SECTOR B

RIVER CONDITIONS AND RIVER CHANNEL IMPROVEMENT PLAN

VOLUME 3: SUPPORTING REPORT

SECTOR B: RIVER CONDITIONS AND RIVER IMPROVEMENT PLAN

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SECTOR B RIVER CONDITIONS AND RIVER CHANNEL IMPROVEMENT PLAN

1. PRESENT RIVER CONDITIONS

1.1 River System

In the jurisdiction area of Islamabad (i.e., the upper reaches of the Lai Nullah), the river system is composed of three (3) major tributaries (i) "Saidpur Kas", (ii) "Tenawali Kas" and (iii) "Bedarawali Kas"[1] (refer to Fig. B.1). These tributaries originate from Margalla hills and flow into the mainstream of Lai Nullah just upstream from Kattarian Bridge (RD17+210)[2].

Below Kattarian Bridge (i.e., in the jurisdiction area of Rawalpindi), the mainstream meets other three (3) major tributaries, namely (i) Nikki Lai, (ii) Pir Wadhai Kas and (iii) Dhok Ratta Nullah one after another, then flows down through the center of Rawalpindi City and finally pours into Soan River (refer to Fig. B.1). In addition to these major tributaries, the Study Team further recognized through field reconnaissance and clarification of the satellite image that there are other six (6) tributaries or drainage/sewage channels, which joins the mainstream between the confluences of Dhok Ratta Nullah and Soan River. The name and the catchment area of the whole tributaries are as listed in Table R B.1.

Table R B.1 Tributaries of Lai Nullah

Location of Confluence with Main Stream	No. and Name of Tributary		Catchment Area (km^2)
	No.*1	Name*2	
Islamabad	-	Saidpur Kas	24.7
	-	Tenawali Kas (Including Kanitawali Kas as the secondary tributary)	39.7
	-	Bedarawali Kas (Including Johd Kas as the secondary tributary)	79.9
	Sub-total		144.3
Rawalpindi	R5	Nikki Lai Kas	20.9
	R4	Pir Wadhai Kassi	11.2
	R3	Dhok Ratta Nullah	10.8
	R2	Unknown	22.8
	R1	Saddar Tributary	
	L2	Arya Nullah	
	L1	Dhok Chiraghdin Tributary	
	L4	Workshop Tributary	6.8
	L3	Unknown	
	-	Residual Area	18.0
	Sub-total		90.5
Grand Total			234.8

*1: Identification numbers assumed by the Study Team (The numbers corresponds to those shown in Fig. B.1).
*2: The tributaries were named with referring to "Feasibility Report on Flood Control of Lai Nullah in Rawalpindi City" by NESPAK-NDC in 1987.

[1] There are further two secondary tributaries; namely: Kanitawali Kas for Tenawali Kas and Johd Kas for Bedarawali Kas.

[2] The bridge connects Khayaban-I-Sir Syed (or I-J Principal Road), which forms the administrative boundary between Islamabad and Rawalpindi. The figure with RD at the head hereinafter means the distance from New G.T. Road Bridge located 320m upstream from the confluence of Soan River. That is, RD17+210 is the point 17,210m upstream from G..T. Road Bridge.

The tributaries as well as the mainstream of Lai Nullah are the natural stream but also used as the channels for drainage/sewage disposal from the built-up areas in Islamabad and Rawalpindi. A substantial volume of drainage/sewage disposal is untreated. As the results, the tributaries and the mainstream are significantly polluted giving off a stench during a period of low flow discharge in particular.

1.2 River Features

The Lai Nullah shows the distinctly different river features among the following four (4) stretches; (i) the upstream from Kattarian Bridge (RD17+210), (ii) the middle stream from Kattarian Bridge to Chaklala Bridge (RD6+251) (iii) the middle stream from Chaklala Bridges to the waterfall below Murree Brewery (RD3+800), and (iv) the downstream from the waterfall to the confluence with Soan River (RD0-310). The principal river features of these stretches are as described below:

1.2.1 Upstream from Kattarian Bridge (RD17+210)

As described above, the river system of Lai Nullah in the upper reaches of Kattarian Bridge is divided into three (3) major tributaries, namely Bedarawali Kas, Tenawali Kas and Saidpur Kas. These tributaries have the rather spacious channel cross-sections with less meandering alignment. The channel bed-slopes of the lower stretches of Bedarawali Kas, Tenawali Kas and Saidpur Kas are more than 1/500, which is far steeper than that of 1/1,250 of the mainstream of Lai Nullah below Kattarian Bridge. The upper stretches of the tributaries out of the extent of backwater effect of Lai Nullah have the large channel flow capacity, and have never caused any serious flood overflow since establishment of Islamabad in 1966 due to the spacious and rather steep channels.

On the other hand, the lower stretches of the tributaries is under influence of the backwater effect by the water level of Lai Nullah, because all flood runoff discharge from the tributaries concentrates into the mainstream of Lai Nullah at Kattarian Bridge, raising its water level of the mainstream. This backwater effect occasionally causes the serious flood overflow and the extensive flood inundation along the lower stretches of the tributaries. In the flood 2001, the water level of mainstream of Kattarian rose above EL. 508m, which is far higher than the bank level of the mainstream (i.e., EL. 500m), and the extensive flood inundation occurred in the area administratively called Block Nos. I-8 and I-9 of Islamabad along the lower reaches of the tributaries.

1.2.2 Middle Stream between Kattarian Bridge and Chaklala Bridge (RD6+251)

Below Kattarian Bridge, Lai Nullah passes through the area of Rawalpindi. The area is on the flat alluvium plain, and the section of Lai Nullah in the area has the gentle riverbed slope of about 1/1,250 with several meandering portions.

The river channel improvement for this stretch is now in progress by PMU, RDA (the detailed clarification of the channel improvement is as described in the following section 1.3). Before the channel improvement, the stretch had a single cross-section with a narrow channel width; the width of several bottlenecks in the stretch is less than 20m. Moreover, there have been many encroachments of structure in the river channel. Due to these river conditions, the stretch has frequently caused the flood overflow.

According to the simulation by non-uniform calculation, the bank level of the stretch before the on-going channel improvement could confine the flood water level for only less than 300m^3/s which corresponds to a probable flood with recurrence probability of less than 3-years (refer to Fig. B.2). On the other hand, the channel flow capacity is expected to increase to more than 600m^3/s upon completion of the on-going river channel improvement. Detailed clarification of this incremental channel flow capacity is as described in the following section 1.4.

1.2.3 Middle Stream from Chaklala Bridge to Waterfall (RD3+800)

Below Chaklala Bridge, the Lai Nullah passes through the residential area of the Cantonment Area. This stretch has the gentle channel bed-slope, which is almost same as that of the upper on going channel improvement section (i.e., 1/1,250) as shown in Fig. B.3.

There was a heavily meandering section of about 1,150m around Murree Brewery Area from RD4+077 to RD5+227 (i.e., about 2.1km to .1.0km downstream from Chaklala Bridge). The meandering section had a limited channel width causing a rather frequent flood overflow. According to the interview survey with the residents, Askari Estate located at the left bank of meandering section had the flood inundation depth therein reached 1.5m above ground level in the flood in 2001. In order to offset the flood overflow, realignment (short-cut) together with widening of the river channel has been made by PMU, RDA as an extension of the aforesaid on-going channel improvement of Lai Nullah from Chaklala Bridge to Kattarian Bridge. Through this channel improvement, the short-cut section has a channel flow capacity of more than 1,600 m^3/s.

The section of about 1.0km in length sandwiched between the aforesaid realignment/widening of the meandering section and the on-going channel improvement above Chaklala Bridge is, however, left behind without any channel. The section contains the several bottlenecks, the cross-sections of which are far smaller than the design cross-section at Chaklala Bridge. As the

results, the floodwater level tends to abruptly rise just upstream of the section due to the water head swelled at the bottlenecks of the section. The floodwater level thus abruptly raised causes the adverse backwater effect to the upper on-going channel improvement sections. The backwater effect would extend to the upstream section near to Gunj Mandi Bridge, which is about 6km upstream from Chaklala Bridge. Should the existing meandering section be remained as it is without any improvement, the actual channel flow capacity within the extent of the backwater effect would be decreased to be below the design flow capacity of the on-going channel improvement project (refer to section 1.4 in detail).

1.2.4 Downstream from Waterfall to Confluence with Soan River (RD0-310)

The Lai Nullah meets the first waterfall about 3,800 m upstream from New G.T. Road Bridge (RD0+000). Below the water fall, the Lai Nullah passes through less populated area, having the rather large channel width and channel depth with steep channel slope of about 1/70 as shown in Fig. B.3. Due to these conditions, the flood damage along this stretch could be evaluated to be nil.

1.3 On-going River Improvement Works

As described above, the channel improvement is currently in progress for the stretch from Chaklala Bridge to Kattarian Bridge. The heavily meandering section around Murree Brewery Area (RD4+077 to RD5+227) has also been realigned (short-cut) and widened as a part of the on-going channel improvement. This channel improvement started, on experiencing the disastrous flood damage in 2001, as a part of the project of the on going “Urban Water Supply and Sanitation Project Phase-1 for Rawalpindi City” under the financial assistance of ADB Loan {Loan No. 1260 Pak (SF)}.

The project is composed of (i) widening and realignment of the section of 10.96km from Chaklala Bridge (RD6+251) to Kattarian Bridge (RD17+210), (ii) reconstruction of the three (3) bridges, namely: Dhoke Chiragh Din Bridge (RD8+050), Gawal Mandi Bridge (RD12+976), and Pir Wadhai Bridge (RD13+760) and (iv) realignment/widening of meandering section around Murree Brewery Area from RD4+077 to RD5+227 (i.e., about 2.1km to .1.0km downstream from Chaklala Bridge).

The actual construction works had started upon award of contract in January 2002, but demolishing of the structures for securing of the right of way could not start until July 2002 in spite of efforts of the relevant government agencies. Due to difficulties in demolishing, the actual work progress was much delayed, and the target completion time was extended to September 2003 from January 2003. The salient features of the improvement works as well as

the dimensions of the design cross-sections are as listed in the following Tables R B.2 and R.B.3, respectively:

Table R B.2 Salient Features of On-going Channel Improvement of Lai Nullah

Item	Description
Design scale	25-year return period at non-bridge sections, and 100-year return period for bridge sections
Design discharge	About 600 to 1,000m^3/s (refer to Table R B.3 in detail)
Improvement section	(a) Section of 10,959m from Kattarian Bridge (RD17+210) to Chaklala Bridge (RD6+251) (b) Meandering Section of 1,150 m from around Murree Brewery Area from RD4+077 to RD5+227 (Short-cut to 775m)
Shape of cross-section	Single cross-section with the side slope of 1 to 1.5
Side protection	Stone pitching for the sections of 50m in length along twelve (12) bridges
Depth of cross-section	6.5m at the design high water level (HWL) and 7.5m at the top of the bank (i.e., height of free board is 1m)
Width of cross-section	Top width of 47.0 to 69.7 m within the Right of Way of 56 to 79m (refer to Table R B.3 in detail)
Reconstruction of bridge	Three (3) bridges; namely, Dhoke Chiragh Din Bridge (RD8+050), Gawal Mandi Bridge (RD12+976), and Pir Wadhai Bridge (RD13+760)
Side drain	The concrete drain with its top width of 0.37m placed along the bank of the river channel as required.

Source: Design Report Vol.1, Urban Water Supply and Sanitation Project Phase 1 for Rawalpindi City, March 2002., and interview from PMU, RDA

Table R B.3 Typical Cross-section Designed in the On-going River Channel Improvement

Section				Design Flow Capacity (m^3/s)	Channel Width (m)		Channel Depth (m)	Width of Right of Way (m)
Downstream		Upstream			Bottom	Top		
Description	RD	Description	RD					
Short-cut section	4+077	Short-cut section	5+277	N.A*	47.3	69.7	7.5	N.A*
Chaklala Bridge	6+215	Dhoke C. Din Bridge	8+060	1,009	44.4	66.9	7.5	79.0
Dhoke C. Din Bridge	8+060	Railway Road Bridge	8+325	968	42.4	64.9	7.5	77.0
Railway Road Bridge	8+325	Murree Road Bridge	8+628	962	42.2	64.7	7.5	76.0
Murree Road Bridge	8+628	Gawal Mandi Bridge	9+814	957	41.9	64.4	7.5	76.0
Gawal Mandi Bridge	9+814	City S. Road Bridge	10+790	942	41.2	63.7	7.5	75.0
City S. Road Bridge	10+790	Ratta A. Road Bridge	11+780	934	40.8	63.3	7.5	75.0
Ratta A. Road Bridge	11+780	Gunj Mandi Bridge	12+630	923	40.3	62.8	7.5	74.0
Gunj Mandi Bridge	12+630	Pir Wadhai Bridge	14+428	873	37.9	60.4	7.5	72.0
Pir Wadhai Bridge	14+428	Khayaban S.S. Bridge	14+100	819	35.4	57.9	7.5	69.0
Khayaban S.S. Bridge	14+100	Parrian Bridge	16+178	633	26.4	48.9	7.5	58.0
Parrian Bridge	16+178	Kattarian Bridge	17+210	594	24.5	47.0	7.5	56.0

Source : Design Report Vol.1, Urban Water Supply and Sanitation Project Phase 1 for Rawalpindi City, March 2002, and Variation Order No.05 Contract No. CW/LCB/DW-08A on Straightening of Chaklala Loop, PMU RDA.
Note* : Not specified

1.4 River Channel Flow Capacity

The river channel flow capacity of Lai Nullah and its major tributaries were estimated by non-uniform calculation method with using the channel cross-sections and the probable runoff discharges as the basic data. Among others, the probable runoff discharges are derived from the results of the hydrological analysis (refer to Sector A), while the channel cross-sections are from the results of the river channel survey carried out in the Study and/or the construction drawing for the on-going river channel improvement. The extent and the Manning's Roughness Coefficient adapted to the estimation of channel flow capacity are as listed below.

Table R B.4 Stretches for Estimation of Channel Flow Capacity

Name of River	Extent	Length (km)	Manning's Coefficient	Source of cross-sections
Bedarawali Kas	From Kattarian Bridge to 2.3km upstream	2.2	0.035	Results of river channel survey carried out in the Study
Tenawali Kas	From confluence with Saidpur Kas to 2.2km upstream*	2.2	0.035	- ditto -
Saidpur Kas	From confluence from Kattarian Bridge to 2.2km upstream	3.5	0.035	- ditto -
Lai Nullah	From Waterfall (RD3+800) to outlet of short-cut section (RD4+077)	0.3	0.035	Variation Order No.05 on Straightening of Chaklala Loop, PMU RDA.
	Short-cut section (RD4+077 to RD5+277)	0.8	0.030	Construction drawing for the on-going river channel improvement
	From inlet of short-cut sec. (RD5+277) to Chaklala Bridge (RD6+251)	1.0	0.035	Results of river channel survey carried out in the Study
	Chaklala Bridge (RD6+251) to Kattarian Bridge (RD17+210)	10.1	0.030	Construction drawing for the on-going river channel improvement

*: The confluence of Tenawali Kas and Saidpur Kas is located about 600m upstream from Kattarian Bridge

1.4.1 Tributaries in Islamabad

The probable water levels of Lai Nullah at Kattarian Bridge were first estimated by the non-uniform calculation from waterfall (RD 3+800) up to Kattarian Bridge based on the critical flow at the waterfall as the boundary condition at the downstream end. The results of the estimation are as listed in Table R B.5.

Table R B.5 Probable Water Level and Discharge at Kattarian Bridge

Return Period	Probable Discharge (m^3/s)*				Water Level of Lai Nullah at Kattarian Bridge (EL. m)
	From Tributaries			Lai Nullah at Kattarian Bridge	
	Bedarawali Kas	Tenawali Kas	Saidpur Kas		
5	180	95	55	330	498.0
10	340	175	105	620	499.8
25	640	315	195	1150	502.1
50	930	450	280	1660	503.7
100	1270	620	380	2270	505.3

* Estimated by the flood runoff simulation (refer to Sector A)

The profile of water level along the tributaries, Bedarawali Kas, Tenawali Kas and Saidpur Kas was further estimated applying the above probable water level of Lai Nullah at Kattarian Bridge as the initial water stage (i.e., the boundary condition) at the downstream end of the tributaries. The probable water level of the tributaries thus estimated were then compared with their existing bank levels, and the channel flow capacity of the tributaries were estimated through the comparison as listed below (refer to Fig. B.4):

Table R B.6 Channel Flow Capacities of Tributaries in Islamabad

Name of Tributaries	Length of Channel Surveyed	Flow Capacity	Flood Scale to be coped by Flow Capacity*
Bedarawali Kas	2.2 km	730 m^3/s	30-year return period
Tenawali Kas	2.2 km	320 m^3/s	25-year return period
Saidpur Kas	3.5 km	200 m^3/s	25-year return period

*: The values are estimated by interpolation of the flow capacity into the probable runoff discharges listed in Table R B.5.

As listed above, the channel flow capacity of the lower stretch of Bedarawali Kas is about 730m^3/s, which could cope with the probable flood discharge of 30-year return period. As for Tenawali Kas and Saidpur Kas, their channel flow capacities are estimated at 320 m^3/s and 200 m^3/s, respectively, which would correspond to the probable flood runoff discharges of 25-year return floods, respectively.

As described in the following subsection 1.4.2, the on-going channel improvement section of Lai Nullah has the channel flow capacity of 640m^3/s at Kattarian Bridge, which corresponds to the probable runoff discharge of about 10-year return period, provided that the bottlenecks between the inlet of short-cut section (RD5+277) and Chaklala Bridge (RD6+251) are widened. Accordingly, it is evaluated that the tributaries of Bedarawali Kas, Tenawali Kas and Saidpur Kas have the larger channel flow capacity than the mainstream of Lai Nullah, even after completion of the on-going channel improvement of the mainstream.

1.4.2 Mainstream of Lai Nullah from Waterfall (RD3+800) to Kattarian Bridge (RD17+210)

The profile of the water levels for probable flood flow discharges along Lai Nullah from waterfall to Kattarian Bridge was estimated through the aforesaid non-uniform calculation based on the depth of critical flow at the waterfall (RD 3+800) as the boundary condition at the downstream end of the stretch. As the results, the probable flood discharge, which has its corresponding water level below the bank level, was estimated as the channel flow capacity of Lai Nullah. The results of the estimation are as listed below (refer to Fig. B.5):

Table R B.7 Estimated Channel Flow Capacity of Lai Nullah
{In case of Non-Channel Improvement of the Section (RD5+277 to RD6+215)}

Section				Flow Capacity (m^3/s)
Downstream		Upstream		
Description	RD	Description	RD	
Short-cut section	4+077	Short-cut of mender	5+277	1,810
Non improvement section	5+277	Non improvement section	6+215	800
Chaklala Bridge	6+215	Dhoke C. Din Bridge	8+060	620
Dhoke C. Din Bridge	8+060	Railway Road Bridge	8+325	770
Railway Road Bridge	8+325	Murree Road Bridge	8+628	780
Murree Road Bridge	8+628	Gawal Mandi Bridge	9+814	800
Gawal Mandi Bridge	9+814	City S. Road Bridge	10+790	850
City S. Road Bridge	10+790	Ratta A. Road Bridge	11+780	880
Ratta A. Road Bridge	11+780	Gunj Mandi Bridge	12+630	890
Gunj Mandi Bridge	12+630	Pir Wadhai Bridge	14+428	890
Pir Wadhai Bridge	14+428	Khayaban S.S. Bridge	14+100	880
Khayaban S.S. Bridge	14+100	Parrian Bridge	16+178	690
Parrian Bridge	16+178	Kattarian Bridge	17+210	640

As described above there are bottlenecks along non-improvement section of 1.0 km in length below Chaklala Bridge (RD5+277 to RD6+215). The bottlenecks swells the water head and brings about the abrupt rise of the flood water level just upstream of the bottlenecks and, its

backwater effect extends about 6km upstream near to Gunj Mandi Bridge as shown in Fig. B.5. The backwater effect causes the unfavorable conditions such that the channel flow capacity of the lower section reversibly drops below that of the upper section within an extent from Chaklala Bridge up to Gunj Mandi Bridge; the channel flow capacity of at Gunj Mandi is 890m^3/s, while the flow capacity drops to 620m^3/s at Chaklala Bridge as listed in Table R B.7.

The reversal of the channel flow capacities from the upper to lower sections inflicts the risk of flood overflows and therefore, should be unconditionally dispelled. In order to offset the reversal of the channel flow capacities, it is indispensable to improve the bottlenecks. The necessary channel improvement could be made through enlargement of the cross-sections. Designed channel profile, typical cross-sections and alignment for the bottlenecks are as described in subsection 1.5.3.

On the premises that the channel improvement of the bottlenecks, the channel flow capacity of the Lai Nullah could be recovered and almost compatible to the design discharge adapted to the on-going channel improvement project as listed in Table R B.8 (refer to Fig. B.6).

Table R B.8 Estimated Flow Capacity of Lai Nullah and Design Discharge Adopted to the On-going River Channel Improvement

{In case of Channel Improvement of the Section (RD5+277 to RD6+215)}

Section				(1) Estimated Flow Capacity*1	(2) Design Discharge*2
Downstream		Upstream			
Description	RD	Description	RD		
Short-cut section	4+077	Short-cut section	5+277	1,810	-
Proposed improvement section	5+277	Proposed improvement section	6+215	1,010	-
Chaklala Bridge	6+215	Dhoke C. Din Bridge	8+060	1,010	1,000
Dhoke C. Din Bridge	8+060	Railway Road Bridge	8+325	1,010	970
Railway Road Bridge	8+325	Murree Road Bridge	8+628	1,000	960
Murree Road Bridge	8+628	Gawal Mandi Bridge	9+814	970	960
Gawal Mandi Bridge	9+814	City S. Road Bridge	10+790	960	940
City S. Road Bridge	10+790	Ratta A. Road Bridge	11+780	950	930
Ratta A. Road Bridge	11+780	Gunj Mandi Bridge	12+630	940	920
Gunj Mandi Bridge	12+630	Pir Wadhai Bridge	14+428	910	870
Pir Wadhai Bridge	14+428	Khayaban S.S. Bridge	14+100	890	830
Khayaban S.S. Bridge	14+100	Parrian Bridge	16+178	690	630
Parrian Bridge	16+178	Kattarian Bridge	17+210	640	590

Note

*1: The flow capacity estimated by non-uniform calculation assuming widening of the sections below Chaklala Bridge (RD5+227 to RD6+215)

*2: The rounded values of design discharge adopted to the on-going channel improvement (Source: Design Report Vol.1, Urban Water Supply and Sanitation Project Phase 1 for Rawalpindi City, March 2002)

As listed above, the flow capacities adapted to the design of the on-going channel improvement (i.e., the values under the column of (2) in Table R B.8) tend to be slightly lower than the values estimated in the Study (i.e., those under the column of (1) in Table R B.8), which are subject to the widening of the existing channel section below Chaklala Bridge (RD5+227 to RD6+215).

The channel flow capacity adapted to the on-going channel improvement is estimated by the uniform calculation method, where considered is not given to the possible increment of the flow

capacity due to the downward expansion of the designed typical cross-sections (refer to Fig. B.7).

Taking the above conditions into consideration, the values estimated by non-uniform calculation in this Study (i.e., the values under column of (1) in Table R B.8) are assumed as the design channel flow capacity of the on-going channel improvement section from Chaklala Bridge to Kattarian Bridge. As described above, however, the design flow capacity adapted in the Study is on conditions that the channel improvement of the existing non-channel improvement section below Chaklala Bridge (RD5+227 to RD6+215) is made in accordance with the proposed channel profile and cross-sections as specified in subsection 1.5.3.

2. PROPOSED RIVER CHANNEL IMPROVEMENT

As described above, the on-going channel improvement of Lai Nullah above Chaklala Bridge could cope with the probable flood peak discharge of only 10-year return period, which is below the target design level of the aforesaid short-term project (i.e., 25-year return period). Hence, the further channel improvement is considered as one of the potential flood mitigation measures.

2.1 Extent of Channel Improvement

Judging from the river features and channel flow capacities as evaluated in the foregoing section 1.2, the maximum extent of the channel improvement may cover the following stretches of the mainstream and tributaries:

(1) Mainstream from Chaklala Bridge (RD6+251) to Kattarian Bridge (RD17+210): The channel improvement is required to increase the channel flow capacity of the on-going river channel improvement;

(2) Mainstream of about 1.0km in length (RD5+227 to RD6+215) sandwiched between the aforesaid short-cut section around Murree Brewery Area and the on-going channel improvement above Chaklala Bridge: This section is out of the extent of the on-going river channel improvement, but unconditionally requires a certain extent of enlargement of the cross-sections in order to avoid the unfavorable adverse backwater effect to the channel flow conditions of the stretch of above item (1) (refer to the section 1.2 in detail)

(3) Three (3) tributaries of Bedarawali Kas, Tenawali Kas, and Saidpur Kas, which concentrate to the mainstream of Lai Nullah at Kattarian Bridge; the flood flow of these tributaries are influenced by the backwater from the mainstream at Kattarian bridge, and may require a certain extent of channel improvement; and

(4) Eight (8) tributaries, which flow into the mainstream between Chaklala Bridge and Kattarian Bridge; these may require a certain extent of channel improvement associated with the channel improvement of the mainstream (refer to Table R B.1).

The necessity of channel improvement for the above stretches are evaluated, and the channel improvement plans is proposed as described in the subsections 1.5.2 to 1.5.6.

2.2 Channel Improvement Plan for Mainstream from Chaklala Bridge (RD6+251) to Kattarian Bridge (RD17+210)

Through the on-going channel improvement, the substantial extent of land acquisition has been made in the densely populated area of Rawalpindi. The further land acquisition has to require demolishing of the tremendous number of house/buildings closely packed along the river, which would cause the extremely serious frictions with the residents.

Judging from these social problems anticipated, the Steering Committee Meeting for the Study concluded in August 2002 that the right-of-way secured for the on-going channel improvement should be the maximum limit, and that the further widening of the river channel is no longer applicable. In accordance with this conclusion, the possible measure posterior to the on-going channel improvement is to be oriented to deepening of the riverbed, instead of the river widening.

Deepening of the riverbed had been already proposed by the Rawalpindi Electric Supply Company in 1944 by blasting of the waterfall located about 2.5km downstream from Chaklala Bridge, while the proposal was finally ruled out due to adverse effects to the upstream bridges as well as the buildings along the river. Nevertheless, the adverse effects to the bridges and buildings could be offset by reconstruction and/or reinforcement for them, controlling of the flood flow velocity and/or providing of the bank protection and, therefore would not be the critical issue to rule out the proposal.

The proposed alignment, longitudinal profile, typical cross-sections and the relevant works for the channel deepening are as described hereinafter:

1) Alignment

The channel deepening is made on the designed riverbed of the on-going channel improvement. Accordingly, the proposed channel improvement follows the alignment of the on-going channel improvement.

2) Longitudinal Profile

The ongoing channel improvement maintains the existing channel bed slope of about 1/1,250. This bed slope has been formed by the long-term flow regime, and judged to be

stable minimizing sedimentation and/or erosion. From these viewpoints, the existing channel slope of 1/1,250 is preferred as the optimum channel bed slope even after deepening of the channel improvement.

Partial deepening of the channel with using the groundsill will not be applicable to increase the overall channel flow capacity, and, the channel bed of the entire target river stretch should be lowered by a uniform depth with maintaining the channel bed slope 1/1,250.

On the premises of the above conditions, the optimum depth for lowering is assumed as 2m taking the following conditions into account:

(a) The on-going channel improvement is now in progress with its designed channel depth of 7.5m, which causes the maximum channel flow capacity of more than 3m/s. The excessive channel deepening would increase the unfavorable channel flow velocity far faster than 3m/s, causing difficulties in maintaining the river channel. In this connection, the allowable maximum channel velocity is provisionally assumed as 4m/s, and the allowable extent of channel deepening is assumed at 2m to control the channel flow velocity below the allowable limit.

(b) The consistent channel bed slope of 1/1,250 would need to be maintained up to waterfall (RD3+800) about 2.5km downstream from Chaklala Bridge (refer to the following subsection 1.5.3). Under this condition, the channel deepening of more than 2m would require removal of waterfall and the extensive excavation of hard rocks, which outcrops below Murree Brewery (located about 700m upstream of the waterfall).

(c) The channel deepening of 2m could avoid channel improvement of the upper tributaries of Bedarawali Kas, Tenawali Kas, and Saidpur Kas, as well as reconstruction of 11 bridges crossing over the tributaries[3].

The longitudinal profile for channel deepening is delineated, on the premises of the channel deepening by 2m with the channel bed slope of 1/1,250 as shown in Fig. B.8.

3) Typical Cross-Sections

A compound section with high and low water channels is preferable in general due to advantages such as minimizing of embankment height and assuring of channel stability. The on-going channel improvement, however, adopted a single cross-section with a

[3] According to the results of the channel survey for the tributaries undertaken in the Study, it is clarified that the tributaries have the rather adequate channel flow capacity, and the channel improvement is not required, as long as the channel deepening of the mainstream is limited to 2m.

side-slope of 1 to 1.5, and the further channel improvement would also need to follow the same shape of cross-section due to difficulties of land acquisition. The dimensions of the typical cross-sections for the proposed channel deepening of Lai Nullah are as listed in the following Table R B.9 (refer to Fig. B.9):

Table R B.9 Typical Cross-section of Proposed Channel Deepening

Section (Name of Bridge)				Width (m)		Depth (m)
Downstream		Upstream		Bottom	Top	
Name of Bridge	RD	Name of Bridge	RD			
Chaklala	6+215	Dhoke C. Din	8+060	38.4	69.9	9.5
Dhoke C. Din	8+060	Railway Road	8+325	36.4	67.9	9.5
Railway Road	8+325	Murree Road	8+628	36.2	67.7	9.5
Murree Road	8+628	Gawal Mandi	9+814	35.9	67.4	9.5
Gawal Mandi	9+814	City S. Road	10+790	35.2	66.7	9.5
City S. Road	10+790	Ratta A. Road	11+780	34.8	66.3	9.5
Ratta A. Road	11+780	Gunj Mandi	12+630	34.3	65.8	9.5
Gunj Mandi	12+630	Pir Wadhai	14+428	31.9	63.4	9.5
Pir Wadhai	14+428	Khayaban S.S.	14+100	29.5	60.9	9.5
Khayaban S.S.	14+100	Parrian	16+178	20.4	51.9	9.5
Parrian	16+178	Kattarian	17+210	18.5	50.0	9.5

4) Side Slope Protection

The on-going river channel improvement provides the side slope protection by stone pitching only along right and left banks of about 50m in length around each of the existing nine (9) bridges and reconstructed three (3) bridges. Other substantial parts of the stretch are left unlined without any side slope protection. According to the site inspection by the Study Team, however, the gully erosion has appeared on the surface of side slope along the unlined stretch, and it may develop further serious bank erosion and lead to collapse of riverbank.

The necessity of the side protection all along the stretch was once acknowledged in the design meetings for the on-going channel improvement, but finally turned down considering compatibility with the further channel improvement proposed in this Study. Thus, the side protection works for the on-going channel improvement could be regarded as the expedient, and it is indispensable to provide side slope protection all along the stretch for channel improvement as the permanent measure. Considering the current progress of bank erosion observed and the other channel conditions such as the channel dept of 9.5m and the expected maximum channel flow capacity of about 4m/s, the wet-stone-masonry should be preferable as the type of the side protection instead of the stone pitching as proposed in the on-going river channel improvement.

5) Reconstruction and Reinforcement Works of Bridges

There exist nine (9) bridges crossing over the target river stretches (refer to Fig. B.10). According to interview survey, the depth of their foundations, although it is unknown, is

likely to be very shallow. Moreover, the top level of foundation is rather high as compared with the riverbed level and will be exposed by the channel deepening. Due to the these unfavorable conditions, all of the existing bridges would need to be reconstructed, should the channel deepening be implemented. The approximate length and width of these bridges to be reconstructed are as listed in Table B.1 at the back of this report.

In addition to the existing bridges, reconstruction works are now being undertaken for the following three (3) bridges through the on-going channel improvement: namely, (a) Dhoke Chiragh Din, (b) Gawal Mandi and (c) Pir Wadhai. All of these new bridges have the adequate foundation depth of more than 18m. However, as for Dhoke Chiragh Din, and Pir Wadhai Bridge, their top foundation would be exposed above the proposed riverbed level, should the riverbed be lowered by 2m as listed in Table R B.10. Accordingly, these two (2) bridges would require the reinforcement works for their foundations.

Table R B.10 Foundation of Bridges Reconstructed in On-going Channel Improvement

Name of Bridge	Riverbed Level after Deepening*	Number of Foundation	Level of Foundation		Foundation Depth	Exposure of Foundation
			Top	Tip		
Pir Wadhai	EL. 488.5m	4	EL. 490.5 m	EL. 471.3 m	20.2 m	2.0m
Gawal Mandi	EL. 485.6m	4	EL. 483.6 m	EL. 464.4 m	20.2 m	-2.0m
Dhoke Chiragh Din	EL. 484.1m	6	EL. 484.0 m	EL. 467.0 m	18.0 m	0.1m

Source: Drawings for Reconstruction of Bridge, Urban Water Supply and Sanitation Project-Phase 1 for Rawalpindi, Mott Macdonald, 2002

2.3 Channel Improvement Plan for Main Stream from Waterfall (RD3+800) to Chaklala Bridge (RD6+251)

As described in the foregoing section 1.3, realignment (short-cut)/enlargement of the meandering section (RD4+077 to RD5+277) has been completed by PMU, RDA having the design longitudinal profile and cross-section as shown in Fig. B.11, which could accommodate an adequate channel flow capacity, even when the channel above Chaklala Bridge is deepened by 2m. The existing channel from waterfall (RD3+800) to the short-cut section has also extensive cross-sectional flow area, which is far larger than the design cross-section of the above short-cut section. The channel improvement is, however, required to the section of about 1.0km in length (RD5+227 to RD6+215) sandwiched between the short-cut section around Murree Brewery Area and the on-going channel improvement above Chaklala Bridge in order to adverse backwater effect to the upper river section regardless to aforesaid channel deepening of the upper stretch from Chaklala Bridge.

1) Alignment

The objective channel improvement section (RD5+227 to RD6+215) has almost strait alignment, and any realignment is not required to the section (refer to Fig. B.12).

2) Longitudinal Profile

The channel bed slope from waterfall (RD3+800) to the upstream end of short cut section (RD5+277) is about 1/1,250, almost same as that of the on-going channel improvement section from Chaklala Bridge (RD6+251) to Kattarian Bridge (RD17+210) (refer to Figs. B.8 and B.11). On the other hand, the channel depth from waterfall to the upstream end of short cut section is about 2m deeper than that of the on-going channel improvement section (refer to Fig. B.8).

The objective improvement section has a bed slope of 1/180 forming a transition of the channel bed profile from the on-going channel section above Chaklala Bridge to the short-cut section. It is also recognized that an extent of about 20 to 50m in width along the right and left bank of the objective channel improvement section (RD5+227 to RD6+215) is currently remained as vacant land.

Taking these river features into consideration, widening of the channel is preferred as the optimum channel improvement rather than channel deepening, and the existing channel bed profile should be remained with a minimal excavation.

3) Typical Cross-section

The typical cross-sections were prepared for the following two (2) cases: (a) the on-going channel improvement section above Chaklala Bridge is remained without further channel deepening; and (b) the on-going channel improvement section is further deepened by 2m as described in the above subsection 1.5.2).

The typical cross-sections should have the channel flow capacity to offset the aforesaid adverse backwater effect to the upstream section. On the premises of this required channel flow capacity and the above proposed longitudinal profile, the dimensions of the typical cross-sections for the above two cases are determined as listed in the following Table R B.11 (refer to Figs.B.13 and B.14):

Table R B.11 Typical Cross-section for Section from Waterfall to Chaklala Bridge

Case	States of Upstream from Chaklala Bridge	Dimensions of Cross-section		
		Width (m)		Depth (m)
		Bottom	Top	
Case A	The on-going channel improvement section is remained without channel deepening	20.0	48.5	9.5
Case B	The on-going channel improvement section is further deepened by 2m	44.4	72.9	9.5

Note: (1) A single cross-section with a side-slope of 1 to 1.5 was adapted in the same way as the upstream of Chaklala Bridge.
(2) High water level is set at 1m below the bank level assuming 1m depth of free board

4) Side Slope Protection

Considering the channel depth of 9.5m and the expected maximum channel flow capacity of about 4m/s, the wet-stone-masonry should be adapted as the type of the side protection in the same way as the side slope protection adapted to the upper stretch from Chaklala Bridge.

2.4 Potential Channel Flow Capacity and Design Discharge of Lai Nullah

As described in the above subsections 1.5.3, two (2) cases of channel improvement is proposed for the bottleneck section (RD5+277 to RD6+215) of about 1km in length below Chaklala Bridge. The first case is on the premises that the on-going channel improvement section above Chaklala Bridge is remained without further channel deepening. This first case is unconditionally required to offset the adverse backwater effect and secure the design discharge of the on-going channel improvement (refer to Tables R B.7 and R B.8).

The second case is subject to channel deepening of the on-going channel improvement above Chaklala Bridge as proposed in subsection 1.5.2. In this second case, the typical cross-section of the bottleneck section below Chaklala Bridge is enlarged as shown in Table R B.11, and the riverbed of the on-going channel improvement is deepened by 2m. Due to these channel enlargement, the channel flow capacity would increase from 640m^3/s to 900m^3/s at Kattarian Bridge and from 1,000m^3/s to 1,400m^3/s at Chaklala Bridge as listed below.

Table R B.12 Potential Channel Flow Capacity of Lai Nullah before and after Proposed Channel Improvement

Section of Lai Nullah				Potential Channel Flow Capacity (m^3/s)	
Downstream		Upstream		Before Deepening	After Deepening
Description	RD	Description	RD		
Short-cut section	4+077	Short-cut section	5+277	1,810	1,810
Proposed improvement section	5+277	Proposed improvement section	6+215	1,010	1,500
Chaklala Bridge	6+215	Dhoke C. Din Bridge	8+060	1,010	1,400
Dhoke C. Din Bridge	8+060	Railway Road Bridge	8+325	1,010	1,400
Railway Road Bridge	8+325	Murree Road Bridge	8+628	1,010	1,400
Murree Road Bridge	8+628	Gawal Mandi Bridge	9+814	970	1,370
Gawal Mandi Bridge	9+814	City S. Road Bridge	10+790	960	1,350
City S. Road Bridge	10+790	Ratta A. Road Bridge	11+780	950	1,330
Ratta A. Road Bridge	11+780	Gunj Mandi Bridge	12+630	940	1,320
Gunj Mandi Bridge	12+630	Pir Wadhai Bridge	14+428	910	1,290
Pir Wadhai Bridge	14+428	Khayaban S.S. Bridge	14+100	890	1,260
Khayaban S.S. Bridge	14+100	Parrian Bridge	16+178	690	960
Parrian Bridge	16+178	Kattarian Bridge	17+210	640	900

It is herein noted that the above channel flow capacities of Lai Nullah before the proposed channel improvement is fixed by the design for the on-going channel improvement, and do not necessarily accord with the probable runoff discharge estimated in this Study. In order to clarify the difference between the channel flow capacity and design discharge, the probable runoff discharge of 10and 25-year return floods are enumerated as below from the results of the hydrological simulation (refer to Sector A).

Table R B.13 Probable Flood Runoff Discharge to Lai Nullah

Section of Lai Nullah				Probable Flood Runoff Discharge (m^3/s)	
Downstream		Upstream		10 years	25 years
Description	RD	Description	RD		
Short-cut section	4+077	Short-cut section	5+277	910	1,740
Proposed improvement section	5+277	Proposed improvement section	6+215	890	1,700
Chaklala Bridge	6+215	Dhoke C. Din Bridge	8+060	870	1,660
Dhoke C. Din Bridge	8+060	Railway Road Bridge	8+325	840	1,580
Railway Road Bridge	8+325	Murree Road Bridge	8+628	830	1,570
Murree Road Bridge	8+628	Gawal Mandi Bridge	9+814	820	1,550
Gawal Mandi Bridge	9+814	City S. Road Bridge	10+790	810	1,510
City S. Road Bridge	10+790	Ratta A. Road Bridge	11+780	800	1,490
Ratta A. Road Bridge	11+780	Gunj Mandi Bridge	12+630	800	1,480
Gunj Mandi Bridge	12+630	Pir Wadhai Bridge	14+428	750	1,390
Pir Wadhai Bridge	14+428	Khayaban S.S. Bridge	14+100	700	1,300
Khayaban S.S. Bridge	14+100	Parrian Bridge	16+178	650	1,200
Parrian Bridge	16+178	Kattarian Bridge	17+210	630	1,170

As listed above, the channel flow capacity of the on-going channel improvement at Kattarian Bridge ($640m^3/s$) is almost equivalent to the probable flood runoff discharge of 10-year return period ($630m^3/s$). On the other hand, the channel flow capacity at Chaklala Bridge ($1,000m^3/s$) is far larger than the probable runoff discharge of 10-year ($870m^3/s$). Thus, the on-going channel improvement is designed to provide the relative larger channel flow capacity to the lower sections than those of the upper sections. On the other hand, the proposed channel improvement is made by channel deepening of the on-going channel improvement section, and, it is virtually difficult to increase the channel flow capacity of the upper sections without channel improvement of the lower sections.

Taking the above particular conditions into consideration, the channel flow capacity at Kattarian Bridge, the upstream end of the stretch becomes as a critical factor to determine how much of the recurrence probability of the runoff discharge is allowable to the entire stretch of Lai Nullah, and the design discharges for the on-going channel improvement as well as the proposed channel improvement are determined based on the channel flow capacity at Kattarian Bridge as listed below.

Table R B.14 Design Discharge of Lai Nullah for On-going Channel Improvement and Proposed Channel Improvement

Section of Lai Nullah				Design Discharge (m^3/s)	
Downstream		Upstream		On-going Improvement	Proposed Deepening
Description	RD	Description	RD		
Short-cut section	4+077	Short-cut section	5+277	920	1280
Proposed improvement section	5+277	Proposed improvement section	6+215	900	1270
Chaklala Bridge	6+215	Dhoke C. Din Bridge	8+060	880	1240
Dhoke C. Din Bridge	8+060	Railway Road Bridge	8+325	850	1200
Railway Road Bridge	8+325	Murree Road Bridge	8+628	840	1190
Murree Road Bridge	8+628	Gawal Mandi Bridge	9+814	830	1170
Gawal Mandi Bridge	9+814	City S. Road Bridge	10+790	820	1160
City S. Road Bridge	10+790	Ratta A. Road Bridge	11+780	810	1140
Ratta A. Road Bridge	11+780	Gunj Mandi Bridge	12+630	810	1140
Gunj Mandi Bridge	12+630	Pir Wadhai Bridge	14+428	760	1070
Pir Wadhai Bridge	14+428	Khayaban S.S. Bridge	14+100	710	1000
Khayaban S.S. Bridge	14+100	Parrian Bridge	16+178	660	930
Parrian Bridge	16+178	Kattarian Bridge	17+210	640	900

2.5 Necessity of Channel Improvement for Tributaries above Mainstream of Lai Nullah

As described above, the channel flow capacity of Lai Nullah is expected to increase to 900 m^3/s at Kattarian Bridge by the proposed channel deepening. It is estimated from the results of the hydrological analysis in Sector A that the increased channel flow capacity of 900 m^3/s corresponds to the flood runoff discharges of 504m^3/s from Bedarawali Kas, 244 m^3/s from Tenawali Kas and 152 m^3/s from Saidpur Kas. On the other hand, the existing flow capacities of the tributaries are estimated at 730 m^3/s for Bedarawali Kas, 320 m^3/s for Tenawali Kas and 200 m^3/s for Saidpur Kas (refer to the foregoing Table R B.6). Thus, all of the tributaries have the adequate channel flow capacities larger that the runoff discharges equivalent to the increased flow channel capacity of Lai Nullah at Kattarian Bridge (refer to Table R B.15). Accordingly, as long as the design discharge of Lai Nullah is set below 900m^3/s at Kattarian Bridge, any channel improvement associated with the channel deepening of the mainstream is not required to the tributaries of Bedarawali Kas, Tenawali Kas and Saidpur Kas.

Table R B.15 Existing Channel Flow Capacity and Probable Runoff Discharge of Tributaries above Kattarian Bridge

Name of Tributaries	Existing Channel Flow Capacity of Tributaries	Probable Runoff Discharge Equivalent to Design Discharge of 900m^3/s for Lai Nullah at Kattarian Bridge
Bedarawali Kas	730 m^3/s	504 m^3/s
Tenawali Kas	320 m^3/s	244 m^3/s
Saidpur Kas	200 m^3/s	152 m^3/s
Total	1,250 m3/s	900 m^3/s

2.6 Necessity of Channel Improvement for Tributaries below Kattarian Bridge

As described in the foregoing section 1.2, there are nine (9) tributaries flowing into the mainstream of Lai Nullah from Kattarian Bridge to Chaklala Bridge. Among others, the channel cross-sectional survey was carried out for eight (8) tributaries during the first field survey. The field reconnaissance was further carried out to crosscheck the results of cross-section survey with using the results of GPS survey on the ground level along the tributaries. As the results, it was finally clarified that almost all part of the whole tributaries has the adequate bank level above the design high water level of the on-going channel improvement of the mainstream as shown in Fig. B.15. Accordingly, any major flood protection work for the tributaries would not be required. Nevertheless, necessity of some minor bank protection is detected at the downstream end of the tributaries of Pir Wadhai Kassi (No. R4), Workshop Tributary (No. L4), Saddar Tributary (No. R1) and Dhok Churaghdin Tributary (No. L1).[4]

[4] The location of the tributaries are as shown in Fig. B.1.