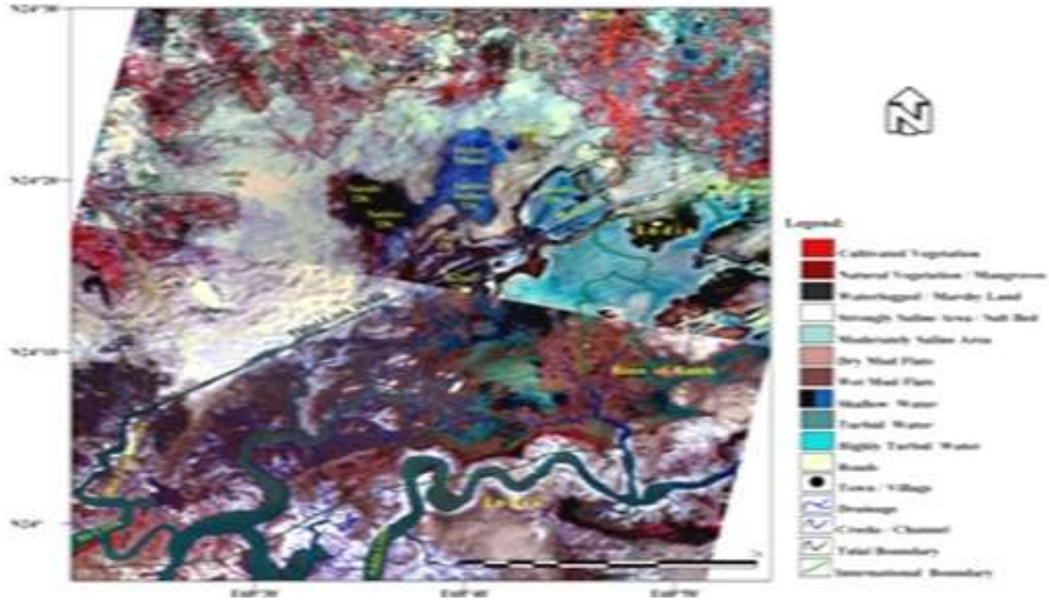


Figure 9: High resolution (2.5m) SPOT–5 color image acquired on 5th December, 2005

2.7 Monitoring the Dynamic Changes in the Dhands Areas

For monitoring the dynamic / geomorphologic changes in the Dhands areas from 1989 to 2005, the extent of water or boundaries of dhands and other water bodies in each year have been digitized and integrated, and overlain on SPOT 2005 image and the changes taking place in dhands areas have been detected and represented in Figure 10. From the analysis of SRS data of different time frames, i.e., 1989 to 2005, it is observed that the seawater coming from sea to Rann of Kutch side to dhands areas has been stopped or reduced after the construction of Tidal Link.

It may be possible the water channels (canals and open drains) supplying water for irrigation and other purposes are not feeding water to dhands and they were drying and disappearing from the land surface. Most of the dhands; like the Cholri, Pateji and Khadi Dhands have been dried up and appear in the 2003, 2004 and 2005 images as high moisture mudflats. The Gadap, Baghari, Talwar and Bakrar Dhands are completely dried up and disappeared in the 2003, 2004 and 2005 images; and appear as salt bed or strongly saline area. The areas of Shakoor and Sinatri Dhands have been shrinking from 1989 to 2003 and finally in 2004, they are completely dried up and appear as salt bed, this may be due to reduction in supply of water from Dhoro Puran. Areas of some of the dhands have been shrinking and the white areas around most of the dhands are surface salt deposits, indicating that the surface areas of the dhands have declined.

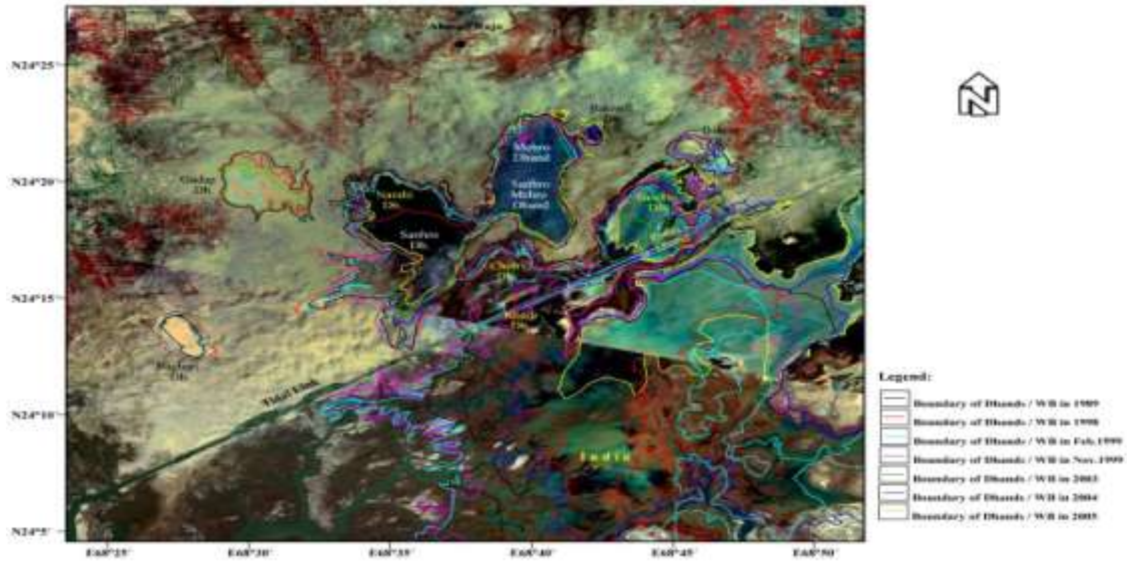


Figure 10: Integration of boundaries of Dhands and Water bodies (WB) of different years 1989 to 2005 with SPOT image of 5th December, 2005

2.8 Tidal impact towards the land area

With regard to sea intrusion towards the land area, the tidal boundaries have been drawn from Landsat MSS, TM and ETM data of 1976, 1989, 1998 and 2003, respectively and integrated with Landsat image of 2003, as shown in Figure 11. From this image, it is observed that the impact of coastal process has been more on the southern and eastern parts of the delta, especially from Keti Bandar (Thatta Dist.) to Ahmad Rajo (Badin Dist.) and very little variation has been seen on the western part of the delta. From the analysis of multi-temporal SRS data, it is observed that most of the cultivated lands have been turned into waterlogged and under high saline areas. The effect of waterlogging and high salinity appears prominently in the 2003 image with black and white tone in colour composite image and with blue (waterlogged) and yellow/red colour (saline areas) in landuse / landcover thematic map especially in the eastern part of the study area, i.e., in Badin District.

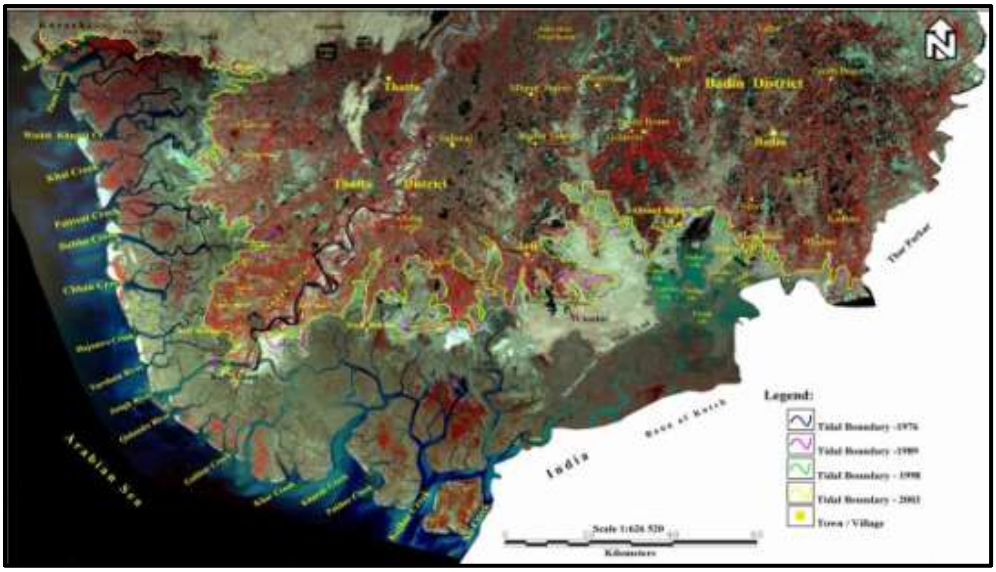


Figure 11: Integration of Tidal Bounbaries of different years with Landsat ETM image 2003 for monitoring of coastal process.

The intrusion of seawater deteriorated the agricultural lands of Thatta & Badin Districts and converted most of the cultivable areas into barren, i.e., under waterlogging and high salinity. This has further stressed the Indus Delta eco-system, because of increase in salinity in creeks water and on mud flats, which prevails all along the coast, especially in the middle and eastern parts of the Indus Deltaic region, as seen in the satellite images of Keti Bandar and Shah Bandar and also in the ground picture of mud flats at Shah Bandar area, and in result deterioration of riverine forest near Thatta–Sujawal bridge, as shown in Figures 12 (a, b, c), respectively.

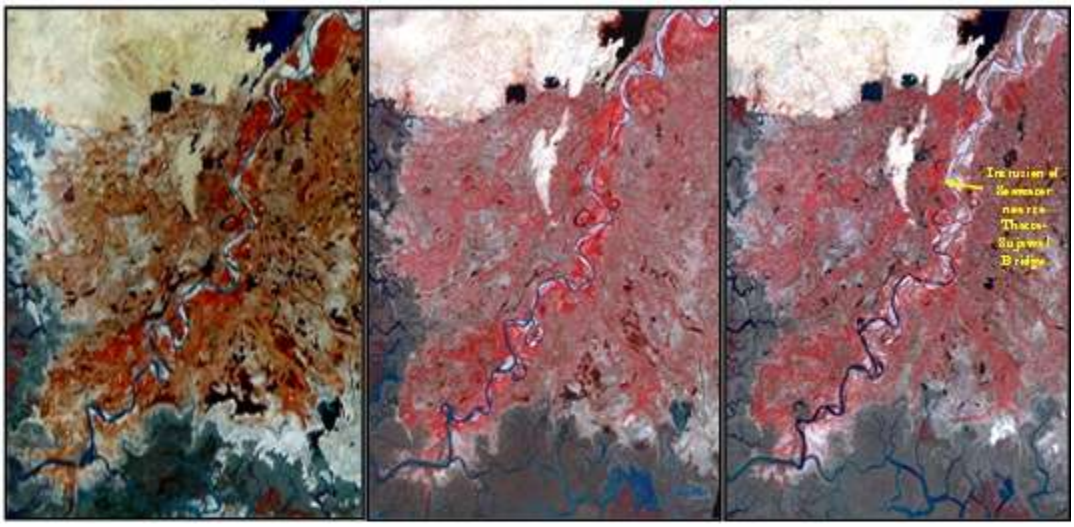


Figure 12: Multi temporal satellite of lower Indus Plain Intrusion of Seawater in the Reverine trace

3 Cyclones in the Area

The coastal Sindh is prone to storm surges associated with the severe cyclonic storms generated in the adjacent Arabian Sea. A significant number of the cyclonic storms produced in the Arabian Sea move towards North and Northeast and some of them hit Pakistan Coast. The Arabian Sea is known to generate frequent cyclonic storms and some these were among the worst severe cyclonic storms of the world resulting in huge losses to life and property in the coastal areas. However, most of these cyclones leading towards Southern parts of Pakistan Coast very often curve towards eastern coast of India. The southern and southeastern part of Pakistan Coast is comparatively more vulnerable than the west coast of Pakistan.

3.1 Tropical Cyclone "2a" May 1999

The Cyclone "2A" was formed over the Arabian Sea on May 16^{TH} 1999 and initially started moving Northward. Later, it changed its course to Northeastward and hit Sindh Coast. The cyclone remained stationary about 400-km south of Karachi on 18^{th} May 1999. It was located at 21.5 N, 68.5 E shown in Figure 13. Its tidal surge at coastal waters was anticipated to range between 3.65 m to 4.6 m. However, the observations reported from the Southeast coast of Sindh revealed that during high waters the water levels were above 7.1 m confirming the anticipated height of the storm surge in the area.

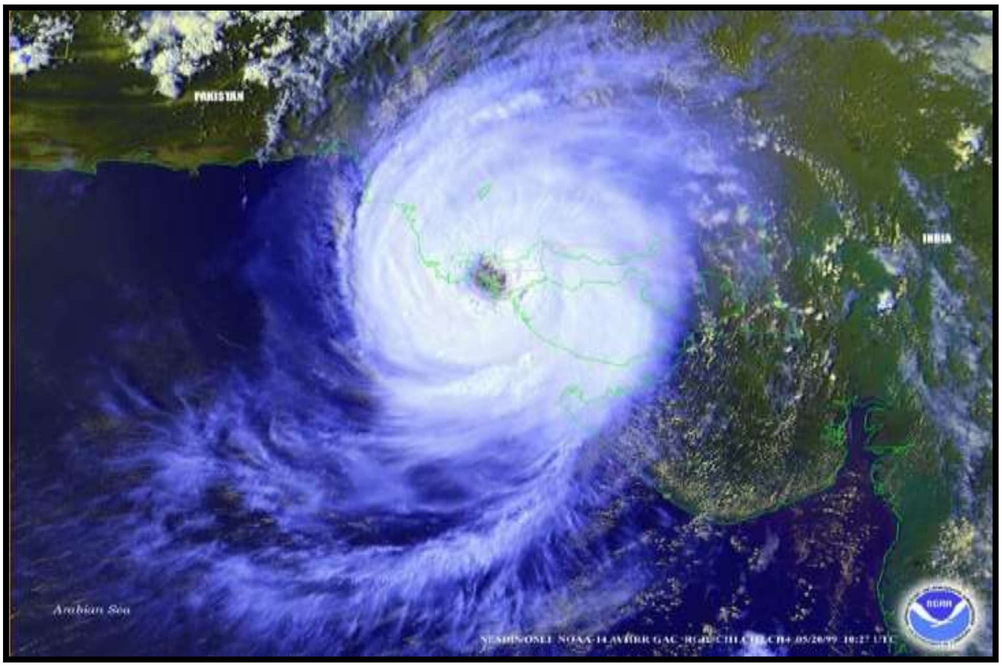


Figure 13: Satellite view of Tropical Cyclone 2A hitting Pakistan-India Coast in May 1999.

The cyclone wind speed varied between 100 knots to 150 knot per hour. The internal sustained wind speed of above 110 to 115 knots. On 20th May 1999 its location was Latitude 23.9 N, Longitude 68.1 E which was 170 km South-east of Karachi. Its direction then re-curved from NNE to NE. Wide spread heavy rain and thunderstorms were associated with gusty winds that ranged from 80 knots to 100 knots. Its landfall was recorded at 11: a.m. on May 20, 1999 on the coasts of Thatta and Badin covering Indus River Delta at the Southern coast of Sindh. The storm and gusty winds were accompanied by a tidal storm surge between 4.6 m to over 7.2 m. The seawater inundated low-lying coastal areas adjacent lands in this part of Indus Delta. The main hit areas include the Districts of Thatta, Badin and Tharparker. On land the South and southeastern parts of Thatta and Southern parts of Badin received the main thrust of the cyclone. The worst hit villages being Kadhan, Serani,, Ali Bandar, Keti Bandar, Shah Bandar and the worst hit coastal towns include Jati, Mirpur Sakro and Sujawal.

3.2 Reported Cyclones in the Area

The available data on cyclones and storms for the last 109 years demonstrate that the coastal area of Pakistan is vulnerable to the severe cyclonic storms mostly during the period April to June (on set of S.W monsoon) while no storms was observed during January to March (N.E monsoon). The period of 100 years 4 cyclones landed at Balochistan Coast and about 15 Cyclones landed on Sindh Coast. In general, all the cyclonic storms originating from the Arabian Sea have been observed either to curve sharply into the Gulf of Kutch or to cross the Arabian Sea from East to West and end up in the Arabian Peninsula creating some storm surge at the coast. Sometimes depressions do cross the coast in June and generate winds of 30-35 knots. The maximum Storm surge of 2.6 feet has been recorded at Karachi due to the cyclonic storms. In addition, a storm surge of about 1.5 feet has also been observed at Karachi when cyclones cross over the Arabian Sea about 300-400 miles away from Pakistan Coast.

Reported Cyclones Along The Pakistan Coast Line Are Given Below:-

Month	**Year**	**Coastal Area**
June	1897	Sindh Coast
April	1901	Makran Coast
April	1902	Sindh and Rann of Kutch
May	1902	Sindh Coast
June	1902	Sindh Coast
June	1907	Sindh Coast
October	1907	Sindh Coast
September	1925	Sindh Coast
September	1936	Sindh Coast
June	1945	Makran Coast
June	1985	Makran Coast
November	1994	Sindh Coast, Rann of Kutch
May	**1999**	**Sindh Coast and Rann of Kutch**
June	2007	Sindh cost, Rann of Kutch, Blochistan cost

3.3 Depressions and Cyclonic Storms

(a) Frequency of Depressions

During the last 109 years about 106 Depressions have been reported from the Arabian Sea. The average annual number of depressions is about 1 while the annual number of depressions is about 47.75 % of the annual number of cyclonic disturbances. The frequency of Depressions ranged between 8 and 22 during September to December with highest in November, which is about 21 % of annual total. It ranged between 8 to 20 during May to July with 19 % of annual total in June. During rest of the months about 4 depressions per month were formed. In February no Depression was reported.

(b) Cyclonic Storms

During the last 109 years about 51 severe cyclonic storms have been reported from the Arabian Sea. May - June and September - December are favourable periods for the formation of cyclonic storms in the Arabian Sea with highest frequency in October which is about 27 % of the annual total. There is secondary highest frequency of 7 in June, which is about 14.5 % of the annual total. There were 6 cyclonic storms reported in November and 5 cyclonic storms each during May, September and December and 2 each in January, April, July and August. There were no cyclones in February and March. The average annual number of cyclonic storms is about 0.5. The annual number of cyclonic storms is about 22.1 % of the annual number of cyclonic disturbances.

(c) Severe Cyclonic Storms

The cyclonic and severe cyclonic storms combined together are termed as "cyclones". The average number of cyclones over the Arabian Sea is about 1.2 per year. The Temporal the maximum frequency of 27 and 20 in November and May respectively while minimum frequency during January-March and July-August periods. The low number of cyclonic storms formed during these months is attributable to the strong vertical wind shear present during these months over the Arabian Sea. On the contrary, during the months of May-June and October-November, little or no vertical wind shear situation in the atmosphere offers favorable conditions for the formation of cyclonic and severe cyclonic storms in the Arabian Sea.

During the last 109.years about 69 Severe Cyclonic Storms have been reported from the Arabian Sea. The maximum number of severe cyclonic storms were noticed during May - June and October - November with highest frequency of 21 in November which is about 31.3 % of the annual total and second highest of 15 in May which is about 22.4 % of the annual total. There were 12 severe cyclonic storms formed in October, 4 in April, 3 in September and 2 in December. No severe cyclonic storm has been reported in January, February and March. The average annual number of severe cyclonic storms is about 0.68 while the annual number of severe cyclonic storms is about 69 which are about 31% of the annual number of cyclonic disturbances.

3.4 Vulnerability of Pakistan Coast to Landfall of Cyclones

The available data on tropical cyclones from (1891 to 1999) indicate that only 10 tropical cyclones crossed Pakistan Coast of which 4 cyclones crossed Makran Coast and 6 cyclones crossed Sindh Coast during 1891 to 1999. The Sindh Coast is more vulnerable to cyclones than Makran Coast. Monthly distribution of cyclones show that May and June are the most vulnerable months for Pakistan Coast with highest frequency of landfall for the cyclones while September also shows occurrence of landfall for the tropical cyclones along the coast. Last 100 years tracks of Cyclones in the surrounding region of Pakistan shown in Figure 14 and Table 1.

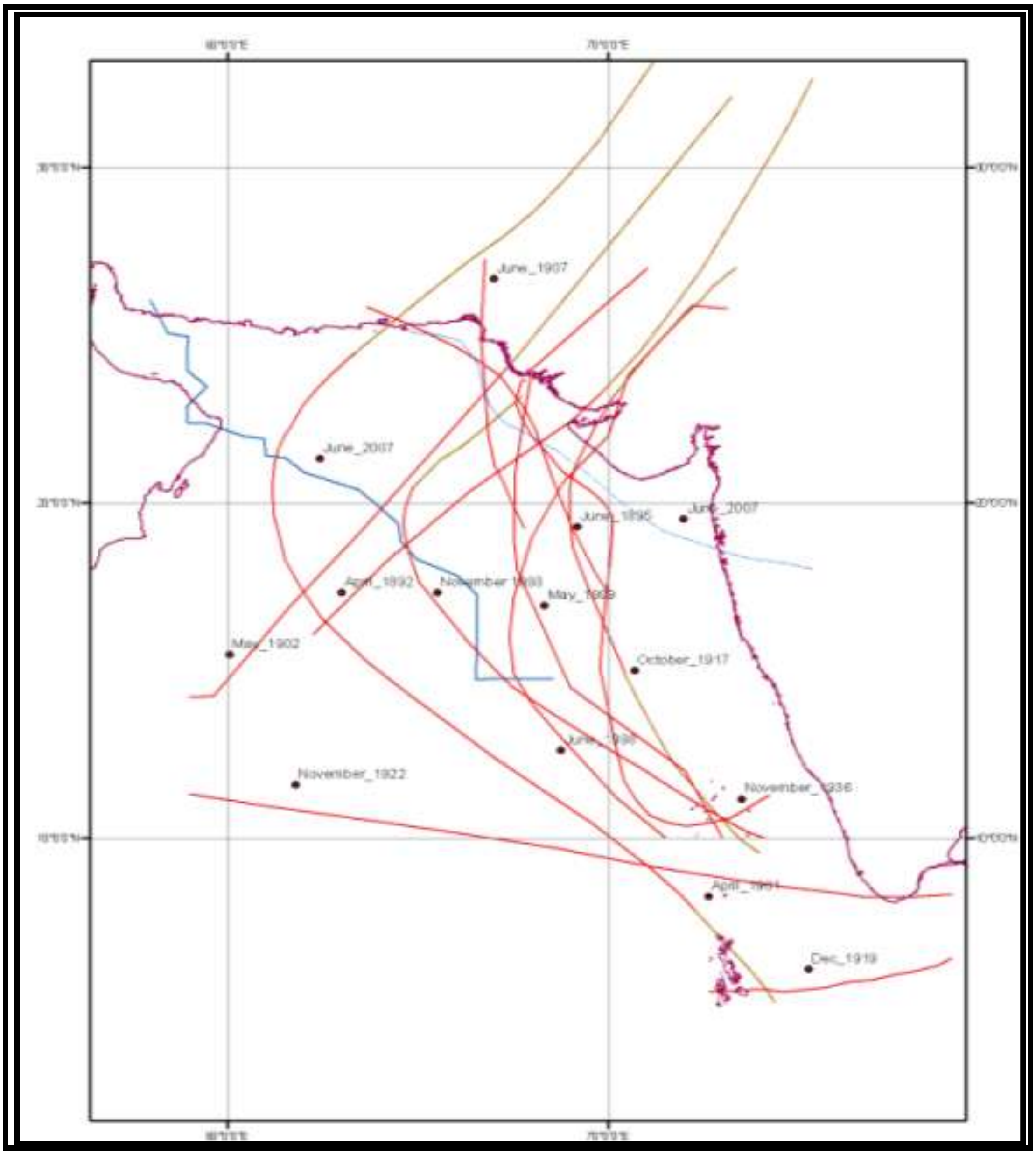


Figure 14: Last 100 years tracks of Cyclones in the surrounding region of Pakistan.

Table 1: Monthly Distribution of Frequency of Cyclone Landfall and vulnerability to cyclones along Makran and Sindh Coast for the periods 1891 to 1999 and for 1900 to 2000.

Months	Makran Coast		Sindh Coast		Total Frequency		Vulnerability
	1891-1991	1900-2000	1891-1991	1900-2000	1891-1991	1900-2000	Low to High
January	0	0	0	0	0	0	Nil
February	0	0	0	0	0	0	Nil
March	0	0	0	0	0	0	Nil
April	0	1	0	1	0	2	Moderate
May	1	1	1	2	2	2	Moderate
June	2	2	3	3	5	4	High
July	0	0	0	0	0	0	Nil
August	0	0	0	0	0	0	Nil
September	1	1	0	2	1	2	Moderate
October	0	0	0	1	0	1	Low
November	0	0	0	1	0	1	Low
December	0	0	0	0	0	0	Nil
Total	4	5	4	10	8	15	

3.5 Morphological Changes and Impacts of Cyclone "2A"

The following morphological changes were detected after the cyclone. This study was evaluated by the available data and specific area information. The data collection was not specifically focused to evaluate on the impact assessment. For an in-depth assessment a detailed survey and focused field study is recommended.

(a) Morphological changes in the High Water Mark

As most part of the coastal area of Sindh constituting Indus Delta mud flats, creeks, marshes/ mangrove swamps are inundated with water during High Tides and are usually in-accessible. Therefore, the satellite images of the area provide a synoptic view of the general morphology and position of High water mark before and after the landfall of cyclone 2A on the coast. These are read and interpreted with reference to the area map of WAPDA based on satellite image of the area in 1991.

(b) Situation during 1991

The Highest High Water Mark during 1991 was clearly visible from North end Sir Creek to the beginning of Jati Outfall Drain and then moving in a zigzag fashion somewhat parallel towards Cholri Dhand close to RD -90 position at Tidal Link Drain and then follows the water boundary of Cholri Dhand in the South and of Sanhro Dhand in the North. The road from Jati City coming down to High water mark in the south-southeast direction crossed the High Water Mark some close to the beginning of Jati Out-fall Drain and then it runs in the Intertidal area in Southeast direction reaching up to the proposed site of RD -125. The Tidal Link Drain was not in place therefore, the original natural conditions were displayed in the satellite image of the area.

(c) Situation during 23rd May 1999 (two days after the landfall of cyclone 2A)

- ✓ Most of the area between dhands and the Jati Outfall Drain has gone underwater and the all the low lying areas showing salt encrustation in the October 1998 Satellite image have accumulated turbid water and the drain waters from uplands;
- ✓ The receding turbid waters after the cyclone area visible flowing over and flowing across the Tidal Link Drain in Southern and Southern and southeastern direction towards Sir Creek;
- ✓ All major dhands in the area appear to be merged into one single large dhand with original dhands keeping their identity as deeper parts of this new single large dhand;
- ✓ There appear to be two different High water marks: one showing deeper parts and other from areas around Jati Out-fall and roughly follows the eastern embankment of Tidal Link Drain upto RD -90 and then follows the original boundary of old dhands; the other HHWM or H.A.T. in the area which roughly follows the boundaries of low lying areas which appeared as salt encrusted land on the satellite image and now covered with turbid waters;
- ✓ All the roads in the area have been submerged in water their remnant are barely visible;
- ✓ All coastal settlements, infra-structure, UTP facilities, etc. were washed away;
- ✓ The Tide Gauging station at RD -125 was washed away;
- ✓ The UTP Bridge at the Tidal Link Drain at RD -93 was severely damaged and parts of it washed away by the cyclone 2A.
- ✓ The tidal storm surge was found to flow over above 7.1m the height of UTP Bridge at RD -93;
- ✓ All the intertidal part of Road from Jati to RD -125 and beyond was at the mercy of High High Waters; the original water drainage passage through Cholri dhand to Rann of Kutch and the Southern creeks was re-opened and established by the cyclone. This was earlier blocked by the construction of the embankments of Tidal Link Drain.

(d) Situation on 25th April 2000.

The main morphological changes taken place in the area since 21st May 1999 and are more pronounced in the satellite image of the area taken on 25th April 2000. These are summarized below: -

- ✓ The storm waters have receded back, leaving behind the turbid waters in depressions and low-lying areas where water has stagnant. This situation has created large new dhand representing merger of all the major dhands in the area. The new large dhand extends from the area much beyond east of Jati Outfall drain and continues in the Northeast direction to join the old dhands in the area. The shape of old dhands is visible because of their comparatively deeper depths, which have allowed settlement of suspended load and turning water clearer. The turbid waters in the new large shallow dhand do exhibit some variations in water levels.
- ✓ A considerably large area between dhands and the Jati Outfall Drain has become turbid; the roads leading to this area from Land ward side are washed out and are completely submerged.The areas with some vegetation and some old net works less affected by the cyclone are visible in the land areas adjacent to the new large dhand area in the North and Northeast.The embankments of the Tidal link Drain in the area appears to be breached at many places allowing free exchange of waters between Tidal Link Drain and adjacent intertidal areas and dhands.

- ✓ There appear to be a new and different High water mark and new HAT in the area: the High Water mark delineating deeper parts and run from areas around Jati Out-fall and roughly follows the eastern embankment of Tidal Link Drain upto RD -90 and then follows the original boundary of old dhands; Similarly there is a new H. A.T. in the area which roughly follows the boundaries of low lying areas and cover the boundaries of which appeared as salt encrusted land on the satellite image and now covered with turbid waters / salt encrustation.
- ✓ The remnants of old and submerged roads are barely visible in some areas while no roads are visible in theis of interest around RD -93 or RD -125. All coastal settlements, infra-structure, UTP facilities, etc. were washed away;
- ✓ The Tide Gauging station at RD -125 was completely demolished.
- ✓ The exposed parts of the UTP Bridge at the Tidal Link Drain at RD -93 severely damaged and parts washed away by cyclone;
- ✓ The tidal storm surge from the water flow marks suggested that the water flow was over above 7.1m the height of UTP Bridge at RD -93;
- ✓ All the intertidal part of Road from Jati to RD -125 and beyond are now at the mercy of High Waters during High Waters from Shah Samando Creek as well as from possible flooding from Tidal Link Drain;
- ✓ The Tidal Link Drain has been found breached at more than a dozen sites all along RD -40 to RD -155;
- ✓ The original water drainage passage through Cholri dhand to Rann of Kutch and the Southern creeks has been re-opened and established by the cyclone. This was earlier blocked by the construction of the embankments of Tidal Link Drain.

3.6 Major Morphological Changes and Physical Impacts

<u>Extent of Tidal Influence and Inundation</u>

It has now been observed that a new High Water mark has been established as a consequence of the morphological changes in the area therefore the extent of Tidal flooding and Inundation has been extended as is visible in the satellite imagery of 2003 Figure 11.

<u>Shifting of High Water Mark and H.A.T</u>

It has now been observed that a new Highest Astronomical Tide mark has been established as a consequence of the morphological changes in the area due to flooding and Inundation by the Cyclone "2A". The new H. A. T. has been extended.

<u>Changes in the Hydraulic Regime</u>

The Tidal Flows, local topography, gravity gradient and local water discharge / Water Exchange points now regulate the hydraulic regime rather than the Tidal Flows and gravity gradient before the landfall of cyclone "2A"; the major changes are summarized below:

a. Merger of dhands

Creation of a very large new dhand is representing merger of all the major dhands in the area. The new large dhand extends from the area much beyond east of Jati Outfall drain and continues in the Northeast direction to join the old dhands in the area.

b. Restoration of Old Natural Drainage passage

The original water drainage passage through Cholri dhand to Rann of Kutch and the Southern creeks has been re-opened and established by the cyclone. This was earlier blocked by the construction of the embankments of Tidal Link Drain.

c. New Water Circulation patterns / New Water Discharges and Water Flow Points

The embankments of the Tidal link Drain in the area appears to be breached at many places allowing free exchange of waters between Tidal Link Drain and adjacent intertidal areas and dhands. This situation has created a number of water discharge points at the Tidal link Drain as well as water-inflow points. The increase in the number of water discharge and Inflow Points along the line of Tidal Link Drain has created new water flows and water circulation patterns.

d. Increase in Water Salinity

The water salinity of the area has increased due to the increased inflows of seawater in the area from Shah Samando Creek.

e. New Erosion and Sedimentation Patterns

The new water flows and circulation patterns in the area have changed the erosion and sedimentation patterns in the area. The erosion and sedimentation patterns in the Tidal Link Drain have also changed and this has also altered the water discharge patterns within the Tidal Link Drain.

3.7 Socio-Economic Impacts

Loss of Life and Property

a. Inundation of villages, fruit farms and agriculture lands with crops

A number of small coastal settlements doted along the coast between Shah Bandar to Shah Samando Tomb, were completely washed away by the 7.1 m (3.8 m tide + 3.4 m storm surge) high water wave followed by the cyclone in the area. The houses and agriculture lands in 10 villages situated close to H.A.T. along the coast in the North, were completely inundated. The downpour and the Cyclonic storm badly affected the agriculture lands, fruit orchards and vegetable fields over a vast area in Southern central parts of Thatta District and in Southern parts of Badin. The civic amenities were badly damaged Power lines were broken and areas remained without power for months in many parts of the district. Communication was badly affected. The road network was washed away in the lower part of Sindh.

b. Human life loss and misery / disaster

More than 6,000 persons were reported dead / missing. About 40 % of the human population in the Districts of Thatta and Badin were affected by the ravages of the Cyclone 2 A leaving in its wake 400,000 victims in Badin and 300,000 victims in Thatta.

c. Housing losses

Around 50,000 houses and huts were damaged and 152,000 acres of farmland has been seriously damaged.

Damage to Tidal Link Drain

The LBOD was completed at the cost about Rs. 30 billion and its most expensive component is the Tidal Link Drain which has been seriously damaged by the cyclone "2A". It estimated that it would require huge expenditure for its repairs to bring it back to pre-cyclone status. ***The effective length of discharging agriculture saline drain waters by the Tidal Link Drain has been reduced upto RD -35 only***. The Tidal Drain is not performing its designed functions with efficiency. There are more than a dozen breaches in the Tidal Link Drain and their repairs in the intertidal zone would cost huge expenses. In addition, the Tidal Link Drain has been severely damaged with its embankments and it is being further eroded by the increased erosion and sedimentation processes taking place after free flow of seawater induced by cyclone changes in the area. The new morphological changes have increased erosion and sedimentation and the hydraulic performance of the Tidal Link Drain in discharging the saline drain waters in to the sea has been severely affected and it has stopped regulating the water discharge at Cholri Weir to maintain water levels and water quality at dhands.

Damage to Communication Setup

(Telephone lines, Access Roads and UTP Roads)

Power and Telephone lines were washed away in the main hit areas and the areas remained without power and telephones for many months. Power and Telephone lines also remained out of order in less affected areas for considerable time.

The Access Roads became totally submerged and washed away at many places rendering the area in-accessible for months; The road net work of UTP in the area was also submerged and washed away at most places.

Damage to Oil & Gas Exploratory Facilities in the Area

Some of the facilities for Oil & Gas Exploration present at the site on the eastern side of the Tidal Link Drain across RD -93 have been reported to be washed away. Losses and Damage have also been reported on the site present at Sanhro Dhand and Sanhro-Mehro Dhand. The UTP Bridge at RD -93 and UTP Road between RD -93 and Sanhro-Mehro Dhand have been completely submerged in the water and severely damaged. The exact details of the losses are not known.

Losses / Damages to Live Stocks and Fish Farms

Around 152,000 acres of estimated farmland was seriously damaged. A huge number of livestock was also reported dead in the coastal areas of both the districts i.e. Thatta and Badin and other areas (areas like Nindo Shaher, Kadhan of Tehsil Badin where fish farms occur). It was reported that at least 2000 fish ponds and 200 fish farms were affected by the storm surge, other than vast area of impounded water, lacs of fish seedlings have also been totally washed away. A large number of fishing boats anchoring in the area have been capsized washed away or severely damaged by the cyclone.

Effects on Coastal and Artisanal Fisheries

As the influence of seawater has increased manifold in the Tidal Link Drain, dhands and in the adjacent tidal areas therefore the brackish water fauna and flora has disappeared from the scene. The oceanic fauna and flora suitable for high water salinity areas has replaced the estuarine and brackish fauna and flora after the Cyclone "2A" in the area. Although the potential of the area having good shrimping grounds in the offshore areas adjacent to Sir Creek remain intact but these areas are not easily accessible to local fishermen. This is due to loss of their large sized boats and the increased tidal water currents making it very difficult and dangerous for maneuvering and anchoring by smaller sized boast as required for various types of local fishing techniques.

Unfortunately no data on fishery statistics is available from this area for before and after situation to compare and assess an accurate impact. However, based on the interviews of the local fishermen in the area supplemented by regular field visits to the area for hydraulic monitoring of the Tidal Link Drain for the last five years by NIO scientists some indirect assessment on the fisheries of the area could be made. It is assessed that there was a good coastal fishing industry established in the areas of dhands, Tidal Link Drain, Shah Samando Creek, Sir Creek and in the adjacent offshore shrimping grounds. The area was believed to have very good fishing and shrimping grounds for a variety of shrimps and some fish species before the landfall of Cyclone 2A. This was further supplemented by the existence of a dependable local and artisanal fishery in the area. This was evident by the presence of a good number of fishing boats always observed to be engaged in profitable fishing business in the area before the landfall of Cyclone "2A". Most of these large sized and medium sized fishing boats have been damaged, capsized or washed away by the Cyclone "2A". The reduced number and reduced size of fishing boats now present in the area is itself a measure of the reduced fishing effort and of economically unattractive rate of return in the capture fishery business in this area at present.

Based on the very limited information available on the biodiversity in the area before and after Cyclone "2A" it is interpreted that the due the higher water salinity and extreme water temperatures due to shallow depths in most parts of the study area the biodiversity has decreased.

Effects on Coastal Forestry

There were healthy mangrove forests in the creek islands and in inter-tidal mud flats about 70-90 years ago which provided a dependable and natural coastal defense to the area from onslaught of cyclones and severe cyclonic storms in the area. However, the area has been without a natural coastal defense for the last many decades. The route followed by the Cyclone "2A" was parallel to the alignment of the Tidal Link Drain in the area and this route without a natural coastal defense and without any regular gates at the end of Tidal Link Drain appear to have provided a clear passage for the incoming Storm Surge riding on the High Tide to extend further the ravages of the Cyclone "2A" up North. The cyclone has further damaged the existing small shrub like coastal vegetation sparsely populated on the land adjacent to HWM. The limited population of mangroves still existing on the southern creek islands appear to be least affected by the cyclone ravages.

3.8 In Cyclones/Storm Surge Prediction and Mitigation

The coastal areas of Indus deltaic region are flat and comprise natural weeks and swamps (Rann of Kutch), which are subjected to flooding from the sides as well as from the water channels / Creeks during the S.W monsoon periods. Flooding coupled with incidents of Cyclones and storm surges inundates vast tracts of low-lying lands for several days causing irreversible damage. When the flooding waters recede, the silted water from the creeks and Tidal Drain make the topsoil too saline. As the ground water table is generally close to the surface in this area so intrusion of salt water through aquifers in the coastal areas present a persistent threat to soil degradation and loss in agriculture productivity. A study of the cyclones storms in the area through models of flooding/storm surge will improve our understanding of seawater penetration and persistence in this part of Indus Delta. Another emerging factor, which could have an influence on cyclones and storm surges, is climate change. Even though there is no universal agreement, the projected sea level rise and changes in cyclone frequency and storm surge intensity are correlated to global temperature variations (warming) coupled with increase in Global Green House Gas emission, it could make things worse in the years to come. A rise in sea level predicted by one meter as a result of global warming of 2-3 ^{o}C over a century and melting/ breaking off large polar ice packs into the oceans will have a serious repercussion in the South Asia as a whole. Although, it is difficult to estimate quantitatively the effectiveness of disaster preparedness and prevention measures, in terms of saving lives and protecting properties. There has been instance where millions of rupees of property were loss a single storm. While a cyclone/storm prediction early warning centre will not avoid all damage but reduction of cyclone path and landfall will bring about a reduction in loss of life, property and damage to the infrastructure in the region. The accuracy of forecast of cyclonic storm and the lead-time on warning have to be improved and the uncertainties in the landfall timing and location need to be reducing. Cyclone and storm prediction demands accurate surface wind forecast for several hours before cyclone landfall hence there is a dire need for development/upgrading of a suitable cyclone prediction centre in the region.

4 Review of Available Data

National Institute of Oceanography carred out the ***Hydraulic monitoring of Tidal Link Drain and adjacent area*** including brackish water bodies called Dhands areas from **1992 to 2008.**

- ✓ Metrological observations
- ✓ Tidal levels measurements in the Tidal Link Drain
- ✓ Sea water currents measurements at different location in the Tidal Link Drain.
- ✓ Bathymetric survey of Tidal Link Drain and dhands.
- ✓ Continuous salinity monitoring in the Tidal Link Drain and dhands.
- ✓ Sedimentological study of Tidal Link Drain and its adjacent areas including dhands.

4.1 Introduction

There are very few studies conducted in the Pakistan on the man made alterations in the drainage systems in the Indus deltaic areas linking drainage of underground saline water and Agriculture drainage to the sea and its impacts. Some relevant information on tides and oceanographic processes operative on southern and southeastern coast of Pakistan is available at the National Institute of Oceanography and Hydrography Department, Pakistan Navy. The relevant Geologic and Geo-morphologic studies undertaken in the Indus Deltaic areas include Milliman et al(1984); on the Sediment discharge from the Indus River to the Ocean;

on Geology on Indus Delta by Kazmi (1984); on the Deltaic Morphology and Sedimentology of Indus River Delta by wells, Indus River Delta by wells and Coleman (1984) and estuarine circulation and sedimentation with reference to Indus Estuary by Schubel (1984).

The Tidal Link Drain of LBOD is an attempt to alter natural flows and drainage pattern form its southeastern direction to south-westerly direction. Moreover, in the present case, the natural river or storm-water drains are not used for draining of underground saline water and agriculture waste waters and instead a man made surface drain was constructed in the inter-tidal area to carry the waste waters directly to the sea but in different direction and at the risk of flooding from the sea to the adjacent drainage area. This situation has blocked the direction of the natural flows and drainage of the area between Jati and Badin to Rann of Kutch - a natural marshy area at the border of Paksitan and India on one hand and on the other hand it has increased the influence of seawter in the Dhands. It is expected to hinder the flow of drain waters from KPOD to Tidal Link at a point between Cholri Weir and KPOD. This man made change in the direction of natural drainage flow has, therefore decreased the hydraulic efficiency of the Tidal Link Drain of LBOD.

4.2 Overview of Site Conditions

The area around Tidal Link Drain of LBOD, in general and Shah Samando Creek in particular is the part of Indus Deltaic region. The site conditions of the Indus Deltaic region including Shah Samando Creek, role of tides, natural drainage and Dhands and the Rann of Kutch area described below.

Indus Delta

The Indus Deltaic region covers an area of approximately 1,000 square miles. The delta is the product of the enormous amount of silt and sand brought down annually by the Indus River in to the Northern Arabian Sea. The present day deltaic complex is comprised of an upper alluvial part consisting of the deltaic flood plan and lower tidal zone, which is the tidal delta. The lower margin of the Deltaic Flood plain is rimmed by tidal delta. The tidal data is comprised of three main parts, Bordering the deltaic flood plain is an arcuate zone of older tidal deposits, formed as a result of the drying and silting up of the distributary channels of the Indus. This zone is followed by the active tidal delta seaward. With the drying and silting up of the major distributions of the Indus the tidal delta has been isolated from the alluvial process and has assumed the form of the large tidal mud flat. The lower remnants of the distributaries have turned into tidal Creeks.

Indus River Delta can be included in the category of dry (arid) topical to sub tropical deltas. The environmental setting of the Indus delta is one of low rainfall (35cm/year), surrounding deserts, fluent discharge and monsoon wind pattern.There are two subdivisions of Indus Delta: 1) an active and 2) abandoned deltaic plain including Shah Samando Creek area and adjacent Dhands. Once Indus River ceased to deliver sediments as a result of artificial levees or natural diversion then that area of the delta becomes an abandoned deltaic plain. The lower deltaic plain is delineated by the landward boundary of salt water intrusion, a boundary that usually does not follow that of active/abandoned deltaic plain boundary. The substantial storm water enter into deltaic region due to southwest monsoon winds during with summer and inundate vast area of both the active and the abandoned deltaic plains with salt water. This area of lower deltaic region is characterized by tidal creek and small over-bank plains that are lined with stunted mangroves on a sand/silt substrate.

The salt water intrusion and sediment transport have been long standing problems in the lower Indus delta. Much of this land such as Rann’s of Kutch receives its salt water flooding from sea level elevation associated with southwest monsoon winds in summer. Likewise the formation of evaporate deposits is most pronounced in areas subject to the rhythm of annual rather than daily flooding. Tides are important in producing reversals in current direction, thus leading to the bi-directional transport of sediment.

Dhands

There are a few very large prominent depressions / low lying areas locally called Dhands are located between the agricultural lands and the High Tidal zone which are filled with brackish / saline water. The low lying areas covered about 400 sq km area and consist of four major dhands namely, Pateji Khand, Cholri Dhand, Sanhro Dhand, Mehro Dhand and all connected to Cholri Dhand through narrow open inter-connections: i.e. between Cholri and Pateji Dhands, Mehro and Sanhro Dhand and between Sanhro and Cholri Dhands. The Pateji Dhand is a land locked shallow basin connected to the western end of Rann of Kutch at an elevation of about 3.3ft. average mean sea level. The Cholri Dhand is directly connected to Rann of Kutch through in the South-east for the drainage of excess waters from the Dhand areas. The average depths in these Dhands very between 0.37m to 1.8m. The maximum water level in Dhand areas has been reported to be 1.698m during 1983 (M. McDonald & Partner, 1984). The brakish / saline water lakes support a diverse ecosystem, fisheries and as sanctuary for a variety of water fowls and migratory birds.

The analysis of the topography of Dhands through satellite imagery of the area indicate that these Dhands have long been used as a natural drainage passage for the run-off from the land, flood waters from lower Sindh area to Rann of Kutch through Shakoor Dhand, Sanhro Dhand, Mehro Dhand and Cholri Dhands. The area has also been used as a natural drainage basin for the drain waters from agriculture waste waters and seepage from agriculture lands. The size and water volumes in these Dhands vary according to the season and availability of drainage water and temperatures of air and humidity.

Rann of Kutch

Rann of Kutch is the large swampy area which is situated partly in the Indian territory adjacent to the Pakistan border at the south western part. It has been used as a natural drainage area for the most part of the lower Sindh area through KPOD. The waters from all the majors Dhands in the south west cost of Sindh also have their natural drainage area in the Rann of Kutch through Cholri & Pateji Dhands. This is an ideal choice for using it as a drain area for the LBOD. (as it falls within the Indian territory). However it could only be used through KPOD and Tidal Link Drain. Secondly the water quality of Dhands might have adverse effect on its echo system and fisheries resources if the drainages of saline and agriculture waste water were allowed to drain in the Dhand areas. Hence the option of conveying the drainage water from KPOD to the Arabian Sea through the Tidal Link appear to be environmentally safe alternative. However there is an increase risk of sea water influence & flooding of sea water in the Dhand areas from the Tidal Link.

The topography of Rann of Kutch area adjacent to Tidal Link Drain indicates that the area has long been used for the natural drainage basin for the run-of from the land, flood waters and drainage from agriculture. There are some indications that the Indus River also used to discharge in the Rann of Kutch area. The areas used to receive drain waters from lower Sindh area to Rann of Kutch through Shakoor Dhand, Sanhro Dhand, Mehro Dhand and Cholri Dhands. ***The comparison of old and new Satellite imagery provides some insight in the morphological changes that have taken place between a span of 10-12 years. These include changes in the shapes and courses of creeks. Some new creeks have developed and some older creeks have been reduced or disappeared.*** As the natural drainage from the Dhands to Rann of Kutch has now been stopped its northwestern parts are now exposed only to tidal action from the sea. This change is expected to promote hyper saline conditions, erosional tendencies and increase in tidal influence in this part of Rann of Kutch.

4.3 Shah Samando Creek and Tidal Link Drain Area

The area around Tidal Link Drain of LBOD, in general and Shah Samando Creek in particular is a part of Indus Deltaic region. The present Link Drain between KPOD and Shah Samando creek passes through intertidal area and is designed to discharge saline water in the tidal mud flat area. All the drainage from Tidal Link drain is designed to drain in the Shah Samando Creek area creeks, leading to sir Creek, Indus delta. The delta is the product of the enormous amount of silt and sand brought down annually by the Indus River in to the Arabian Sea.

The area of the Tidal Link Drain is a very large tidal flat with a very low angle of beach slope resulting in a very wide inter-tidal area (25-35 km wide). This has resulted because of the protection from intense wave action due to Indus Deltaic area and the deposition of silt and clay in the area. Little is known about the environmental characteristics of this large tidal mud flat. However, the area appears to be slightly different from other inter-tidal and inshore areas of the Indus Delta. The area is frequented with a number of low lying and swampy areas called “Dhands”. The Pateji Dhand is a land locked shallow basin connected to the western end of Ran of Kutch at an elevation of about 3.3ft average mean sea level. The “Dhands” (brackish water lakes) support a small scale fishery, dependent birds population and a brackish water eco-system. The area experiences subtropical, hot and dry weather conditions with saline land. This area has long been used as a passage of the natural flow of surface drain waters, run-off and storm water drains. Although sparse mangrove vegetation is visible alongside the Sir Creek area but there are no plants seen in the Link drain area. Sindh Forestry Depth has planted / transplanted mangroves on the Link of Shah Samando Creek which is on the side of Tidal Link Drain but these have not survived to be visible.

4.4 Tidal Link Drain (TLD)

The Tidal Link drain, is a man made drain which will deliver the drainage water across Pateji Dhand and Cholri into the Arabian Sea via Shah Samando Creek. The Tidal Link is 41km long from its point of juncture with KPOD in the North-east upto the Shah Samando Creek in the South-west. The vertical tidal range in the area is about 5 m. The Tidal Link is designed to carry about 3,118 Cusecs of drainage waters. The tidal Link alignment passes across Pateji and Cholri Dhands which are interconnected with Mehro and Sanhro Dhands filled with brackish / saline water and support a diverse ecosystem, fisheries and sanctuary of migratory birds. The excess water from these Dhands has historically drained into the Rann of Kutch which is now blocked by the Tidal Link.

The earthwork on the construction of Tidal Link Drain was completed by WAPDA during 1995 and the Tidal Link was finally commissioned in January 1996. With the operation of the Tidal Link Drain a number of issues concerning the water movements, flow rates of saline water and its impact on Dhands and on the adjacent coastal wet lands and sea areas are being raised by different quarters. The Tidal Link Drain does not pass through any agricultural lands the issues concerning water movements relate to the discharge quantities, net water discharges, changes in tidal behaviour, extent of the influence of sea water upstream of Tidal Link Drain, erosion of embankments, changes in water salinity profiles of Dhands and Shah Samando Creek, contribution of Cholri weir in maintenance of a water balance and water quality in Dhands. The data collected during the present study can answer some of these questions on the basis of the scientific study.

4.5 Dhands and Tidal Link Drain

There are a few very large prominent depressions / low lying areas locally called Dhands are located between the agricultural lands and the High Tidal zone which are filled with brackish / saline water. The low lying areas covered about 400 sqkm area and consist of four major Dhands namely, Pateji Dhand, Cholri Dhand, Sanhro Dhand, Mehro Dhand and all are connected to Cholri Dhand through narrow open inter-connections: i.e. between Cholri and Pateji Dhands, Mehro and Sanhro Dhand and between Sanhro and Cholri Dhands. The Pateji Dhand is a land locked shallow basin connected to the western end of Runn of Kutch at an elevation of about 1.2 m. average mean sea level. The Cholri Dhand is directly connected to Runn of Kutch through in the South-east for the drainage of excess waters from the Dhand areas. The average depths in these Dhands vary between 0.37 m to 1.8 m. The maximum water level in Dhand areas has been reported to be 1.698 m during 1983 (M. McDonald & Partner, 1984). These brackish / saline water lakes support a diverse ecosystem, fisheries and as sanctuary for a variety of water fowls and migratory birds.

The area indicates that Dhands in the area have long been used as a natural drainage passage as well as drainage basin for the run-off from the land, flood waters, agriculture waste waters and seepage form agriculture lands. The size and water volumes in these Dhands vary according to the season and availability of drainage water and temperatures of air and humidity.

The alignment of Tidal Link passes through Pateji and Cholri Dhands and will block the existing natural flow of excess water / drainage from Cholri Dhand to Rann of Kutch. This situation might increase the influence of seawater in Dhands and hence increase their water salinity. A marked increase in seawater influence in the Tidal Link Drain and in KPOD may also hinder the smooth drainage of agriculture saline water from LBOD to the Arabian Sea. In order to provide an alternative drainage to excess water from these Dhands a man made structure – Cholri Weir (600 m long) has been constructed. The Cholri Weir is designed to allow excess water from Dhands to the Arabian Sea via tidal Link Drain for drainage. However, there is a risk of increasing the influence of seawater in Dhand areas through seawater flooding during High Tides through the Tidal Link Drain. The Dhands have different rates of water exchanges between them through wind induced, thermohaline circulation which is also influenced by the input of discharges from drains and run-off. They also exhibit marked seasonal variations in their size of water filled areas: they shrink in dry season and expand during the wet season. The Dhands receive water from Kotri Command area Drains and form the land run-off from the lower Sindh area.

5 The Hydraulic Condition of Tidal Link Drain, LBOD

5.1 Metrological Observations

The study areas fall in the climatic region of Pakistan which is arid having influence of coastal climate. This area lies over southeastern part of Sindh province and the coastal climatic conditions make mild thermal characteristics in this area as compared to the extreme arid zone. The Badin, Karachi and Chor, which are close to the sea lies under this zone.

Air Temperature

The observed yearly monthly mean air temperature variations with maxima and minima for study area (Badin) are shown in Figure 15. In general, mean air temperature variations show three normal phases, warming from February to May, slight cooling from May to November, and abrupt cooling from November to January. Mean monthly temperature has the highest amplitude of variations with maximum in May and minimum in January, about 31^0C and 17^0C respectively shown in Figure 16. However, maximum air temperature shows normal four phases, warming from February to May, cooling from May to August, warming from August to November and then cooling from November to January.

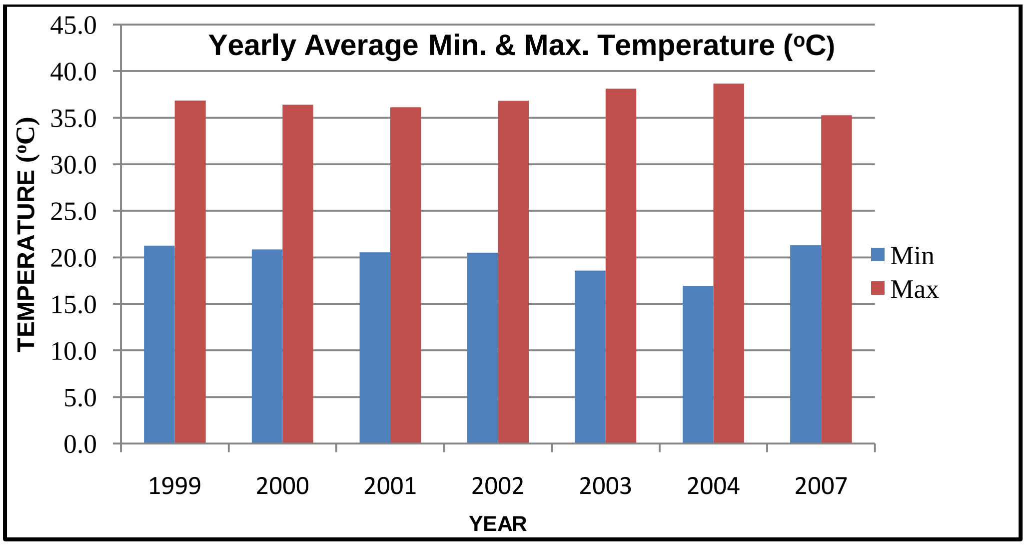


Figure 15: Yearly monthly mean air temperature variations with maxima and minima

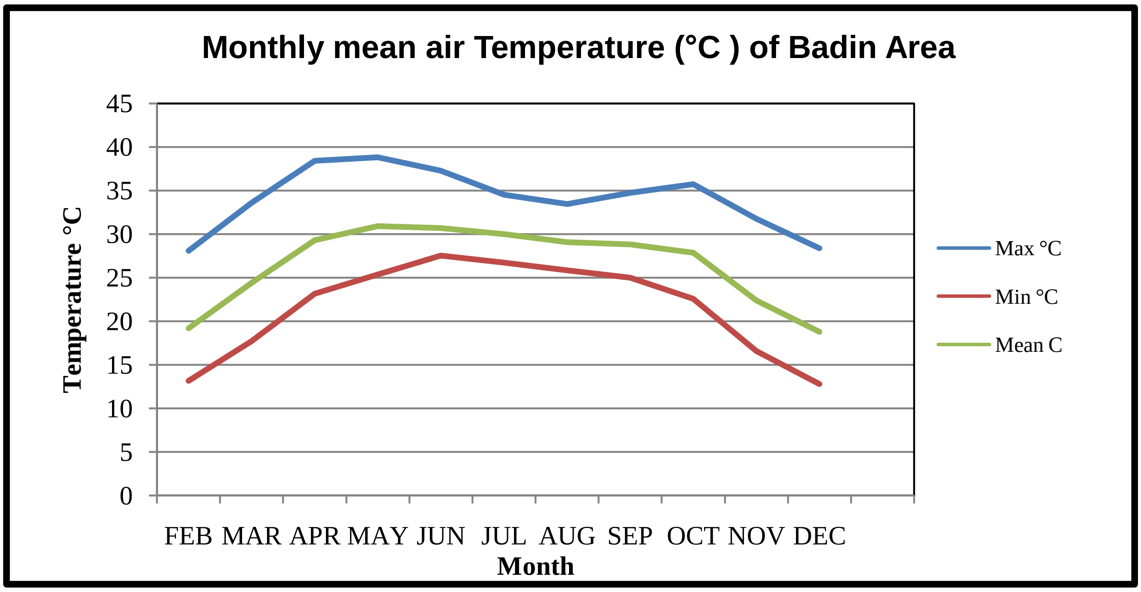


Figure 16: Monthly mean air temperature variations

Atmospheric pressure

The monthly mean air pressure is shown in Figure-17. The southwest monsoon depressions in the Arabian sea and surrounding region drop pressure in southern Sindh and less than 1000 hPa pressure is observed during southwest monsoon season. Therefore, decreasing trends from February to June reflects the domination of SW monsoon winds in the region. During winter season, the Indian subcontinent is under the influence of the Siberian high pressure centered over northern part of Russia. Therefore, high pressure northeasterly winds dominate in the region. The Siberian high is marked in December, January and February having pressure of about 1014 hPa. A concave type curve depicts the monthly variations in pressure. The development of low pressure due to increased heating over land starts in April and May, however in June it is quite prominent over land and lowest pressure is observed in July. In the month of October and November which is a transition period from SW to NE monsoon, again comes under the influence of high pressure Siberian wind.

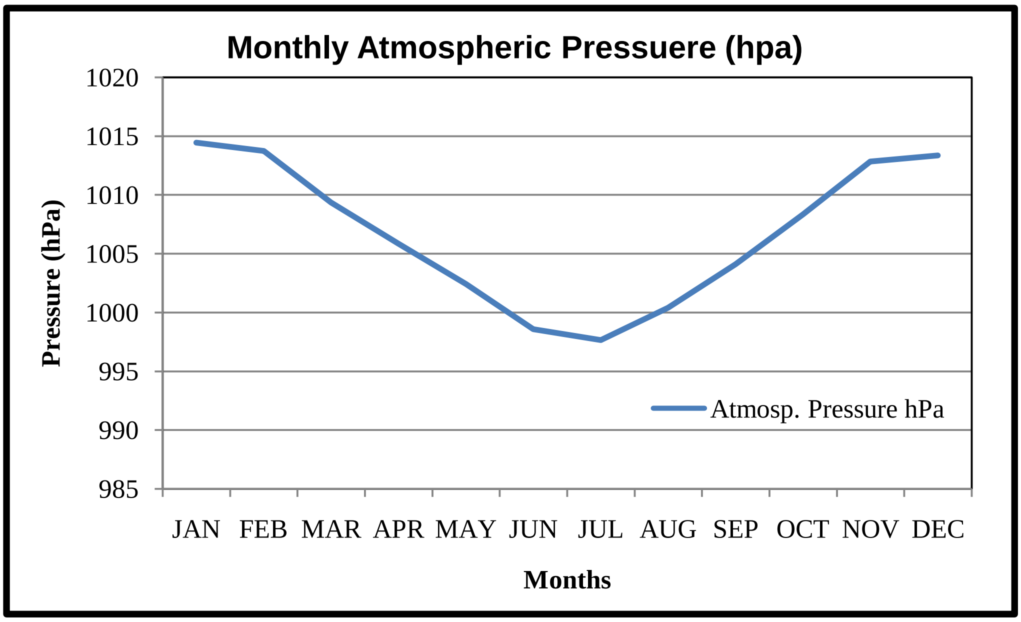


Figure 17: Monthly mean air pressure variations

<u>Wind pattern</u>

The predominant monsoon is the southwest monsoon that occurs between May and September. The southwest monsoon winds having average speed of about 10 m/sec prevails in this area shown in Figure 18, the only strong wind recorded by the NIO Automatic Weather Station at the Tidal Link Drain in 2007 which is more than 12m/sec. shown in Figure 18. The strong and persistent winds generate swell waves with a period of about 12 seconds, which strike the Badin coastline from southwest direction. The pilings up of water along the coast and by strong wind are of extreme importance for flushing of Tidal link Drain water in to sea. However, during Ebb condition, the wave action and strong currents cause speedy flushing of salt water and increase the dispersion and dilution rate.

During winter, a light wind prevails in the region. Most of the time of the season SW light winds 5 m/sec with an average speed of 5 m/s prevails. The winds from northwestern direction is about 10% of the winds prevail in the northeast monsoon season. The recorded winds in Badin for around the year are shown in Figure-3. The winds in the transition periods are mixed and predominantly week southwesterly wind prevails in the Badin and surrounding region. The recorded winds at the site for around the year are shown in the Figure 19.

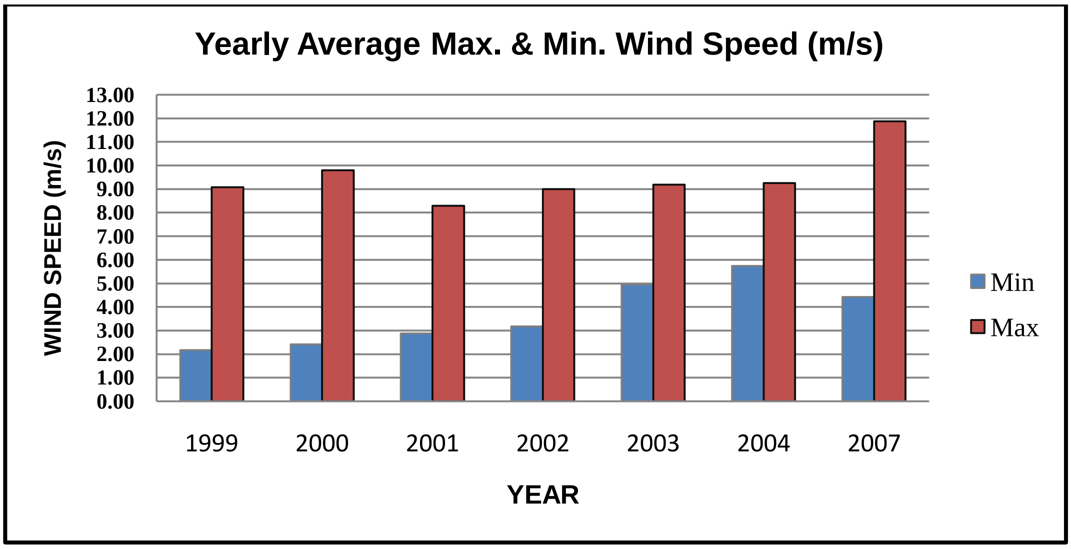


Figure 18: Yearly monthly average wind speed and direction variations with maxima and minima

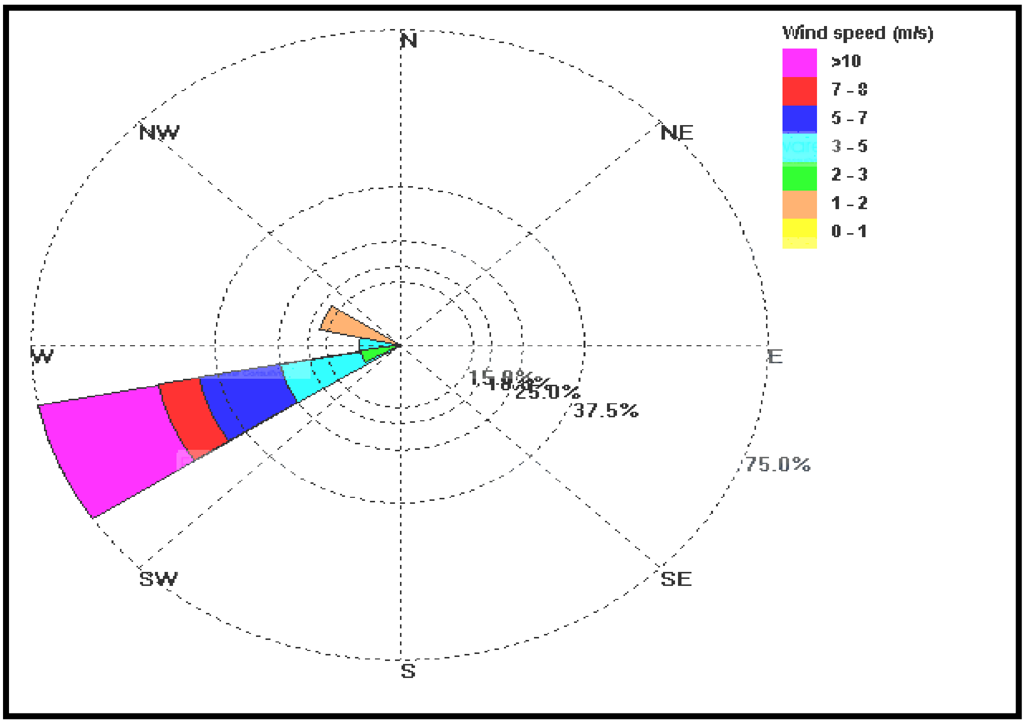


Figure 19: Wind Rose Diagram

Relative Humidity

The relative humidity is high during southwest monsoon and means humidity during southwest monsoon months reaches up to 75% due to prevailing onshore southwest monsoon winds. The lower humidity is observed during northeast monsoon period when the high pressure dry Siberian winds prevail in the subcontinent. The lower humidity in the NE monsoon and pre-monsoon period indicate that the dry winds from the land most of the times prevail in the study area. The mean monthly variations in relative humidity are shown in Figure 20.

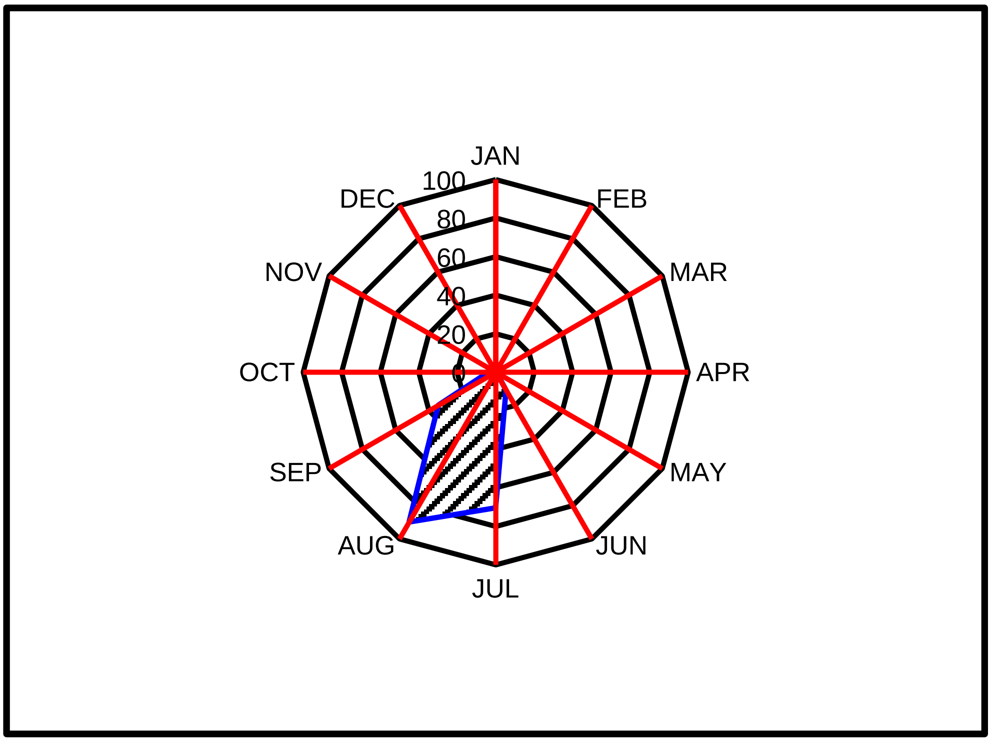


Figure 20: Relative Humidity

Precipitation

This area lies over southeastern part of Sindh province having precipitation around 200 mm/year. The study area southeastern part of country receives very low precipitation is highly. Most of the rainfall is in SW monsoon season, but the amount still very low, ranges 50-200 mm. The pre-monsoon rain is very scanty over this region. The post-monsoon and NE monsoon periods are extremely dry over most part of the country.

5.2 Tidal Levels Measurements in the Tidal Link Drain

Pre – Operational Period of Tidal Link Drain

a. Tides 1993-94

Shah Samando Creek in the Indus deltaic region is under influence of semidiurnal tides. The maximum and minimum tidal heights were recorded / predicted for each month of 1993 & 1994 at Shah Samando Creek, the maximum Spring tide was 2.31 m (7.578 ft) was recorded in June 1993 and 2.25 (7.381 ft) in June 1994. The minimum spring tide was -4.73 m (-15.517 ft) in April 1993 and -4.72 m (-15.485 ft) in April 1994. The average range of Neap Tidal Levels during 1995 was 0.6 m (1.968 ft) and -1.2 m (-3.936 ft) during 1994.

The tides are typically semi-diurnal nature with two high water levels and two low waters levels per 24 hours. The vertical tidal range between highest and lowest water is about 6.0 m (2.2 m to -4.0 m). The tides appear to be have similar values to those collected by Delft Hydraulic in December

1987 at the same site. However, a comparison has been made and concluded that these is no significant difference in the tidal behaviour at the Shah Samando Creek site during the pre-operational period of the Tidal Link / LBOD in 1993 to 1994 and the tidal data in 1995 after the operation of Tidal Link, LBOD.

b. Tides 1995

The continuous record of tidal data is available for several months during the period of January 1995 to July 1995. The data has been reduced to LBOD datum. The range of maximum and minimum spring tidal levels observed / predicted during 1995 was 2.3 m (7.545 ft) in January 1995 and -3.75 m (-12.303 ft) in April 1995 respectively. The average range of Neap tidal Levels during 1995 was 0.5 m (1.64 ft) and -1.16 m (-3.805 ft).

Operational Period of Tidal Link Drain

a. Tides 1996-97

Tidal levels observed / predicted during 1996 were 2.37 m (7.77 ft) in May / 2.41 m in December 1996 to -3.76 m (-12.237 ft) in January 1996. The average range of Neap tidal levels during 1996 was 0.65 m and -1.2 m.

The maximum and minimum spring tidal levels observed / predicted during 1997 was 2.42 m (7.934 ft) in June/July 1997 to -3.88 m (12.721 ft) in May 1997 -3.92 in November respectively. The average range of neap tidal levels during 1997 was 0.65 m (2.131 ft) and -1.2 m (-3.936 ft).

b. Tidal Levels at RD -55 (Cholri Weir):

The water levels at RD -55 are remain usually higher than LBOD datum level because of the fact that there is continuous supply of drain waters reaching at RD -55 from two main sources in addition to the Tidal flows: 1) Drain water Supply from KPOD through upper part of Tidal Link Drain and 2) Drain waters from dhands through Cholri Weir. ***As soon as the water level gets higher than 1.403 m it starts flowing to the Dhands through Cholri Weir, however, the duration of Spring Tides is mostly between 2 to 2.5 hours only. There is a time lag of about 2 hours between the times of High Waters and Low Waters at RD -125 and at RD -55. Therefore, the water flowing towards RD -55 during Flood Tides gets piled up because of the resistance of the water from upper part of the Tidal Link Drain flowing downwards to RD -125.*** The piling effect of water is also observed at Cholri Dhand area adjacent to Cholri Weir during the times of Flood waters entering into Dhand through Cholri Weir. This is also because of the resistance of dhand waters flowing into the Tidal Link drain over the Cholri Weir. As soon as the Flood waters at Cholri Dhand and at RD -55 become equal during a Flooding Tide the water levels at both sites (Cholri Weir/ Dhand and at RD -55) starts going up initially at about same speed and then the water starts flowing from the water level which becomes higher to the lower water level.

Complexity of Water Movements in the Tidal Link Drain

- ✓ Length of the Tidal link (41 km) from the KPOD to the RD-155 (Shah Samando Creek) that continuously receive drain waters from KPOD, Serani, and from Dhands through the Cholri Weir.
- ✓ There is a strong tidal flow entering the Tidal Drain from Shah Samando Creek through RD -155.
- ✓ The angle of beach slope or gradient between High Water Mark and Low Water Mark is very low resulting into about 25-35 km wide intertidal area. This demonstrates that the seawater influence from Shah Samando Creek could extend up to about 35-40 km Northeast.
- ✓ ***The downward flow of drain water in the Tidal Link Drain is supported by Ebb tides. During Ebbing all the forces (hydraulic, gravity gradient and Tidal) join hands and these results in the strong flow towards the sea.*** This strong flow during Ebbing also erodes the embankments of the Tidal Link Drain where-ever these are not compact enough

to withstand the hydraulic pressure and where-ever their alignment offers any resistance to the Ebbing flow;

- ✓ The situation drastically changes by flood tides. During flooding there is an influx of seawater with natural Coriolis force and Ekman flow force from the sea into the Tidal Link Drain. This drastically changes the flow pattern and flow direction in the Tidal Link Drain. This situation leads to a strong hydraulic pressure obstructing flow of drain water in the Tidal Link Drain and pushing the drain water to flow in the opposite direction. This situation results in the flow of seawater into the Tidal link Drain from Shah Samando Creek which is clearly noticeable up to a point between RD -21 and RD +26 and sometimes feebly noticeable up to Serani.

Extent of Tidal Influence

The available data collected during the present study on the Ebb and Flood currents and water level variations suggests that the extent of Tidal influence in the Tidal Link Drain is noticeable significantly all along the length of the Tidal Drain. However, RD -21 site exhibit the minimum tidal fluctuations. The influence is noticeable up to RD +2. At RD -22 and beyond the tidal fluctuations are prominent. The Water Salinity signature indicates that high saline waters (15-20 ppt) are noticeable all along RD -55 up to RD -22. This further confirms that seawater influence and seawater intrusion in the Tidal Link Drain has crept up to RD -22 The yearly average data for Highest High Water (HHW) are shown in Figure 21, to determine the yearly variations in sea water levels and the extent of tidal influences in the upstream of Tidal Link Drain. The yearly average data for Lowest Low Water (LLW) are shown in Figure 22.The average monthly extremes HHW and LLW for the year 1999 -2007 are given in Figure 23.The tidal range varies from 3.6 to 4.78 m during these years and continuously increasing about 10 to 15 cm.

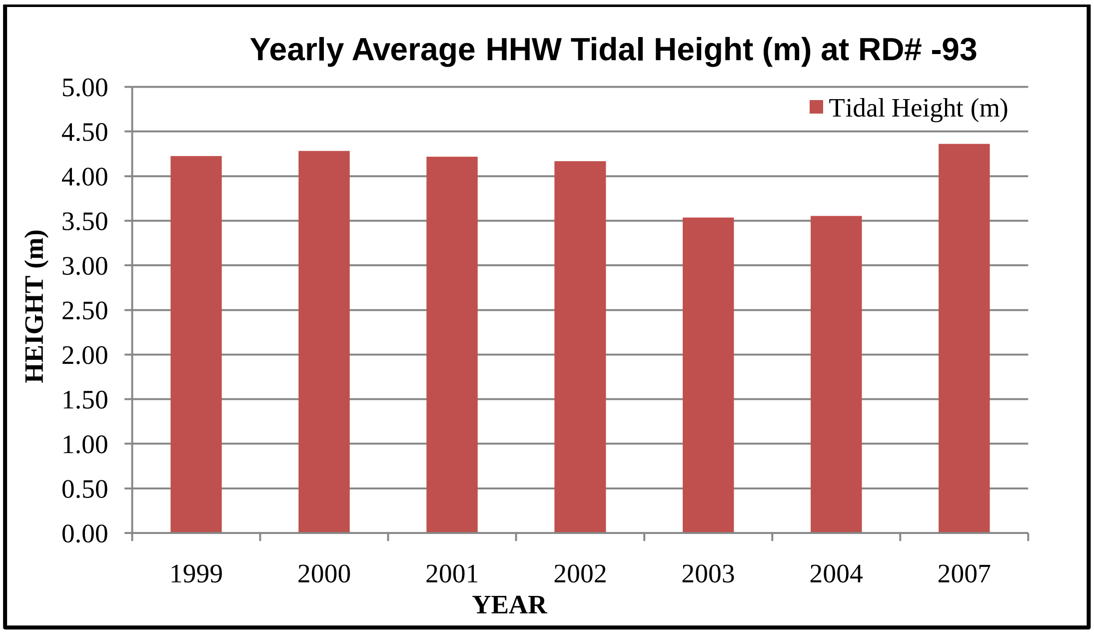


Figure 21: The yearly average data for Highest High Water (HHW)

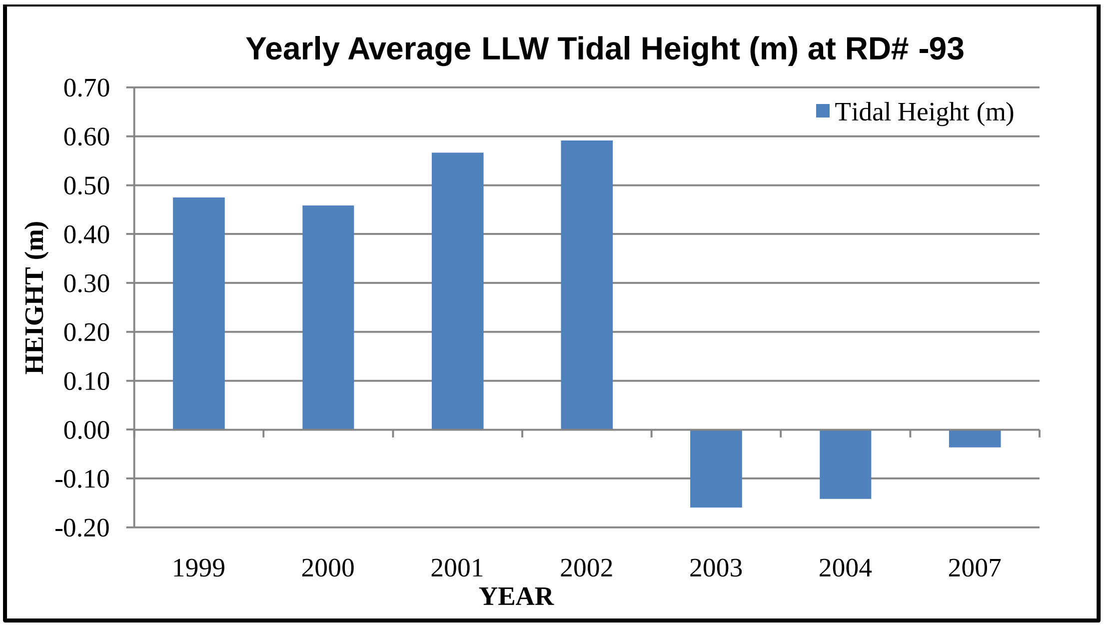


Figure 22: The yearly average data for Lowest Low Water (LLW)

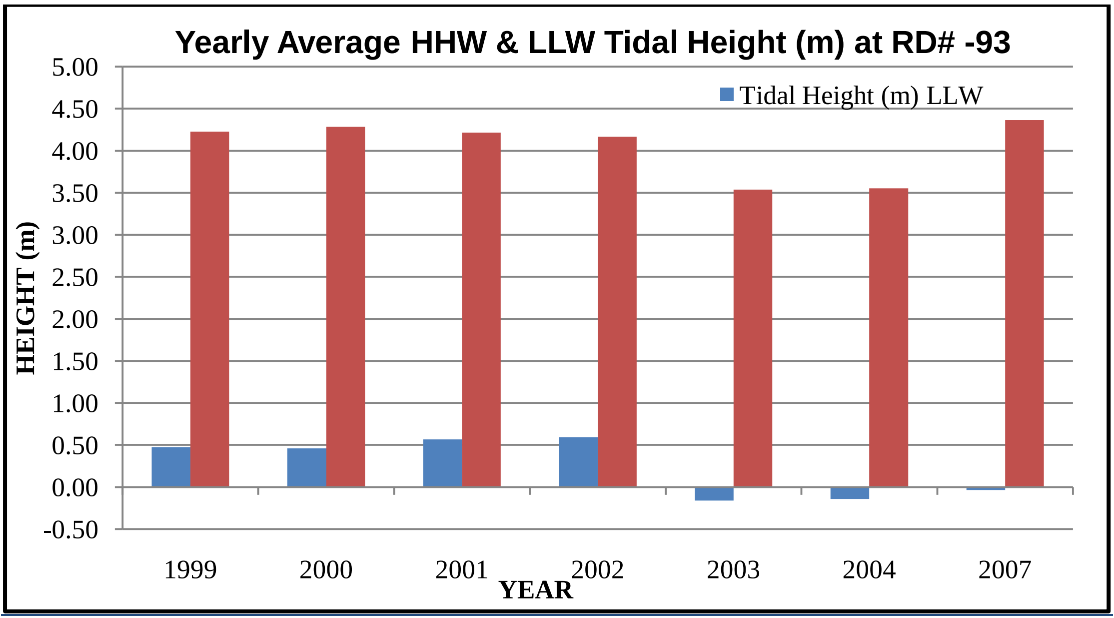


Figure 23: The average monthly extremes HHW and LLW for the year 1999 -2007

5.3 Tidal Currents Measurements in The Tidal Link Drain

The Tidal currents measurements were recorded in the tidal link drain to cover both SW and NE monsoon period. The observations were recorded for 25hrs to cover the one tidal cycle. The measurements were recorded both in the spring and Neap tide at the different locations in the Tidal Link Drain. The Andorra RCM-7 & 8 current meters were used for the observations.

The maintenance of the Tidal Link Drain, apart from other observations, also requires information about speed and direction of water movement within the drain. The measurement of Tidal water current speed and direction is also required for the assessment of water discharges during flooding and ebbing tides as well as in assessing the possible erosion / sedimentation in the vulnerable spots within the drain. The observations on the water current in the year 2007 at RD -60 and RD-95 confirm the expected increase in influences of sea water build up during stronger Ebb and Flood tides at these sites. The situation is likely to increase erosion tendencies in the tidal link and adjacent areas particularly during the period of strong summer monsoon (South –West monsoon) in the study area. The maximum current velocity was recorded at RD- 60 with 198 cm /sec in SW direction and the minimum current velocity was recorded with 18.2 cm/sec in NE direction. The water current observation at RD- 38 in 2007 was also taken and found the value of current velocity with 115.7 cm/sec in SE direction it indicate a strong connection at this place with the Pateji Dhands. The yearly comparison of the current velocity in the Ebb and Flood tide in NE – monsoon and the SW monsoon are shown in Figure: 24-38.

The available data relating to the water movements all along the length of the Tidal Link Drain was used to prepare estimates for the flow and final discharge of water from the Tidal Link Drain to the sea. There is a net outflow of about 20 m^3/Sec of drain waters from KPOD to the Tidal Drain and on its way collects drain waters from Serani Drain it reaches 55 m^3/Sec at RD -30. By the time it reaches to at RD -38 it is already under hydraulic resistance for downward flow because of the two Flood Tide water’s per day. On the other hand the two Ebb waters per day accelerate the downward flow of drain waters in the Tidal link Drain. Therefore, the resultant flow of water is dependent on the speed of water

currents during Flood and Ebb Tides in the Tidal Link Drain. As the Ebb Tidal currents are stronger, therefore there is a net flow out to the sea.

The Tidal Link site appears to be ebb dominated area with stronger ebb tides. This also helps in speedy transport of sediment load as well as drainage of discharge waters to the sea during ebb tides through the tidal cycle. However, there is also risk of increased erosion of Western embankments of channels and creeks and therefore are very much likely to accelerate erosion within the Tidal Link Drain and around its discharge area in Shah Samando Creek site.

During April - May 1999 (the pre-cyclone period) the maximum current speed observed in the Tidal Link Drain at RD -55 during Ebb Tide were 90 - 120 cm/s and be 120 - 155 cm/s during Flood Tide. This situation was unusual as under the normal situation the ebb tides are stronger than the flood tides. This could be attributed to the total wash-out of the Cholri Weir at RD -55 thus disturbing the designed water flow pattern in the area. This situation indicated that overall residual water flow was towards dhands and KPOD instead of the residual flow to sea. However, the normal situation was restored back to normal in months after the "Cyclone 2A" which created a number of breaches in the embankments of Tidal Link Drain and natural flow of water was restored in the area.

During September 1999 (the post "Cyclone 2A" period) the maximum seawater current speed observed in tidal Link Drain at RD -93 was 140 cm/sec (130-174cm/s) during the ebb with the direction 260 degree (West-South-West) while maximum seawater current speed during flood tide was observed 70 cm/s (50-90 cm/s) with the direction 40-45 Degree (East-North-East) at RD -93.

During October 1999 strong Ebb tidal current (100-155 cm/s) while flood tidal current was during October 1999 (50-90 cm/s). During November- December 99 the water current speed during ebb tides was (70 -100 cm/s) while the current speed during flood tides was (50-70 cm/s) at RD -22.

At RD -95 the seawater currents during January 2000 demonstrated a strong Ebb Tide current (175-234 cm/s) while 75-138 cm/s Flood Tide current during the same period. A maximum Ebb water current speed of about 225-234 cm/s and Floodwater current speed of about 106 –138 cm/s was observed. The sea water currents at RD -95 during January 2000 confirm the drastic increase in influence of seawater build up during stronger flood tides at this site. The situation has however stabilized during January and March 2000 and at the onset of summer.

NE-MONSOON, Ebb Tide

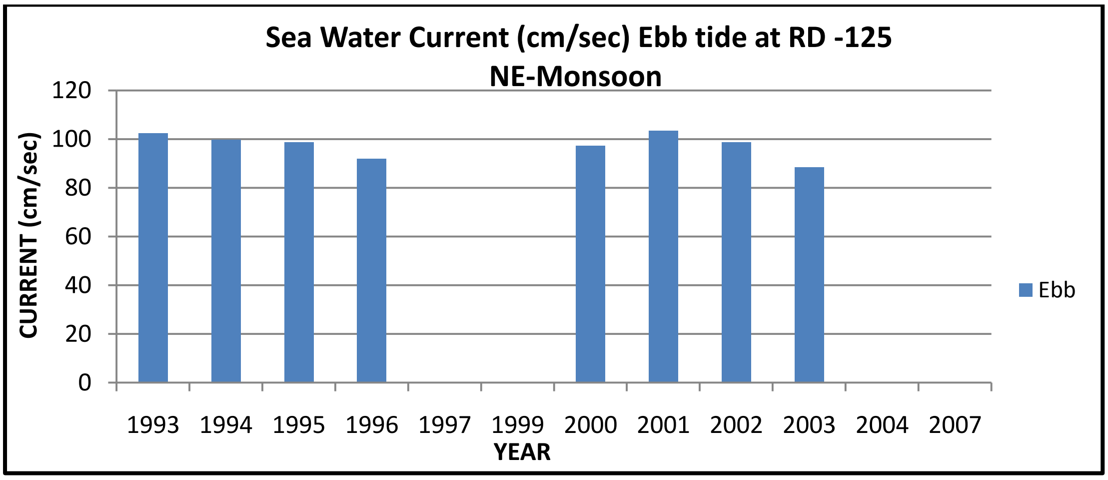
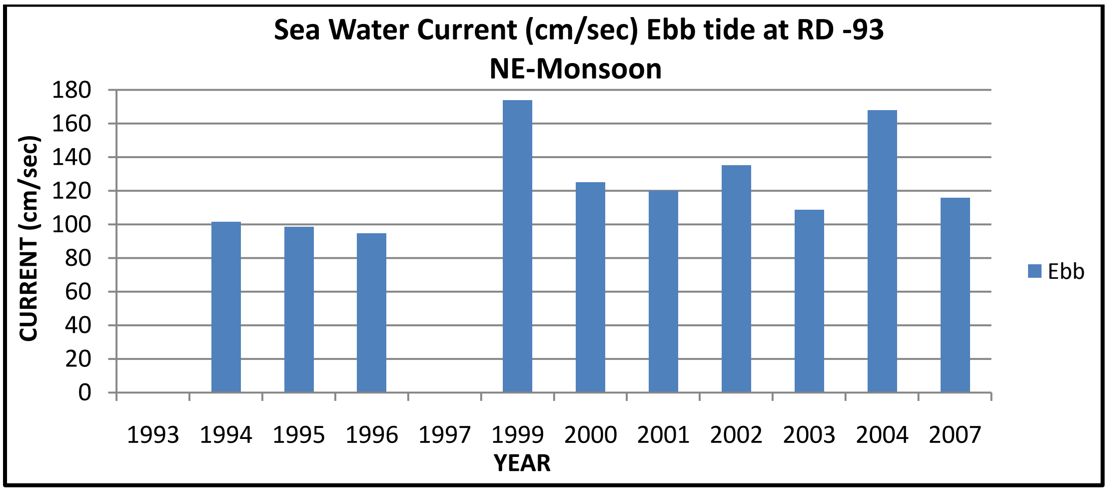


Figure 24:



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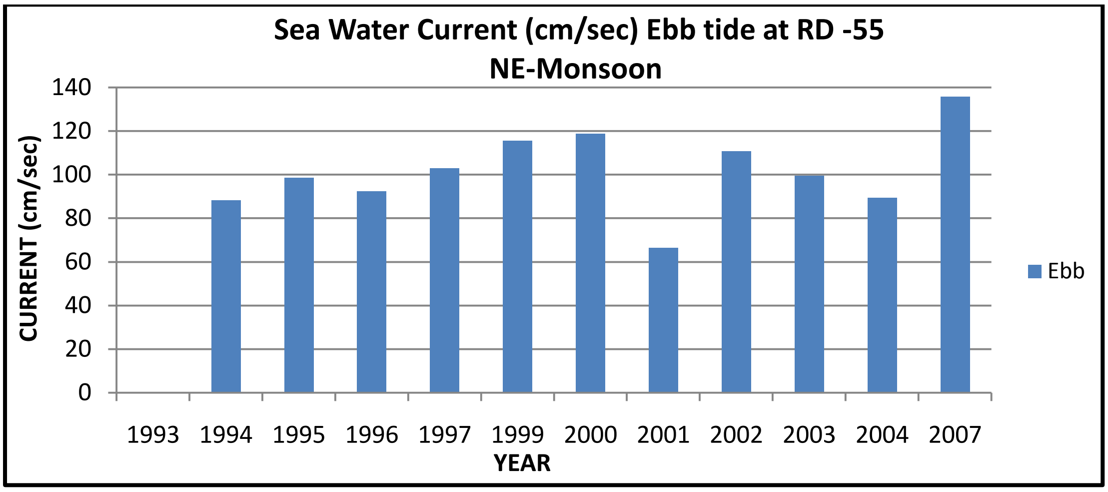

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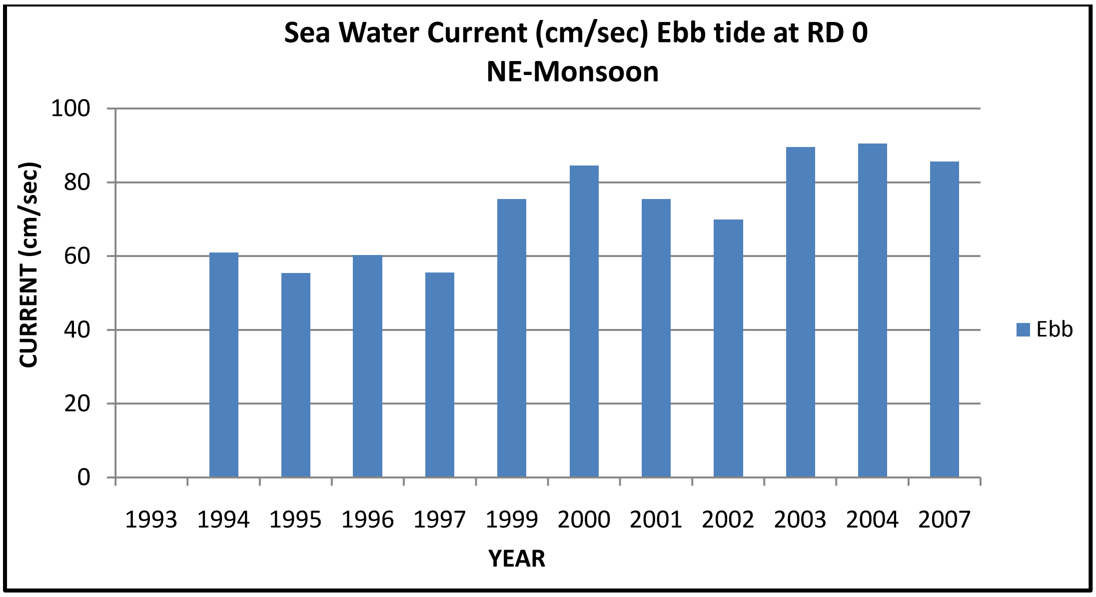

Sea Water Current (cm/sec) Ebb tide at RD 0
NE-Monsoon
CURRENT (cm/sec)
100
80
60
40
20
0
1993
1994
1995
1996
1997
1999
2000
2001
2002
2003
2004
2007
YEAR
Ebb

Figure 27:

NE-MONSOON, Flood Tide

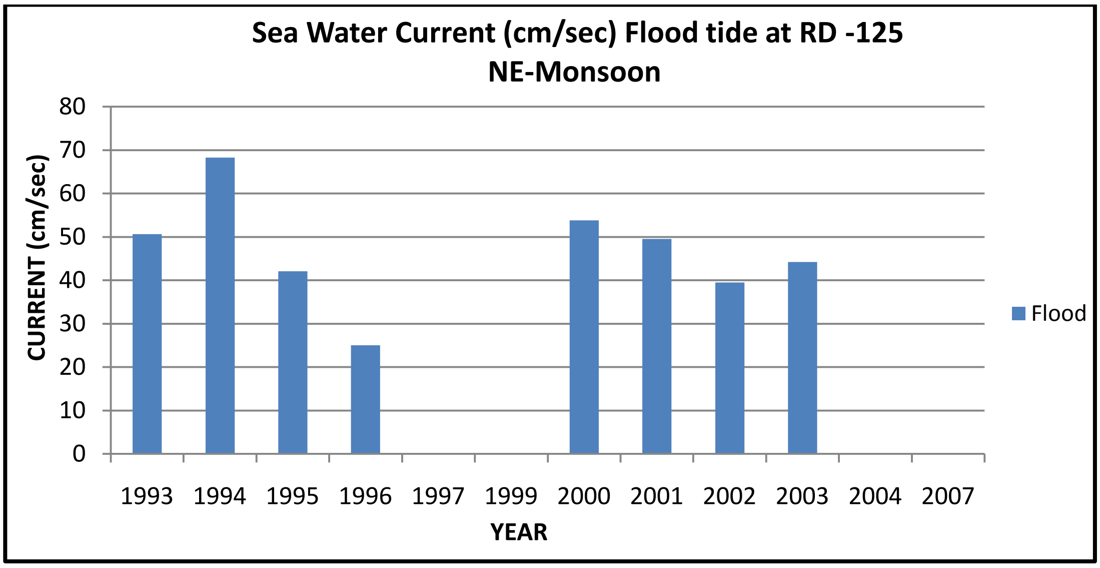


Figure 28:

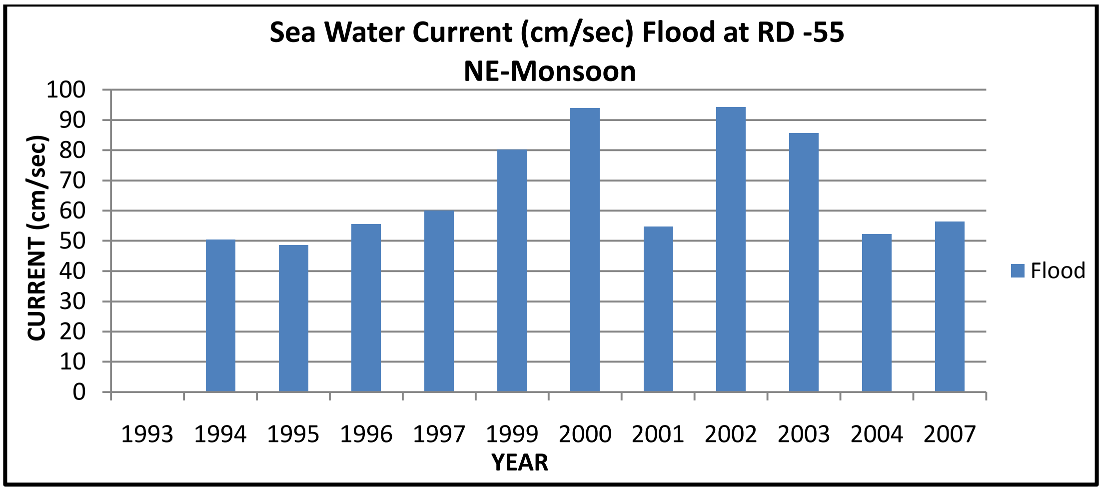


Figure 29:

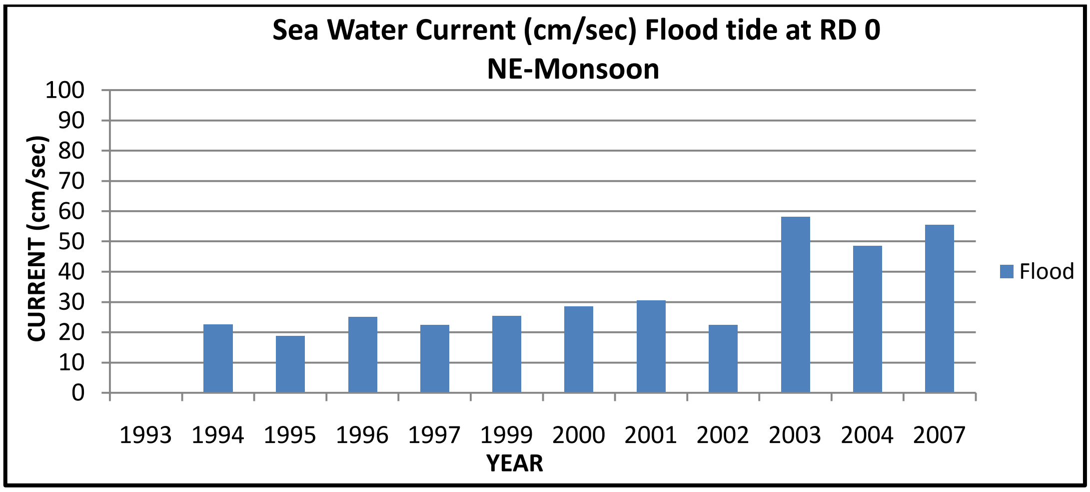


Figure 30:

SW-Monsoon, Flood Tide

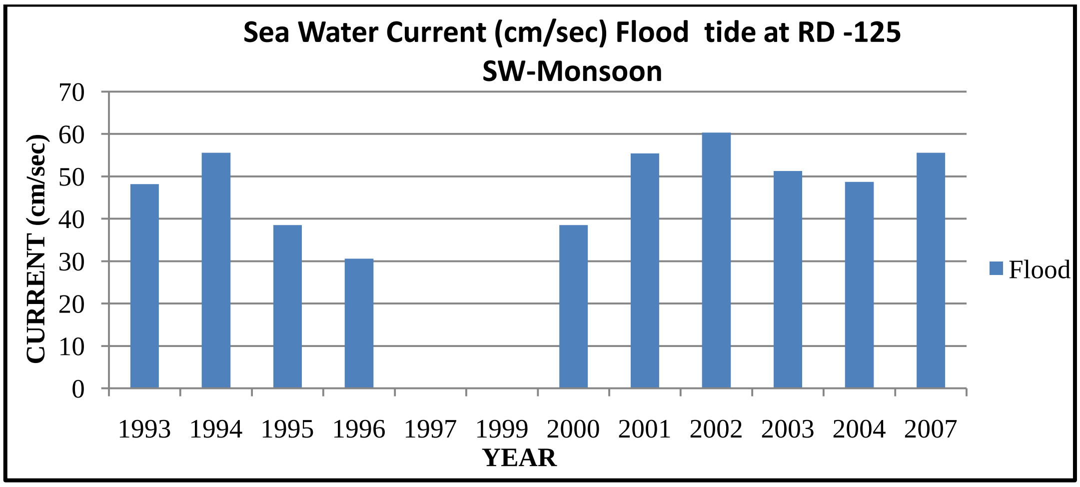


Figure 31:

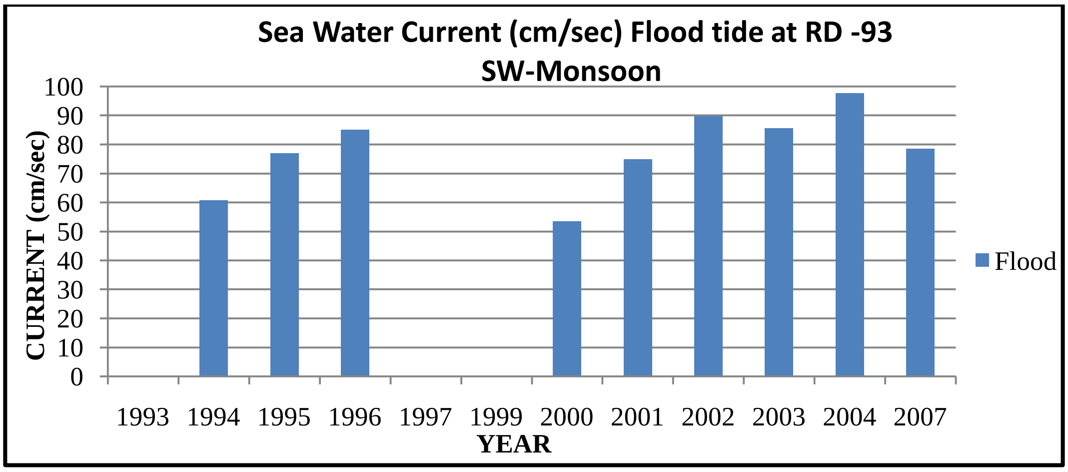


Figure 32:

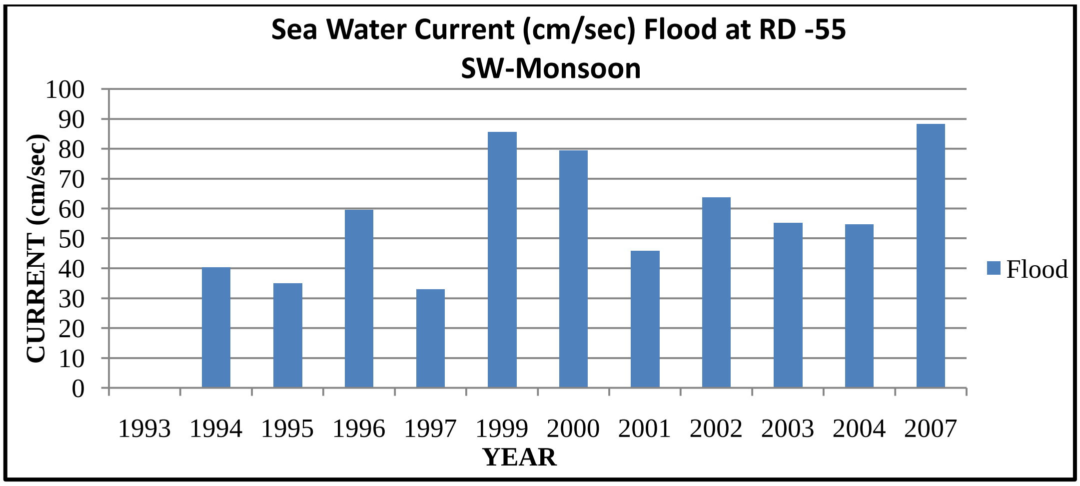


Figure 33:

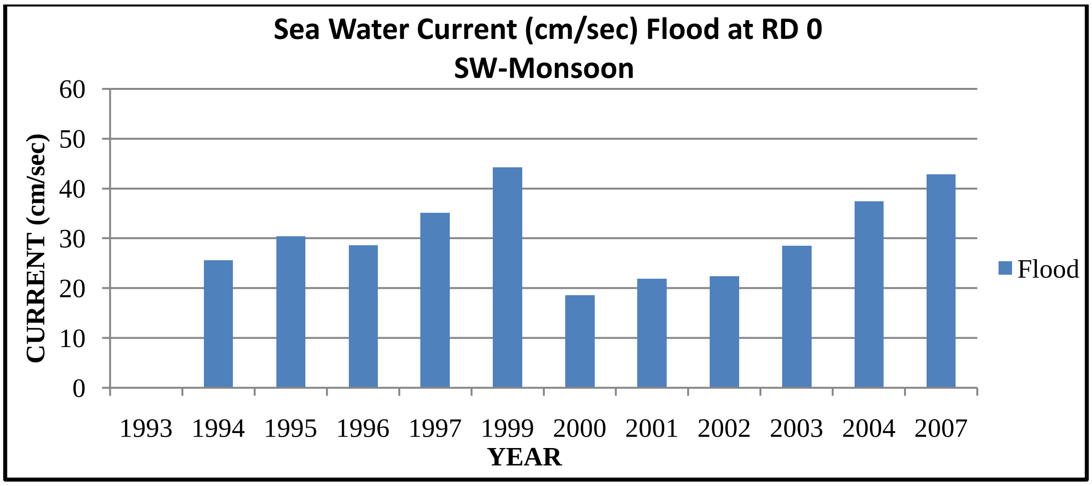

Sea Water Current (cm/sec) Flood at RD 0
SW-Monsoon
CURRENT (cm/sec)
60
50
40
30
20
10
0
1993
1994
1995
1996
1997
1999
2000
2001
2002
2003
2004
2007
YEAR
Flood

Figure 34:

SW-MONSOON, Ebb Tide

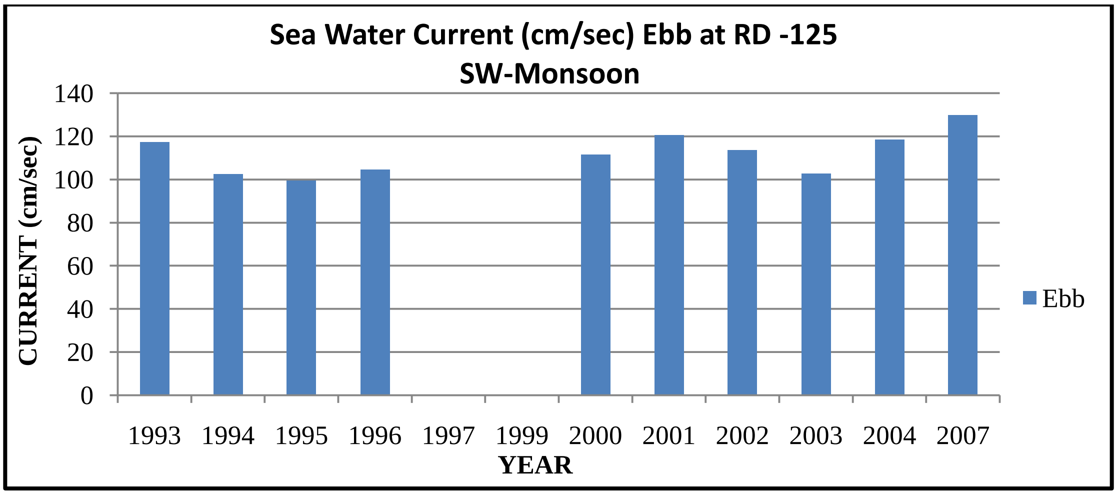


Figure 35:

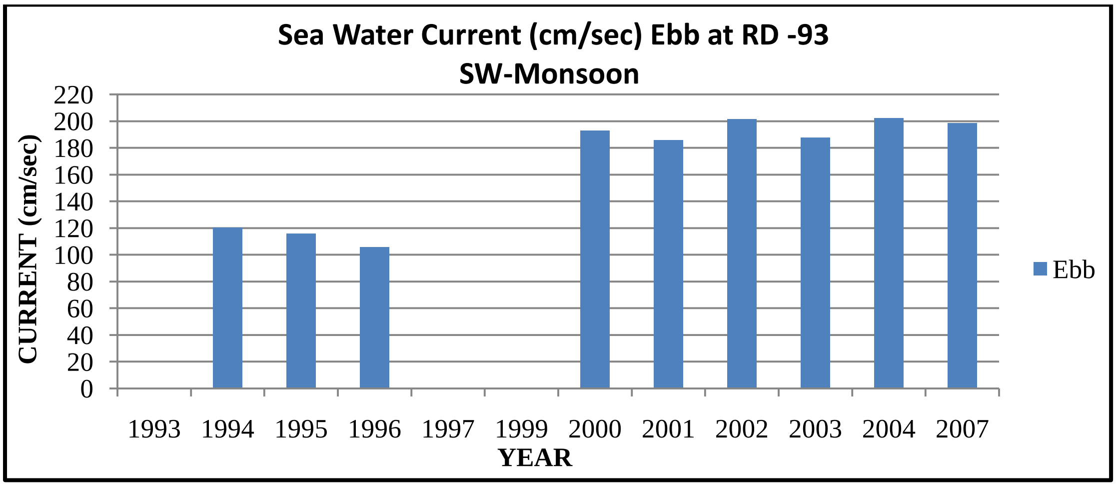


Figure 36:

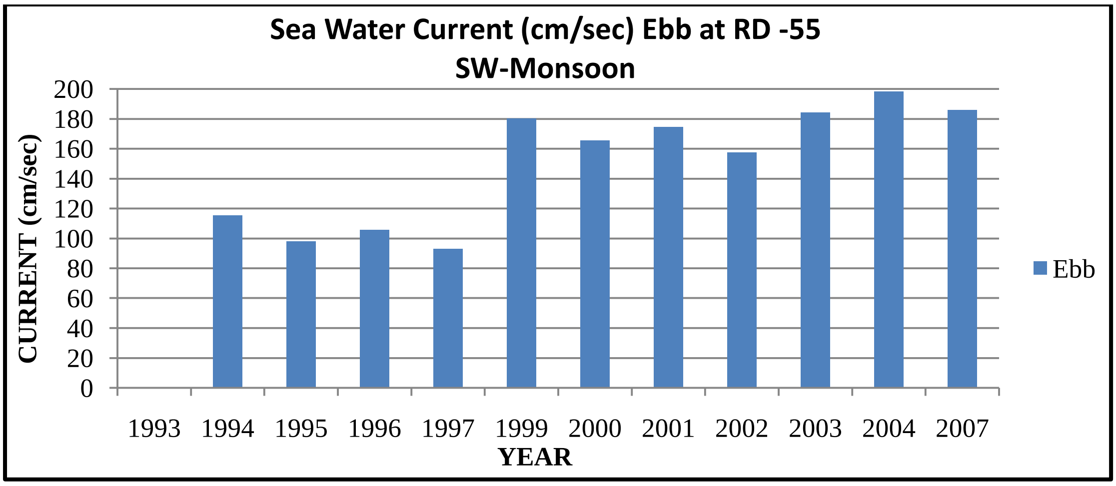


Figure 37:

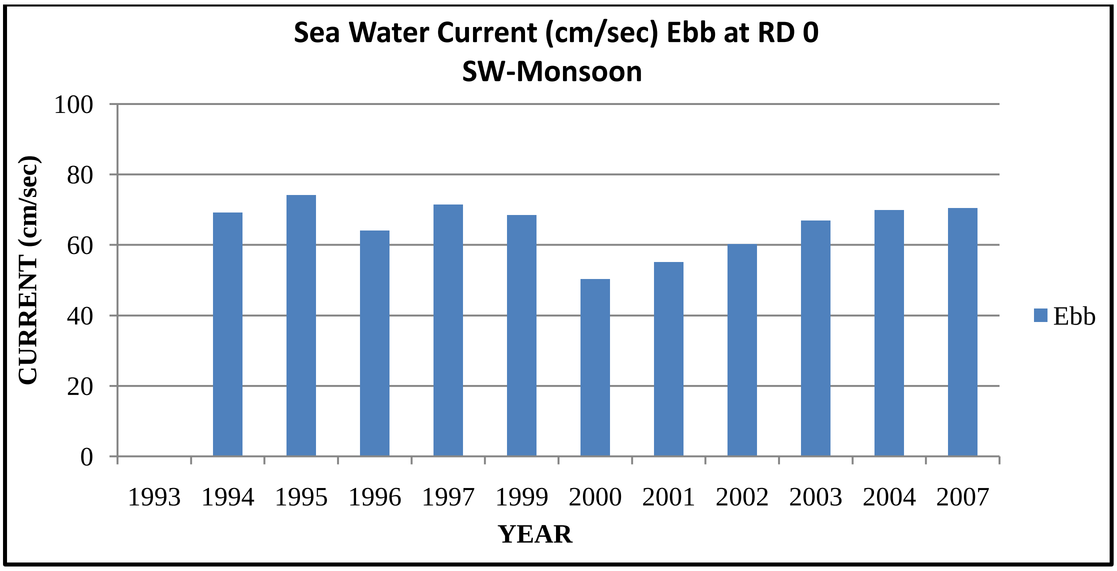


Figure 38:

5.4 Bathymetric Survey of Tidal Link Drain

The bathymetric Survey was carried out in each year. The results are summarized below from the year 1998 to 2007. In the survey results the erosion and accretion observe at the Tidal Link Drain demonstrate that there are different water inflows and outflow points, which have resulted currents were flows. While the weaker water currents caused accretion due to mix up of water inflow and outflow from a number of breaches in the Tidal Link Drain after the cyclones 2A of year 1999. The cross – sections at different RD's were compare yearly from 1998 to 2007 are shown in Figure 39.

According to the data analysis of different RD's from RD's -154 to RD -125 a continuous siltation processes from 1998 to 2007 this shows that the sediment accumulation at the mouth of the Tidal Link Drain and beound up to RD's -125. After RD -125 to RD-55 and near to the Cholri dhand a continuous erosion pattern occurs, this is due to open connection and water exchange from Tidal Link Drain to the adjacent areas. Ultimately siltation occurs, due to no strong movement of water.

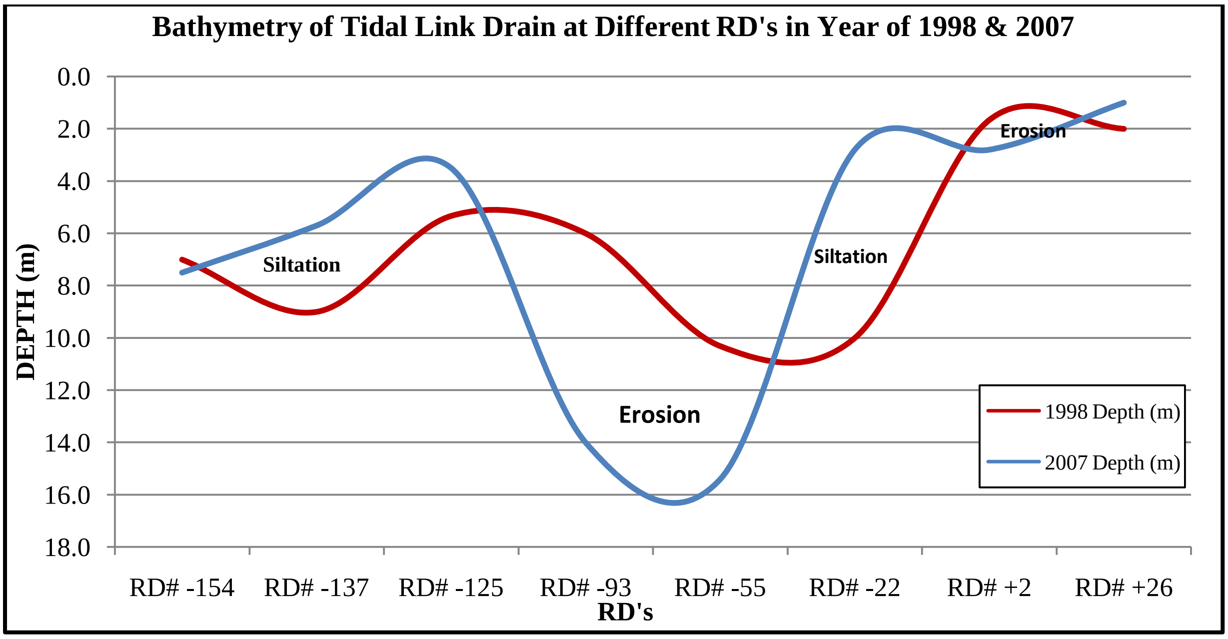


Figure 39: The erosion and accretion observe at the Tidal Link Drain

5.5 Sea Water Salinity Monitoring In the Tidal Link Drain and Dhands

Tidal Link Drain

The water salinity at different RD's was recorded time to time in the Tidal link Drain, it was observed that the high values of salinity were found at RD – 124, RD – 114, RD – 93 and RD – 74 between 40 – 42 ppt, which indicate presence of high salinity sea water. As the Embankments of the Tidal Link Drain have been washed away at several places, this situation has allowed free exchange of water between Dhands, Tidal Link Drain and with the higher saline water at Rann of Kutch during tides. The changes in Bathymetry in the Tidal Link Drain have further promoted the influence of sea water in the Tidal Link Drain.

The water salinity in the Tidal Link Drain at selected RD's, i.e RD +26, RD-0, RD -55, RD – 125 and Shah Samndo Creek from year 1993 to 2007 was plotted shown in Figure 40&41 indicated that the Pre-cyclone period salinity values and post-cyclone period are almost near to the similar values only the middle period year 2000 to 2003 the salinity values are on higher site. Values are given in table 2. The water salinity at the Tidal Link Drain was recorded each month. It was observed that the salinity ranged vary from 6 ppt at RD-0 to 16 ppt at RD +50. The higher values were found in the Lower half of the Tidal Link Drain vary between 15-30 ppt. Sea water salinity was continuously recorded at NIO Base station at RD -0 in the Tidal Link Drain and Serani Drain. In NE-monsoon period the salinity values in the Serani Drain range between 0 to 4 ppt and in the Tidal Link Drain range between 2 to 10 ppt and in the SW-Monsoon period the salnity values in the Serani Drain range between 2 to 6 ppt.

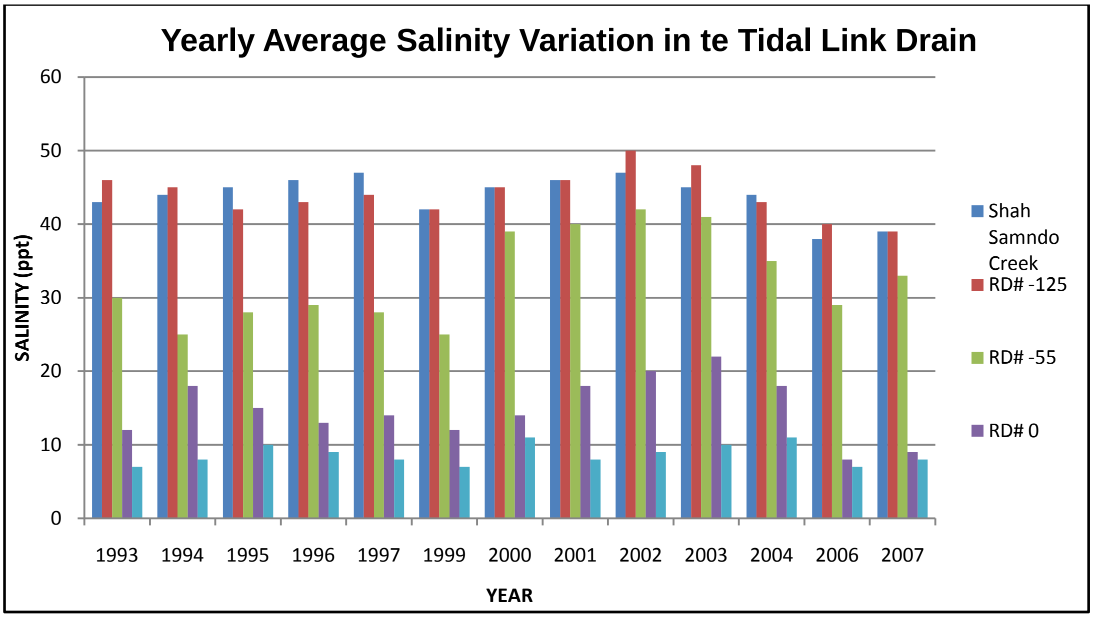


Figure 40: Yearly variation of salinity (ppt) at different locations

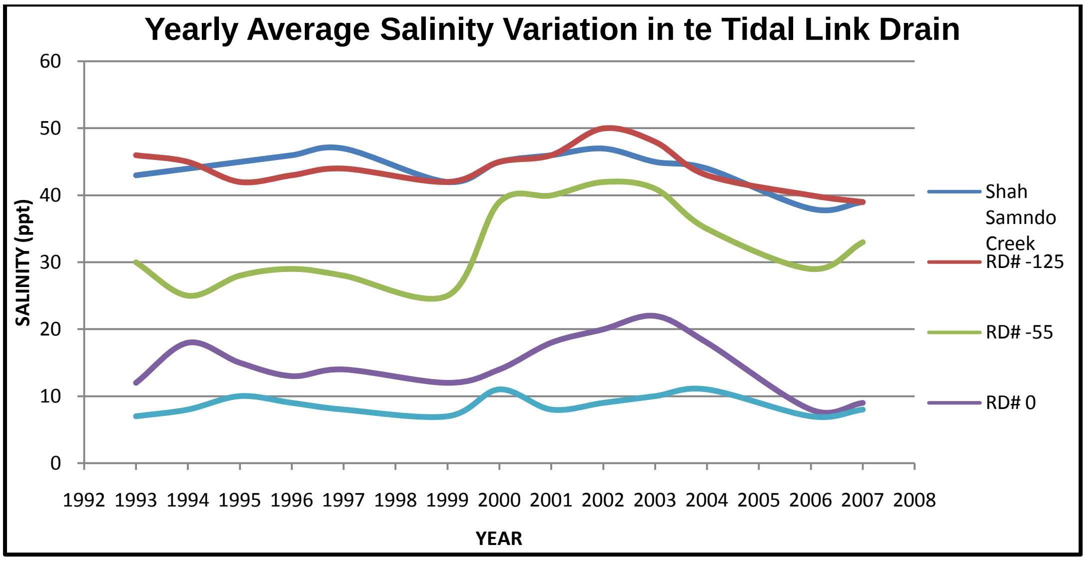


Figure 41: Yearly variation of salinity (ppt) at different locations

Table 2: Water Salinity (ppt) of Tidal Link Drain before & After Cyclone 2a

Sr.No.	Location	Before Cyclone 2a				After Cyclone 2a		
		Sep. 1996	Sep. 1997	1998	Apr. 1999	Sep. 1999	Sep. 2000	Sep. 2001
1.	Karo Gungro Outfall Drain	1.25	5.00	NO DATA	Dry	4.00	Dry	Dry
2.	Phuleli Gunni Drain	1.00	2.00		Dry	1.19	Dry	3.50
3.	Serani Outfall Drain	2.00	10.00		10.35	32.00	9.30	6.20
4.	RD -55	10.00	10.00		14.65	25.00	37.00	40.00
5.	RD -93	20.00	18.00		32.00	35.00	42.50	47.00
6.	RD -125 *	25.00	10.00		42.56	48.00	43.00	50.00

*** Effect of Jati Drain of fresh water**

Dhands (Brackish Water Lakes)

It was observed that the salinity values have been drastically increased in the Dhands. The open connection between the Tidal Link and the dhands has introduced significant tidal fluctuations at least in Cholri Weir, and caused the gradual silting of this Dhand. A tidal creek type drainage network has developed where the Cholri Weir was located; facilitating rapid and excessive drainage of Cholri Dhand at low tide (it is not known how far this effect extends into the dhands). The increased salinity of the dhands is probably caused by a combination of decreased flows in some of the Kotri drains (Kora and Fuleli) that flow into the Sanhro and Mehro Dhands, diversion to KPOD (which collected the eastern Kotri drains and emptied into Pateji Dhand) into the Tidal Link, and the inflow of some sea water through the open connection with the Tidal Link. Evaporation may also be a more important part of the water balance of the dhands than in previous times. It is observed that the dhands may now be under threat from pollution by sugar factories and other polluters upstream on the drains that outfall into the dhands. The surface water salinity yearly values are given in Table - 3 and all four Dhands yearly salinity variations are shown in Figure 42.

Table 3: Surface Water Salinity (ppt) in Dhands

Dhands	YEAR											
	1997 Before Cyclone 2A		2001		2002		2003		2007		2008	
	Salinity	Depth	Salinity	Depth	Salinity	Depth	Salinity	Depth	Salinity	Depth	Salinity	Depth
	(ppt)	(m)	(ppt)	(m)	(ppt)	(m)	(ppt)	(m)	(ppt)	(m)	(ppt)	(m)
Sanhro Dhand	10.00	0.80	35.00	0.70	39.00	0.50	47.00	0.40	17.00	0.40	19.00	0.41
Sanhro Mehro Dhand	25.00	0.60	30.00	0.60	37.00	0.30	41.00	0.30	19.00	0.30	22.00	0.32

Dhands	YEAR											
	1997 Before Cyclone 2A		2001		2002		2003		2007		2008	
	Salinity	Depth	Salinity	Depth	Salinity	Depth	Salinity	Depth	Salinity	Depth	Salinity	Depth
	(ppt)	(m)	(ppt)	(m)	(ppt)	(m)	(ppt)	(m)	(ppt)	(m)	(ppt)	(m)
Cholri Dhand	7.00	1.00	32.00	0.80	40.00	0.80	41.00	0.70	13.00	0.60	18.00	0.62
Pateji Dhand	35.00	0.50	30.00	0.60	36.00	0.60	37.00	0.60	18.00	0.50	20.00	0.55

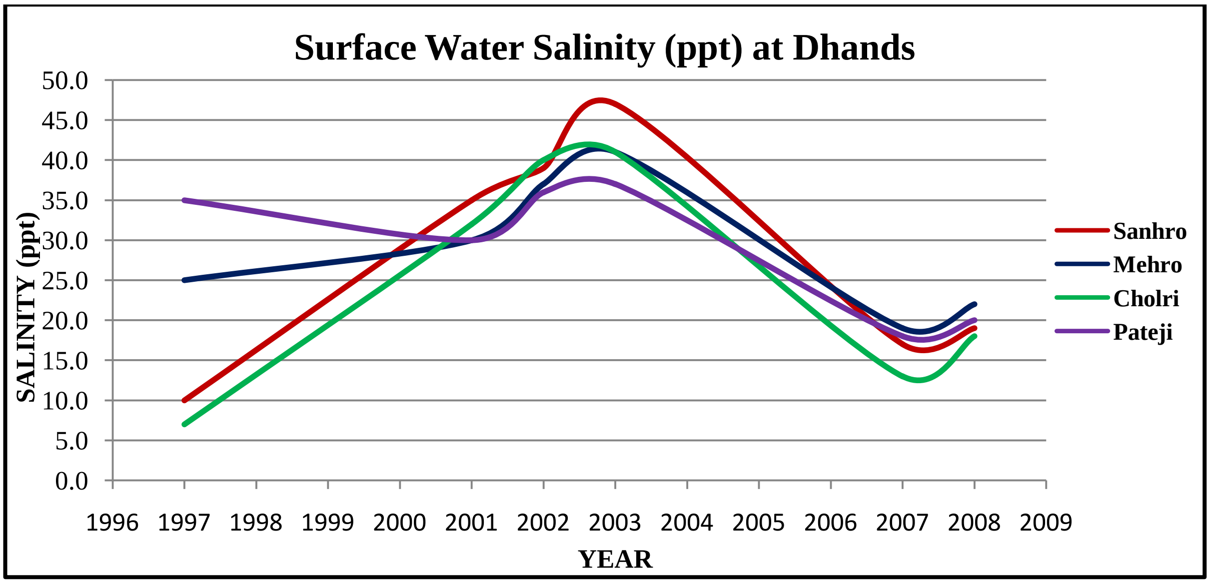


Figure 42: Salinity evolution in Dhands area.

The hyper-salinity of the Rann of Kutch is remarkable, and indicates that it may be influencing salinity in the Tidal Link and the dhands where it flows through the existing breaches in the Tidal Link Canal left bank. Up to 1997 at least, salinity conditions remained very favorable for the basically brackish or estuarine ecosystem that had developed over the years in the dhands. At present, salinity conditions range from those typical for sea water to the hyper-saline Pateji Dhand. The anecdotal evidence seems to conflict over whether the dhand surface area has shrunk, or the depth has substantially decreased because of the direct connection between Cholri Dhand and the Tidal Link as shown in the satellite image in the beginning of this report.

Seawater Flows to Dhands

It was observed that the water exchange from the one large dhand (all old dhands are merged into one large dhand) to Tidal Link Drain continues unrestricted through several breaches created in the embankments of the Tidal Link Drain by the cyclone. The turbid waters from dhands now enter into Tidal Link at many places and also enter into the Rann of Kutch at many places along the length of the Tidal Link Drain. The original natural flow pattern of the drain waters in the area has been restored forcefully by the cyclone towards Rann of Kutch in Southeast and to the South stands. This has reduced the effective length and carrying capacity of the Tidal Link Drain considerably.

At present it is difficult to distinguish between various dhands in the area as all of them have been forced to merge into one large dhand after the recent cyclone in the area. The monitoring done by the present study has demonstrated that the water exchange from this large dhand to Tidal Drain continues unrestricted through several breaches created in the embankments of the Tidal Link Drain by the cyclone.

5.6 Sedimetal Logical Studies

For the better understanding of the sedimentalogical changes in different natural settings the total study area is divided into three groups as shown in the Figure 43.The Group I is comprised of the stations in the dhand area in the north and northwest of the LBOD system. The Group II is comprised of the stations located on the upstream portion of the drainage canal. The Group III is comprised of stations located in the southern most (near to the sea) section of the drainage canal. This report is aimed to give a summarized view of sedimentalogical studies carried out during the last three years up to 2007.

Particle Size Analysis

We used the Sedigraph (5100) for grain size analyses as it give high reproducibility in fine grained sediments and gives the whole size spectrum with satisfactory resolution above 1µm [Singer *et al.*, 1988; Jones *et al.*, 1988; Coakley & Syvitski, 1991]. The procedure adopted for pre-treatment and dispersion of samples was according to British Standard 1377 (British Standard Institution, 1975). Pre-treated samples were sieved through a 0.063mm (63 µm) sieve. The finer fraction that passed through the sieve was collected in 500ml. flasks for Sedigraph analysis. The sand fraction retained on the sieve was dried in the oven for dry sieving. Before analyses, sediment standards of Micromeritics were used for the calibration of Sedigraph. The Sedigraph was operated between the starting diameter of 100µm and ending diameter of 2µm, throughout the analyses. A solution of 0.05% Sodium hexametaphosphate was used for particle dispersion.

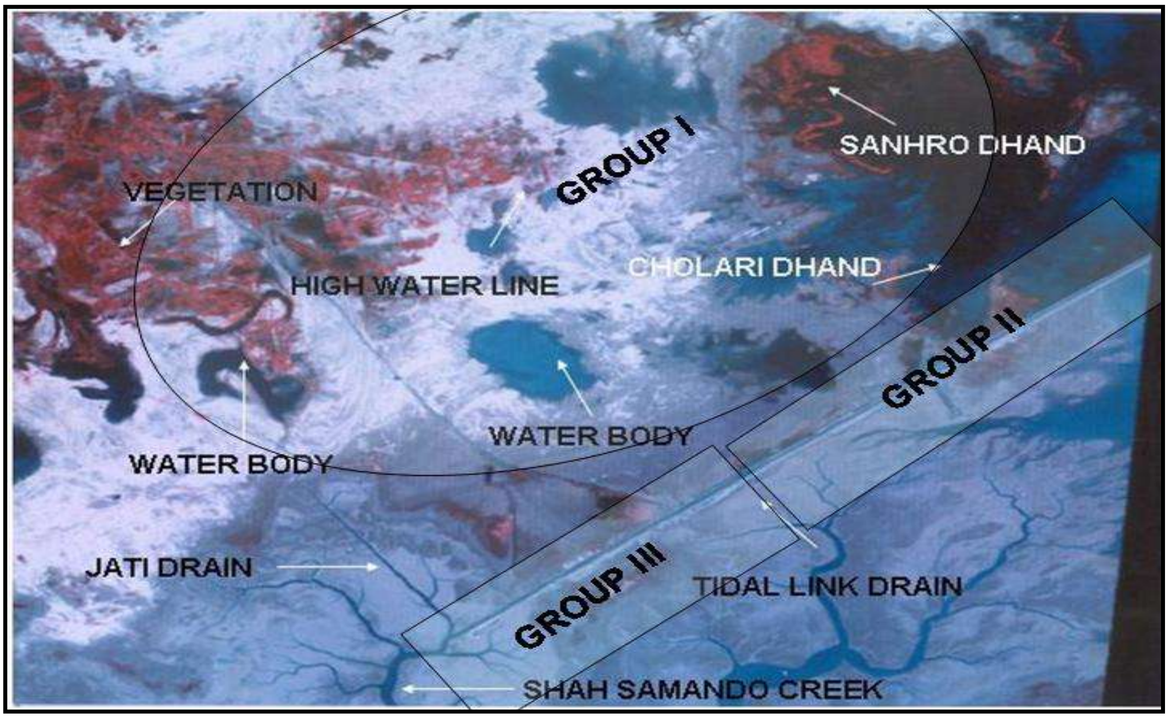


Figure 43: Location map of the sampling area.

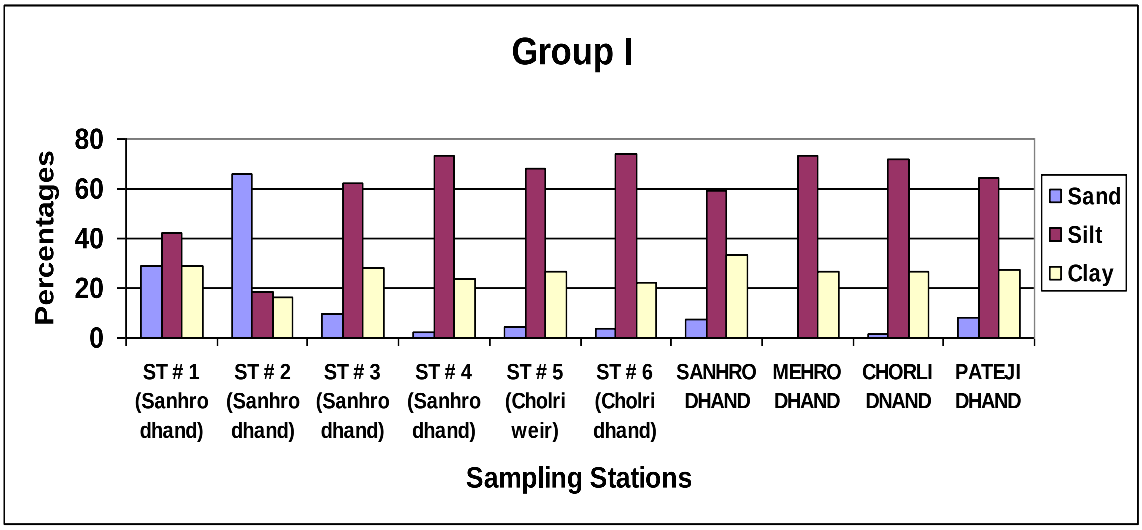
Textural Classification

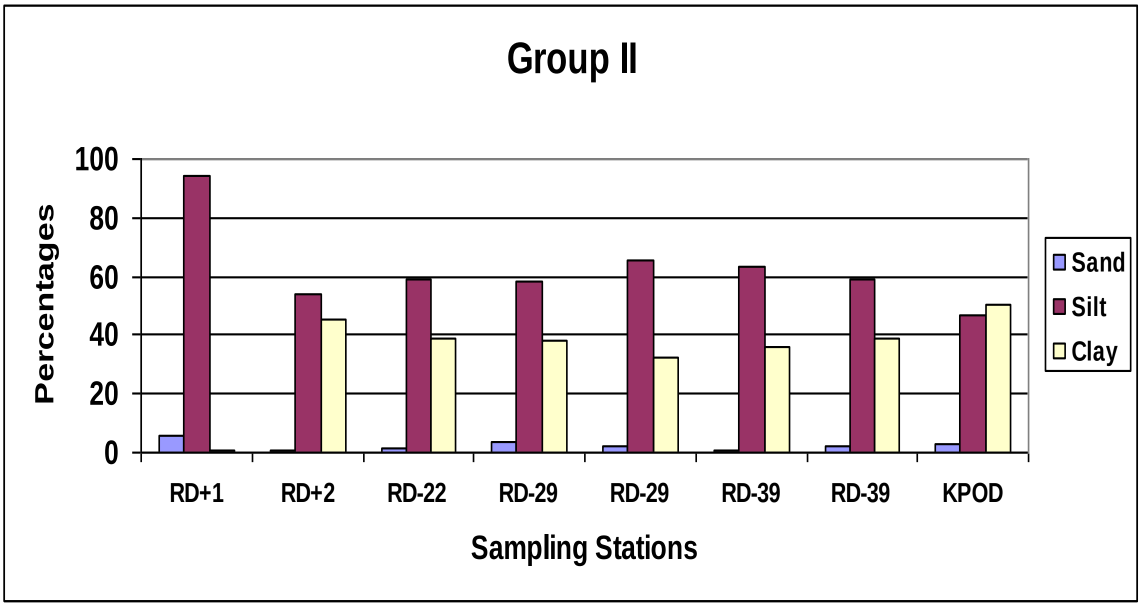
The sediment classification adopted in this study is based upon that of Shepard (1954). Sand, silt and clay boundaries are based upon the Wentworth scale (1922).

Results and Discussion

Due to low percentages of sand in seven samples Mahro Dhand, RD-2, 39, 93, 138, 144 and Shah Samando are predominantly muddy with hardly any sand content therefore it was only possible to carry out dry sieving in samples collected from St. 1-6, Sanhro Dhand, Cholri Dhand, Pateji Dhand and some other RD's as listed in Table 4&5. The sediment samples analysed for their grain size distributions are generally fine-grained. The predominant grain size in the sampling area is medium to fine silt. Sand content in the sediment samples was generally insignificant except at Station 2 (Sanhro Dhand) where it was about 66% (Group I). The silt size fraction averages 54% as it ranges from 18% to 94%. The clay content averages 39% and ranges between 16% and 69% (Group I & III). According to the Shepard's textural classification of 1954, the general texture of these sediments can be defined as Clayey Silt.

The area around Tidal Link Drain of LBOD, in general and Shah Samando Creek in particular is part of Indus Deltaic region. The sampling stations at or near the direct influence of sea (Group III) are comparatively more clayey. Sediment characteristics in the sampling are apparently determined by the sediment source, relief and discharge of the feeding river/channel. The dominance of fine grained sediments in the area apparently does not necessarily indicate depositional environment but rather depicts the general character of the mud dominated Indus Delta. Since the Indus Delta is transformed to tide dominated delta therefore the mud deposited in the area can be classified as slack tide mud drapes and the over bank areas as tidal flats. Nevertheless, the highly turbid water and dominance of silt fraction indicates relatively strong current action in the area. The high percentages of fine-grained sediments also suggest that the sediments deposited at the sampling sites are apparently cohesive. Grain size distributions are shown in Figure 44.





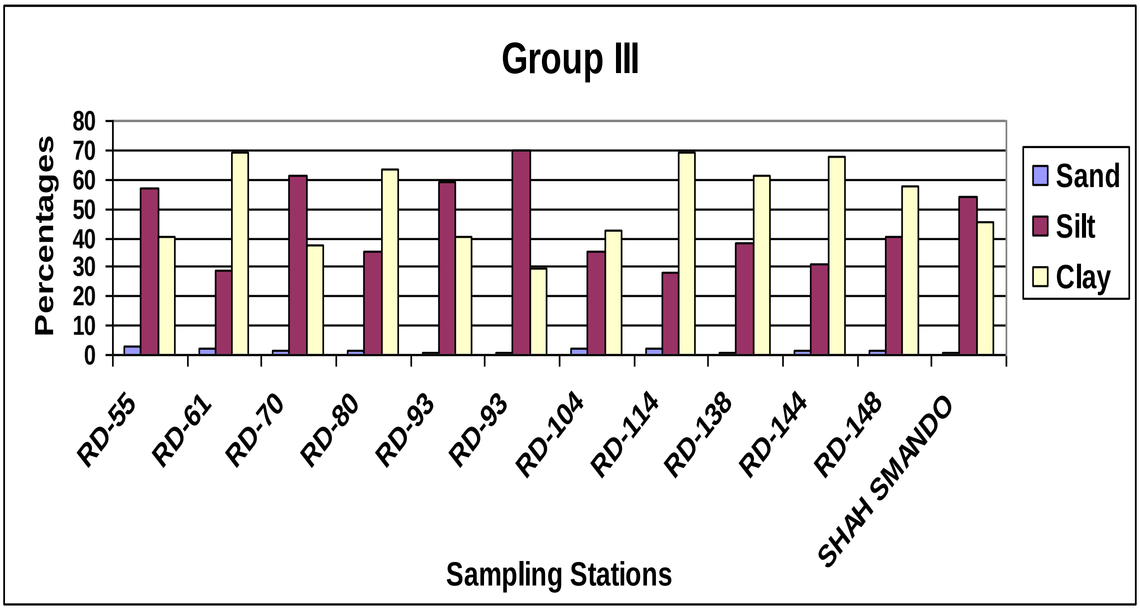


Figure 44: Grain Size distribution along the sampling stations.

Table 4: Sedimentalogical Analyses Results

Group	S. No.	Sample No.	Percentages			Sediment Nature
			Sand	Silt	Clay	
I	1	ST # 1 (Sanhro dhand)	29.0	42.3	28.7	Clayey Sandy Silt
	2	ST # 2 (Sanhro dhand)	65.6	18.4	16.0	Clayey Silty Sand
	3	ST # 3 (Sanhro dhand)	9.4	62.3	28.3	Clayey Silt
	4	ST # 4 (Sanhro dhand)	2.3	73.7	23.9	Clayey Silt
	5	ST # 5 (Cholri weir)	4.8	68.2	26.9	Clayey Silt
	6	ST # 6 (Cholri dhand)	3.8	73.8	22.4	Clayey Silt
	7	SANHRO DHAND	7.2	59.6	33.2	Clayey Silt
	8	MEHRO DHAND	0.0	73.2	26.8	Clayey Silt
	9	CHORLI DNAND	1.3	72.1	26.7	Clayey Silt
	10	PATEJI DHAND	8.3	64.5	27.2	Clayey Silt
II	11	RD+1	5.6	94.0	0.4	Sandy Silt
	12	RD+2	0.6	54.1	45.3	Clayey Silt
	13	RD-22	1.5	59.3	39.2	Clayey Silt
	14	RD-29	3.8	58.3	37.9	Clayey Silt
	15	RD-29	2.3	65.3	32.4	Clayey Silt
	16	RD-39	0.6	63.3	36.1	Clayey Silt
	17	RD-39	2.2	59.2	38.6	Clayey Silt
	18	KPOD	2.7	46.7	50.6	Silty Clayey
III	19	RD-55	2.6	56.9	40.5	Clayey Silt
	20	RD-61	2.2	28.9	68.9	Silty Clayey
	21	RD-70	1.5	61.2	37.3	Clayey Silt
	22	RD-80	1.3	35.2	63.5	Silty Clayey
	23	RD-93	0.7	59.0	40.2	Clayey Silt
	24	RD-93	1.0	69.6	29.4	Clayey Silt
	25	RD-104	1.9	35.6	42.5	Silty Clayey
	26	RD-114	2.3	28.4	69.3	Silty Clayey
	27	RD-138	0.6	38.2	61.1	Silty Clayey
	28	RD-144	1.6	30.7	67.7	Silty Clayey
	29	RD-148	1.7	40.3	58.0	Silty Clayey
	30	SHAH SMADDO	0.9	53.8	45.3	Clayey Silt

Table 5: Comparison of Changes in Sediment Character

S. No.	Sampling Area	1999-2000			2001-02		
		Sand%	Silt%	Clay%	Sand%	Silt%	Clay%
1	SANHRO DHAND	24.6	51.4	24.0	~22.7	~51.3	~26.0
2	MEHRO DHAND	29.0	45.0	26.0	0.0	73.2	26.8
3	CHORLI DHAND	17.7	63.0	19.3	1.3	72.1	26.7
4	PATEJI DHAND	26.5	57.4	16.1	8.3	64.5	27.2
5	RD+2	5.7	50.4	43.9	0.6	54.1	45.3
6	RD-55	2.6	62.0	34.6	2.6	56.9	40.5
7	RD-80	1.63	60.1	38.3	1.3	35.2	63.5
8	RD-93	0.6	41.7	57.6	0.7	40.2	59.0

It appears, from the comparative study of this report with the previous report, that the short outburst of morphological and sedimentological changes that happened during the erosive event of Cyclone “2A” are being adjusted by the nature as depicted by the dominance of fine grained sediments in the area. There are still few sandy pockets (Group I) at the northern end of Sanhro Dhand. This sand was probably transported there during the cyclonic event and became trapped there due to the weak receding tidal currents.

The decrease in the percentage of sand fraction in the sediments of Mehro Dhand, Chorli Dhand and Pateji Dhand either indicates removal of sand by the receding currents or accretion and deposition of fresh mud dominated sediments in the area. The extremely high amount of clay material suspended in the water column indicates continues churning of bed material by the tidal currents and erosion of river/channel banks. This process of stirring up of bed sediments and erosion of bank is expected to remain active till the area gets adjusted, naturally, to new hydrodynamic conditions.

6 Recommendations for the Improvement of Eco-System of the Dhands

6.1 Possible Options to Conserve and Improve the Dhand Ecosystems

First step should be to construct a low embankment or bund separating Cholri Dhand from Sanhro Dhand. The viability of this option might be questioned because of the likelihood of severe wave erosion, but low cost measures might be formulated to adequately protect the embankment. However, this option should be viewed as a serious step because it cuts off all opportunity for water to circulate between the dhands and it prevents the recruitment of juvenile fish, shrimp and other fauna. Moreover this option should not be chosen until the dynamic water balance and patterns of water movement within the dhand system are well known and a verified model of these dynamics can be used to assess the feasibility and impact of this option.

Second, increased flow of brackish, relatively low salinity water into the dhands is the best restoration strategy assuming this would shift the water and salt balance toward a lower salinity environment, something that can be determined by a comprehensive monitoring program designed to provide the data needed to analyze the dynamic water quantity and quality balance in the dhands. At present studies have begun to provide data and analysis to support ongoing negotiations concerning the allocation of Indus River flow to the Indus River and delta below Kotri Barrage. Should these negotiations prove successful from Sindh’s perspective, a percentage of the flow available should be diverted into the Kotri canals and drains to the dhands. This would likely have a significant impact on the restoration process.

Third, a number of non-structural natural measures that might attenuate the influence of the Tidal Link on the dhands and in particular slow or stop its progression beyond Cho lri Dhand. ***A belt of mangroves generally along in the alignment where Cholri Dhand joins Sanhro Dhand has been suggested as a way of trapping sediment and attenuating any tidal pulses or effects that might enter Sanhro Dhand.***

However, past attempts to establish extensive mangrove belts or forests in this area of the coastal zone have not been successful probably because of the soils (they are reported to be flourishing in the area of Shah Samando Creek though over harvested by local people). A third possibility is to try to establish appropriate specie of reeds and other grasses that are well adapted to the prevailing salinities in the shallow silted area between Cholri and Sanhro Dhands. Such a reed and grass belt would behave much like a constructed wetland filtering both sediments, pollutants and nutrients moving from Cholri Dhand to Sanhro Dhand. Care would have to be taken to not prevent the recruitment of fish and young shrimps from the Tidal Link or the movement of breeding fishes toward the delta and the marine environment. If the dhands were to begin a slow recovery initiatives would have to be undertaken to organize fisherman and provide training and awareness to stimulate their management of the fishery by preventing over-fishing and use of fine mesh nets that take excessive quantities of young fish and shrimp.

For the time being the best strategy is to ensure increased flow of brackish water into the dhands from the Kotri drains including the diversion of those drains that currently flow into KPOD, and to intensify the monitoring of water levels, tides, sediment, bathymetry , salinity and drain flows in the Dhands to improve the understanding of the water balance and to find out any negative trends that emerge in order to formulate mitigation measures.

A wide range of interventions have been suggested by both the affected people in the region and District authorities. Most of these proposals are well understood and typical of interventions being implemented elsewhere in many areas of Sindh today. But the context of these interventions in the Sindh coastal zone, and most particularly in the area of the Badin dhands. is unique. This is an area of high risk from natural disasters, especially cyclones and heavy monsoon season storms that cause extensive and damaging floods, in which narrowly conceived, piecemeal interventions appear to have made the risks even greater. Moreover, success depends to a significant degree on managing a highly productive and economically important ecosystem, something with which Sindh has had little experience and even less success in the past. This is so despite the availability of necessary scientific and technical expertise within the Sindh community.

Social and Economic Development of the People of the Region

The abject and pervasive poverty and limited livelihood opportunities of the people living and depending on the Badin dhands needs to be addressed. The specific needs identified by the people are neither extravagant nor impractical. But as pointed out above, meeting these needs may require an innovative strategy and considerable innovation because of the inherent risk that exist in this region. Since the damages and losses cannot be entirely eliminated, the approach has to take into account fully these risks in designing and building new infrastructure.

Integration of the coastal area communities with the rest of the country and economy, includes: (i) better access to basic services including health, education and drinking water supply and sanitation; (ii) increasing incomes through improved crop, fisheries and livestock production, marketing and micro-finance services; (iii) securing access to, and better management of the coastal area natural resources; (iv) forming viable community organization that are inclusive, well governed and can operate in partnership with public and private sector;

(v) integrating these area with national space and economy through developing rural growth centers, integrated development of physical infrastructure including construction of productive infrastructure, such as jetties and wharfs, and developing transport and mobility, through infrastructure grants and micro-credit; (vi) promoting technological innovations, particularly the use of solar and wind energy for pumping of water and generation of electricity; and (vii) reducing physical vulnerability, through the construction of flood protection and sea water containment structures and better coping mechanisms of communities.

Stabilizing and Improving Livelihoods

The core of livelihoods these communities is the fishery supplemented whenever possible by agricultural and other labor. A major effort is needed, in collaboration with the communities, to manage and upgrade the fishery and related infrastructure and technology. This will require better monitoring and management of the Dhands (it is not quite clear who's role it is to manage the Dhands, but SIDA would have an important role in sustaining adequate inflow through the drains), improving access to the fishery by helping the communities to upgrade their technology and access to the fishery (e.g. docks and fish landing and processing points), experimentation with expanded stocking of fish and shrimp in the Dhands (including the development of aquaculture I the Dhands area to produce fish and shrimp larvae to stock the Dhands), and ;iloting the use of solar an/or wind powered fish cooling and storage facilities. There is a risk that the target beneficiaries will be excluded from the benefits of such and initiative by new migrants and others intent on capturing the benefits. Hence, at the outset new approaches to managing the Dhands and the fishery have to be developed incollaboration with the communities to ensure that does not happened.

6.2 Freshwater Inflows

Adequate and reliable inflow of fresh and mildly brackish water into Badin District and to its coastal zone is perhaps the most critical factor influencing the people of this region. Access to safe drinking water in Badin and the coastal zone depends entirely on the flow of water in the canals and drains, as does the stability and productivity of the dhand ecosystem.

6.3 Controlling Pollution

As noted earlier Badin District is not located at the tail end of the entire Indus Basin irrigation system, but the direction of natural drainage (and hence most water conveyance infrastructure such as canals and drains) in lower Sindh is generally southeastward towards Badin and the coastal zone. It is not surprising then that uncontrolled discharges of pollution are concentrating in Badin and in particular in the dhands, and as has been noted that this is a major threat to public health and the economic functions of the dhands. The control of pollution within Sindh would have an enormously beneficial impact on drinking water and on the economically valuable coastal zone ecosystems.

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Annexure IV

PROJECT COSTS

1. General

Project costs include Capital Costs to be incurred for the Rehabilitation of LBOD Drainage System including Kotri Surface Drainage and O&M costs required during and after the construction period. Summary of the capital costs for civil Works is given as Table 01

2. Unit Rates

Unit rates given in Govt. of Sindh Schedule of Rates (General) have been adopted to estimate the base cost and the Non schedule items not covered under schedule have been provided with prevailing Market Price.

3. Capital Costs

Estimated capital costs for the Rehabilitation of New works proposed for LBOD Drainage System Project, for different Components, are given in following below Details of projects. Summary of the capital cost for different civil works is:

Table-1: ABSTRACT SHEET OF COST ESTIMATES OF CIVIL WORKS FOR LBOD DRAINAGE NETWORK

Sr. No	Components of LBOD Project	Estimated Cost (Million Rs.)
1	Spinal Drain	3,997
2	KPOD / DPOD Link	1,728.93
3	Nawabshah Component	914.816
4	Sanghar Component	1,683.9
5	Mirpur Khas Component	1,197.026
6	Badin Component	1,716.6
7	Kotri Surface Drainage System	621.403
8	Provision Flood forecasting & Real time Monitoring System at PD office	200
9	Construction of Building for Drainage Research Institute with Laboratory equipments	265.25
10	Purchase Discharge measuring Equipments for Monitoring Purpose	259
	Total	**12,583.925**

Table-2: COST ESTIMATES OF SPINAL DRAIN

Sr. No.	Item	Nos./ Kms	Unit Cost (Rs. M)	Amount (Millions Rs.)
1	Earthworks	-	-	888.7649
2	Bridges	-	-	-
	i New Construction	6	45	270
	ii Rehabilitation of Bridges	10	2.51	25.1
3	Water Course Aqueducts	-	-	-
	i New Construction (Converted to pipe type (RD 159 to Rd 203)	10	7.0	71.3
	ii Repairs	24	5.0	120.0
4	Drainage Inlets	62	1.0	62.0
5	Construction of 20' wide metallic Road with 10' shoulder treatment on either side.	150	8.0	1200
6	Stone Pitching 200' US and 300' DS of every structure	153	5.73	876.69
7	Plantation along banks of Drain	200	0.015	3.0
8	Construction of raised platforms along Spinal Drain for Displaced Persons	52	1.06	54.86
9	Machinery and equipment	-	-	380
10	Survey and investigation	-	-	1.5
11	Miscellaneous	22	2.0	44.0
	Tentative Cost (Million Rs.)			**3,997**

Table-3: COST ESTIMATES OF KPOD/ DPOD

Sr. No.	Item	Nos./ Kms	Unit Cost (Rs. M)	Amount (Millions Rs.)
1	Earthworks	-	-	135
2	Bridges	-	-	-
	i New Construction	1	44.5	44.5
	ii Rehabilitation of Bridges	3	2.51	7.53
3	Water Course Aqueducts	-	-	-
	i New Construction	-	6.5	-
	ii Repairs	1	5.0	5.0
4	Drainage Inlets	35	1.0	35.0
5	Stone Pitching 200’ upstream and 300’ downstream provided to every structure	27	5.73	154.27
6	Construction of Outlet at RD 52 of KPOD	-	-	11.25
7	Construction of flood Protection Bund for village Khan Bahadur Lund Located Near RD 28 of KPOD	19.31	-	358.94
8	Construction of raised platforms along KPOD for Displaced Persons	60	1.27	76.2
9	Raising Plantation along banks of Drain	54	1.06	57.24
10	Construction of Tidal Regulator at RD 22 Of KPOD			800
11	Miscellaneous	22	2.0	44.0
	Tentative Cost (Million Rs.)			**1728.93**

Table-4: COST ESTIMATES OF NAWABSHAH COMPONENT

Sr. No.	Item		Nos./ Kms	Unit Cost (Rs. M)	Amount (Millions Rs.)
1	Earthworks		-	-	491
2	Bridges		-	-	-
	i	New Construction	4	40.92	163.68
	ii	Rehabilitation of Bridges	14	1.41	19.8
3	Water Course Aqueducts		-	-	-
	i	New Construction	-	-	-
	ii	Repairs	8	0.942	7.536
4	Drainage Inlets		-	-	-
	i	Sub Drain	1279	0.1128	144.27
	ii	Main & Branch Drains	70	0.395	27.65
5	Construction of raised platforms along Nawabshah East & West Main Drain for Displaced Persons		20	0.84	16.88
6	Plantation along banks of Drain		600	0.015	9.0
	Improvement of Outfall Condition		-	-	5.0
	Miscellaneous		15	2.0	30
	Tentative Cost (Million Rs.)				**914.816**

Table-5: COST ESTIMATES OF SANGHAR COMPONENT

Sr. No.	Item	Nos./ Kms	Unit Cost (Rs. M)	Amount (Millions Rs.)
1	Earthworks	-	-	261.86
2	Bridges	-	-	-
	i New Construction	7	20.458	143.21
	ii Rehabilitation of Bridges	14	1.116	15.26
3	Water Course Aqueducts	-	-	-
	i New Construction	26	3.050	109.83
	ii Repairs	25	1.7	42.57
4	Drainage Inlets	-	-	-
	i Sub Drain	1618	0.1128	182.5
	ii Main & Branch Drains	50	3.050	152.5
5	Construction of 18' wide metallic Road with 10' shoulder treatment on either side (2.42 kms of PBD and 25 kms of SMD) .	27.42	10.0	274.2
6	Construction of raised platforms along Drain for Displaced Persons	10	0.84	8.44
7	Plantation along banks of Drain	426	0.015	6.39
8	Stone pitching at ever structure			458.10
9	Improvement of Outfall Conditions	-	-	3.0
10	Miscellaneous	13	2.0	26
	Tentative Cost (Million Rs.)			**1683.9**

Table-6: COST ESTIMATES OF MIRPURKHAS COMPONENT

Sr. No.	Item		Nos./ Kms	Unit Cost (Rs. M)	Amount (Millions Rs.)
1	Earthworks		-	-	389.31
2	Bridges		-	-	-
	i	New Construction	4	40.92	163.46
	ii	Rehabilitation of Bridges	14	1.116	15.5
3	Water Course Aqueducts		-	-	-
	i	New Construction	-	-	-
	ii	Repairs	8	0.942	7.536
4	Drainage Inlets		-	-	-
	i	Sub Drain	600	0.1128	67.68
	ii	Main & Branch Drains	100	0.395	40.36
5	Stone Pitching from RD 200-240 of MMD		-	-	458.11
6	Construction of raised platforms along Drain for Displaced Persons		10	0.84	8.4
7	Raising Plantation along banks of Drain		178	0.015	2.67
8	Improvement of Outfall Conditions		-	-	2.0
9	Miscellaneous		22	2.0	42
	Tentative Cost (Million Rs.)				**1197.026**

Table-7: COST ESTIMATES OF BADIN COMPONENT

Sr. No.	Item		Nos./ Kms	Unit Cost (Rs. M)	Amount (Millions Rs.)
1	Earthworks		-	-	396
2	Bridges		-	-	-
	i	New Construction	20	40.92	818.4
	ii	Rehabilitation of Bridges	-	1.116	-
3	Water Course Aqueducts		-	-	-
	i	New Construction	31	6	184.2
	ii	Repairs	-	-	-
4	Drainage Inlets		-	-	-
	i	Sub Drain	1291	0.1128	145.7
	ii	Main & Branch Drains	80	0.395	31.6
5	Construction of raised platforms along Main & Branch Drains for Displaced Persons		68	1.27	86.7
6	Plantation along banks of Drain		331	0.015	5
7	Improvement of Outfall Conditions		-	-	5.0
9	Miscellaneous		22	2.0	44
	Tentative Cost (Million Rs.)				**1716.6**

Table-8: COST ESTIMATES OF KOTRI SURFACE DRAIANGE SYSTEM

Sr. No.	Item		Nos./ Kms	Unit Cost (Rs. M)	Amount (Millions Rs.)
1	Earthworks		-	-	250
2	Bridges		-	-	-
	i	New Construction	4	40.92	163.68
	ii	Rehabilitation of Bridges	13	1.116	14.5
3	Water Course Aqueducts		-	-	-
	i	New Construction	6	3.050	18.3
	ii	Repairs	9	0.942	8.478
4	Drainage Inlets		-	-	-
	i	Sub Drain	910	0.1128	102.64
	ii	Main & Branch Drains	70	0.395	27.65
5	Raising Plantation along banks of Drain		277	0.015	4.155
6	Improvement of Outfall Conditions		-	-	3.0
9	Miscellaneous		15	2.0	29
	Tentative Cost (Million Rs.)				**621.403**

Table-9: COST ESTIMATE REHABILITATION OF SPINAL DRAIN

EARTHWORK

Quantity	Sr. No.	Item Description	Source	Rate (Rs.)	Unit	Amount
261,274,770 cft	1.	Earth work Excavation in Irrigation Channels, drains etc, dressed to designed section grades and profiles excavated material disposed off and dressed within 50 ft lead.	Ch: No.1, Sr. No.5 (a), page No.1 of Schedule of Rates General-2012, GOS	2420	1000 cft	632284943.4
171,003,715. 00 cft	2	Rehandling of Earth work up to a 50 ft lead.	Ch: No.1, Sr. No.9 (a), page No.2 of Schedule of Rates General-2012, GOS	1058.75	1000 cft	181050183.3
171,003,715 cft	3	Dressing and Leveling of earth work to designed section etc. complete.(Ashes, sand, silt or soft soil)	Ch: No.1, Sr. No.11 (b), page No.3 of Schedule of Rates General-2012, GOS	87.1	1000 cft	14894423.58
171,003,715 cft	4	Earth work compaction (Soft, Ordinary or hard soil) Laying earth in 6" layers leveling dressing and watering for compaction etc. complete	Ch: No.1, Sr. No.13 (a), page No.3 of Schedule of Rates General-2012, GOS	354	1000 cft	60535315.11
				Total		**888,764,865**
					888.7649	**Million Rs.**

Table-10: COST ESTIMATES REHABILITATION OF KPOD LINK

EARTHWORKS

Quantity	Sr. No.	Item Description	Source	Rate (Rs.)	Unit	Amount
9,358,200 cft	1	Earth work Excavation in Irrigation Channels, drains etc, dressed to designed section grades and profiles excavated material disposed off and dressed within 50 ft lead.	Ch: No.1, Sr. No.5 (a), page No.1 of Schedule of Rates General-2012, GOS	2420	1000 cft	22646844
52,918,200.00 cft	2	Rehandling of Earth work up to a 50 ft lead.	Ch: No.1, Sr. No.9 (a), page No.2 of Schedule of Rates General-2012, GOS	1058.75	1000 cft	56027144.25
52,918,200 cft	3	Dressing and Leveling of earth work to designed section etc. complete.(Ashes, sand, silt or soft soil)	Ch: No.1, Sr. No.11 (b), page No.3 of Schedule of Rates General-2012, GOS	87.1	1000 cft	4609175.22
52,918,200 cft	4	Earth work compaction (Soft, Ordinary or hard soil) Laying earth in 6" layers leveling dressing and watering for compaction etc. complete	Ch: No.1, Sr. No.13 (a), page No.3 of Schedule of Rates General-2012, GOS	354	1000 cft	18733042.8
				Total		**102,016,206**
					102.0162	**Million Rs.**

Table-11: COST ESTIMATES REHABILITATION OF DPOD LINK

EARTHWORKS

Quantity	Sr. No	Item Description	Source	Rate (Rs.)	Unit	Amount
13,060,080 cft	1	Earth work Excavation in Irrigation Channels, drains etc, dressed to designed section grades and profiles excavated material disposed off and dressed within 50 ft lead.	Ch: No.1, Sr. No.5 (a), page No.1 of Schedule of Rates General-2012, GOS	2420	1000 cft	31605393.6
754,630.00 cft	2	Rehandling of Earth work up to a 50 ft lead.	Ch: No.1, Sr. No.9 (a), page No.2 of Schedule of Rates General-2012, GOS	1058.75	1000 CFT	798964.5125
754,630 cft	3	Dressing and Leveling of earth work to designed section etc. complete.(Ashes, sand, silt or soft soil)	Ch: No.1, Sr. No.11 (b), page No.3 of Schedule of Rates General-2012, GOS	87.1	1000 CFT	65728.273
754,630 cft	4	Earth work compaction (Soft, Ordinary or hard soil) Laying earth in 6" layers leveling dressing and watering for compaction etc. complete	Ch: No.1, Sr. No.13 (a), page No.3 of Schedule of Rates General-2012, GOS	354	1000 CFT	267139.02
				Total		**32,737,225**
					32.73723	**Million Rs.**

Table-12: COST ESTIMATE FOR BRIDGE OF SPINAL DRAIN (NEW CONSTRUCTION)

Sr. No.	Description		Unit	Qty	Rate	Amount
1.	Lean Concrete	Chapter 18, Item 98, Page 111 of SCSR-2012	cft	299.700	171.9702	51,539.469
2.	Concrete Class "A1" 1:1.5:3	Chapter 4, Item 6 (II), Page 16 of SCSR-2012	cft	261.375	309.78	80968.7475
3.	Concrete Class "A3" 1:2:4	Chapter 4, Item 5 (f), Page 15 of SCSR-2012	cft	10,907.508	144.2925	1573871.526
4.	Concrete Class "D1" 1:2:4	Chapter 4, Item 5 (i), Page 15 of SCSR-2012	cft	2,572.959	112.8875	290454.8809
5.	Reinforcement As Per Aashto M. 31 Grade 60	Quated Rates on 2012	ton	135.000	120000	16200000
6.	Launching Of Girder	Quated Rates on 2012	ton	186.489	1081.26	201642.5733
7.	Elastomeric Bearing Pads (According To Size And Thickness)	Quated Rates on 2012	cu.m	2,160.000	6.3	13608
8.	Providing and casting in situ bored RCC piles in 1:1.5:3 (Class AS), 457 mm " dia (18" dia)	Quated Rates on 2012	ft	1,575.000	8228.34	12959635.5
9.	Pile Load Test Up To 360 Ton	Quated Rates on 2012	each	1.250	519890.2	649862.75
10.	Bridge Expansion Joint (Tentative Rate)	Chapter II, Item B-2, Page 56 of volume (IV) part VI,SCSR-2012	ft	90.000	86	7740
11.	R.C.C Railling	Quated Rates on 2012	ft	350.000	787.6737805	275685.8232
12.	Add 35% Over for Excavation, Back Fill, Other Common and formation works Mising Works & Rate settings					11,629,803.00
					Sub Total Amount (Rs.)	**43,934,812.27**
					Add 2 % Contingencies	**878,696.25**
					Grand Total	**44,813,508.52**
					Say	**45**

Table-13: COST ESTIMATE FOR BRIDGE OF SPINAL DRAIN (DECK SLAB REPLACEMENT, REHABILITATION)

Sr. No.	Description		Unit	Qty	Rate	Amount
1.	Lean Concrete	Chapter 18, Item 98, Page 111 of SCSR-2012	cft	44.955	171.9702	7,730.920
2.	Concrete Class "A1" 1:1.5:3	Chapter 4, Item 6 (II), Page 16 of SCSR-2012	cft	39.206	309.78	12145.31213
3.	Concrete Class "A3" 1:2:4	Chapter 4, Item 5 (f), Page 15 of SCSR-2012	cft	545.375	144.2925	78693.5763
4.	Concrete Class "D1" 1:2:4	Chapter 4, Item 5 (i), Page 15 of SCSR-2012	cft	385.944	112.8875	43568.23213
5.	Reinforcement As Per Aashto M. 31 Grade 60	Quated Rates on 2012	ton	6.850	120000	822000
6.	Elastomeric Bearing Pads (According To Size And Thickness)	Quated Rates on 2012	cum	2,160.000	6.3	13608
7.	Providing and casting in situ bored RCC piles in 1:1.5:3 (Class AS), 457 mm " dia (18" dia)	Quated Rates on 2012	ft	118.125	8228.34	971972.6625
8.	Bridge Expansion Joint (Tentative Rate)	Chapter II, Item B-2, Page 56 of volume (IV) part VI,SCSR-2012	ft	90.000	86	7740
9.	R.C.C Railling	Quated Rates on 2012	ft	350.000	787.6737805	275685.8232
10.	Add 35% Over for Excavation, Back Fill, Other Common and formation works Mising Works & Rate settings					223,314.00
				Sub Total Amount (RS.)		**2,456,458.53**
				Add 2 % Contingencies		**49,129.17**
				Grand Total		**2,505,587.70**
				Say		**2.51 Million**

Table-14: COST ESTIMATES OF WATER COURSE AQUEDUCT (PIPE)

Sr. No.	Description	Source	Unit	Quantity	Rate (Rs) (As per SCSR 2012	Amount (Rs)
1.	Cement concrete plain including placing, compacting, finishing and curing complete (1:4:8 Class D) (Lean)	Chapter 4, Item 5 (i), Page 15 of SCSR-2012	cft	1100.0	113	124176
2.	Reinforce cement concrete works (1:1.5:3 Class A)	Chapter 4, Item 6 (II), Page 16 of SCSR-2012	cft	2400.0	310	743472
3.	Cement concrete plain including placing, compacting, finishing and curing complete (1:2:4 Class BS)	Chapter 4, Item 5 (f), Page 15 of SCSR-2012	cft	1300.0	144	187580
4.	Supply and fabrication of mild steel reinforcement	Quoted Rate 2012	ton	21.0	120000	2520000
5.	Errection and removal of centering for RCC or plain cement concrete work (Vertical)	Chapter 4, Item 19a (ii), Page 17 of SCSR-2012	sft	2500.0	70	175000
6.	Errection and removal of centering for RCC or plain cement concrete work (Horizontal)	Chapter 4, Item 19a (i), Page 17 of SCSR-2012	sft	6853.1	77	527218
7.	RCC Pipe of 2 feet dia	Quoted Rate 2012	ft	220.0	5000	1100000
						5377446
	Cartage (30% of the Construction Cost)					**1613234**
	Total (Rs. Millions)					**6477446.000**
	Say (Rs. Millions)					**7.000**

Table-15: COST ESTIMATES OF WATER COURSE AQUEDUCT REHABILITATION

Sr. No.	Description	Source	Unit	Quantity	Rate (Rs)	Amount (Rs)
1.	Excavation in foundation including dibbling, dressing, refilling around structures	Chapter 1, Item 18 (b), Page 4 of SCSR-2012	cft	1000.0	31.8	31763
2.	Cement concrete plain including placing, compacting, finishing and curing complete (1:4:8 Class D) (Lean)	Chapter 4, Item 5 (i), Page 15 of SCSR-2012	cft	550.0	112.9	62088
3.	Reinforce cement concrete works (1:1.5:3 Class A)	Chapter 4, Item 6 (II), Page 16 of SCSR-2012	cft	8250.0	309.8	2555685
4.	Cement concrete plain including placing, compacting, finishing and curing complete (1:2:4 Class BS)	Chapter 4, Item 5 (f), Page 15 of SCSR-2012	cft	3458.2	144.3	498989
5.	Supply and fabrication of mild steel reinforcement	Quated Rates on 2012	Ton	5.5	120000.0	660000
6.	Expansion Joint	Chapter II, Item B-2, Page 56 of volume (IV) part VI,SCSR-2012	ft	234.2	86.0	20141
7.	Bitumen coatings to plastered or cement concrete surface	Chapter 12, Item 10, Page 12-4 of WSR-2008	sft	551.3	3.3	1830
8.	RCC Railing	Chapter 14, Item 36, Page 14-7 of WSR-2008	ft	3214.4	315.1	1012793
9.	Stone pitching hammer dressed on surface	Chapter 6, Item 9 (a), Page 29 of SCSR-2012	cft	5622.8	23.9	134386
10.	Supplying and fixing PVC water stop 190 mm wide (7.5 in)	Chapter II, Item B- 2, Page 56 of volume (IV) part VI,SCSR-2012	ft	289.3	86.0	24879
	TOTAL (Rs.)					5002554
	TOTAL (Rs. Millions)					**5.003**

Table-16: COST ESTIMATES OF CULVERT TYPE FALL INLET

Sr. No.	Description	Source	Unit	Quantity	Rate	Amount (Rs)
1.	Cement concrete plain including placing, compacting, finishing and curing complete (1:4:8 Class D) (Lean)	Chapter 4, Item 5 (i), Page 15 of SCSR-2012	cft	2800.0	72.24	202272
2.	Reinforce cement concrete works (1:1.5:3 Class A)	Chapter 4, Item 6 (II), Page 16 of SCSR-2012	cft	1400.0	246.48	345072
3.	Supply and fabrication of mild steel reinforcement	Quoted Rate 2012	ton	1.0	120000	120000
4.	Stone pitching hammer dressed on surface	Quoted Rate 2012	cft	600.0	48.07	28842
5.	Earth work compaction by sheep foot roller and power roller, with optimum moisture content for 85 % modified	Quoted Rate 2012	ft	800.0	93.86	75088
			Sub Total (Rs. Millions)			**0.771**
			Cartage (30% of The Construction Cost)			**0.231**
			Sub Total (Rs. Millions)			**1.003**

Table-17: COST ESTIMATES OF PURCHASE DISCHARGE MEASURING EQUIPMENTS FOR MONITORING PURPOSE

(Rs. Millions)

No.	Description of Item	Qty	Unit Price	Y1	Y2	Y3	Total
1	Fiber Glass Boat, 14 to 16 ft. long (approx.) with flooring Seats, oars, storing tank, kind. Local	4	0.28	1.12	-	-	1.12
2	ADCP Water Flow Meter (Portable Unit)	10	20	200	-	-	200
3	Digital Current Meter	4	0.45	1.8 r:	-	-	1.8
4	Sounding Reels	4	0.075	0.30	-	-	0.30
5	Stop watch	12	0.001	0.012	-	-	0.012
6	Outboard Motor Engine 55 HP with accessories (Imported)	4	0.65	2.6	-	-	2.6
7	Outboard Motor Engine 16 HP with accessories (Imported)	4	0.30	1.20	-	-	1.20
8	Four wheel crane with boom heavy duty. Local	4	0.125	0.50	-	-	0.50
9	Total Station with accessories (Laser target less range 350 m. LCD dual axis, in build application programs, automatic calculation of spiral curves and long distance with battery along with build in memory)	4	0.80	3.20	-	-	3.20
10	GPS (latest version) color, With standard accessories)	4	0.060	0.24	-	-	0.24
11	Life Jacket (Imported) Good quality	12	0.025	0.30	-	-	0.30
12	Electronic weighing balance (digital) precision type with Standard accessories. Germany	4	0.025	1.0	-	-	1.0
13	Weighing Balance	4	0.010	0.04	-	-	0.04
14	Distillation Unit	4	0.030	0.12	-	-	0.12
15	Generator 7 KV A	6	0.080	0.48	-	-	0.48
16	Miscellaneous	Lump sum		1.0		-	-
17	Vehicles	6	0.050	3.6	3.6	3.6	10.80
	Sub-Total:	-	-	23.51	3.6	-	30.71
	GST@16%	-	-	3.76	-	-	3.76
	Income Tax @3%	-	-	0.71	-	-	0.71
	Total	**-**	**-**	**27.98**	**3.6**	**3.6**	**259**

Table-18: PROCUREMENT OF PUMPING SETS

Sr. No.	Name	No.	Unit Cost Million Rs.	Total
A.	**Cost Of Fixed Pumping Stations At RD 792 Of Spinal Drain**			
1.	Supply of P&W propeller type KSB German Pumps Capacity 30 CS each	40	7.5	300
2.	Construction of Pumping House Including Electric Works			120
			Sub Total	**420 Millions RS.**
B.	**Mobile Pumping Sets Mounted On A Truck**			
1.	Purchase of 4 Nos. Diesel Engine For Suction Head of 10 feet	20	4	**80**
			Total	**500 Millions RS.**

Annexure - V

OPERATIONS AND MAINTENANCE OF DRAINAGE NETWORK

A. Maintenance

Maintenance of Open Canals

Drained land generally has a rather dense system of open type of drains, the maintenance of which poses a heavy physical as well as a financial burden. The length of the communally maintained open drains varies from some 40-60 m per ha in the polders of The Netherlands, 30-50 m/ha in the Mekong delta of Vietnam, 7-10 m/ha in the Nile valley of Egypt, 5-7 m/ha in the Imperial Irrigation District, California, USA to some 2-5 m/ha in a typical irrigation command in India/Pakistan. The total canal maintenance costs in The Netherlands in 1985 averaged US$ 1.00-1.50 per.

Problems

Almost all maintenance needs of drainage canals derive from the occurrence of one or more of the following three flow restricting processes.

Weed growth: canals generally provide a conducive environment for plant growth (water, nutrients, sunlight). The occurrence of various types of aquatic plants in a cross-section is shown in Figure 22.1. Some plant growth on the side slopes is generally welcome as it provides stability but, most of the abundant growth of aquatic plants is unwelcome as it hinders the flow of water.

The composition of the vegetation varies per climatic zone and depends on the specific ecological conditions in the canal. The growth cycle of the canal vegetation is usually quite similar to that of the field vegetation. In mid-season, the underwater biomass may easily occupy some 20-50% of the wet cross-section and proportionally reduce the transport capacity. The vegetation also traps much sediment and provides habitat for some waterborne diseases (malaria, mosquitoes, bilharzia, snails). Decomposing biomass and detritus sediments may adversely affect fishery and other aquatic life.

Aquatic Vegetation Commonly Found In Drainage Canals

Siltation: sediment may enter the canals with the drainage water (especially with the overland flow drainage water) but much of it may also be generated by internal morphological processes (erosion, scouring, sloughing of side slopes, and banks, etc.). Even properly designed canals will frequently operate under non-regime flow and/or bed conditions under which sediments are deposited and/or picked up. Bed deposits in drains often also include various debris, detritus, rotting biomass and tree remains.

Sloughing/erosion of side slopes/banks: sloughing/erosion may be caused by lack of sufficient vegetative and/or mechanical bank protection, irregular flow regimes, uncontrolled inflow of runoff water, unstable layers, excessive bank loading, inflow by seepage and piping, etc. Risks are most acute for fresh cuts before the side slopes have become vegetated and have stabilized.

Requirements

Drainage systems are generally designed to meet certain performance targets (usually a combination of water levels and discharges) when the canals are in a good state of maintenance. As the canal capacity is directly proportional to both the cross-section and the roughness, canals which are not in the assumed good state of maintenance, can only carry the design discharge at a higher water level. High canal levels hinder the proper functioning of the field drainage systems and may even lead to flooding. Figure 22.2 shows how the canal water levels (at design discharge) may be expected to vary, depending on the timing of the maintenance activities.

Impact of Vegetation and Siltation on Canal Water Level

For siltation and sloughing, the impact is straightforwardly due to the reduction of flow section. The impact of dense vegetation, although hydraulically most correctly evaluated through the k_m-value (n-value, Manning/Strickler see section 9.1), may in practice often also be seen as a restriction in available flow section as the flow velocities in dense vegetation are close to nil (Querner 1995).

Canal maintenance requirements should rationally be based on a comparison of the costs of controlling the maintenance induced high water levels and the damage caused by these high levels (see also methodologies as used in section 2.4). In practice this is 'almost never done although it may generally be assumed that the applied maintenance frequencies and other empirical rules are implicitly based on the above considerations.

Applied maintenance frequencies and practices are also much more based on experience than on scientific research. Study of the factors and processes which cause the drainage systems to become less functional can, however, greatly help to make the maintenance more effective. Understanding of the anatomical and physiological characteristics of the weeds and the origin and transport of the sediments can help to make the canal maintenance measures better timed and targeted.

Some indicative information on applied frequencies have been compiled in Table 22:1. The weed clearance timings should be attuned to the cycles of the weed growth and functional demands of the canals. In temperate climates, growth is heavy in spring and in early summer. As high discharges occur mostly in autumn and winter, it is most critical that the canals are well cleared before the onset of autumn. Maintenance during summer can, however, not be neglected as otherwise the canals may become too choked to cope adequately with the occasional high summer rains. In tropical climates with pronounced dry and rainy seasons, drains should be cleared before the arrival of the rainy season. The weed control requirements during the dry season are quite minimal as drainage canals dry up and hardly any growth and discharge occur. In irrigated areas, drains should be in a well cleared state at the start of the main irrigation season.

Table-1: Maintenance Frequencies And Costs

Country	Costs
Egypt (main drainage canals in Fayoum, 1990) – Mechanical weed clearance: 1 x per yr	US $ 0.50 per m for small canals US $ 0.75 per m for large canals
India (small open drains in Chambal command, 1995) – Manual weed clearance (Slashing): 1 x per 2 yrs – Manual desilting/resectioning: 1 x per 5 yrs	US $ 0.10 per m US $ 0.50 – 1.00 per m
India (Uttar Pradesh 1999) – Small drains (Q < 5 m³/s) – Medium drains (Q=5-15 m³/s) – Large drains (Q > 15 m³/s)	US $ 0.2 per m US $ 0.4 per m US $ 0.8 per m
Netherlands (main drainage canals, 1985) – Mechanical weed clearance: 1-2 x per yr – Desilting/resectioning: 1 x per 5-10 yrs	US $ 0.3 – 0.5 per m for small canals US $ 0.4 – 0.6 per m for large canals US $ 0.6 – 1.0 per m for small canals US $ 1.5 – 2.0 per m for large canals
USA (main canals in the Imperial Irrigation District, 1992) – Mechanical weed clearance: 1 x per yr Rule of thumb	US $ 0.5 per m O&M ~ 2% of the construction costs

Silt clearance (desilting) and re-sectioning (reshaping) requirements are more variable and specific. Siltation may be minimized by designing for non-eroding flow velocities and providing for smooth curves, energy dissipation, bank protection, silt traps, etc. Weeds may reduce flow velocities to the extent that fines that would otherwise remain suspended become deposited. Mature canal sections may need very little maintenance but new sections normally remain unstable for two to three years until a good sod has become established. Sloughing of side slopes is often due to seepage inflow and/or a combination of saturation of banks and steep slopes and can best be solved by appropriate interception drainage. Siphons in drains (e.g., to cross an irrigation canal) are notorious silt/debris traps and should wherever possible be avoided.

Design can reduce but not obviate the need for maintenance. Weed growth in canals is enhanced by light and so deep narrow shaded canals are less conducive to weed growth than wide-open shallow canals. Low flow velocities, allowing suspended load to settle and thus light to penetrate deeply, also enhances weed growth. Cuneate (wedge shaped) type low flow sections can help to dry up canal beds during periods of only trickle flow (to reduce weed growth and/or to allow for grazing). There are many different plant species growing in canals and designs which retard the development of one type, may well promote another.

Methods and Equipment

The applied canal maintenance methods are quite diverse but may generally be grouped into the following categories.

Mechanical Weed Clearance

Mechanical weed clearance is by far the most widely applied method and a range of equipment has been developed to suit the range of prevailing conditions (canals of various shapes and sizes, different weed types and densities, different accessibilities and means of weed disposal, etc.). Some types of equipment clear the vegetation by uprooting the plants while others are cleared by mowing. Mowing has to be done quite frequently but is often preferable to uprooting as it is less destructive to the section. Another distinction is between self-harvesting equipment (collection of the cleared biomass) and non-harvesting equipment (leaving the cleared biomass in the canals and/or on the side slopes and banks). Harvesting may of course also be done in a separate operation.

Most popular are the cutter bar/flail mowers and the mowing-bucket type of equipment (Figure 22.3). The mowers are mostly used for the weed control of the dry section (banks and upper side slopes) while the mowing- buckets are mostly used for the wet section (bed and lower side slopes), clearing weeds as well as some silt and depositing the cleared material on the canal bank for later transport and disposal. The equipment is usually attached to and operated by a tractor (side) mounted hydraulic arm. Sturdy agricultural wheel tractors (90-115 HP) are suitable for light work but heavy duty industrial wheel or track tractors are required for the sturdy long reach equipment used for the larger canals.

Weed Clearance by Tractor Mounted Mowing Bucked (Courtesy Harder BV, From Government of Pakistan 1993)

Extra heavy duty work (reach > 6-7 m) may require the equipment to be attached to a more stable regular excavator. Suitable access roads to and service paths along the canals are essential for the effective use of all tractor based equipment. Boat mounted equipment is an alternative but unfortunately its application is often serious constrained by the prevailing obstructions.

The need for harvesting and disposal depends on the quantity of the cleared biomass, the floating biomass canal transport capacity and on environmental considerations (section 22.3.4). Spreading of floating weeds may largely be controlled by a strategic location of regularly cleaned trash racks. The transport/disposal of the collected biomass from the canal banks is often quite costly (may well cost more than the actual clearance).

Manual Weed Clearance

In most developed countries manual maintenance is more costly than mechanical maintenance and is generally only applied in cases where machines cannot operate or where mechanical work is environmentally undesirable. Manual work is however in many cases still the most cost-effective and most widely applied method of canal maintenance in the developing countries. It is simple to organize and does not require costly equipment, logistical support, roads/service paths. It is most suitable for community maintained small canals (< 5-6 m top width). Efficiencies may often be increased by the introduction of improved tools (hand sickles, chain sickles, rakes, portable power mowers, etc.). Long handle tools, which allow working from the banks, should be used when there are risks of contacting bilharzia or other water born diseases.

Burning

For canals which periodically dry out burning provides a cheap and effective method of weed control. The burning should of course he under control and not cause undue damage to structures and adjoining land.

Chemical Weed Control

Herbicides can be very effective for weed control in canals but their use requires knowledge of the type and growth cycles of the prevailing vegetation and of the safe methods of herbicide application.

Indiscriminate use may destroy desirable side slope vegetation, harm aquatic life and endanger the health of the maintenance personnel. For further details on environmental concerns, reference is made to section 22.3.4.

Biological Weed Control

A fair number of experiments have been conducted around the world on the control of aquatic weed by biological methods. Work on grass carp in California, Egypt and The Netherlands has shown successes but also that it requires elaborate measures to keep the carp population at the desired level and to keep it contained. Grazing by goats, sheep and ducks have been shown to help with the weed control on the service roads, banks and side slope and some of the aquatic weeds. As mentioned earlier, good design can make canal conditions less conducive for weed growth. None of these methods have however yet been proven to be fully operational, robust, reliable and (cost) effective. The desired degree of weed control could generally not be achieved without some additional mechanical clearance.

Silt Clearance/Resectioning

This work calls for equipment which is suitable for heavy silt removal as well as for accurate re-sectioning of the beds, and side slopes. In the past, this work was mostly done by draglines and this equipment is still widely used for the desilting of large canals. Draglines may, however, leave jagged side slopes (starting point for re-growth and degradation) and for small to medium sized canals, the more maneuverable hydraulic excavator is often more suitable. The equipment (mostly dredging buckets) may be tractor attached/mounted but for heavier work requires regular hydraulic excavators. Small type floating suction dredgers for desilting of canals have also been developed but this equipment is mostly used for special cases only.

Manual desilting/re-sectioning is physically demanding, time consuming and not always most cost effective. Badly neglected canals may require some prior manual brush and tree clearance for machines to be able to work. Badly damaged side slopes should not only be repaired but causes should also be addressed (provision of dedicated inlets, timely stoppage of rain cuts). Banks, service roads, bunds and spoil banks should also be regularly inspected and maintained.

Environmental Considerations

Ideally, the applied maintenance practices should meet both the land use and environmental requirements. While the former focus on the need for reliable discharge, the latter focus on conservation of an ecological diverse canal habitat. Broader societal and various technical, operational and financial considerations need also to be taken into account. As described below, compromises satisfying all parties can often be found.

Frequency and timing of the weed clearances: the agricultural interest is to keep weeds under control and the drain functional throughout the main rainy/crop season while the environmental interest is to have the weed control practices attuned to the demands of the habitat. Weed control should also not interfere with the recreational use of the area. Acceptable compromises can often be found by mapping the critical environmental values and adapt the scheduling of the weed clearance events accordingly.

Biomass disposal: agricultural and environmental interests largely coincide on this issue. Farmers do not like to have the cleared material on their land while the aquatic life is not burdened by oxygen consuming decomposing material. Weed growth in the canals is also reduced as with the biomass also nutrients are removed.

The compromises generally do not represent the most efficient and cost effective practices from an operational point of view. More staff and equipment may be needed to meet the diverse requirements and to compensate for the constraints in scheduling. The biomass disposal also involves high costs. For environmentally friendly maintenance, the involved stakeholders must generally be prepared to pay a cost.

Maintenance of Pipe Drains

Pipe drains need to be cleaned regularly when there is a danger of entry and deposition of fines in the pipe or when the flow becomes restricted for any other reason.

Pipe Cleaning

Deposits in the pipe used to be removed by a combination of flushing and rodding (pushing a jointed bamboo rod through the pipe to loosen the deposits) but with modern flushing, using pressurized water jetted from a self-propelling nozzle (Figure 22.4) rodding is rarely needed. Water pressures at the nozzle of 10-15 atm. suffice to remove loose deposits but fail to remove deposits that have become consolidated (e.g., due to lack of regular maintenance). Such deposits may be removed by flushing at higher pressures but this can disturb the stabilized soil around the pipe and lead to renewed entry of fines.

Entry of sediments is especially to be expected shortly after installation when the soil above and around the pipe has not had time to consolidate. Pipes therefore usually need to be cleaned soon after installation (one to two years) while from then on a frequency of five to ten years is normally sufficient. Instead of cleaning at regular intervals, it may also be done 'as required' with the latter to be established by some low level of performance monitoring (casual inspection of outflows in manholes/outlets will generally be quite sufficient). This approach is particularly appropriate for areas with minimal sedimentation risks.

Drain Pipe Cleaning By Means of a Jetting Nozzle

Most commercially available drain pipe flushing machines have a maximum effective reach of about 250-300 m. The cleaning may be done from the pipe outlet into a ditch (as in Figure 22.3) or from a manhole. Mounted tanks or water trailers may be used when the flushing water cannot be abstracted from the system. In composite systems with long drain lines, special access points may have to be provided for cleaning purposes (see discussion in section 22.4.4). While best practice is to enter the pipe from the downstream end, flushing from both ends is quite possible when gradients are small and the pipe downstream is not completely blocked.

Entry of Roots

The well drained soil around the pipe generally constitutes a favorable growth environment which therefore is often readily occupied by roots when the drains are in or near their regular root zone. The roots will then generally also enter into the pipe through the perforations. Strong root growth in the pipes is specially to be expected when the pipe becomes dry periodically during the active growth season (as will often be the case with uncontrolled pipe drainage).

Roots of annual field crops rarely enter drain pipes installed at normal depths (1.0 - 1.2 m and more). Problems may, however, occur with perennial crops (observed with sugarcane and bananas). In fruit tree plantations, the pipe drains should preferably be installed mid-way between the tree rows. The problem is most acute where drain lines pass beneath hedges or tree rows. At these locations, it is generally recommended to install, as a pre-caution, non-perforated pipes.

The above-described regular pipe cleaning methods will generally remove young roots, For weak rootlets, medium pressure flushing may suffice but with stronger roots, flushing may have to be combined with some kind of mechanical loosening and/or destruction (e.g., by rodding. Mature roots may form thick hardy bundles, which can completely block the flow. The bundles may be pulled out over short lengths (couple of meters, e.g., from under a narrow tree row) but certainly not from the full pipe length. In such cases, replacement is often the only solution.

Chemical Clogging (Iron Ochre, Gypsum)

In poorly drained iron sulphide (FeS_2) holding soils, water soluble ferrous sulphate. ($FeS0_4$) may form when the soils are drained and oxidized. At low pH, the ferrous sulphate may enter the drains where it is liable to oxidize to insoluble ferric hydroxide, $Fe(OH)_3$, either by direct contact with the air or by bacterial action, which shows up as an orange-brown slimy filamentous deposit in and around the drain. By drying and ageing, the ferric hydroxide eventually turns into ferric oxide deposits which clog the pipe entry points and in extreme cases may totally clog the envelope and the pipe.

The problem is to be expected with the first time drainage of lowland peat, recently reclaimed marine soils and soils containing iron pyrite in the parent material. The leaching of iron usually rises to a peak rate some two to three years after the installation of drains, subsequently falling off until eventually it ceases to be a problem. When serious problems are expected, it is advisable to start with ditches and later switch to pipes. In areas where there is only a slight risk of ochre clogging, pipes may be used immediately provided they are frequently flushed. The problem can be diagnosed on the basis of the pH of the groundwater and its divalent iron content (Eggelsmann 1981) but in most cases the problem will be clearly evident by the visible signs (occurrence of the orange-brown slimes in the ditches).

The deposition of lime and gypsum in pipe drains leading to blockage of the perforations or even to full blockage of the pipe has also been observed in some incidental cases. Such deposition is to be expected when slowly moving lime/gypsum rich effluent is exposed to strong evaporation conditions which may occur at pipe outlets during prolonged dry and hot periods.

Access Facilities

The access facilities for maintenance, inspection and monitoring of pipe systems have already been described in section 4.5. Figure 22.5 presents three different designs for the installation of these facilities.

Design A: in this design a dense network of manholes has been installed which provide easy access for the maintenance to the entire pipe system. It is quite costly while surface manholes are known to be sensitive to abuse. This design is suitable for situations where there is little experience with pipe drainage since construction errors can be readily diagnosed and corrected. The dense network also provides ample opportunities for inspection, monitoring, research, demonstration and learning.

Three Maintenance Design Approaches

Design B: this design is suitable for situations where considerable experience with pipe drainage has already been gained. Top quality installation can, however, not yet is guaranteed while some access for inspection and monitoring is also still valued. The manholes are mostly of the buried type and do not provide cleaning access for the entire pipe system. Malfunctioning pipes cannot be directly located but enough open manholes are provided for the search to be compartmentalized and the digging-up limited.

Design C: in this design it is assumed that the installed system has been so well designed and installed that it requires virtually no maintenance. Well tested envelopes are used, competent contractors have been employed and high quality construction control has been applied. All junctions are deeply buried tee or cross pieces. Inspection and monitoring can only be done at the outlets. Malfunctioning can only be located by extensive and rather random digging up. This design is obviously only suitable in situations where full confidence, based on ample experience, exists in the applied design and construction methods.

Costs

Flushing capacities range from 400 m per hr under normal conditions to about 200 m per hr for highly silted pipes. At a machine operating cost (incl. labor) of US$ 60-75 per hr, a working rate of 300 m per hr, a cleaning frequency of 1 x 5 years and pipe length of 200 m per ha (50 m spacing), the annual flushing cost may be calculated at some US$ 8-10 per ha. Adding some US$ 2-5 per ha for structures (manholes, outlets, etc.) and materials, the total annual O&M costs comes to US$ 10-15 per ha. This estimate would apply to a pipe drainage system for salinity control with a gravity outfall (for a pumped sump, it would be higher). Roughly the same estimate would have been arrived at with the '~2 % of the construction costs' rule of thumb.

Developing Countries

Maintenance of drainage systems is often an arduous task while the benefits are often indirect, delayed and random (hardly any benefits in dry years). The benefits only become apparent in the long run often well beyond the time horizon of a subsistence farmer. Under these conditions, also considering the many other urgent needs; the basic maintenance philosophy of 'paying today to avoid tomorrows problems' understandably often has little ready appeal in the developing countries. This applies especially to infrastructure which has been installed by a distant third party and is not part of the traditional cultural heritage of the community (Jurriens and Jain 1993, IPTRID 1999).

The problem of inadequate maintenance is not restricted to drainage but applies to all infrastructures (irrigation, roads, water supply, etc.). As long as the above identified generic constraints to good maintenance continue to prevail, it is almost illusory to expect high standards of maintenance in the developing countries. Better maintenance is realistically only to be expected when:

- ✓ The beneficiary and community appreciation of the need for maintenance has culturally been sufficiently accepted
- ✓ The systems are planned and constructed in a more participatory manner (section 21.2.2).
- ✓ The maintenance arrangements are devised in such a manner that they are within the financial means (see section 21.4.2).

Moreover, farmers can only be expected to pay for maintenance when they get 'value for their money' i.e., when responsible maintenance institutions are responsive to their needs and when the payers see the impact of their contribution (IPTRID 1999). As described earlier (section 20.A), fee payments should also not exceed a reasonable percentage of their net income.

B. Performance Assessment and Benchmarking

During at least 90% of the cropping season; the system should at any time be able to lower the water table to 30 cm depth within two days after the ending of the recharge event. The system should (in conjunction with the water supply system) prevent salt built up in the root zone. The system should mobilize as few solutes as possible to minimize downstream impacts

- ✓ *Surface (field) drainage:* the system should be able, in the case of a 1 x5 yrs rainfall event, to remove the excess water from the land within two days after the ending of the rainfall while during the entire disposal period, there should be no erosion of the land and no overtopping of the canals and embankments
- ✓ *Main drainage:* the system should be able to convey the inflows to the outlet point(s) while maintaining water levels which allow unconstrained discharge of the field system and flow velocities which cause no harmful scouring or sedimentation
- ✓ *Controlled drainage:* the system should balance removal and conservation of water i.e., the maximum amount of water should be stored in surface and subsurface facilities, and solute mobilization should be as low as is reasonably achievable (ALARA principle).

For standard operational PA work, the observed state of performance may normally be evaluated on the basis of compliance with the standards for which the systems were designed. However, not all of these standards may have been explicitly expressed in the design criteria. This applies, for instance, to the control of soil salinity, which is clearly a major drainage objective but is, generally, not an explicit design criterion. Design criteria stipulate the required removal of excess water/salts but not the beneficial effects of this removal. Although such objectives are not captured in the design criteria they should of course be included in the PA. In addition, water quality aspects and environmental consideration are to be considered. INDICATORS

Indicators play a crucial role in PA. It is precisely the use of indicators which distinguishes PA from other comparable assessment efforts like M&E programs. Bos et al. (1994) give an overview of the desirable attributes of PA indicators while Vincent et al (2003) present a long list of potential indicators for drainage purposes. For operational PA of drainage systems, indicators may be classified as follows:

- ✓ *Primary indicators:* these indicators capture the goals which are directly addressed by the design. These goals would either be explicitly mentioned in the design criteria or if not, they would be directly linked to these criteria (the mentioned case of soil salinity). Examples are:
- ✓ Water table Regime
- ✓ average seasonal or annual water table depth (suitable for assessing water logging and partially suitable for assessing salinity control)
- ✓ rate of draw-down (suitable for assessing aeration and workability control)
- ✓ water table fluctuations over time (for assessing trends and periods of high water tables and over drainage)
- ✓ Flooding, Ponding and Erosion
- ✓ frequency and duration of excess water on the land
- ✓ Occurrence of perched water tables
- ✓ Seasonal and annual soil loss by erosion
- ✓ Soil Salinity
- ✓ Soil salinity conditions in the root zone during the critical growing stages of the crops

- ✓ Annual salt balances at the root zone, field, catchment or basin level
- ✓ Effluent Quality
- ✓ Solute concentration and composition to assess quantity and type of mobilization of solutes other than salts
- ✓ Seasonal balance of minerals to assess danger of eutrophication etc. (e.g. the mandatory mineral book keeping in the Netherlands, MINAS programme).
- ✓ *Secondary indicators:* the purpose of these indicators is to provide additional information on the state of performance, principally to help the identification of under-performance causes. They would only be applied when the causes of under-performance are not clear. Examples: hydraulic indicators (water levels in manholes, drain discharges), maintenance indicators (sediment in pipes and open drains, and weed growth in the canals), etc.
- ✓ *Special indicators:* these indicators would be used to assess impacts on the system performance of agricultural, environmental, water management, socio-economic and institutional and other relevant conditions.

Performance Assessment Procedure

Figure 23.1 shows as an example, the PA procedure applied to the rehabilitation of an existing drainage system. It involves sequential steps with each subsequent step only undertaken when the previous step has confirmed its necessity and, therefore, the PA process may end after each step. The procedure may for example be stopped when the complaint assessment indicates that the complaints require no further action (and it would be resumed when the complaints persist or when other new information becomes available). Each step requires a set of indicators which will generally become more specific and detailed as the procedure enters the next step.

Preliminary Investigations (First Step)

This first step is proposed to include the following four activities:

- ✓ Complaint management
- ✓ File/database search: this includes the age of the project together with the applied technology (materials and construction methods); the applied quality control; the contract documents; and other indications may be included and each indication may have value singularly or in combination with others
- ✓ Agricultural data search: crop productivity and cropping pattern
- ✓ Rapid appraisal: a short field survey to assess the drainage conditions.

During this first step, the need for the second step is assessed. The latter step requires considerable field work and expenditure and should only be undertaken when the preliminary investigations have confirmed that there are sound indications that there are indeed water logging and/or salinity problems in the area or in a considerable part of the area, and that these problems are most probably due to a malfunctioning of the drainage systems.

Standard Performance Assessment Procedure

Primary Investigation (Second Step)

This step is followed when there is a major water logging and/or salinity problem in the area and these problems are due to a malfunctioning of the drainage system. In this step, this assumption is confirmed or rejected by collecting indicator data (e.g., water table depth and soil salinity) and comparing these to the accepted standards of good performance. This step may be broken down into two sub-steps:

- ✓ Data collection and processing: monitoring the selected indicator parameters followed by some form of processing to facilitate the use of the collected data
- ✓ Data evaluation: comparing the collected indicator data with the accepted standards on the basis of which judgments can be made on the performance or the drainage systems.

It is of course possible that these Primary Investigations reveal that there is no real water logging and salinity in the area or that the prevailing conditions are not due to malfunctioning of the drainage systems. In this case the observed problems are properly reported and the performance assessment is ended.

Cause Analysis (Third Step)

This phase is entered when the Main Investigations have confirmed that the performance of the installed drainage systems do not meet the expected standards. The remaining task is then to identify the cause(s) of the under-performance of the system(s). An example of such a cause analysis in presented in section 23.4.

Performance Checking Of Pipe Systems

The overall functioning of a pipe drainage system may be checked by water table observations, individual malfunctioning drains being identified by observing discharges. The causes of malfunctioning of a pipe drain may be diagnosed and localized by measuring the flow resistances as evidenced by the head losses along the flow path as shown in Figure 23.2 (Cavelaars 1974, see also section 7.1).

Checking of the Functioning of a Pipe Drain By Means Of Piezometers

Case 1: impeded infiltration or percolation, usually evident by water ponded on the surface or by the occurrence of a perched watertable at some depth. Where the flow impedance is due to a hardpan Iayer, ripping may solve the problem. Often the cause of impeded infiltration is soil compaction, e.g., due to field traffic under wet conditions.

Case 2: high resistance in the groundwater flow towards the drain, usually due to under-design. Either the hydraulic conductivity was over-estimated, the impermeable layer occurs higher in the profile than was assumed, the drainage coefficient was under-estimated or the drain spacing calculation formula used was not applicable. Horizontal flow and radial flow resistances may in principle be separated by placing an additional piezometer at about 0.7 D from the drain, although this is seldom necessary (they are normally correlated, when one is high so is the other); The appropriate remedial measure is to install additional drains.

Case 3: high entry resistance, a common cause of malfunctioning where drains have been installed in a trench by unsuitable methods, under unsuitable wet conditions or by the trenchless method below the critical depth. Also, an envelope may have been omitted or may have become clogged. Not much can be done other than installing new drains. There is a high risk of drain failure when installation in a trench is done under wet conditions (high watertable, during rain, etc.). Puddled soil around the pipe hinders the entry of water and such installation should, as a matter of principle, be avoided.

Case 4: obstructed pipe flow due to either:

- ✓ Too high a water level in the collector ditch (to be corrected by cleaning or deepening the ditch and/or by lowering the local drainage base)
- ✓ Too small a pipe diameter (to be corrected by installing additional drain lines)
- ✓ Misalignment of the pipes e.g., due to poor installation or due to mechanical damage to the pipe (to be corrected by repairing the line; the trouble spot may be located during cleaning by measuring the length of flushing line inserted at the outlet to clear the blockage)
- ✓ Clogging of the pipe by fines or by iron compounds (ochre) or blockage of the flow by root growth in the pipe (see section 22.4). Siltation should be prevented as much as possible by providing a good filter in problem soils and should otherwise be alleviated by regular pipe cleaning. The problems and possible remedies of ochre clogging are described in section 22.4.3.

The detailed investigations can generally be restricted to a few representative sites, from which extrapolations may be made (the same causal factors generally being instrumental across a wider area). Drain failure mostly occurs or will become apparent within the first year to two years after installation. Once past this initial period, pipes can function almost permanently when maintained regularly.

Causes of Under-Performance of Drainage Systems

The performance assessment, to be really useful, should generally not be confined to the identification of the under-performance of systems but also provide enough insights in its causes to provide guidance to more detailed diagnostic investigations, or even directly to the required remedial measures. The main and most common causes of under-performance of drainage system are reviewed below.

Poor or Faulty Construction: Clearly, systems cannot perform as designed when they are not constructed as designed. Construction quality should be assured by using the correct materials, the correct machinery and the correct methods and procedures, by preparing proper construction documents and specifications, by selecting qualified contractors and generally by providing good quality control through adequate testing and supervision. The appropriate remedial measure for poor construction is partial or full rehabilitation of the malfunctioning systems or system components.

Inadequate Main Drainage: Poor performance of (subsurface) field drainage systems may be caused by poorly functioning (surface) main drainage systems. High water levels in open disposal drains, and non-functioning pumping stations are typical examples. Remedial measures to remove the cause of non-functional (subsurface) field drainage system are necessary.

Inadequate Maintenance: Systems generally need maintenance to keep them in a good functional state and cannot perform as designed when this maintenance is not provided. This is one of the most common causes of under-performance of systems managed by the chronically under-funded public agencies in the developing countries. It requires efficient institutional and organizational arrangements and availability of a steady stream of finance. Depending on the state of neglect, the problems may be solved by accelerated maintenance hut it may also require considerable rehabilitation.

Faulty Design: This may be due to inadequate problem diagnosis and/or inadequate field investigations or due to the use of inappropriate design methods and/or criteria. Such systems may either under-perform or perform as designed but still not solve the drainage problems. Very little can be done in such cases, except to prepare a new project design (rehabilitation), based on proper diagnosis and field investigations.

Inadequate Secondary Measures: Structural drainage systems often perform better when supported by secondary drainage measures such as chemical amendments (gypsum), (green) manuring, sub-soiling, deep ploughing, suitable crop rotations with deep rooting crops, land leveling, etc. These measures may have to be repeated from time to time.

External Constraints: Factors external to the drainage system can render them ineffective. Examples are: high soil salinity due to under irrigation and non-response of farmers to the improved conditions due to lack of incentives (product prices, lack of credit, land tenure, market prices, inadequate or inappropriate government policies and regulation, institutional short-comings, etc.). In the case of under-irrigation, the solution to the problem is technically straight forward but, as with the measures to overcome the non-responsiveness of farmers, only sound government policies can alleviate the external constraints.

C. General Operation & Maintenance Procedures for Operation and Water Measurements

Calibration Procedures for Discharge

General

The calibration process is like any other program in that it follows a generalized format.

- ✓ Planning
- ✓ Data collection
- ✓ Procedure equipment and staff
- ✓ Establish field procedures and work program
- ✓ Perform work program
- ✓ Analyze, evaluate and document results
- ✓ Prepare recommendations.

The calibration of an irrigation system is not an undertaking that requires a major effort. It does require a well trained field crew, survey and water measurement equipment and transportation. Even the date collection step can be minimized as it is used more for planning and evaluation than for conducting the actual field work.

Planning

It is a continual process that proceeds as the program proceeds. Initially it involves the decision of what is to be done, how to do it, what and who to do it, obtaining necessary personnel and equipment including transportation and communication, providing any training or instruction required to make the team more efficient and preparing the work program and making adjustments as required.

Data Collection

Since calibration is the first step of developing a flow monitoring program it is necessary to start at the beginning. Therefore, the first step is to obtain a copy of the following data:

- ✓ System map
- ✓ Schematic diagram locating all structures
- ✓ As-built drawings or latest long-sections
- ✓ List of all outlets and RD's (location)
- ✓ Location and datum for all bench marks located near canal.
- ✓ Stage-discharge tables or curves.

Staff and Equipment Requirements

The calibration requires two specialists; a surveyor and a hydrographer. This constitutes the bare minimum and they should really have an assistant to help with all of the work. As it is, the surveyor and hydrographer would have to assist each other as much of the work requires two people.

The size of the crew depends on the speed at which the team should work. A team for man, a 5-man survey crew, a 2-man hydrographer team, a 12-man flume measurement team, driver and a couple of casual laborers could cover one or two circles a year. Reductions would obviously decrease the work rate. A 6 to 7-man crew should be adequate at the division level; saya foreman, surveyor, hydrographer and 3 to 4 assistants. The number of assistants depends somewhat on the number of portable flumes to be used. A 3-man crew appears to be the minimum requirement.

Transportation and communication are required for two reasons; (1) to move the team and its equipment along the canal and (2) to continuously know what the discharge in the canal is in order to establish water surface elevations at known canal discharges. Calibration should be made throughout the normal range of flows.

A pickup truck would be the most practical transportation unit that could be used. It has the capacity of carrying all the equipment including the portable flumes or full a boat trailer. Other vehicles including vans could be used but the field requirement must be considered carefully.

Field procedures

A primary objective of this lecture is to make minimum use of existing facilities for water measurement. This will require calibration and rating of various hydraulic structures. The primary problem will be submerged flow conditions. Unfortunately, in many cases, submergence may exceed 95 percent, making measurements less reliable. It is expected that gated and up gated head works for distributaries as well other water control structures will form the basic of measurement discharge stations.

Under the best of conditions hydraulic structures built for the purpose of measuring the rate of low consist of a converging transition, where subcritical flowing water is accelerated and guided to the threat without flow separation; a threat where accelerates to supercritical flow so that the discharge is controlled, and a diverging transaction where the flow velocity is gradually reduced to an acceptable subcritical velocity and potential energy is recovered.

Under most field conditions, may hydraulic structures used for the control of flows eliminate or ignore one or more of these parts. The two most common divisions are; first, tail water conditions that submerge the flow through the throat and eliminate modular flow and second, most canal head works are set 90° to the streamlines in the senior canal. The latter often cause non-uniform flow patterns which affect both the water and sediment discharge patterns.

It is assumed that most of the existing stage-discharge relations are based on the engineer's field observations. In addition, changes in channel control due to sedimentation or other reasons require a periodic check on the stage- discharge relations.

Field Measurement Accuracy

The need for all calibration team members to work in a professional manner cannot be over emphasized. We are referring to the requirement that all work be accomplished in a meticulous manner includes eat and detailed notes, accurate measurements, attention to details, checking and rechecking of measurements, completion of all measurement, data collection and entries on the appropriate forms.

Discharge measurements can be consistently be made in the field with errors on the order of 2 or less if all measurements are carefully made. It is important to know which measurements are the most critical. For instance, an error of 0.010 feet (1/8th inch) in the water surface elevation (the sill reference height) on an outlet results in an error of more than 2 in the measurement of discharge. Fortunately, errors in measurements are not all additive, some compensate each other.

Scale is an important concept to remember. This refers size of the difference with respect to the total. For instance, 2 cfs in 200 cfs versus 2 cfs in 20 cfs or 0.01 inch in 12 inches and 1 inch in 50 feet. The most important dimension is the water surface elevation. The water surface elevation, W.S.Elev., should be read to the closest 1/6th or 1/8th inch depending on canal and water surface movement or bounce.

Location of Flow Measurements

In general, flows are measured at any point where the conveyance system flows are divided between two or more Drains. As an everyday procedure, flows are not directly measured into watercourses. Flows should normally be measured into main drains, although there are cases where it is not practical to measured flows in main or branch canals each time a small distribuaery is measured. The flow in the main canal would be measured at the next downstream control structure.

Flow measurements are made at outfall points in order to account for all water coming into a system as well as its distribution throughout the system.

Annexure-VI

DISCHARGE MEASUREMENT OF A CANAL/DRAIN AND CALIBRATION OF HYDRAULIC STRUCTURES

Table-1: Summary of Discharge Measurements On LBOD System				
Sr. No.	**Name of Drain**	**Date of Measurement**	**Gauge (ft)**	**Discharge (cfs)**
1	Nawabshah East Main Drain	29-Jun-12	1.9	125
2	Nawabshah West Main Drain	29-Jun-12	1.9	205
3	Spinal RD 815+223	29-Jun-12	4.2	403
4	Sanghar Main Drain	29-Jun-12	1.5	163
5	Singhoro Branch Drain	29-Jun-12	0.6	40
6	Spinal RD 710+00	29-Jun-12	3.5	714
7	Patoyun Branch Drain	29-Jun-12	0.5	11
8	Spinal RD 159+700	26-Jun-12	5.0	1394.5
9	Spinal RD 568+00	14-Jul-12	4.6	815
10	Spinal RD 305+740	14-Jul-12	5.4	920
11	Spinal RD 297+00	14-Jul-12	4.9	965
12	Spinal Drain RD 711+000	3-Sep-12	5.0	1108
13	Singhoro Branch Drain	3-Sep-12	1.0	74
14	DPOD RD 126+00	3-Sep-12	0.5	295
15	Sanghar Main Drain	3-Sep-12	1.3	136
16	Mirpur Khas Main Drain	10-Sep-12	3.3	772
17	Spinal Drain RD 159+700	11-Sep-12	1.9	5105
18	DPOD RD 126+00	11-Sep-12	1.9	1542
19	Shadi Bahadur Branch Drain	11-Sep-12	4.2	421
20	inlet of SBBD	11-Sep-12	-	2.5
21	Tando Bago Branch Drain RD 63+250	11-Sep-12	1.5	593
22	Lowari Branch Drain	11-Sep-12	0.6	232
23	3R of Lowari Branch Drain Outfall	11-Sep-12	3.5	86
24	Fuleli Guni Outfall Drain RD 107	11-Sep-12	0.5	627
25	Karo Ghungro Outfall Drain	11-Sep-12	4.6	1036
26	Nawabshah West Main Drain	15-Sep-12	3.9	633
27	Sanghar Main Drain	23-Sep-12	1.9	222

RATING CURVES FOR LBOD DRIANGE NETWOK

Figure 1: Rating Curve for the Discharge Measurement at RD 159+700

Sr. No.	Gauge (ft)	Discharge (cfs)
1	5	1394.5
2	7.9	3500
3	9.9	5104

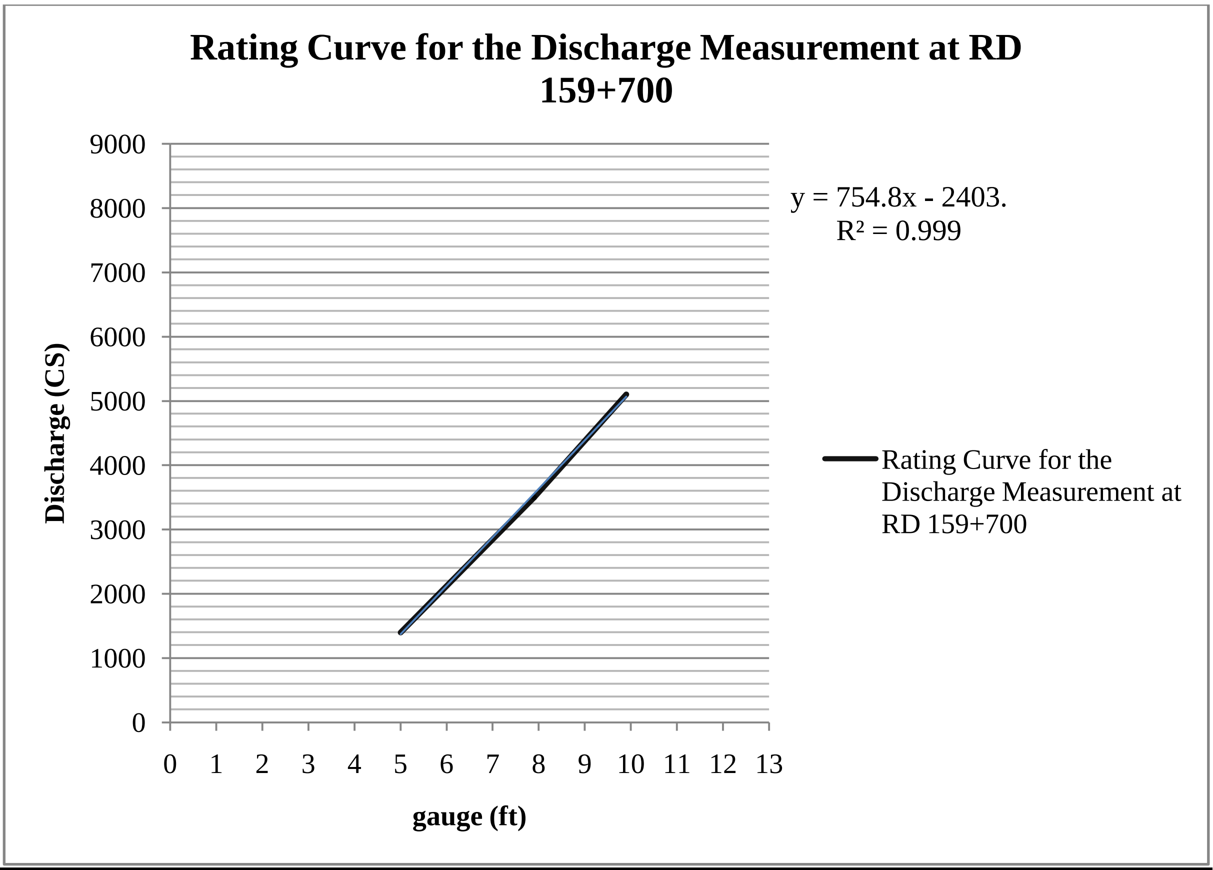

Figure 2: Rating Curve for DPOD Weir RD 127+000

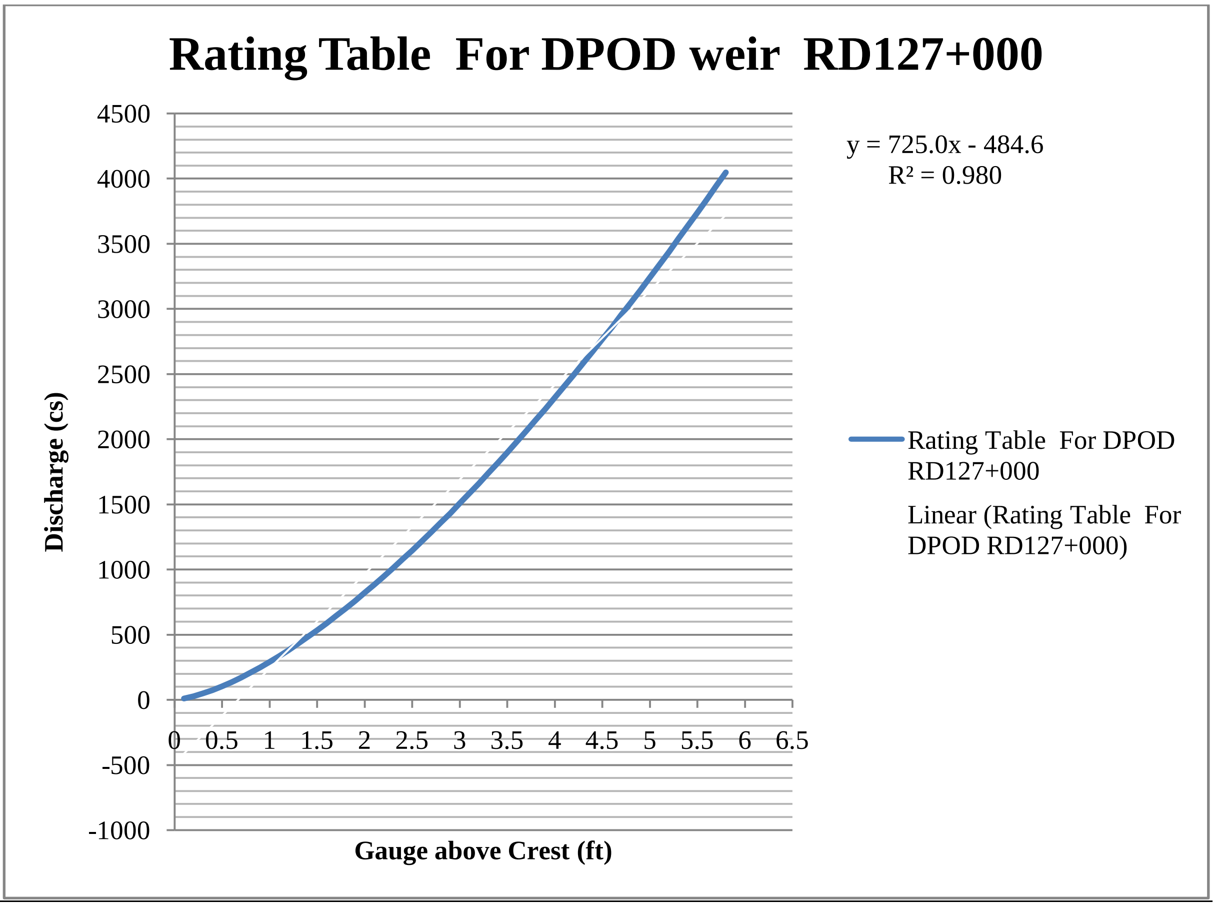

Figure 3: Rating Curve for ENMD RD 00+000

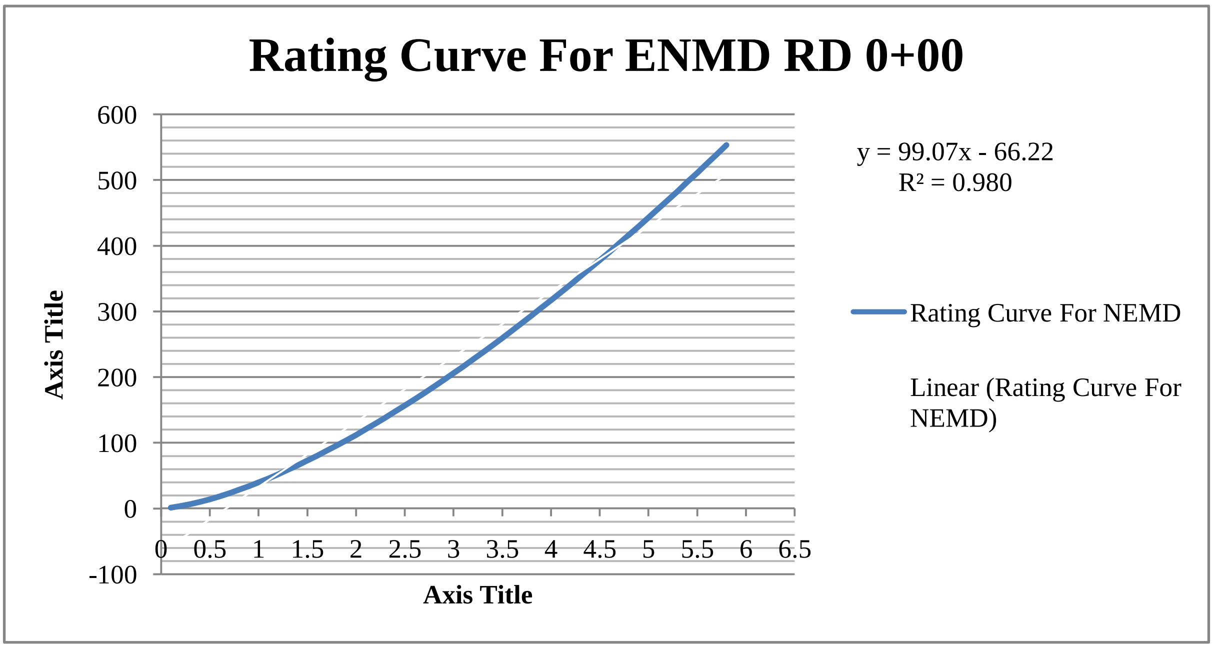

Figure 4: Rating Curve for WNMD RD 00+000

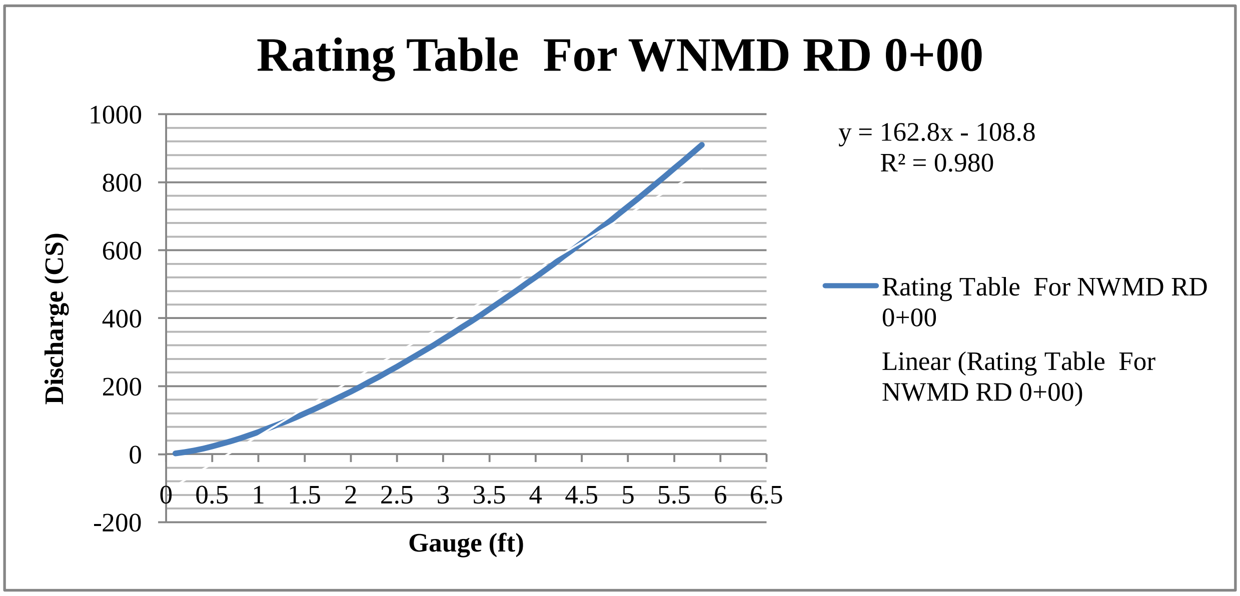

Figure 5: Rating Curve for SMD RD 00+000

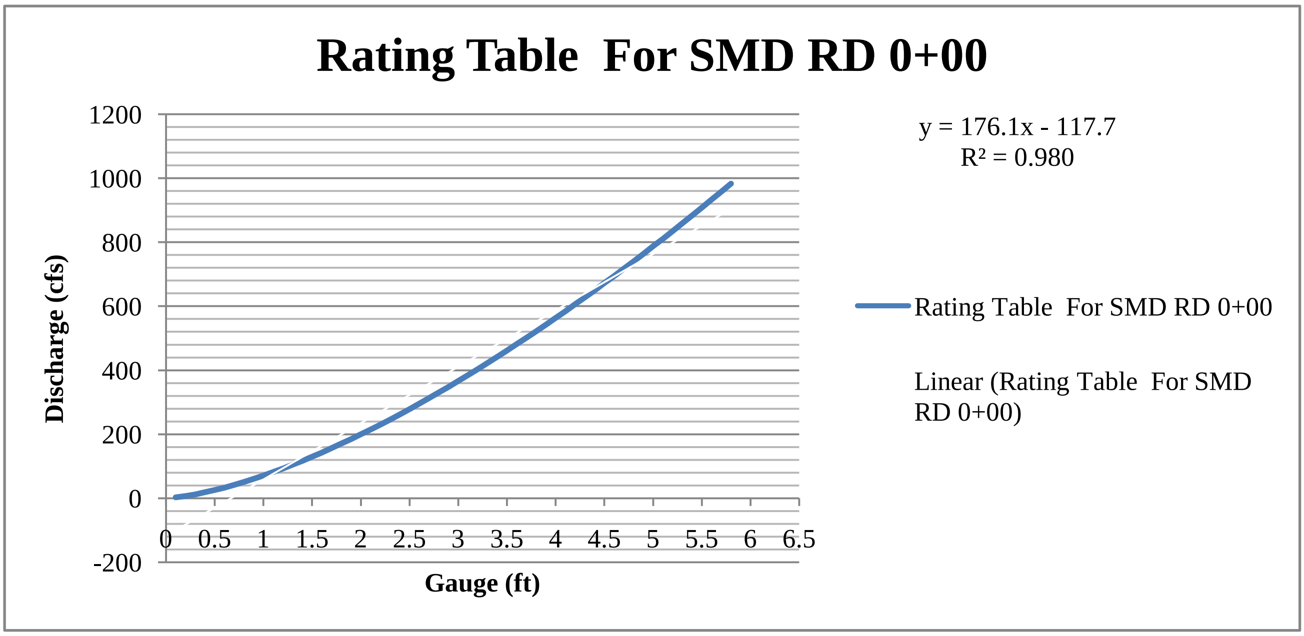

Figure 6: Rating Curve for SIBD RD 00+000

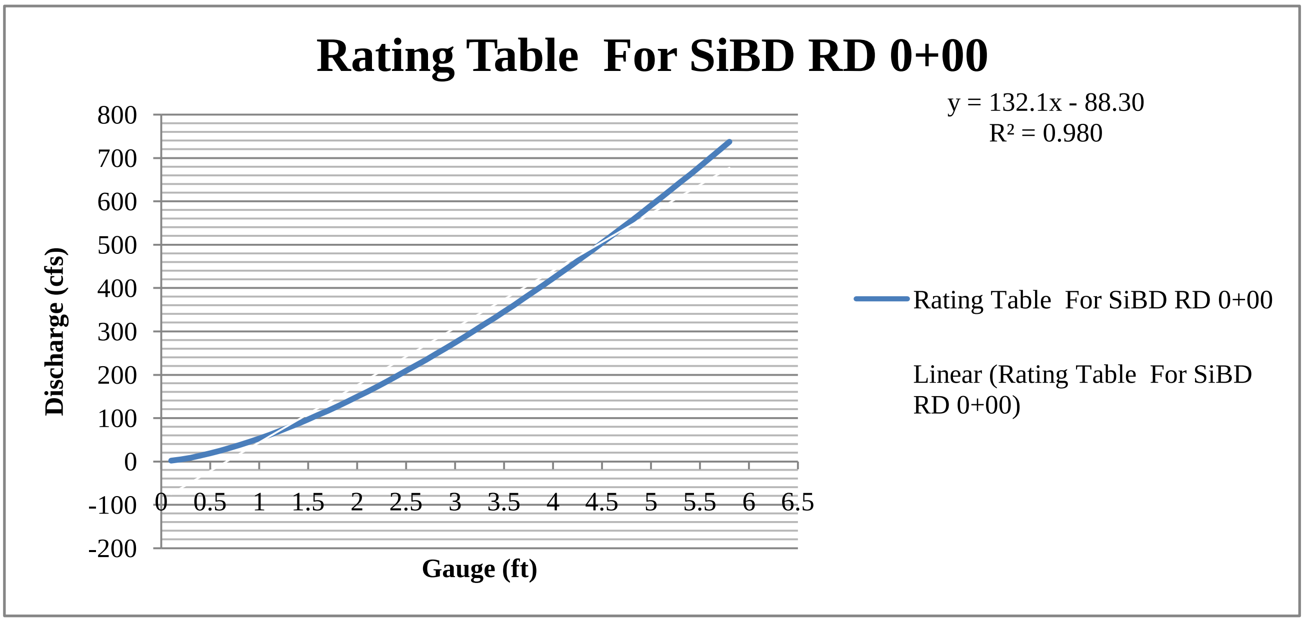

Figure 7: Rating Curve for PBD RD 00+000