EMERGING PHENOMENON OF UN-TIMELY RAIN FLOODS IN SINDH AND WAYS TO MITIGATE THEIR DAMAGING EFFECTS

By

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1. INTRODUCTION

It is anticipated that the change of global weather conditions particularly in Pakistan, would cause untimely rains / floods in coming years. The example of super flood 2010 in river Indus and unprecedented rain falls during 2011 is a paradigm like a mirror before us.

No doubt, province of Sindh has sustained enormous physical / financial losses during super flood 2010 and succeeding unprecedented rainfall during 2011, which caused death blow to the economy of Sindh which is called 'bread basket' of Pakistan. What happened in the past is history but there is dire need to proceed ahead for better planning and foolproof management to avert such damaging and devastating situation in future, so much so that if at all we can not be able to overcome upon the whole disaster, we should confine at least to minimize the losses.

The floods in Sindh Province can be categorized in following three (3) groups:

(i) Floods in River Indus

(ii) Rainstorm and cyclone floods in coastal belt and central area

(iii) Flash floods of hill torrents emerging from the catchment areas of mountainous range on right side of Indus

The major contributing factor in all above type of floods is heavy rains, but each type posses its distinct problem and specific geographical effect. Each type of flood can be controlled and mitigated by its own structural and non-structural remedial measures. Accordingly each flood type is discussed separately as under:-

2. FLOODS IN RIVER INDUS

2.1 Causes and Frequency

High magnitude floods occur in lower Indus when the peaks of the Indus river above Mithankot coincide with high peaks leaving Punjnad. The situation worsens when there are wide spread rains in Koh-e-Suleman range and flows from Kabul, Kohat Toi, Kurram and Gomal rivers enter into Indus.

The graph showing yearly maximum discharges at Sukkur for the period 1901 to 2010 is shown in Figure-1. The review of this chart reveals many interesting factors. The construction of systematic protective bunds along banks of river Indus were taken up soon after completion of Sukkur Barrage and the network was completed in 1940. This system of bunds though controlled overflowing of banks but resulted in bringing high peak discharges in lower part of Sindh. The flood peaks which were of the order of 3 lacs to 7 lac cusecs at Sukkur before construction of bunds have increased to order of 8 lacs to 12 lac cusecs. The global warming and melting of glaciers have further aggravated the recurrence of high floods.

The morphology of river Indus is such that in Sindh Province it flows mostly on ridge with its banks higher than the adjacent lands on both sides. Thus there is always high potential of inundation of land

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and property in the event of bank failure. This has caused a number of Damaged Flooding both on left and right river banks in near past.

Table-1: Major Floods of Indus Basin in Pakistan

Year	Monetary Losses	Lives Lost	Villages Affected	Area Flooded
	(Billion Rs.)	(No.)	(No.)	(miles^2)
1950	9.08	2,910	10,000	7,000
1955	7.04	679	6,945	8,000
1956	5.92	160	11,609	29,065
1973	5.52	474	9,719	16,200
1975	12.72	126	8,628	13,645
1976	64.84	425	18,390	32,000
1978	41.44	393	9,199	11,952
1988	15.96	508	100	4,400
1992	56	1,008	13,208	15,140
1995	7	591	6,852	6,518
2010	860	1,980	1.6 million homes	39,000

The floods in Indus are also being caused by construction of encroachment bunds within bed of river. This has reduced waterway resulting in high velocities and pressure on protective bunds. At some places the river waterway is reduced to half of the original. One of the cause of failure of protection bund at Tori during year 2010 was reduction in river waterway at location.

Another reason for breaches due to tribal fights and worsening situation of law and order. There are certain reaches along river Indus where inspection and repair works on bunds can not be carried out in time due to precarious law and order situation.

2.2 Problems and Risks of Floods in Indus

The major floods in river Indus from 1950 to 2010 are listed above in Table-1. The flood in the year 2010 was the most devastating in which about 2000 people lost their lives and 39,000 sq miles were inundated, affecting 1.6 million homes.

The floods in Indus not only cause inundation of large area but they are threatening the three majestic barrages within Sindh province. These barrages have already passed through the discharges more than their designed capacities. God forbid anything happens to any of the barrage the agriculture and economy of the province will be badly affected. The province can not bear the interruption in operation of these barrages even for a very short period of time.

2.3 Measures to Control Damages of Floods in Indus

<u>Flood Forecast and Flood Warning System</u>

An effective flood forecast and flood warning system can reduce the damages by forewarning the communities living downstream of the river system about likelihood of approaching of higher discharges. This system can facilitate them:

- Taking real time evacuation / preventive / safety measures on immediate basis, and
- Structural and non-structural measures on medium and long term basis.

The present flood control system includes the following setup :

- Flood Forecasting Division (NFFD), at Lahore
- Weather Radar Systems:
  - 10 cm weather radars at Sialkot, Lahore and Mangla
  - 5 cm weather radars at Karachi, Rahim Yar Khan, D.I. Khan and Islamabad.
  - Radio Communication sets for rainfall, river flow / stream flow data
  - Meteor burst Telecommunication System
  - Flood maps
- Indus Basin Flood Forecasting System (FFS) through rainfall – runoff Computer modeling
- Co-ordination committee at Federal level

The present flood forecasting system is not adequate. The example of 2010 flood has indicated that warnings about high floods could not be communicated in time. Nevertheless certain developments have been made, but yet the recommendations made by the study carried out in 1975 for Appraisal of Flood Management System in Pakistan have not been implemented. There is dire need to prepare and implement a comprehensive flood management plan. Automatic warning system need to be installed in hazard areas. Telemetry system on Indus river should be made reliable and working. In addition to NFFD at Lahore, the flood warning sub-centers should be established at Multan, Sukkur and Karachi. The capacity building of understanding, forecasting and handling of flood should also be developed in Khyber Pakhtunkhwa, Sindh and Balochistan.

Reservoir Operation for Flood Mitigations

Tarbela and Mangla are two large dams constructed in Indus basin. Recently construction of Gomal Zam has been completed on a tributary of Indus. The work on dams on some other tributaries such as Kurram Tangi, Daso, Binji etc is also in progress.

The reservoirs can play a vital role in mitigation of flood effects. But past experience has shown that even after construction of 14 billion cubic meter Tarbela reservoir, the floods peaks are not reduced, on the contrary those have increased. This points to the fact that operation procedures of these reservoirs are such that instead of keeping reservoir empty to accommodate flood volumes, on the onslaught of flood season the reservoirs are kept full. There is need to carry out a study as to how storages of reservoirs in Indus basin system can be used for flood mitigation and the recommendation of study be setforth as rules and should be implemented effectively.

Flood Inundation Maps

Flood inundation maps have already been prepared to indicate the areas which will become under water during different flood discharges in Indus. But these maps are prepared without indication of breaches of bunds. The inundation maps will be more useful if the vulnerable points along river Indus are identified where breaches can occur. Based on this information maps should be prepared to mark the areas which will be inundated if any such breach occurs. This information, shall identify the "high risk" areas during flood season. These maps will help develop necessary alertness and prepare emergency action plans (EAP). The maps will also help evacuation of life and property in timely manner. If such maps would have been available, lot of lives and property could have been saved during catastrophic breach at Tori bund on Indus in the year 2010.

Provision of Breaching Sections on River Indus

Almost on every barrage in Punjab Province there is provision of breaching section or fuse plug. The purpose of these sections is that in case of exceptionally high floods, the part of discharges can be escaped by breaching on pre-determined sites for safety of the hydraulic structures (barrages and bridges). The total number of such breaching section in Punjab is 17 out of which 12 are operated by Irrigation Department, 4 by Pakistan Railways and 1 by Highways Department. There is provision of fuse plug embankment on Ghazi Barrage on river Indus. No Such provision is on any of three barrages located within Sindh Province. This keeps these barrages always on risk. There is need to identify such locations and construct necessary sections or spillway to reduce pressure on barrages or bunds passing through thickly populated areas. The breach / spillway routes have to be carefully selected to divert flows to less populated areas or deserts or safely return back after mitigation to the river. The Sindh Irrigation Department has initiated such study.

Improvement of Protection Bunds

The protection bunds / levees along both banks of Indus were constructed in 1940 with manual labour with old concepts of design. These bunds are maintained and upgraded from time to time. There is need to further improve these bunds on modern lines which may include the following actions:

(i) Carryout a detailed topographic survey of existing bunds, including their profiles, plans, cross-sections and condition survey. The data shall be transferred to GIS database

(ii) Planning, designing and construction of bunds should be done as per modern practices as under:

- Flood frequency analysis should be used for determining levels of protection
- Latest hydraulic methods should be used to simulate flow conditions for various discharges.
- The morphology of river Indus be understood to state-of-art river engineering techniques.
- River bed and slope protection works, sizes of stones should be designed after necessary geotechnical investigations and hydraulic analysis.
- Construction and surveillance practices should be improved.

In addition to above there is need to increase the number of surveillance and maintenance personnel and their transportation vehicles for monitoring of the bunds. The law and order situation has to be improved in river areas, where sometime safety situation do not allow to carryout inspection and repair works in time.

3. STORM WATER FLOODS IN COASTAL AND CENTRAL SINDH

The flood of year 2003 in coastal area and flood of 2011 in central and lower Sindh on left bank of river Indus are manifestation of heavy monsoon rains and cyclones. The frequency of these floods have increased with global climate change.

The flood of 2011 in Sindh began during monsoon season in mid August 2011, resulting heavy monsoon rains in Sindh, eastern Balochistan and southern Punjab. The rainfall recorded at various stations of Sindh is shown in Figure-2. The flood caused catastrophic damages and approximately 500 civilian were killed, with 5.3 million people and 1,525,000 houses affected. Sindh is a fertile region and often called the ‘bread basket’ of the country; the damage and toll of the flood on the local agrarian economy is extensive. At least 15 million acres of land was inundated as a result of the flooding.

The President of Pakistan personally monitored the flood situation and relief works. The Prime Minister, the Chief Minister of Sindh and federal and provincial ministers visited affected areas. A special wing of the ministry of the Government of Sindh was created to deal with flooding. Pakistan Army and Navy were actively engaged in flood relief and helping victims. The international reaction and support to flood victims was highly appreciable. Local and international relief organizations set up relief camps for shelter, flood and medicines.

The Sindh Irrigation Department (SID) and Sindh Irrigation Drainage Authority (SIDA) took on war footing basis the tasks of fast drainage of inundated areas, maintenance of drainage channels, closure of breaches in drains and canals and monitoring.

The 2011 flood not only caused heavy damages, but also exposed the shortcomings of existing drainage system on the left bank of river Indus in Sindh Province.

The restriction and hindrances to natural drainage created by network of roads, railway, canals and new developments also came in picture. The old river routes and dhoras which in past used to provide natural drainage in event of high storms were found to be blocked and thus became ineffective. Though the rains of August – September 2011 were of extreme event, but deficiencies in drainage system caused delay in evacuation of inundated lands and gave wake up call to make necessary improvements in the system.

3.1 Recurrent Risks of Flooding in Lower Sindh

Although average annual rainfall is low, southern parts of Sindh, particularly the coastal areas, are prone to intense rainfall and cyclone events, with rainfall amounts in excess of the average annual rainfall occurring in a span of a few days. The terrain is generally flat, with an average slope of 0.014 percent southeastwards, away from the course of Indus River, which flows on a ridge higher than the adjoining areas and thus does not act as a natural drain. Natural drainage is ill-defined and to a large extent, blocked by roads and irrigation bunds and channels. Since 1959, at least seventeen heavy rainfall events (with at least three of them accompanied by cyclones) have been recorded. Due to the flat topography and lack of natural drainage, such events resulted in severe local flooding on average about once in three years, leading to loss of lives and damage to properties and crops.

3.2 Existing Drainage System

Natural Drainage

The left bank area lacks natural drainage. The few natural drainage lines which were existing in the past were severed by the network of irrigation canals, built in 1932 or subsequently. The poor drainage conditions coupled with perennial irrigation supplies have resulted in the rise of watertable.

Drainage in Makhi Dhand Area

A small scheme comprising network of open shallow drains was excavated by the Irrigation Department in the Makhi Dhand area which lies between Dim Branch, Jamrao, Mithrao and Nara canals to check the rising watertable. 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 watertable could not be achieved.

Kadhan Pateji Outfall Drain (KPOD)

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 Rann of Kutch.

Left Bank Outfall Drain (LBOD)

To check the rising watertable and to provide relief from surface runoff generated by rainfall in Nawabshah, Sanghar and Mirpurkhas areas, extensive networks of surface drains, drainage tubewells, 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. Figure-3 and 4 shows the schematic arrangement of LBOD System. Geographical units, where this surface drainage system is located, are:

	Component	**Length (Canal miles)**
i)	Nawabshah	394
ii)	Sanghar	280
iii)	Mirpurkhas	295
	Total	**968**

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

i. Surface Drainage Network of Nawabshah Component Project
ii. Surface Drainage Network of Sanghar Component Project
iii. Surface Drainage Network of Mirpurkhas Component Project
iv. Surface Drainage Network of Badin Area
v. Spinal Drain
vi. Dhoro Puran Link Drain
vii. Dhoro Puran Outfall Drain (DPOD)
viii. Kadhan Pateji Outfall Drain (KPOD)
ix. 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 discharged by sub-surface facilities like drainage tubewells 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. Chemical quality of the storm water will be non-saline. Apart from the surface drains, several escape channels carrying surplus water from the irrigation system also contribute to the drain flows.

3.3 Problems and Limitation of Existing Drainage System

General

No man-made system is perfect and every engineering project has its limitations. The left bank outfall drain though a mega project was constrained due to funding problems. Also the drainage system is mainly designed to reduce water logging and salinity and to handle storm floods of certain frequency. Thus the drainage system can not handle extreme floods in timely manner. The flood of year 2003 and recent flood of 2011 have daylighted a number of problems, limitations and deficiencies in the existing system. For future master planning, it is necessary to have an understanding of those problems. The following points have been identified at this stage :

Area Coverage

As already pointed out, the existing drainage system covers only drainage of districts of Benazirabad, Mirpurkhas, Badin, Sanghar and Tando Muhammad Khan. Even in Benazirabad, Badin and Sanghar large areas are without any drainage system. Also the tertiary drainage systems are missing. The intensity of drains in these areas is also low (1 m/ha in comparison to an international average of 35-50 m/ha; in the Netherlands, 100 m/ha).

Low Frequency Design Floods

The original system was designed for 24 hour rainfall of 5 year frequency which was worked out for different rainfall stations as under:

Badin	:	113 mm
Mirpurkhas	:	95 mm
Padidan	:	54 mm

To avoid losses to property crops and life, the drainage system needs to be redesigned for 10 to 20 year frequency flood, as recommended by International Institute for Land Reclamation and Improvement, 1994 (ILRI).

Delayed Evacuation of Inundated Areas

Due to above two reasons, the existing drainage could not drain out flood water in timely manner, i.e. within 5 days, resulting in loss of most of crops in inundated areas.

Unstable Channel Banks

It has been noted that wherever the drainage channels were crossing natural depressions and consequently theirs banks were high, the dimensions of fill banks were not adequately wide. This resulted in breaches of banks in those portions. This happened so, particularly in areas of silts and fine sands. These breaches need to be strengthened against piping failure.

Situation of Channels

The survey carried out by WAPDA during 2006 and study on LBOD has shown that at most of the sections, the drains are filled with sediments, which has reduced their discharge capacities. This resulted in heading up of water and at places overtopping of banks and breaches.

Maintenance of Drains

Due to shortage of funds, the maintenance of drains and their banks is not done in satisfactory manner. This has created weaknesses in the drain banks.

Overstressing of Drainage Channels

Not only, the drains are under designed, during floods the system becomes overloaded due to cuts made by the farmers to expedite the evacuation of rain water from their lands. The situation is further aggravated due to flows from canal escapes and breaches which enter into LBOD.

Obstructions by High Tides

High tide in sea and high level in Shakoor Dhand obstructs the flow of Tidal Link DPOD and KPOD. This phenomena occurred during flood year 2003.

Obstruction of Natural Drains (Dhoras)

Due to development the routes of old natural dhoras have been obstructed. Except Dhoro Naro and lower part of Dhoro Puran, most of them are no more available for drainage disposal.

3.4 Proposed Improvement in Stormwater Drainage System

After review of existing system and observations made during floods 2011 and year 2003 the following measures are proposed for improvement and extension in existing storm water drainage system.

Revision in Drainage Criteria and Increase in Size of Drains

The existing LBOD drainage system is designed for draining floods generated by 5 year frequency rainfall. It is proposed to enhance and remodel the existing system having return period of 20 years as recommended in Drainage Principles and Applications; International Institute for Land Reclamation and Improvement (ILRI), 1994. It is noted that the discharges for 20 years frequency flood are increased by almost four times to that of 5 year frequency rainfall.

The discharge capacity can be increased by following methods:

i. The channel bed width can be increased by 30 to 40 ft as on both sides of drainage channels 15 to 20 ft berms are provided

ii. Channel water depth may be increased by raising channel banks by 2 to 3ft.

A major hindrance may be at bridges and cross-drainage structures. Though bridges normally do not cause hindrance to flow, provided the water way on upstream and downstream is wide. However protection works with stone pitching will be required at bridges against abutment erosion.

Additional Drains

It was observed that there are large areas where no drainage system has been provided to dispose of water.

Due to non-availability of drainage system, stranded pockets spread in scores of square kilometers were formed, which could not be drained except by pumping or leading cuts. These remained under water for more than 3 months. Such areas are listed below:

- Area between Lower Nara and Mithrao Canal in Sanghar and Umerkot districts
- Area near Berani and Jhando Marri in Sanghar and Mirpurkhas districts
- Entire Tando Allahyar district
- Northern area of Tando Adam in Sanghar district
- Area north of Matli and Rajo Khanani in Badin district
- Area in vicinity of Biro Zardari in Shaheed Benazirabad
- Lower area of District Mirpurkhas

To provide relief from future floods, it is necessary to provide drainage channels in those areas.

Activation and Utilization of Old Dhoras

It is proposed to activate following 4 dhoras for drainage purpose:

- Naro Dhoro - Hakro Dhoro

- Sohni / Bhai Khan Dhoro

- Dhoro Puran

The utilization of these dhoras is proposed as under.

(a) Dhoro Naro

The Dhoro Naro starts from tail end of Lower Nara Canal and joins Dhoro Puran. It is proposed to connect all new drains in command areas of Lower Nara, Khipro and Mithrao between Kundho to Naokot with Hakro Dhoro, which will ultimately dispose into Dhoro Puran.

(b) Hakro Dhoro

The Hakro Dhoro is active from downstream of Samaro and joins Dhoro Naro near Naokot. The proposed new drains in command area of Nabisar and Mithrao Canal in South of Samaro town shall be drained into Dhoro Naro.

(c) Sohni Dhoro / Bhai Khan Dhoro

The Sohni Dhoro / Bhai Khan Dhoro starts from north of Shahdadpur on right side of Ali Bahar Branch (offtaking from Rohri Canal) and passes on right side of Shahdadpur town. After passing between Berani and Tando Adam, Sohni appears to be blocked at village Dasori. It is proposed to discharge new drains between Shahdadpur, Tando Adam and Tando Allahyar towns into Sohni Dhoro. Flows collected by Sohni Dhoro will be disposed into Bhai Khan Doro or lower Sohni Dhoro. The drainage water of Shoni Dhoro will be diverted into Dhoro Puran through Sarfaraz Dhoro, which exists between Gulab Leghari and Digri.

(d) Dhoro Puran

The Dhoro Puran starts from Mirpurkhas and passes near Mirwah Gorchani, Dighri, Tando Jan Muhammad, Jhudo Station, Naokot, Pangrio, Kaloi and ultimately drops into Shakoor Dhand.

The Mirpurkhas Main drain almost traverses along this Dhoro and is received by Spinal Drain at RD 297. Thereafter the Spinal Drain deviates from Dhoro Puran, though it crosses at number of places. At RD 159, a weir divides flows into KPOD and DPOD (Dhoro Puran outfall Drain, the old Dhoro route).

It is proposed to divert flows from Spinal Drain at RD 297 to Dhoro Puran and straighten its path or remove blockages. By this arrangement, flows from Spinal Drain upstream of RD 159, and flows from Hakro Dhoro and Dhoro Naro will be diverted to Dhoro Puran and disposed into Shakoor Dhand. On the way, flows can also be diverted to dhands (ponds) and depressions on its left side. This arrangement will divert flows from Benazirabad, Sanghar Mirpurkhas and Umerkot areas to Dhoro Puran, without entering into KPOD and Badin district. This arrangement will thus reduce pressure on Tidal Link.

4. HILL TORRENT FLOODS IN RIGHT BANK AREA

Rainfall runoff from Marri Bugti hills in the north and Khirther range in the west carries considerable flow in foothills and plains of Sindh and Balochistan. The natural ground slopes allow most of this water to reach right bank of river Indus and into it. After the construction of Sukkur barrage, its canal system irrigates most of the area on right bank and flood protection embankment along the river, it became necessary to protect this command area from the uncontrolled runoff as stated above. A flood protection bund (the F.P. bund) was, therefore, constructed to control the flow from north and west getting into the Sukkur barrage command area. During the normal floods water flows through Main Nara Valley Drain (MNVD) parallel to the bund down to the Hamal lake and further onwards to the Manchar lake in the south, with outlets to the Indus river. In case of high flood conditions breaching of FP bund occurred at different places and damages were reported in the command area.

Further to the south of the Khirthar range, originates the Baran Nai passing through a narrow gorge known as Darwat pass in a minor hill range. The Nai which is a torrential non-perennial river terminates in Indus river in the south east. On its way to the Indus, the Nai is crossed by K.B. Feeder super passage along with its guide banks and canal banks which get damaged during high floods. Indus highway crosses the Nai with a bridge over it.

Kinjhar lake lies further ahead at the foothill of kirther range. Embankments have been constructed on the eastern side increasing the size of the natural lake stability of the embankment and lack of provision for spillage of excess waters has been the cause of concern with respect to safety of Thatta town. Also the area in vicinity of the embankments is affected by seepage.

In short the existing protective facilities include F.P bund, Hamal Lake, Manchhar Lake, works at Baran Bai super passage, and Kinjhar Lake periphery bunds. Pat feeder canal right bank bund is one of the facilities in the province of Balochistan.

4.1 Flood Potential and Historical Floods

The flood problems of F. P. Bund Complex present a unique, complicated and characteristic situation. The area is surrounded by a group of three hill ranges, almost enclosing the F. P. Bund complex from north to south-west. Since the monsoon track commonly follows the same pattern, the precipitation generated floods get intensified while moving along the bund from north-east (Pat Feeder and Khirther end) towards south-west (Manchhar Bank end). These hill torrents around F. P. Bund may be grouped into three sub groups.

- Marri-Bugti Hill Torrents
- Nari- Bolan Range Hill Torrents
- Khirther Range Hill Torrents

A brief description of each of these groups is as follows:

(a) Marri-Bugti Hill Torrents

Marri Bugti Range is a part of Kachhi Basin and comprises the eastern part of Balochistan Province. Hill torrents from this range drain an area of about 25,000 square miles and yield about 2.0 MAF or 2466 MCM of runoff in an average year of precipitation. Flood flows from the Nallahs damage the Pat Feeder and Khirther Canal and further the F.P.Bund. Since cross drainage facilities have not been adequately provided in the canal systems, this creates a potential danger to these canals and the part of F.P. Bund along Khirther Canal. On a number of occasions, breaches have occurred in the canals resulting in heavy losses.

(b) Nari Bolan Hill Torrents

The Hari River catchment comprises an area of 8,300 square miles Major hill torrents of the basin are Lorali River, Beji River, Anamber River, Ziarat Manda and Khost River. These hill torrents generate a runoff of about 1.00 MAF or 1235 MCM in an average year of precipitation. The combined flows of these nallahs debouch onto the Kachhi Plain near Sibi.

On the right of the Hari River Catchment, is situated the Bolan River Catchment, which comprises 825 square miles. The Bolan River emerges from the hills at Bolan pass near Dhadar in Kachhi District. The flow of Nari and Bolan Rivers join in the Kachhi Plain and come down towards Pat Feeder and Khirther Canal areas. These flows hit the canals and the F.P. Bund through Qabula Nallah and Bagh River between RD 30 to RD 70.

Generally the floods from Marri-Bugti Area and those of the Nari-Bolan Basin combine in the Kachhi Plain and it is often difficult to quantify the flood damage separately in the F. P. Bund Area.

(c) Khirther Range Hill Torrents

The reach of F. P. Bund from a point near Shahdadkot to the southern most end of the Bund suffers from a direct on rush of the torrents emerging from the eastern gorges of Khirther Range. With respect to their location and ultimate disposal of their flood, these torrents can be categorized into the following sub-groups :

i. Torrents contributing to Hamal Lake

ii. Torrents striking F. P. Bund between Hamal Lake and Gaj Nai.

iii. The Gaj Nai

iv. Torrents contributing to Manchar Lake

The characteristics of each of these sub-groups area described below.

(i) Torrent Contributing to Hamal Lake

There are eight major hill torrents that contribute their flows to the Hamal lake directly or indirectly bringing major flows into the lake. Drain a total area of about 435 square miles and their cumulative discharge for a 25 years return period is 85,000 cfs.

(ii) Hill Torrents Intervening Hamal Lake and Gaj Nai

Seven major hill torrents emerge from Khirther Range in between Hamal and Gaj River catchment. These hill torrents drain an area of about 800 squre miles. Since the catchment areas are small and the channel lengths are short, their time to peak and time of concentration are small. The slopes being very steep and the F.P.Bund being fairly close to their basin outlet, the rate of runoff is considerably high. It is estimated that a total flow of 80,000 cfs may occur along F.P.Bund in this reach, for a 25 year return period flood.

(iii) Gaj Nai

Gaj Nai, which is known as Kulachi in its upstream reaches, is the largest of the Khirther Hill Torrents, and is the only one that pierces the ridge. The mountainous catchment has an area of about 2,750 square miles and is almost completely barren. The climate is influenced both by westerly disturbances and monsoon. Heavy rainfall in the catchment causes relatively short, intense flash floods. The high flows usually occur in July and August and the floods are the most important sources of water.

Gaj Nai leaves the Khirther hills through a deep narrow gorge, flows through several kilometers of foothills in a narrow valley, and crosses a large alluvial fan formed where it discharges on the Indus Plain. Flow is not perennial in this area. Earthen banks have been constructed to intercept and store flood waters for irrigation. Groundwater is withdrawn by tubewells for irrigation and domestic use in the downstream areas.

Gaj Nai is the major source of floods along F. P. Bund preceding the Manchhar lake. It has been estimated that a flood with a 25 year magnitude brings about a peak of 100,000 cfs. The runoff matching this event is of the order of about 360,000 Acre ft.

(iv) Torrents Contributing to Manchhar Lake

Major torrents emerging from Khirther Range in this group have a total drainage area of about 950 square miles and generate a total runoff of about 133,300 Acre ft for a theoretical return period of 25 years.

It has been estimated that the total runoff including the flow of these six hill torrents, entering the Manchhar Lake with a 25 year recurrence interval would be of the order of about 0.9 MAF.

4.2 Alternate Solutions

Hill torrents draining mountainous areas cause severe flash floods consequent to occasional intense rainstorms. The catchments are barren and steep and the stream flows generated by these rainstorms transport and deposit large quantities of coarse sediment. The flows are extremely variable and the sediment loads are high with the result that prospects of development of storage for irrigation supply are limited. Control of hill torrents by storage reservoirs does not generally prove to be feasible and where it can possibly work, large storages are required.

After comprehensive study of the area and its problems, the plans prepared by the Irrigation Department Government of Sindh and other agencies, the following alternatives were considered:

The F. P. Bund (Flood Protection Bund)
Control of hill torrents mainly depends on the F. P. Bund. The only reservoir to be considered is Hamal Lake, there being no other storage site along the route.

(i) Strengthening or Remodeling of F. P. Bund. The strengthening of the F. P. Bund includes measures from amongst the following:

- Provision of adequate free-board by raising the height of the embankment.
- Increasing the top width.
- Flattening of side slopes.
- Upstream slope protection
- Downstream berm for stability of the embankment Section where required.
- Sand coring in areas where embankment fill is poor.
- Proper treatment of embankment at sites where rat holes/animal burrows are detected.

(ii) Catch Water Drain
Construction of a catch water drain along the western side of F. P. Bund from Hamal Lake to Manchhar Lake so that obstructions due to low ridges along the storm water flow route are removed.

(iii) Compartmentalization
Construction of second line of defence in the area west of Shahdadkot forming two compartments.

(iv) Soaking Trenches
Construction of trench bund or bunds to provide for soaking and testing of the F. P. Bund.

(v) Construction of flood regulating / dispersion structures on some streams / hill torrents.

(vi) Hamal Lake Development
Hamal lake storage of 88,700 AF at the Madde ridge elevation of 136 (MSL) could be increased to about 267,000 AF at the full reservoir elevation of 138 without any resettlement problem. The flows downstream Hamal Lake could thus be reduced.

Baran Nai
The existing facility includes the protection works for Kalri Baghar Feeder Canal super passage, which has recently been remodeled for Karachi Water Supply project. However, the Baran Nai torrents can possibly be controlled by constructing a dam at Darwat creating a large reservoir. Thus the stream flows downstream of the proposed dam site would be reduced. WAPDA has already started construction of a 60m concrete dam on this location.

Construction of Nai Gaj Dam
The floods of Nai Gaj dam can be reduced by constructing a dam to create a reservoir for mitigation of flood. WAPDA is in process of constructing an earth-core rockfill dam on narrow gorge. After completion of dam it is expected that flood impacts will be reduced.

Construction of Medium Small Dams

Construction of medium and small dams on nai will help reducing the damaging effects of floods. A cascade of small weirs on a nai will reduce the velocity of flows and will have delay action effects. Sindh Small Dams Organization have already constructed about twelve (12) dams in the area. Feasibility study has been prepared for additional 40 small and medium size dams in Kohistan, Karachi and Thatta area. Location of these dams is shown in Figure-5.

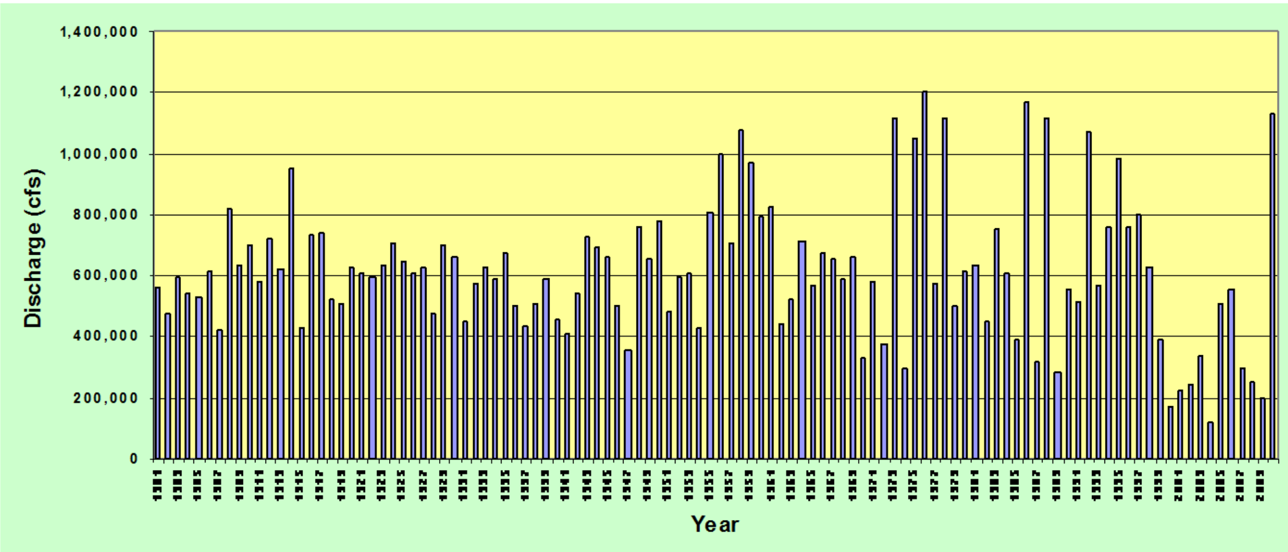

Figure-1: Yearly Maximum Discharge Recorded at Sukkur (1901-2010)

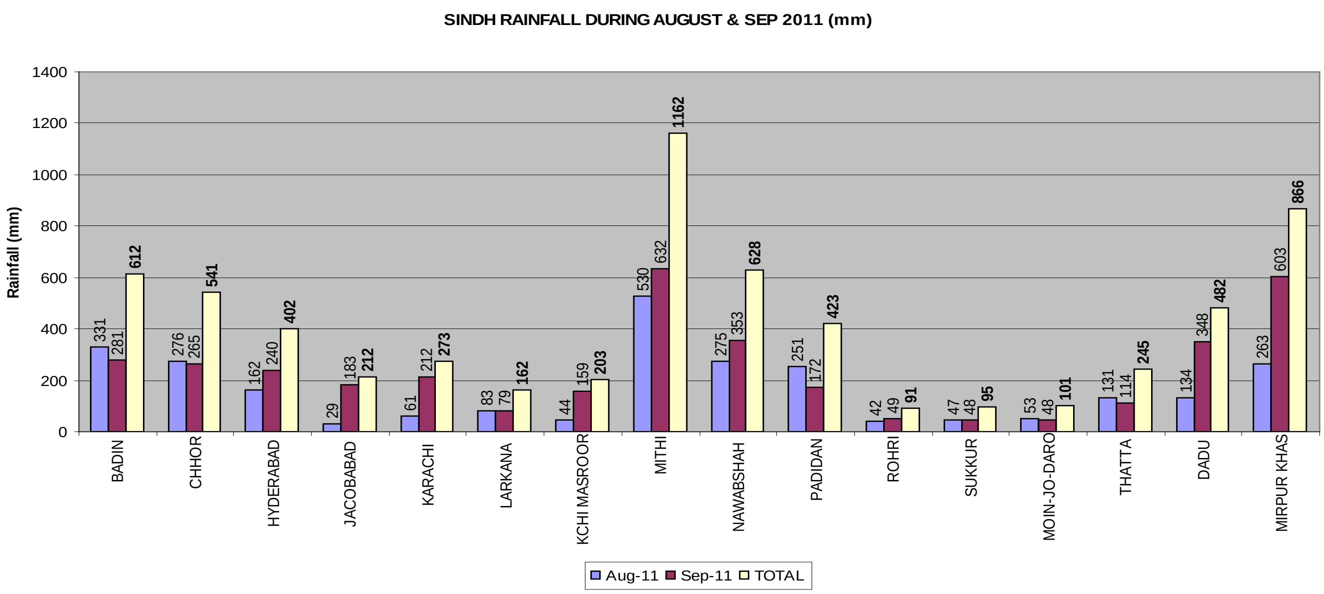

Figure-2: Rains during August and September 2011

[redacted]

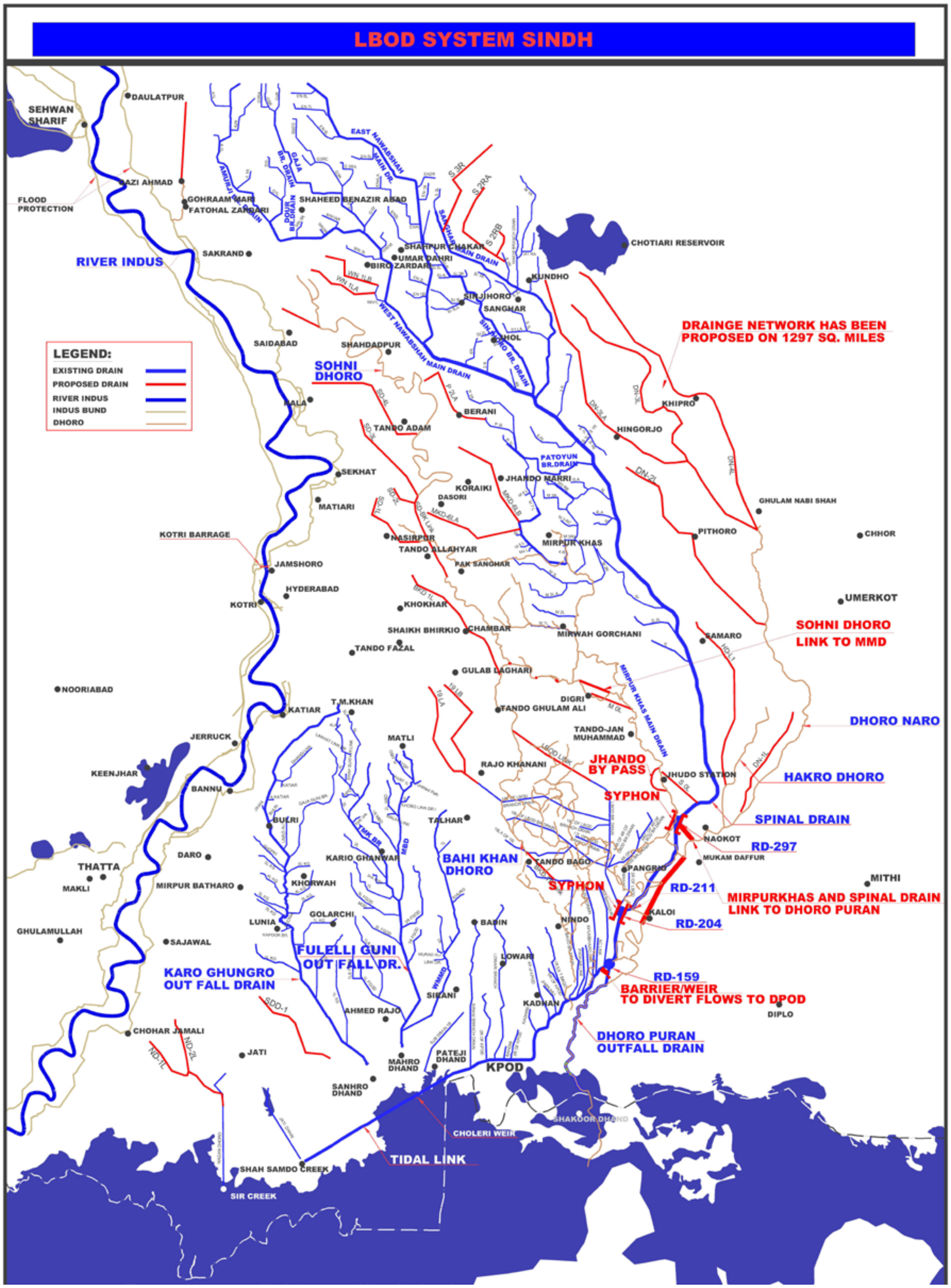

Figure-3: LBOD System Map

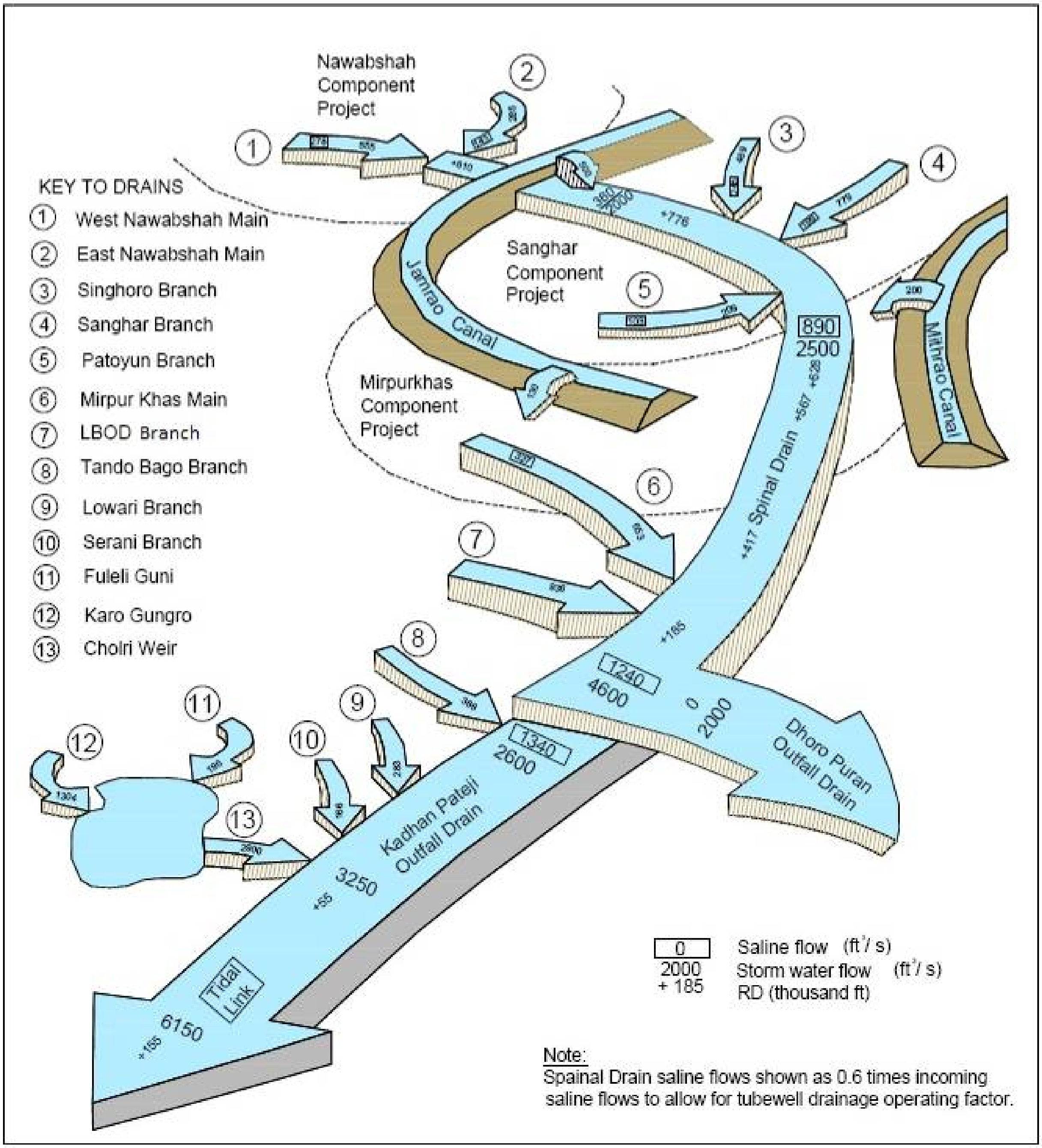

Figure-4: LBOD System

[redacted]

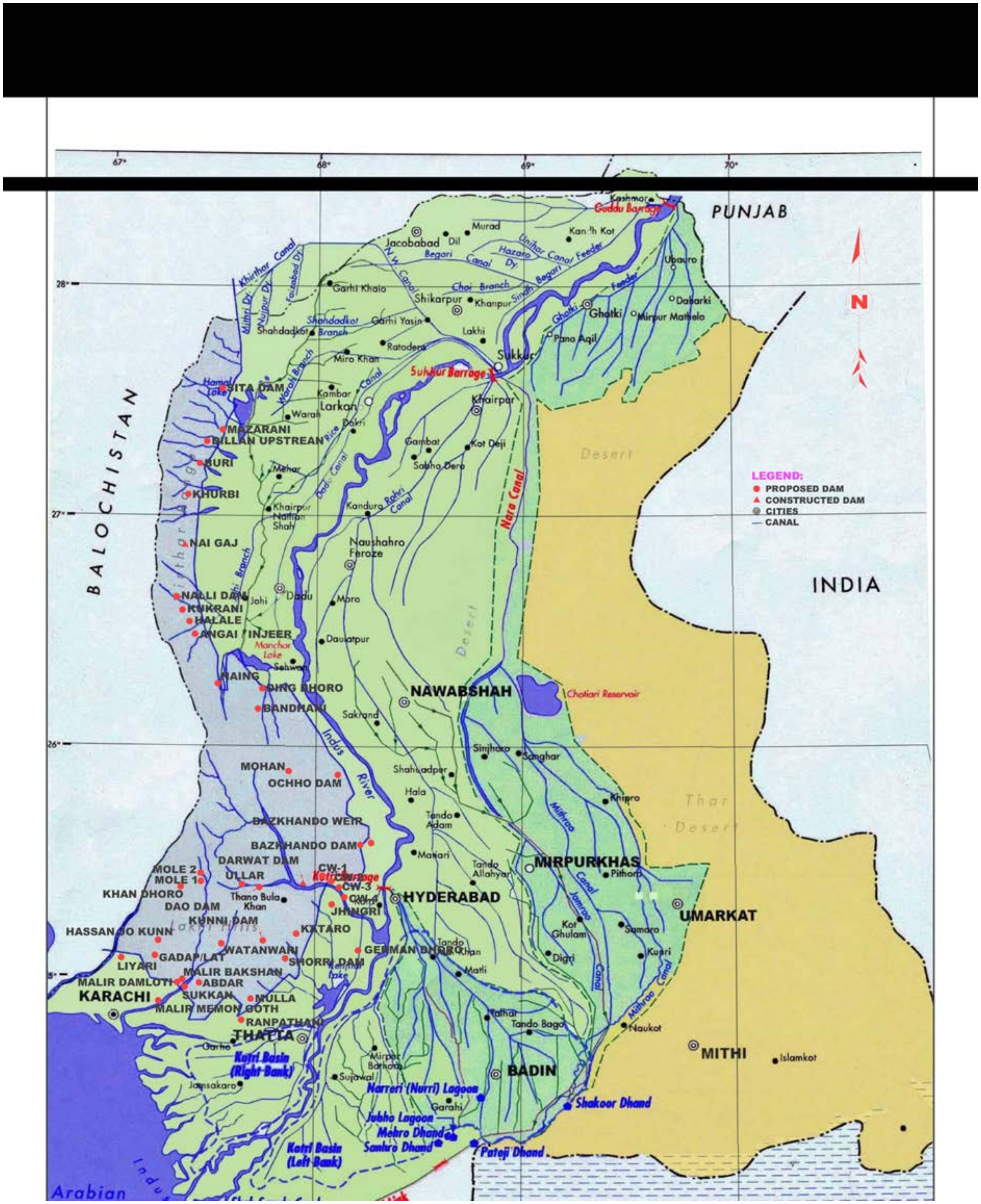

Figure 5: Dam in Kohistan Region