SECTOR A

HYDRAULICS AND HYDROLOGY

VOLUME 3: SUPPORTING REPORT

SECTOR A: HYDRAULICS AND HYDROLOGY

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SECTOR A HYDRAULICS AND HYDROLOGY

1. PHYSICAL CONDITIONS OF THE STUDY AREA

1.1 Topography

The Lai Nullah Basin is located between 33˚33' and 33˚46' North and 72˚55' and 73˚07' East covering a catchment area of 234.8 km^2. The upper part of 161.3 km^2 (69%) falls in Islamabad Capital Territory, and the rest area of 73.6 km^2 in Rawalpindi City and its suburbs.

A color elevation map was elaborated for easy-understanding of the topography of the Lai Nullah Basin based on the GPS survey results conducted under this Study, as shown in Fig. A.1 According to the map, the elevation of the Lai Nullah Basin ranges from 420 m at the confluence with Soan River to 1,240 m at a mountaintop in the Margalla range.

The Lai Nullah Basin might be broadly divided to four areas in view of topography. They are the Margalla range, the higher plain, the lower plain and the valley area in the north to south direction.

1.1.1 Margalla Range

The Margalla range stands behind Islamabad City area as a wall, which forms the north boundary of the Lai Nullah Basin. The foot of the Margalla range stands at the elevations of about 620m, while the top of the mountain, which is only 3km from the foot is at about 1,200m. Several tributaries originate in the mountain range. Four major tributaries are Saidpur Kas, Tenawali Kas, Bedarawali Kas and Johd Kas. In this mountain range, the tributaries are as steep as nearly 10%.

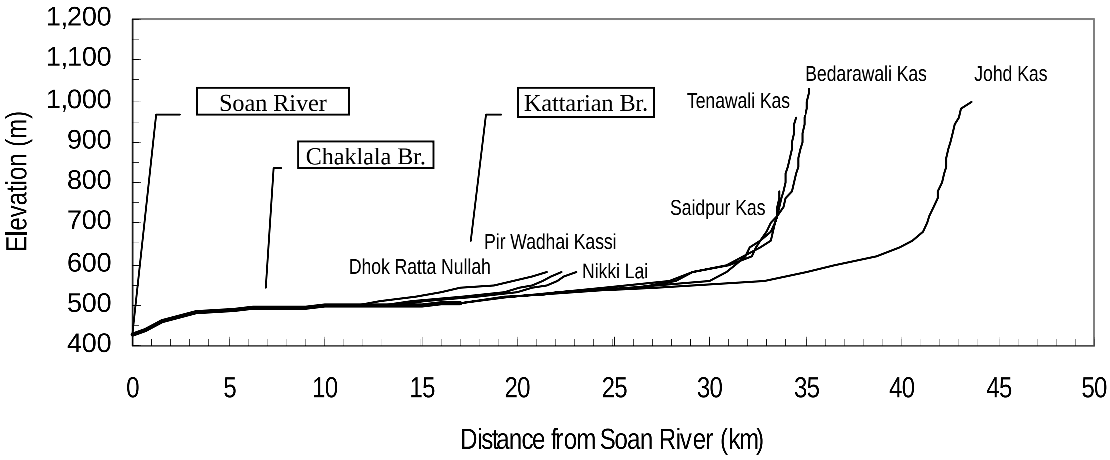

Fig. R A.1 River Profiles

1.1.2 Higher Plain

The higher plain expands over the built-up area of Islamabad City with a gradual slope from North to South. Saidpur Kas, Tenawali Kas and Bedarawali Kas run southward in the plain with a slope of 0.7 to 0.8 %, weaving the build-up areas of Islamabad and finally flow into Lai Nullah just upstream of Kattarian Bridge.

1.1.3 Lower Plain

The lower plain is the upper part of the Rawalpindi area upstream of Chaklala Bridge. This area is flatter than the upper Higher Plain and the lower Valley Area as shown in Fig. A.2, where the ground elevations of Lai Nullah Basin is presented with 5 m interval.

This area forms a bowl-shaped topography as seen in Fig. A.2. The lowest area along Lai Nullah from Gawal Mandi Bridge to Chaklala Bridge is the bottom of the bowl, towards which all floodwater gathers from tributaries as well as the main stream. This bottom area was deeply submerged in the floodwater in 2001. In this area, the river has a rather gentle bed slope of about 0.1% and shallow channel depth of 5 to 6 m. These physical constraints result in the poor flow capacities in this river stretch.

1.1.4 Valley Area

After Chaklala Bridge, the topography changes very much a definite valley. The river turns steeper with several cascades, falling down to Soan River. The river channel is deeper than 10 m, and the average river slope between Chaklala Bridge and Soan River is about 1 %.

1.2 Climate

The climate of the Study Area might be classified as “Subtropical Triple Season Moderate Climate Zone”, which is characterized by single rainfall season from July to September and its moderating influence on temperature.

The Study Area has hot summers and cold winters. In June the daily maximum temperature reaches 40 ℃, while the daily minimum temperature falls near 0 ℃ in December and January. Between July and September, the temperature is slightly moderate due to humidity.

Rains occur in all seasons but the monsoon rain is pronounced and constitutes a definite rain season between July and September. The total rainfall during the rain season is about 600 mm, accounting for 60% of the annual rainfall of about 1,000 mm. These monsoons bring heavy downpours in the Lai Nullah Basin, resulting in flooding of Lai Nullah and the tributaries. In the monsoon season, the thunderstorm activity is higher. It thunders 12 or 13 days in a month in Rawalpindi.

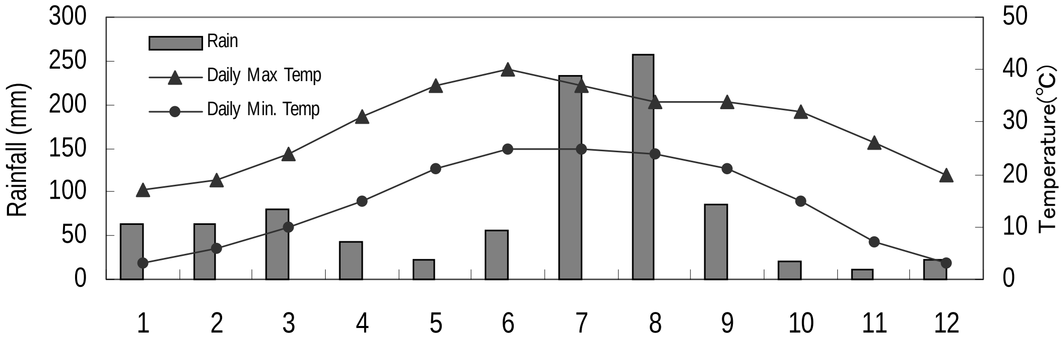

Fig. R A.2 Rainfall and Temperature (Rawalpindi)

2. PREVIOUS FLOOD EVENTS AND PRACTICES FOR FLOOD MITIGATION OF LAI NULLAH

2.1 Past Floods

Flood problems of Lai Nullah have been repeatedly discussed among officials concerned for about 60 years, since a first committee on Lai Nullah was organized through an experience of the serious flood damage on 13 August 1944. Several studies have been carried out proposing various countermeasures against flood including flood diversion, river improvement, and flood warning systems. However, any essential measure was implemented until the river improvement of Lai Nullah was commenced under the financial assistance of ADB in 2002.

2.1.1 Flood Years

Details of the past flood disasters are unfortunately not available, but scraps of descriptions about past floods could be collected from several study reports. According to them, the flood has occurred with the frequently of 19 years at least in 59 years from 1944 to 2002 as listed in Table R A.1 although dates of some of the floods are still uncertain. In other words, flood damage broke out almost once in every three years.

Table R A.1 Flood Years

Year	Date	Year	Date
1944	August 13	1985	No Data
1957	No Data	1988	No Data
1966	July 31	1890	No Data
1970	No Data	1994	July 3
1972	No Data	1995	July 24
1976	No Data	1996	July 29
1977	No Data	1997	August 27
1978	No Data	2001	July 23
1981	No Data	2002	August 13
1982	August 10	N/a	N/a

1) 2001 Flood

The flood in 2001 would be the largest among the recorded floods. On 23 July 2001, the rainfall depth was recorded at 620 mm in 10 hours from 0600 to 1600 hours (in Pakistan Standard Time) at the Islamabad Station. The water level of Lai Nullah and its tributaries remarkably rose and all houses and some road bridges along them were swept away. As mentioned above, there were many other floods in the past, but they were considered insignificant as compared with this worst flood in the twin cities of Rawalpindi and Islamabad.

Heavy rainfall in this South Asian region is generally associated with monsoon depressions formed over Bay of Bengal during summer. The rainfall experienced in the flood in 2001 is, however, exceptionally not associated with any depression. According to PMD, the rainfall was caused by a freak combination of disastrous weather events including: (a) intense heating on the surface, (b) presence of mid latitude westerly trough and (c) moisture feeding through monsoon flow along Himalayas.

A meso-scale rainfall was firstly developed a day before about 50 km north of Islamabad producing more than 200 mm around the origin during the night. It moved in south and southeast direction. In Islamabad, rain started at 0600 hours and attained peak intensity at 1200 hours lasting till 1600 hours. The intensity as well as amount of rainfall was more in Islamabad than in Rawalpindi. The swollen flow of Lai Nullah invaded Rawalpindi causing several times more damages than Islamabad. Loss of 74 human lives has been reported in this disaster.

2) Habitual Flood Inundation Areas

Habitual inundation areas have been identified by the administrations. In Rawalpindi low-lying areas along Lai Nullah and the tributaries suffer from even small floods. The serious flood tents to occur along in particular: the mainstream between Gunj Mandi Bridge and Railway Bridge, and the tributaries of Arya Nullah, Dhok Ratta Nullah and Donk Charaghdin. According to TMA, flood inundation starts in these areas once the water level of Lai Nullah reaches 18 feet (491.5 m) at Gawal Mandi Bridge. In this connection, TMA blow sirens over the low-lying areas when the water revel reaches the alert water level at 16 feet (491.3 m).

Due to the geophysical features, Islamabad is safer against floods than Rawalpindi. Residential areas in Islamabad are generally placed on the relatively high ground level and surrounded by extensive green spaces, which might function as retention ponds or buffers from flood water. Nevertheless, there still are habitual inundation areas in Islamabad too. They are low-lying areas along Saidpur Kas and Tenawali Kas in I-Block areas. In addition, the community called "Kachi Abadi", who is living in the right-of-way of the tributaries is also exposed to flood inundation as discussed in Sector I.

2.1.2 Flood Discharges

The flood marks at Gawal Mandi Bridge have been recorded by TMA for these 13 years, although the records do not contain the dates of their occurrences. Table R A.2 gives the maximum water levels and their corresponding discharges estimated from the water level-discharge relationship by the non-uniform flow calculation in Sector B. Among others, however, the discharge of the flood in 2001 (2,870 m^3/s) was estimated through the flood simulation model instead of the water level-discharge relationship due to the massive volume of flood inundation. This discharge thus estimated is subject to an assumption that all the floodwater had been confined in the river.

Table R A.2 Observed Max. Water Levels and Estimated Discharges at GawalMandi Bri.

Year	Maximum Water Level		Discharge (m^3/s)
	(ft)	(m)	
1966	25	494.02	450
1970	30	495.54	700
1972	26	494.32	500
1976	25	494.02	450
1977	30	495.54	700
1978	25	494.02	450
1981	29	495.24	650
1982	32	496.15	850
1994	31	495.85	770
1995	26	494.32	500
1996	20	492.50	270
2001	41	498.90	2,870*
2002	22	493.10	320

2.2 Interview Survey

An interview survey on the past flood inundation conditions was made to collect supplemental information that is hardly available in forms of documents.

2.2.1 Methodology

Interviews were conducted between September and October 2002 at 500 points in Rawalpindi and Islamabad, to clarify the past flood conditions especially the 2001 flood that people still remember well.

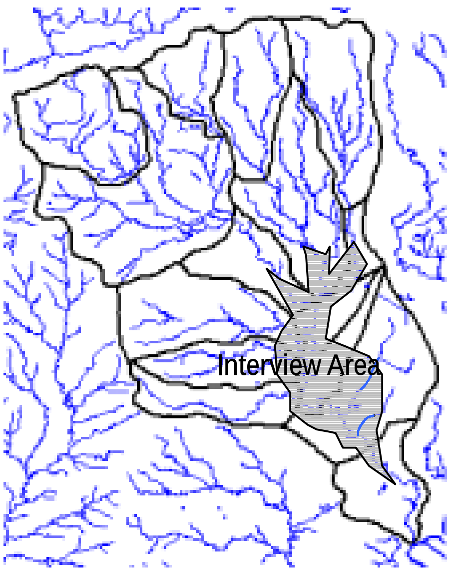

Fig. R A.3 Interview Area

The 500 interview points spread over the low-lying areas and their surroundings along Lai Nullah and the tributaries that were specified in advance through a preliminary study on topography, interviews to officials concerned and site-inspections. The questionnaire includes:

(1) Attributes of interviewee (name, address, occupation,

properties, latitude and longitude of interview, etc.);

(2) Inundation depth and duration and causes of past floods;

(3) Evacuation activities during the 2001 flood; and

(4) Request of flood mitigation and environmental measures.

2.2.2 Survey Results

The results of interview survey results are summarized as below (refer to Data Book):

1) Inundation Depth, Duration and Causes

The interviewees did not remember well about flood situations other than those of the 2001 flood, probably because the other flood events were more years back and the floods themselves were less significant. Therefore, only the hot information of the 2001 flood could be collected satisfactorily from the interviews.

The interview results on the 2001 flood are plotted on three maps in Fig. A.3. The first map indicates the maximum inundation depths, the second the duration of the inundation, and the third the causes of the flood inundation that the interviewees believed. The maximum inundation depths are as deep as 4 m or over in the low-lying areas along Lai Nullah and the tributaries, where the inundation duration is also as long as 6 hours or over. This information was utilized for the verification of the flood simulation model as discussed in subsection 3.2.2.

As for the causes of the flood damage, the overflow of Lai Nullah was raised by more interviewees, followed by the overflow of the tributaries and the combination of the overflow of Lai Nullah and the local rainfall. In some low-lying spots, the local rainfall was also raised as one of the principal causes of the flood.

2) Evacuation Activities

Out of the 500 interviewees, 152 interviewees evacuated somewhere during the 2001. Most of the evacuation places were the rooftops of their houses followed by the neighbors' houses. It is noted that almost none of evacuees was given any advice on the evacuation by the administrations but they acted by themselves. In addition, about 130 interviewees answered that the flood was too fast to allow them to evacuate.

3) Request on Flood Mitigation and Environment Measures

Fig. R A.4 shows requests from the interviewees for the future flood mitigation and environmental improvement. Garbage control and river improvement are more prefered by them. Flood Forecasting and Warning System, which is proposed as the urgent project as described in subsection 4.1, is also desired by nealy half of the interviewees. Not a few interviewees mentioned flood diversion of Lai Nullah in the upper reaches as a conceivable flood mitigation measure that was not included in the questionnaire list.

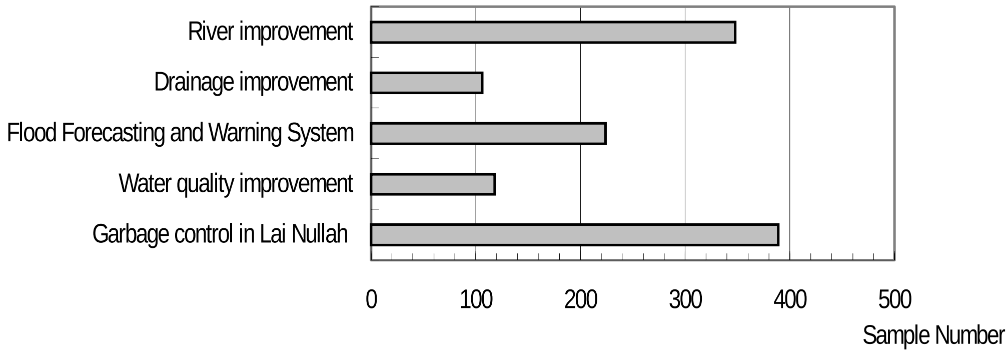

Fig. R A.4 Requests from Interviewees

3. RESULTS OF HYDROLOGICAL AND HYDRAULIC ANALYSIS

3.1 Rainfall Analyses

3.1.1 Rain Gauge Stations

There exist in the Study Area four rain gauge stations that are all being operated by PMD. They are the Chaklala (Islamabad International Airport), Islamabad (National Agromet Centre), Rawalpindi Agromet Center (RAMC) and Saidpur (Seismological Observatory) Stations (refer to Appendix).

According to “the Feasibility Report on Flood Control of Lai Nullah in Rawalpindi City, NESPAK – NDC Joint Venture, January 1987”, five self-recording rain gauges were installed by CDA in 1960s, but they were very shortly closed after 3.5 to 5 years of operation. The present Islamabad Station used to be called Rawalpindi Station before it was moved from a place near the present RAMC Station to the present location in 1967.

1) Rainfall Observation

Locations and main features of the existing four stations are presented in Fig. A.4 and Table R A.3 respectively. The four stations are lining up along the eastern boundary of the Lai Nullah Basin with an order of Saidpur, Islamabad, RAMC, and then Chaklala in the north to south direction. The Chaklala and Islamabad Stations have comparatively long histories more than 30 years, but the Saidpur and RAMC Stations are so new that they started measurement only 8 and 14 years back respectively.

Table R A.3 Existing Rainfall Stations in Study Area

Station	Location			Year of Establi-shment	Frequency of Measurement	Year of Installation of Self-recorder	Remarks
	Latitude (North)	Longitude (East)	Altitude (m)				
Chaklala	33°37’	73°06’	500	1931	Every 3 hours	(1951)**	Islamabad International Airport
Islamabad	33°41.00’	73°03.87’	520	1967*	Every 3 hours	1999	National Agromet Centre
RAMC	33°38.88’	73°05.13’	500	1989	Three times a day	1989	Rawalpindi Agromet Centre
Saidpur	33°44.56’	73°03.91’	660	1994	Once a day	N/a	Seismological Observatory

Note: * The Islamabad Station (National Agromet Center) moved in 1967 to the present location, Zero Point, Islamabad, from Rawalpindi.

** According to the Feasibility Report by NESPAK – NDC Joint Venture, at the Chaklala Station was installed in 1951 a self recording gauge, which is no more existing although it was reportedly operational until 1987 at least.

The frequency of rainfall measurement differs according to the purposes of each station. Rainfall measurement is made every three hours at 0200, 0500, 0800, 1100, 1400, 1700, 2000 and 2300 hours (PST) at the Chaklala and Islamabad Stations, three times a day at 0800, 1400 and 1700 hours at the RAMC Station, and once a day at 0800 hours at Saidpur Station. A self-recording rain gauge is annexed to two stations, Islamabad and RAMC. In addition, the Chaklala Station also used to have a self-recording gauge between 1951 and 1980s.

2) Data Availability

The Study Team tried to collect short-time rainfall data such as hourly and 3-hourly data recorded during selected heavy rainstorms as well as all available daily rainfall data, visiting PMD Headquarter in Islamabad, Regional Meteorological Center in Lahore and the four stations. etc. Unfortunately the data availability does not correspond to the operation periods of the stations as shown in Tables A.1 and A.2. Considerable parts of precious old data are missing or were already lost, according to PMD officials.

The Chaklala Station is the richest in rainfall data with daily data of 58 years, 3-hourly data of 32 years, and hourly data of 21 years, followed by the Islamabad Station of which daily and 3-hourly data are available since 1983. The RAMC Station has daily rainfall data and self-recorder charts of 13 years since 1989. The new Saidpur Station is the poorest with daily data of 7 years.

Focusing on short-time rainfall data, especially hourly data during heavy rainstorms that are indispensable for analyses of flash floods like the 23 July 2001 Flood, the data availability is too low, mostly due to instrument troubles caused by such rainfall intensities. As seen in Table A.2, hourly data are available only for a few rainstorms among the selected 53 storms since 1970. Due to inadequacy of the hourly rainfall data, the rainfall analyses are alternatively based on the 3-hourly rainfall data as described hereinafter (refer to Data Book).

3.1.2 Rainfall Characteristics

Using the collected rainfall data, rainfall analyses was made to know general characteristics of the rainfall in the Study Area in terms of duration and distribution in space and time.

1) Duration

First, accumulated rainfall curves of the Chaklala and Islamabad Stations during past major rainstorms were drawn in Fig. A.5, where the accumulated rainfalls were converted in percentages of the total rainfalls. As seen in the figure, the rain duration was generally short. Almost all the rainstorms ended within 12 hours except for that of 27 August 1997, which lasted 24 hours.

2) Distribution in Space

Three recent floods on 29 July 1996, 27 August 1997 and 23 July 2001 of which data availability is rather good were selected to make maps where sizes of station symbols were graduated according to the total rainfalls, as shown in Fig. A.6.

It can be easily understood from the maps that the three floods show different distribution patterns.

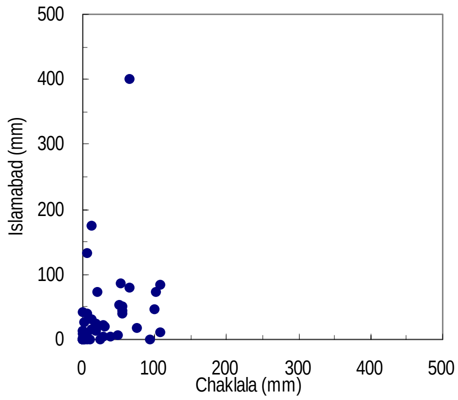

Fig. R A.5 Correlation of 3-hourly Rainfalls

The 1997 flood rainfall seems fairly uniform along the eastern basin boundary. The 1996 flood rainfall was biased towards the south. In the 2001 flood, the rainfall of 620.7 mm at Islamabad Station overwhelms the other three stations located within a radius of only 8 km. The differences are as big as 300 to 450 mm.

The 3-hourly rainfall data of the Islamabad Station were also plotted against those of the Chaklala Station in the above figure to examine correlation between the two stations. The result shows that no clear correlation is found between them.

From the above analyses, it might be concluded that the localization of rainfall is quite significant and the spatial distribution pattern is different from flood to flood.

3) Distribution in Time

Hyetographs were also drawn for the recent three floods as shown in Fig. A.7 to know rainfall distribution in time. The hydrographs were based on the collected 3-hourly data except for the Chaklala Station of the 1997 flood and the Islamabad Station of the 2001 flood for which hourly data are by chance available. The same scales of graph axes were commonly employed for the three floods to facilitate comparison of the rainfall intensities.

First of all, surprisingly intensive rainfall is found at the Islamabad Station in the 2001 flood. Intensive rainfall over 130mm/hr continued 3 hours between 1000 and 1300 hours on 23 July 2001. The hourly rainfall intensity of 180mm between 1200 and 1300 hours is the maximum record in Pakistan according to PMD. Intensity of 90mm/hr was also recorded between 1300 and 1400 hours at the RAMC Station during the same flood.

As for the other floods, the rainfall intensity was quite lower than the exceptional 2001 flood, nevertheless strong 3-hourly rainfalls exceeding 35mm/hr (corresponding to 105mm in three hours) were also observed at the Chaklala Station in the 1996 flood and at the Chaklala and RAMC Stations in the 1997 flood.

3.1.3 Frequency Analysis

As discussed above, the spatial variation of rainfall is very significant in the Study Area and the spatial distribution pattern also differs from flood to flood. In order to correctly evaluate such rainfall in relation to flood discharges on Lai Nullah, therefore, basin mean rainfalls are more important than point rainfalls observed at each station. In this sense basin mean rainfalls were estimated based on the collected rainfall data, and then a frequency analysis was made to estimate probable basin mean rainfalls for several return periods, as follows:

1) Reference Point

As the first step, Gawal Mandi Bridge that is located in the middle of the habitual flood inundation area between Gunj Mandi and Railways Bridges was defined as a reference point for the estimation of the basin mean rainfalls. In other words, the basin mean rainfalls were estimated not for the whole river basin of 234.8 km^2 but for the catchment area of 199.2 km^2 (85% of the whole basin catchment area) upstream of the bridge, taking it into consideration that flood discharges in the habitual flood inundation area are mostly generated by rainfalls falling in the 199.2 km^2 area.

It is noted that Gawal Mandi Bridge is very meaningful for the present flood warning system of TMA too. As explained in subsection 2.1.1, the water level at this bridge is an indicator for the flood warning issuance. Once the water level rises over the 16 feet level, sirens are to be blown at several warning posts in Rawalpindi.

2) Basin Mean Rainfall

The Thiessen Method was applied to estimate the basin mean rainfalls. Fig. A.8 presents divisions of the Lai Nullah Basin by the Thiessen polygon lines according to the rainfall data availability, and the Thiessen coefficients are summarized below:

Table R A.4 Tiessen Coefficients

Station	Number of Stations of which rainfall data are available			
	4 Stations	3 Stations	2 Stations	1 Station
Saidpur	0.30	N/a	N/a	N/a
Islamabad	0.47	0.77	0.85	N/a
RAMC	0.12	0.13	N/a	N/a
Chaklala	0.11	0.10	0.15	1.00

Using the collected 3-hourly data observed at the stations, 3-hourly basin mean rainfall data were calculated to create a basin mean rainfall database for the selected heavy rainstorms of 32 years from 1970 to 2001.

3) Frequency Analysis

Prior to the frequency analysis, annual maximum basin rainfalls of four different durations (3, 6, 9, 12-hourly rainfalls) were extracted from the basin mean rainfall database as given in Table A.3. Several probability distributions including the Gumbel, Log-normal, Pearson Type 3 and Log-Pearson Type 3 distributions were tried for the frequency analysis. In conclusion, the Log-Pearson Type 3 distribution that gives good fitting to all the four extreme rainfalls was regarded as the optimum distribution. The probability plotting of the extreme data on the log-normal probability paper is presented in Fig. A.9 and estimated probable rainfalls are summarized in Table R A.5. The basin mean rainfalls of the actual 2001 flood, probable basin mean daily rainfalls additionally estimated in this Study and probable daily rainfalls by the on-going ADB Lai Nullah Project are also provided in the table to facilitate the comparison with the obtained probable rainfalls. Design hyetographs with different return periods are created from these probable 3, 6, 9 and 12-hourly rainfalls.

Table R A.5 Probable Rainfalls

(mm)

Rainfall	Data Period	Return Period (years)						2001 Flood
		5	10	25	50	100	200	
3-hourly	32 years(1970 – 2001)	105	134	177	216	260	311	239
6-hourly	32 years(1970 – 2001)	128	167	230	287	355	437	349
9-hourly	32 years(1970 – 2001)	146	194	272	346	435	542	401
12-hourly	32 years(1970 – 2001)	151	203	291	376	481	611	444
Daily (This Study)	32 years(1970 – 2001)	152	196	263	324	395	478	411
	42 years(1960 – 2001)	136	175	239	298	371	459	
	58 years(1944 – 2001)	145	186	247	300	361	432	
Daily (ADB)	42 years(1960 – 2001)	136	162	193	215	236	N/a	

*: Annual maximum basin mean daily rainfall data are tabulated in Table A.4 and their probability plotting for three different data periods is given in Fig. A.10.

It is very important to evaluate the exceptional flood on 23 July 2001 in terms of return period of rainfall. The 3, 6, 9 and 12-houly rainfalls of the 2001 flood are all slightly smaller than those of the 100-year return period, and the flood could be evaluated at 75 to 90 years of return period.

4) Comparison of Design Rainfall with ADB Project

According to the Design Report of the ADB Project, design rainfalls with duration of 3 hours, which almost corresponds to the concentration time of the La Nullah catchments on the project stretch, were applied to estimate design peak discharges for the river improvement. The design rainfalls were created by converting probable daily rainfalls that were estimated from daily rainfall records of 42 years observed at the Chaklala Station. Since no information of the probable 3-houly design rainfalls is presented in the Design Report, it is virtually difficult to compare them with those of this Study. Instead, the probable daily rainfalls that are luckily presented in the report are compared with the probable basin mean daily rainfalls estimated additionally in this Study by applying the same methodologies as for the 3, 6, 9 and 12-houly rainfalls.

The ADB's daily rainfalls are generally smaller than those of this Study as seen in Table R A.6. The gap is bigger as the return period becomes longer, for example the ADB's 100-year daily rainfall of 236 mm is smaller by 135 mm than this Study's daily value of the same 42 years. This gap is mainly because the ADB estimation was grounded on only the Chaklala Station data that recorded the smallest rainfall among the four stations during the 2001 flood while this Study considers all the four stations to estimate the basin mean rainfalls.

It is also guessed that the ADB design 3-hourly rainfalls are significantly smaller than those of this Study, because they were based on smaller daily rainfalls. In other words, the ADB project might have underestimated the design rainfalls. This rainfall gap seems to further lead to a gap of design discharges between this Study and the ADB project as discussed in the following.

3.2 Hydrological and Hydraulic Simulation

Following the above rainfall analyses, hydrological and hydraulic flood simulation analyses are discussed in this section. Objectives of the simulation analyses are as follows:

(1) To clarify the flood inundation mechanism in the Lai Nullah River Basin;

(2) To determine the basic hydrological parameters for designing countermeasures, such as design discharge and design water level; and

(3) To examine effects of conceivable countermeasures.

3.2.1 Software and Model-Set up

The flood simulation is generally made in two steps, namely calculation of runoff from the sub-basins and flood routing along the rivers. For some special cases, flood inundation maps are additionally generated for the purposes of verification of the established simulation model, estimation of flood damages or just simply generation of flood risk maps. Mike11 software that is an integrated software developed by DHI Water & Environment for river management was used for all the above procedures, selecting appropriate methods for each procedure among a variety of optional methods provided in the software.

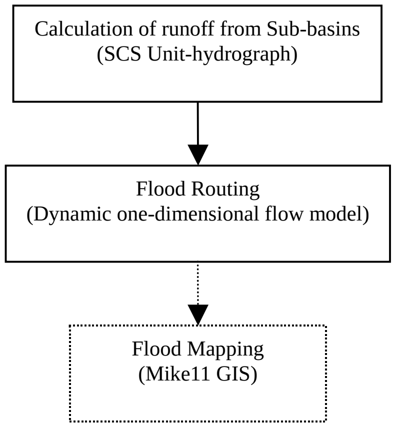

Fig. R A.6 Flow of Flood Simulation

A unit-hydrograph method based on the SCS Curve Number that were used often in the previous studies for Lai Nullah was again selected to estimate runoff discharges from the 15 sub-basins presented in Fig. A.4. The estimated runoff discharges were further used as inflow data to the river network for the flood routing as shown in Fig. R A.6.

The main river, Lai Nullah, and four major tributaries, Saidpur Kas, Tenawali Kas, Bedarawali Kas and Johd Kas were considered to build the river network for the flood routing.

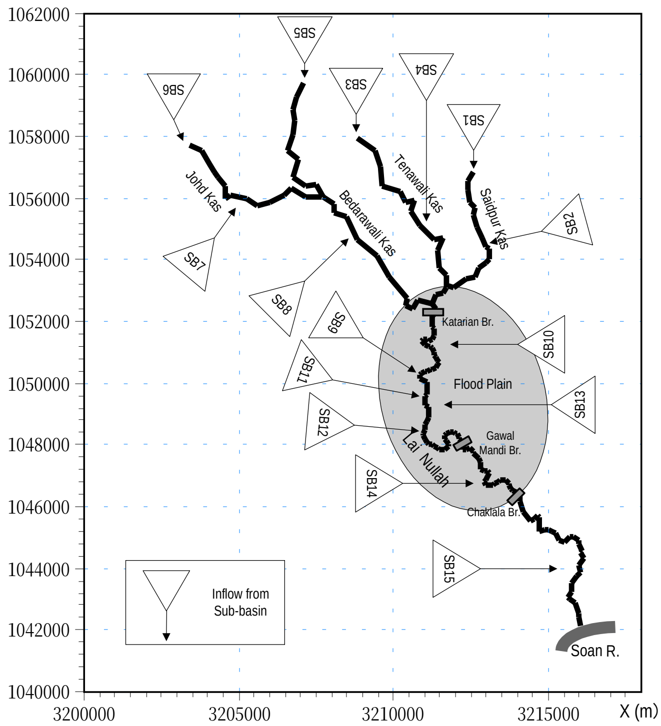

Fig. R A.7 River Network

A dynamic one-dimensional flow model of Mike11 that can simulate hydraulic phenomena more precisely was applied to estimate discharges and water levels in the river network.

The estimated water levels were further exported for the flood map generation to Mike11 GIS, which is an interface module of Mike11 with Arcview GIS software. Flood inundation depths were calculated in Mike11 GIS by interpolating and extrapolating the river water levels over the digital elevation models (DEM) of the flood plain.

1) Runoff Calculation by SCS Unit-hydrograph Method

The US Soil Conservation Service developed a method for computing abstraction from storm rainfall, introducing a concept of the Curve Number. The Curve Number CN is a kind of runoff parameter representing soil, land use and antecedent moisture conditions. The Curve Number is generally defined for normal antecedent moisture conditions (AMC II) and further modified to those for dry conditions (AMC I) or wet conditions (AMC III) according to the antecedent rainfall conditions. Using the Curve Number CN, the depth of excess precipitation P_e is given as follows:

$$P_e = (P - 0.2S)^2/(P + 0.8S) \qquad (A.1)$$

$$S = 25.4 \times (1000/CN - 10) \qquad (A.2)$$

where:

P: depth of precipitation.

S: potential maximum retention in mm.

The excess precipitation is converted into runoff discharge by the SCS triangular unit-hydrograph. The lag time t_l is calculated from the catchment characteristics using the standard SCS formula:

$$t_l = (L \times 3.28 \times 10^3)^{0.8} \times (1000/CN - 9)^{0.7}/(1900 \times Y^{0.5}) \qquad (A.3)$$

where:

L: hydraulic length of the catchment area in km.

Y: slope.

CN: SCS Curve Number (AMC II).

2) Dynamic One-dimensional Flow Calculation

The dynamic one-dimensional flow calculation module that is based on the 'Saint Venant' equations is a core of Mike11. The equations of continuity and momentum are:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q \qquad (A.4)$$

$$\frac{\partial Q}{\partial t} + \frac{\partial\left(\alpha \dfrac{Q^2}{A}\right)}{\partial x} + gA\frac{\partial h}{\partial x} + \frac{gQ|Q|}{C^2 AR} = 0 \qquad (A.5)$$

where:

Q: discharge.

A: flow area.

Q: lateral inflow.

h: water level.

C: Chezy resistence coefficient ($C=R^{1/6}/n$).

n : Manning roughness coefficient.

R : hydraulic radius

α : momentum distribution coefficient

The flood routing is made along the river network consisting of the five rivers. Pre-defined water levels at the confluence with Soan River and the estimated runoff discharge from the sub-basin at each of the four upstream ends are given as the boundary data of the river network.

Table R A.6 Rivers in River Network

River	Stretch	Length (km)
Lai Nullah	Kattarian Br. to Soan River	17.5
Saidpur Kas	Zero Point to Tenawali Kas	5.8
Tenawali Kas	Jinnah Avenue to Bedarawali Kas	8.7
Bedarawali Kas	E-9 to Lai Nullah	12.7
Johd Kas	Golra Village to Bedarawali Kas	7.3

3) Flood Mapping

The flood mapping covers some 100 km^2 including the lower Islamabad area (H and I blocks) and the Rawalpindi area as the flood inundation interview survey. A DEM (Digital Elevation Model) is essential for the flood mapping and accuracy of the flood map greatly depends upon that of the DEM. In this Study topographical data obtained from the GPS survey were used to divide the 100km^2 area into 40,000 square cells of 50 m x 50 m size, each of which was assigned a ground elevation value. Fig. A.2 is the elevation map created from the 50 m DEM.

Mike11 GIS has the function for calculating water levels over each of the DEM cells by interpolating or extrapolating the water levels in the rivers. Finally the water level of each cell is converted to the inundation depth by subtracting the ground elevation.

3.2.2 Reproduction of 2001 Flood and Model Verification

The flood on 23 July 2001 that could provide the richest hydrological data, was selected as the target flood for the model verification, and reproduced to clarify the flood mechanism.

1) Model Calibrations and Model Parameters

The river cross-sectional data was availed from the results of survey by the ADB Project and this JICA Study. The survey by the ADB Project that was carried out immediately after the 2001 flood covers the project stretch between Kattarian and Chaklala Bridges on Lai Nullah. In this Study, the supplementary cross-sectional surveys were conducted between October and November 2002 for lower Lai Nullah downstream of Chaklala Bridge, several tributaries, and Soan and Kurang Rivers. These cross-sectional survey data were incorporated into the river network model.

To express the retarding effects by flood inundation, additional off-stream storage areas, of which area-elevation data were extracted from the generated DEM, were connected to the Lai Nullah cross sections between Kattarian Bridge and Chaklala Bridge, where inundation was so extensive in the 2001 flood.

The rainfall data observed at the four stations, of which hyetographs are presented in Fig. A.7, were applied for the runoff calculation of the 15 sub-basins. The basin mean rainfalls were firstly estimated for each of the sub-basins based on the Tiessen polygons, and the basin mean rainfalls were input to the SCS unit-hydrograph method.

Trial runs of runoff calculation were made until acceptable accuracy was attained, changing and adjusting model parameters including the SCS Curve Numbers and the Manning's roughness coefficients of the rivers. The SCS Curve Number by land use was finally determined as given in Tables R A.8 and those of the 15 sub-basins were estimated as shown in Table A.5 based on the 2001 land use map given in Sector I. The roughness coefficients of all the rivers were determined at 0.035 for the low water channels and at 0.050 for the high water channels.

Table R A.7 SCS Curve Number by Land Use

Land Use	Curve Number CN
Agricultural area	70
Residential area/Densely populated	90
Residential area/Moderately populated	75
Residential area in the Suburbs	70
Forest (Mountain area)	70
Forest (Flat area)	65
Green and grass area	65
Water Body	100

Note: under normal antecedent moisture condition (AMC II)

2) Reproduction Results

Fig. A.11 presents the discharge and water level hydrographs at Kattarian, Gawal Mandi and Chaklala Bridges. As shown in the Fig., the temporal variation of the water level and discharge in the hydrographs is gradual, which could be attributed to the flood retarding effects of the river basin. The peak water level appears around 1400 hours at Kattarian Bridge and around 1800 hours at Gawal Mandi and Chaklala Bridges. The duration of flood Inundation around Gawal Mandi Bridge is estimated at about 10 hours judging from the temporal variation of water level in the hydrograph. These timings and the inundation duration agree with the memories of inhabitants and officials concerned. Fig. A.12 compares the estimated maximum water levels along Lai Nullah with the elevations of flood marks left at several bridges. It can be said that the estimated water levels match the flood marks very well.

In addition, the flood map is simulated to overview the maximum extent and depth of flood inundation and, it is confirmed that the simulated flood map could well accord with the results of the interview survey as shown in Fig. A.13. As shown in the simulated flood map as well as the results of interview survey in Fig. A.13, the flood inundation expands over low-lying areas along Lai Nullah and the tributaries. The extent of the whole flood inundation area and its corresponding inundation volume were estimated at 9.2 km^2 and 23 million m^3 respectively from the generated flood map.

3.2.3 Flood Simulation for Future Scenarios

The flood simulation was made based on the aforesaid SCS simulation model, the design hyetographs developed in this Study, the projected land use of Lai Nullah Basin in 2012, and the river conditions of Lai Nullah posterior to the on-going river channel improvement by RDA.

1) Design Hyetograph

100-year, 50-year 25-year, 10-year and 5-year design hyetographs with 12 hours of duration were created for the future scenario flood simulation, based on the frequency analysis of 3-hourly, 6-hourly, 9-hourly and 12-hourly rainfalls discussed before.

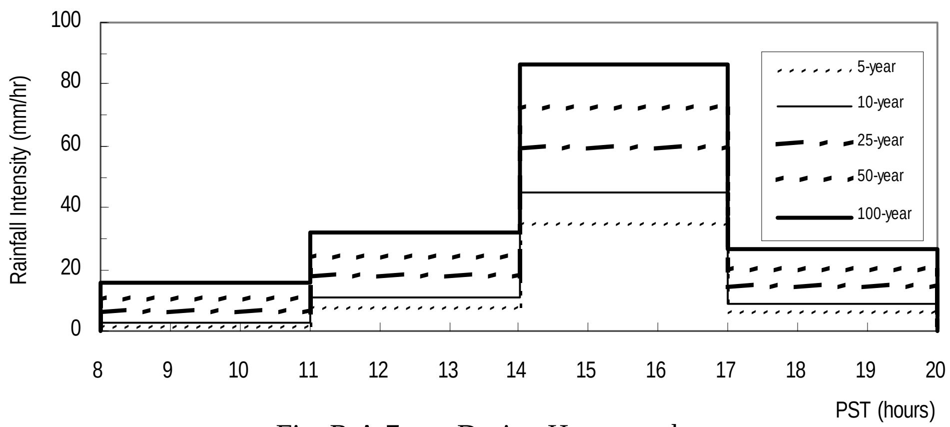

Fig. R A.7 Design Hyetograph

2) Consideration of On-going River Improvement Project by RDA

The Lai Nullah improvement project that is now in progress under the financial assistance of ADB is scheduled to complete in early 2003. The Lai Nullah will be widened by 20 to 30 m in the project. The completion of this on-going river improvement was premised for the flood simulation, and the existing cross sections of Lai Nullah that were used for the reproduction of the 2001 flood were replaced by cross sections designed by the project, of which roughness coefficient were set at 0.030 as designed.

3) Confinement of Flood Discharges in Rivers

The additional off-stream storage areas connected to the cross sections of the simulation model for the 2001 flood were removed to confine all the flood water in the rivers not allowing any spillage because this future scenario simulation aimed to estimate river discharges under no flood inundation.

4) Simulated Standard Flood Discharges

The aforesaid standard flood discharges under the without-project condition were estimated through a model slightly modified from the simulation model for the 2001 flood. The results of estimation are as shown in Fig. A.14. The standard flood discharges thus estimated at the two principal reference points, namely Kattarian Bridge and Gawal Mandi Bridge are compared with the probable discharges estimated from the observed water level as well as those estimated in the ADB Project as shown in Table R.A.8.

Table R A.8 Standard Flood Discharge by Return Period

Reference Point	By	Description	5 years	10 years	25 years	50 years	100 years
Kattarian Br.	This Study	Simulated as Standard Flood Discharge	330	620	1,150	1,660	2,270
	ADB project	Estimated by Runoff Analysis	324	425	571	682	784
Gawal Mandi Br.	This Study	Simulated as Standard Flood Discharge	390	720	1,340	1,940	2,640
		Estimated From observed Water levels	490	840	1,500	2,200	3,000
	ADB project	Estimated byRunoff Analysis	563	719	942	1,109	1,264

As listed above, it could be evaluated that the values simulation as the standard flood discharge well accords with the value estimated from the observed water level. As expected in frequency analysis, however, the considerably big gaps are seen between the values simulated in the Study and estimated in the ADB Projects. These gaps become bigger as the return period is longer. The values simulated for the 100-year return period in the Study are about three times of the values estimated in the ADB project.

5) Increase of Discharge by Urbanization

Land use is also an important factor affecting flood discharges. Urbanization that is generally accompanied by pavement, building and drain installation leads to an increase of flood discharges, as experienced all over the world. It is very important to know the extent of such discharge increase caused by land use change.

In this Study, land use maps at three stages, namely in 2001, 2012 and 2030 were developed as shown in Sector I. In Table A.5, areas by land use and SCS Curve Numbers of the sub-basins are presented for the three stages. The change of land use is reflected to the change of the Curve Numbers, whereby the average Curve Numbers will gradually increase to 73 in 2012, 74 in 2030 from 72 in 2001 as shown in Table A.5. In accordance with the increment of the Curve Numbers, the probable flood runoff discharges will gradually increase as summarized as below.

Table R A.9 Maximum Discharges by Land Use

Reference Point	100-year Discharge (m^3/s)			25-year Discharge (m^3/s)		
	2001	2012	2030	2001	2012	2030
Kattarian Br.	2,200	2,270	2,300	1,110	1,150	1,180
Gawal Mandi Br.	2,551	2,640	2,711	1,260	1,340	1,375

6) Flood Map under Future Land Use

The flood maps were developed for the five (5) cases as shown in Table R A.10. Among the cases, the Case1-2 presents the probable maximum extent and depth of the flood inundation caused by the flood 2001 assuming the flood occurs immediately after the completion of the ADB Project. This flood map will be useful to let inhabitants know what will happen if the awful 2001 flood occurs again.

Cases 2-1, 2-2 and 2-3 presents the maximum extent and depth of the flood inundation caused by the probable flood of 25, 50 and 100-year return period assuming any flood mitigation structures other than the on-going ADB Project is not given to Lai Nullah. These flood maps could be used to estimate flood damages according to the return periods. The generated flood maps and the extents of the flood inundation area are as shown in Fig. A.15, and Table A.6, respectively.

Table R A.10 Summary of Flood Mapping

Case No	Facility Condition	Land Use	Rainfall	Estimated Inundation Area (km2)	Remarks
1-1	Existing Condition	2001	2001 Flood	9.2	Reproduction of 2001 Flood
1-2	After Completetion of ADB Project	2001	2001 Flood	7.2	Flood Risk Map
2-1	After Completetion of ADB Project	2012	100yr Rain	7.6	Without-project Condition
2-2	After Completetion of ADB Project	2012	50yr Rain	4.5	Without-project Condition
2-3	After Completetion of ADB Project	2012	25yr Rain	2.6	Without-project Condition

4. PROPOSED NON-STRUCTURAL FLOOD MITIGATION WORKS

4.1 Flood Forecasting and Warning

The Pakistan Metrological Department PMD has monitored the storm rainfall of Lai Nullah through the existing four rainfall gauging stations and one weather surveillance radar installed in the compound of PMD Headquarter near Zero Point. TMA had also previously operated two (2) manual (off-line) water level gauging station at Gawal Mandi Bridge and Ratta Amral Bridge to monitor the flood water level of Lai Nullah. The existing rainfall gauging stations operated by PMD are, however, not equipped with the automatic data transmittal system, which cause difficulties in collecting the accurate gauged data in real-time base. The water level gauging stations used by TMA were also abandoned due to reconstruction of the bridges after the July 2001 flood.

The storm rainfall observed by PMD has been informed to by the relevant authorities (such as TMA, RDA and CDA) through the public telephone lines. Based on the information of storm rainfall and the flood water level of Lai Nullah, TMA in particular has disseminated the flood warning to the residents through the patrol cars and the sirens. However, the patrol cars hardly achieved the immediate dissemination of the flood warning, and the warning sires are decrepit decreasing reliability of function.

In the event of July 2001 flood, (PMD) observed an extra-ordinary scale of rainfall intensity in Lai Nullah through its weather surveillance radar and rainfall gauging. Judging from the results of the observation, PMD predicted a possibility of serious flood overflow along Lai Nullah a few hours before its actual occurrence. In spite of the advanced awareness of the flood, the flood caused the death of 74 people.

Should the existing flood gauging, communicating and warning system be strengthened, the more accurate and immediate flood information could be systematically collected, and the death calamity as experienced in 2001 flood would be relieved. From these viewpoints, the improvement of the existing flood forecasting and warning system is proposed as an eligible measure to immediate effect mitigation of the flood damage, the calamity of death in particular.

4.1.1 Proposed Organization Set-up for FFWS

For smooth operation of FFWS, the following improvement for existing organization is proposed (refer to Fig. A.16):

(1) PMD would be the most eligible agency to undertake the integrated hydrological observation of the storm rainfall as well as the water level and the flood prediction. PMD would also take responsibilities to inform the results of the flood prediction to the relevant local government agencies such as CDA, TMA, RDA and RDB.

(2) The above local government agencies operation would take the responsibilities of flood dissemination to the residents in their respective jurisdiction areas based on the flood prediction by PMD.

(3) FFC should be the coordination body for the above relevant agencies such as PMD and the relevant government agencies to facilitate the daily overall maintenance and management for the whole facilities/equipment of FFWS and the basin-wide flood fighting and/or evacuation works as required.

4.1.2 Proposed Equipment and Telecommunication Network for FFWS

The proposed FFWS is composed of (a) rainfall/water level gauging stations, (b) Master Control Station, Monitoring Station, (c) Executive Warning Control Room and, (d) Warning Posts. Location map of these gauging stations are as shown in Fig. A.17 (refer to Appendix). The proposed telecommunication network for these stations and the equipment required are as shown in Fig. A.18 and Table7**,** respectively. Details of the these stations/posts are further described hereinafter:

1) Rainfall Gauging Station

The telemetry rainfall gauging stations would be installed at the following six (6) locations, and the gauging data are automatically transferred to the Master Control Station through 400 MHz telemetry line:

Name of Station	Existing or New	Location		
		Latitude	Longitude	Located at
Chaklala	Existing	$33^0$37’	$73^0$37’	Islamabad International Airport
Islamabad	Existing	$33^0$41’	$73^0$03	National Agronomical Center
RAMC	Existing	$33^0$37’	$73^0$37’	Rawalpindi Agronomical Center
Saidpur	Existing	$33^0$88’	$73^0$05’	Seismological Observatory
Golra	New	$33^0$41’	$72^0$58’	Modern Veterinary Health Center
Bokra	New	$33^0$33’	$73^0$00’	Construction Machinery Training Institute

2) Water Level Gauging Station

The telemetry water level gauging station would be installed at the five (5) following locations and the gauging data are automatically transferred to the Master Control Station through 400Mhz telemetry line:

Name of Station	Existing or New	Location
Kattarian Bridge	New	At Kattarian Bridge on Khayaban-I-Sir Syed (I-J Principal Road)
Rawalpindi Fire Brigade	New	In the compound of Rawalpindi Fire Brigade Headquarter located downstream of Gawal Mandi Bridge
Park-A	New	Upstream end of Tenawali Kas within the compound of Fatima Jinnah Park
Park-B	New	Upstream end of tributary of Tenawali Kas within the compound of Fatima Jinnah Park
Park-C	New	Community Pond proposed in Fatima Jinnah Park

3) Master Control Station

The Master Control Station is installed within the compound of PMD Headquarter at Zero Point. All rainfall and water level gauging data are transmitted to and processed by a sever installed at the Master Control Center on real-time base through 400MHz telemetry line connected between the Master Control Center and the aforesaid rainfall and water level gauging stations. The flood information processed at the Master Control Station are further shared to the under-mentioned Monitoring Stations and the Executive Warning Control Room through WAN using excusive 5.2 GHz Wireless LAN.

4) Monitoring Station

The Monitoring Station is installed at FFC, WASA and the control office of the community pond proposed in Fatima Jinnah Park. All flood information collected and processed by the Master Control Center is monitored by the Monitoring Stations on real-time base through WAN with using excusive 5.2 GHz Wireless LAN. The Monitoring Stations would decide and arrange the necessary issues of the basin-wide flood warning, flood evacuation/rescuer, and control of community pond if required. Based on the monitors of the basin-wide flood conditions.

5) Executive Warning Control Room

The Executive Warning Control Room is installed at Rawalpindi Fire Brigade Headquarter. All flood information collected and processed by the Master Control Center is monitored by the Executive Warning Control Room on real-time base through WAN with using excusive 5.2 GHz Wireless LAN. The Executive Warning Control Room would evaluate the flood risk based on the monitored flood information and disseminate the flood warning to the residents through the under-mentioned warning sirens.

6) Warning Post

Out of the proposed on-lined ten (10) waning posts, the four (4) would be installed at the following locations. Other six (6) warning posts would be determined during the time for detailed design of the system.

Name of Station	Location		
	Latitude	Longitude	Located at
Gawal Mandi	33^{0} 60’	73^{0} 05’	Gawal Mandi Fire Office
Pir Wadhai	33^{0} 63’	73^{0} 03’	Pir Wadhai Fire Office
Warning Post C	33^{0} 60’	73^{0} 07’	Waqar-un-Nisa College
Fatima Jinnah Park	33^{0} 43’	73^{0} 04’	Within the compound of Fatima Jinnah Park

All of the warning posts are connected to the Executive Warning Control Room by telemetry line (400MHz). The Executive Warning Control Room will send the signals to the warning posts, as required, to blow warning sirens to the residents. The Executive

Warning Control Room will also receive the signals from the warning post so as to confirm the execution of warning sirens

7) Configuration of Telecommunication Network

The above hydrological gauging stations, the control station/monitoring station and warning posts are linked by the following telecommunication network:

a) Telemeter line of Remote Transmission Unit (RTU) with UHF band:

To link between the rainfall/water level gauging stations and the Master Control Station in order to automatically transmit the flood information gauged by the rainfall gauging stations and the water level gauging to a server installed at Master Control Station.

To link between the Executive Warning Control Room and warning posts in order to transmit the signal to blow warning sirens to the residents.

b) WAN with using excusive 5.2 GHz Wireless LAN:

To link among the Master Control Station, the Monitor Station and Executive Warning Control Room in order to monitor the flood information collected and processed by the Master Control Station

4.2 Flood Risk Map

Dissemination of the flood risk map is broadly adapted in the world as one of the useful non-structural flood mitigation measures. Through dissemination of the flood risk map, the residents could aware the extent of the possible flood inundation area and the available evacuation routes during a flood. The flood risk map could also be the guidance for appropriate urban planning and land development.

The flood risk map, in general, contains the information on: (a) the probable extent and depth of flood inundation and (c) the evacuation centers and evacuation routes to be taken during a flood. The base maps for the extent and depth of the probable flood inundation was delineated as shown in Fig. A.19. The available evacuation centers as well as evacuation routes for each unit of the local communities should be further selected by the relevant local government agencies based on the base maps, and the flood risk map should be finalized. The flood risk map thus prepared should be disseminated to the public through a bulletin, an information board and other available information tools.

The total inundation area deeper than 0.3 m is estimated about 7.2 km^2, and deep inundation over 4 m is still anticipated in 1.3 km^2 low-lying areas along Lai Nullah and the tributaries even after the completion of the on-going ADB's Lai Nullah improvement project.

Table R A.11 Flood Inundation Area

Inundation Depth	Inundation area by city (km^2)		
	Islamabad	Rawalpindi	Total
0.3 – 1m	0.26	1.57	1.84
1 – 2m	0.30	1.54	1.84
2 – 3m	0.15	1.11	1.26
3 – 4m	0.13	0.81	0.94
Greater than 4m	0.34	0.98	1.31
Total	1.18	6.01	7.18