HYDRAULIC STUDY REPORT

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HYDROLOGY AND HYDRAULICS STUDY REPORT

1.1 GENERAL

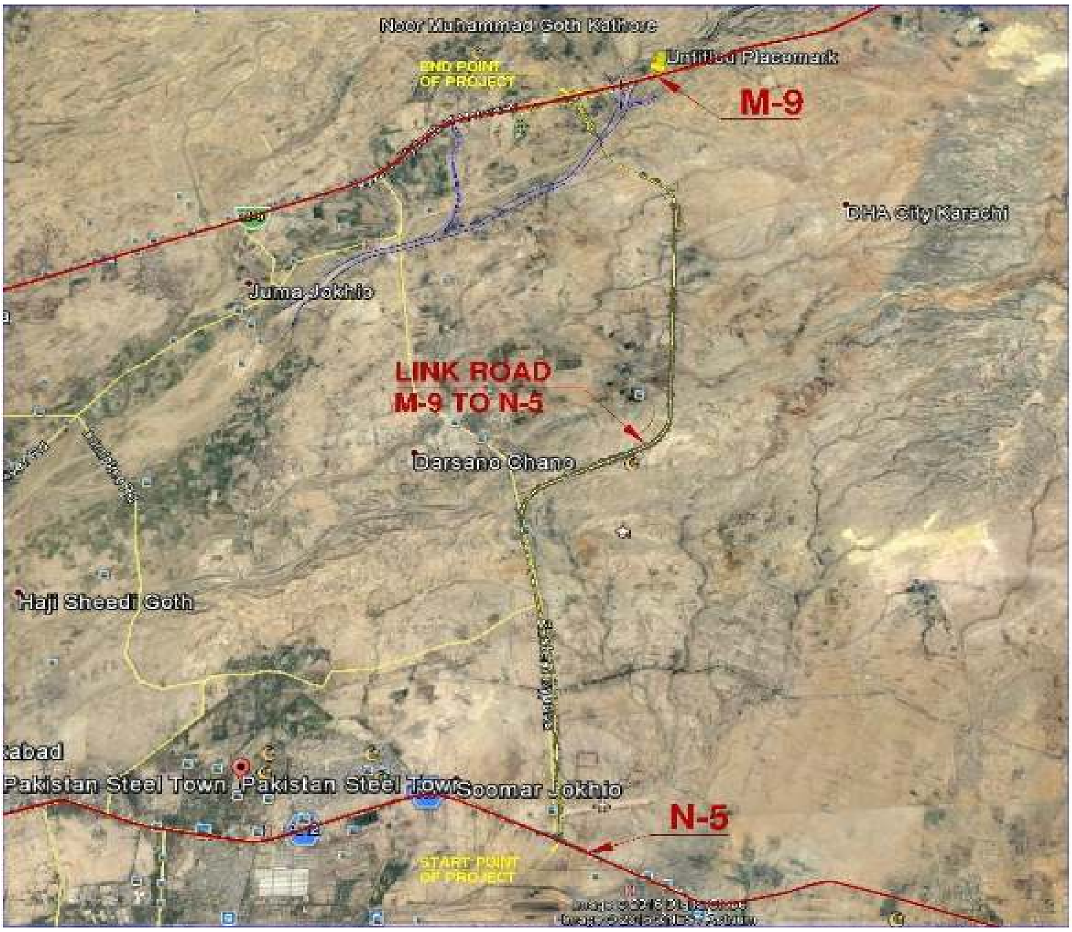
The design of drainage and hydraulic structures such as bridges and box culverts are based on information of water discharge due to rainfall. Peak flow generally depends on the catchment area, its shape and slope, vegetation conditions, land use in the catchment and rainfall intensity & extent.

1.2 PROJECT AREA

The coastal part comprises only a small part of this region and climate above coastal parts in Baluchistan as well as in Sindh province is mostly arid to hyper arid. The project area is located in rainfall zone with mean annual precipitation ranging from zero to 200 mm as per PMD rainfall map. Due to low rainfall and high losses, many storms fall on dry ground, which is well able to absorb a high proportion of the rainfall. However, difference in soil dryness and storm rainfall depths and intensities produce considerable variation in the percentage runoffs and hence in the amount of runoff generated.

The proposed Link Road consists of 21.4 km long 4-lane dual carriageway connecting M-9 and N-5 highways. It is one of the important road connecting M-9 and N-5 highways near Karachi as shown below in the route location plan.

Figure-1: Link Road between M-9 and N-5 Location Plan



1.3 HYDROLOGIC DATA

Hydrological information consists of following items:

- **Topographic Maps**
  Survey of Pakistan maps of 1: 50,000 scale has been used to study the highway alignment in relation to the drainage characteristics of basin area being traversed.

- **Land Use**
  Using the topographic maps, satellite imagery, Google Earth Professional (Pro) and site visits, individual types of land use, vegetation and soil type have been identified.

  The drainage area has mostly Pasture land consisting of bushes and grass. The general soil types are sand and gravel mix.

- **Rainfall Data**
  Pakistan Meteorological Services (PMS) data has been used in the analysis and design of drainage structures of the project. The rainfall shows a significant variation in rainfall pattern and magnitude over the period of data records as shown below:

Table-1: 24 Hour Maximum Rainfall (mm)

Year	Depth of Rainfall (mm)
1990	57.2
1991	19.5
1992	370
1993	9.8
1994	39.3
1995	81.3
1996	33.2
1997	24
1998	24.1
1999	4.5
2000	19
2001	52.5
2002	47
2003	108.3
2004	26.3
2005	31
2006	65.9
Year	**Depth of Rainfall (mm)**
2007	124.2
2008	54
2009	143
2010	77.1
2011	75
2012	48.7
2013	102.6

1.4 HYDROLOGIC ANALYSIS

The peak runoff studies have been carried out for all the streams crossing the proposed road. For culverts with smaller catchments, rational formula is used and for the bridges, NRCS (SCS) dimensionless hydrograph approach is adopted.

The following Flood Return Periods are used for the estimation of peak flow:

Bridges	100 Years
Culverts	50 Years

The hydrologic analysis comprises of following methodology:

1.4.1 Design Rainfall and Selected Rainfall Intensity

The annual 24 hours maximum rainfall and selected rainfall intensity have been used in the analysis of watershed analysis. Frequency analysis of annual 24 hours maximum rainfall values has been carried out using Gumbel Distribution. The frequency analysis of 24 hour maximum rainfall for 25 years, 50 years and 100 year recurrence interval has been worked out depending upon the objective of the analysis. Similarly, rainfall intensities for different return periods have been estimated subject to the availability of PMD rainfall data.

The rainfall of certain critical duration may be derived from daily rainfall using the following relationship:

$$r = r_{24}/24 \times (24/D)^{0.667}$$

Where,
r = rainfall intensity in mm per hour
r_{24}=daily rainfall in mm
D = rainfall duration (hours),

T_C may be estimated by generally accepted formula by Kirpich (1940):

$$T_C \text{ (hours)} = 0.00032\, L^{0.77}/S^{0.385}$$

Where
L=maximum channel length (m)
S=average channel slope (m/m)

1.4.2 Drainage Basin

By using topographic maps/ Google Earth Pro data boundaries of the drainage basin have been established. Once boundaries of the catchment contributing areas are established, these are marked on a base map and the drainage areas estimated using Google Earth software & Survey of Pakistan topographic sheets.

1.4.3 Watershed Parameters/Characteristics

Drainage basin characteristics which include length, slope, imperviousness, infiltration and roughness coefficient have been obtained from available topographic data/soil data/maps. Combined losses accounting for interception, depression storage, evaporation & infiltration concurrently have been calculated using the SCS runoff curve number method. Channel slope, roughness and cross-section have been determined from the field data/maps available.

1.4.3.1 Hydraulic Length

It is the length of channel (principal watercourse) from the farthest point of catchment to the structure location. The hydraulic lengths have been calculated from topo sheets and Google Earth Pro.

1.4.3.2 Average Slope of Watershed

It is the average slope of channel from the farthest point of catchment to the structure location. Average slope of watershed have also been calculated from topo sheets and Google Earth Pro.

1.4.3.3 Time of Concentration

The time of concentration of an area is the time taken for water to reach the point under consideration after falling on the surface of the most remote part of the area. The time of concentration is estimated by the Kirpich formula.

T_C (minutes) = 0.0195 (Length of channel in meter)$^{0.77}$ / (Slope)$^{0.385}$

1.5 FLOOD MODELS (DESIGN RUNOFF/ PEAK FLOW)

The land area that contributes flow to a storm water structure is called the watershed, catchment, or drainage basin of that structure. The location of structure is called the design point, the watershed outlet, or the basin outlet. Storm water structures are designed to accommodate a design runoff.

Following methods are/have been used in formulating the design runoff (peak runoff) for the design of storm water structures:

1.5.1 Rational Method

The rational model is used for runoff model in small catchments. In small catchments, the response to rainfall is sufficiently rapid and the catchment is sufficiently small that runoff during a relatively short time interval can be adequately modeled by assuming a constant rainfall in space and time. The maximum possible discharge (peak runoff) under a constant rate of effective rainfall will be reached if the effective rain duration is equal to the time of concentration of the basin associated with a storm water structure.

Rational Formula shown below is used for discharge estimation:

Q = 2.78 CIA,
Where
Q = Peak Discharge in m^3/sec
I = Intensity of Rainfall cm/hour
A = Catchment Area in Sq.Km
C = Run off Co-efficient

The Project area consists of Pasture/Range land with rolling terrain (mixture of sand and gravel), accordingly the value of C has been taken as 0.25. The Annexure A gives the average runoff coefficients according to the type of drainage area.

1.5.2 US Soil Conservation Service Method

The US Soil Conservation Service (now called the Natural Resources Conservation Service), division of the USDA (USA Department of Agriculture) has worked for decades developing equations and conducting experiments to determine reliable models for predicting peak discharge from storm events. Relying upon extensive research, Technical Release 55 (TR-55: SCS, 1986) presents a methodical and reliable approach to predict peak discharge for 24-hr storm event. TR-55 is valid for watersheds that have a time of concentration from 0.1 to 10 hr.

For a given storm, the depth of excess precipitation or direct runoff "Pe" is always less than or equal to the depth of precipitation P, likewise, after runoff begins, the additional depth of water retained in the watershed, Fa, is less than or equal to some potential maximum retention S. There is some amount of rainfall Ia (initial abstraction before ponding) for which no runoff will occur, so the potential runoff is (P— Ia). Depth of excess precipitation or direct runoff is calculated by the following formula:

$$\mathrm{Pe} = \frac{(\mathrm{P}-\mathrm{Ia})2}{(\mathrm{P}-\mathrm{Ia}+\mathrm{S})}$$

Where,

Initial Absorption, Ia = 0.2S

$\text{Potential Maximum Retuntion, S} = \frac{1000}{\mathrm{CN}}$ -10

CN = curve number.

Curve numbers have been tabulated by the Soil Conservation Service on the basis of soil type and land use. Four soil groups are defined below:

- Group A: Deep sand, deep loess, aggregated silts
- Group B: Shallow loess, sandy loam
- Group C: Clay loams, shallow sandy loam, soils low in organic content, and soils usually high in clay.
- Group D: Soils that swell significantly when wet, heavy plastic clays, and certain saline soils.

Soils can be classified as A, B, C and D according to the runoff potential and hydrological characteristics as follows:

GROUP	RUN OFF POTENTIAL	HYDROLOGICAL CHARACTERISTICS
Group A	Low Run Off	Soil having high infiltration rate
Group B	Moderate Run Off	Soil having moderate infiltration rate
Group C	High Run Off	Soil having slow infiltration rate
Group D	Very High Run Off	Soil having very slow infiltration rate

Considering the project area, the curve number is estimated on the basis of the land use description, the treatment, the hydrological conditions and the hydrological soil group.

The area is considered as Pasture range land. A type "A" Hydrologic soil group with fair Hydrologic condition is considered based on site conditions. The Curve No. is estimated as "49" for Antecedent Soil Moisture Condition (AMC)-II. The values of CN for various land use description for different soil types are given in the Annexure B.

The peak discharge can be calculated by the following formula: (SCS Dimensionless unit hydrograph Method)

Qp = 2.08*A*Q/T

Where
Qp = Peak discharge in Cumecs
A = Catchments area in Sq. km
Q = Excess rainfall in cm
T = Time of Peak in hours = 0.67* T

1.6 HYDRAULIC STUDY AND DESIGN

1.6.1 Waterway of Bridges

In case of bridges on the large natural streams, the width of waterway is determined from the design discharge. The following formula is used to calculate the width of required waterway for the bridges as per code of practice 1967 for Highway Bridge:

$W = 4.75\ (Q)^{0.5}$
Where Q=Discharge in cumecs

1.6.2 Average Flow Velocity

Average flow velocity and/or the design discharge of a channel flow can be calculated from the Manning's formula, if data is available, and is elaborated below:

$V = Q/A = (1/n)*R^{2/3}*S^{1/2}$

Where:
V =the average flow velocity in the channel or water course
Q =the design flow (discharge) of the channel (m^3/sec)
A = the cross-sectional area of the flow m^2)
R = the hydraulic radius, which equals the area of flow divided by wetted perimeter (m
S = the slope (m/m)
n = Manning coefficient of roughness

1.7 FREE BOARD FOR BRIDGES AND BOX CULVERTS

Free board is provided to accommodate the flood encountered unexpectedly. A 0.3 m free board for box culverts and 1.0 m free board for the bridges have been provided as per standard guidelines of the relevant manuals.

1.8 PROTECTION WORKS FOR THE EMBANKMENT

Riprap at abutments of bridges is usually placed on the slopes under structure and around the corners of upstream and downstream openings and slopes of embankment to the extent where erosion of embankment is anticipated. Slope protection shall be provided on embankment slopes where parallel flow along embankment may occur. Protection works for openings of culverts shall be provided to guard against progressive erosion of embankment.

Figure-2: Catchment Area for Bridges

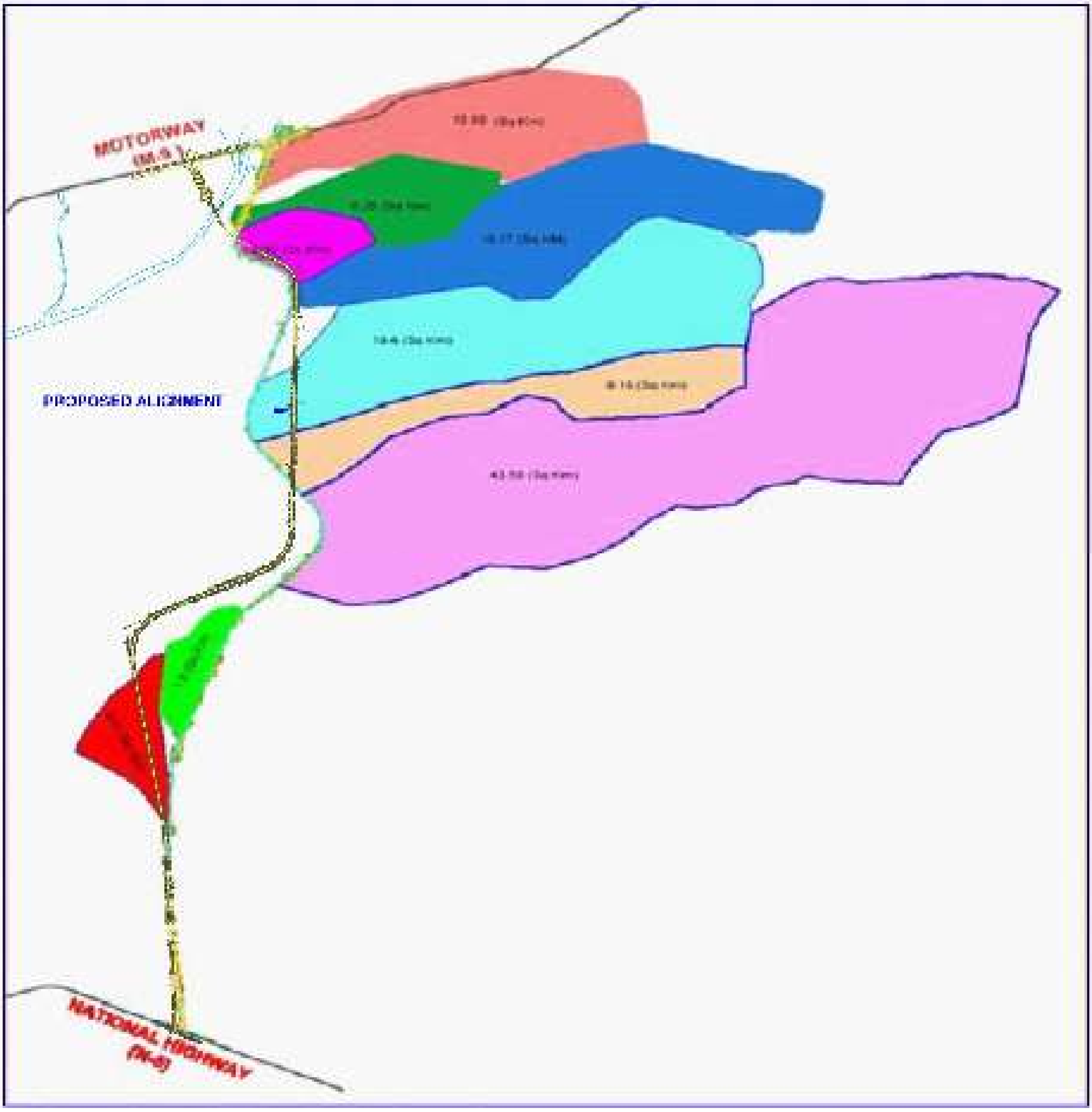


Figure-3: Mean Annual Rainfall PMD Map

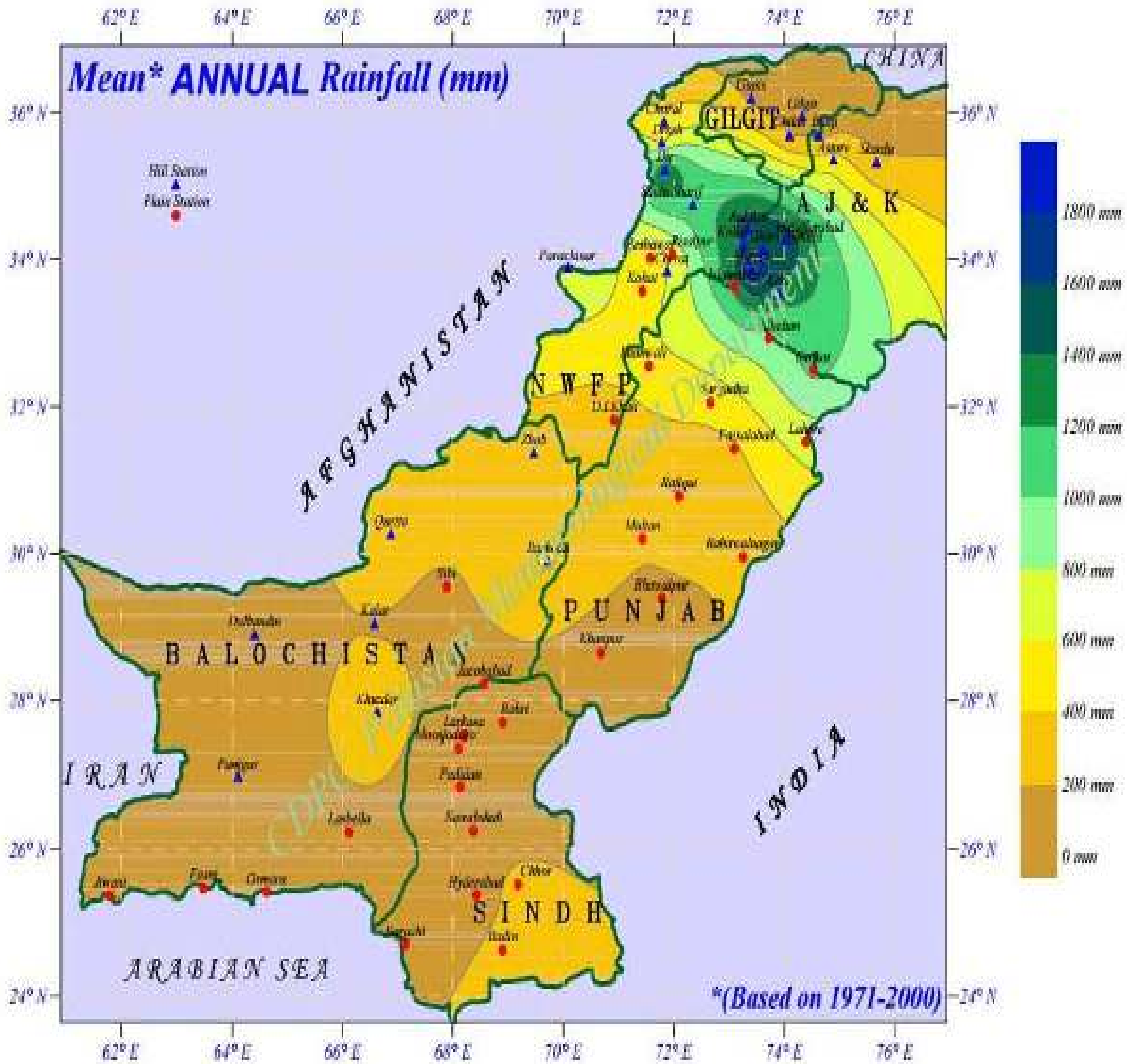


Table 2: Daily Maximum Rainfall Data of Karachi PMD Station

Sr No	Year	1	2	3	4	5	6	7	8	9	10	11	12	Annual
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	P24
1	1990	16.0	13.9	0.0	0.0	0.0	0.3	0.0	57.2	0.6	0.0	0.0	1.8	**57**
2	1991	3.0	19.5	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**20**
3	1992	13.0	8.0	0.9	0.0	0.0	0.0	370.0	91.7	20.8	0.0	0.0	0.0	**370**
4	1993	7.0	9.8	0.0	0.0	0.0	0.0	6.3	0.0	0.0	0.0	7.3	0.0	**10**
5	1994	2.2	2.5	0.0	0.0	0.0	0.0	39.3	38.2	30.0	0.0	0.0	12.0	**39**
6	1995	81.3	3.0	0.2	0.0	0.0	0.0	72.8	18.0	0.0	0.0	1.0	0.0	**81**
7	1996	13.0	33.2	0.7	0.0	0.0	30.0	9.8	0.5	0.0	0.0	0.0	0.0	**33**
8	1997	8.5	0.0	18.0	3.6	5.0	9.4	12.4	9.6	24.0	6.1	0.3	4.4	**24**
9	1998	5.9	2.0	0.7	0.0	0.0	19.0	7.5	0.4	0.0	24.1	0.0	0.0	**24**
10	1999	4.5	1.2	1.8	0.0	0.0	0.0	0.2	0.0	0.0	4.0	0.0	0.0	**5**
11	2000	19.0	0.0	0.0	0.0	0.0	0.0	0.0	14.4	0.0	0.0	0.0	0.0	**19**
12	2001	0.0	0.0	0.0	0.0	0.0	10.6	52.5	14.5	0.0	0.0	0.0	0.0	**53**
13	2002	0.0	2.4	0.0	0.0	0.0	0.0	0.0	47.0	0.0	0.0	0.5	0.3	**47**
14	2003	6.4	13.1	0.0	0.0	0.0	16.3	108.3	5.2	0.0	0.0	0.2	0.0	**108**
15	2004	5.0	0.0	0.0	0.0	0.0	0.0	1.0	5.6	0.0	26.3	0.0	4.3	**26**
16	2005	6.6	6.8	0.0	0.0	0.0	0.0	0.0	0.3	31.0	0.0	0.0	17.1	**31**
17	2006	0.0	0.0	0.0	0.0	0.0	0.0	65.9	56.1	20.3	0.0	3.1	36.1	**66**
18	2007	0.0	13.0	31.0	0.0	0.0	40.6	39.8	124.2	0.0	0.0	0.0	11.0	**124**
19	2008	8.0	0.0	1.0	0.0	0.0	0.0	54.0	16.4	0.0	0.0	0.0	10.2	**54**
20	2009	2.0	0.1	0.0	0.1	0.0	3.0	143.0	41.0	69.0	0.0	0.0	2.0	**143**
21	2010	0.0	0.5	0.0	0.0	0.0	77.1	38.3	62.0	20.3	0.4	0.0	0.0	**77**
22	2011	8.5	1.0	0.0	0.0	0.0	0.0	7.2	16.0	75.0	0.0	0.0	0.0	**75**
23	2012	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.3	48.7	0.0	0.0	**49**
24	2013	0.0	8.8	2.8	23.0	0.0	0.0	2.1	102.6	4.0	1.2	0.0	0.0	**103**
Average		**8.8**	**5.8**	**2.5**	**1.1**	**0.2**	**8.6**	**42.9**	**30.0**	**12.6**	**4.6**	**0.5**	**4.1**	**68.2**
Std Dev		**16.4**	**8.1**	**7.1**	**4.7**	**1.0**	**18.1**	**79.4**	**36.0**	**21.2**	**11.8**	**1.6**	**8.3**	**73.9**

Table 3: Annual Max. 24 Hr. Rainfall (mm) and Frequency Analysis

Sr. No.	Year	Max 24 hour Rainfall (Y)	Mean Rainfall (Ỳ	Deviation from Mean (Y- Ỳ)	(Y- Ỳ)^2	Σ(Y- Ỳ)^2	Std Dev
1	1990	57.2	68.2	-11.0	121.7	121.7	73.9
2	1991	19.5	68.2	-48.7	2374.7	2496.4	73.9
3	1992	370.0	68.2	301.8	91064.6	93561.0	73.9
4	1993	9.8	68.2	-58.4	3414.2	96975.2	73.9
5	1994	39.3	68.2	-28.9	837.0	97812.2	73.9
6	1995	81.3	68.2	13.1	170.8	97983.0	73.9
7	1996	33.2	68.2	-35.0	1227.2	99210.1	73.9
8	1997	24.0	68.2	-44.2	1956.4	101166.5	73.9
9	1998	24.1	68.2	-44.1	1947.5	103114.0	73.9
10	1999	4.5	68.2	-63.7	4061.6	107175.6	73.9
11	2000	19.0	68.2	-49.2	2423.7	109599.3	73.9
12	2001	52.5	68.2	-15.7	247.5	109846.8	73.9
13	2002	47.0	68.2	-21.2	450.7	110297.5	73.9
14	2003	108.3	68.2	40.1	1608.7	111906.3	73.9
15	2004	26.3	68.2	-41.9	1758.2	113664.5	73.9
16	2005	31.0	68.2	-37.2	1386.1	115050.6	73.9
17	2006	65.9	68.2	-2.3	5.4	115056.0	73.9
18	2007	124.2	68.2	56.0	3132.5	118188.6	73.9
19	2008	54.0	68.2	-14.2	202.5	118391.1	73.9
20	2009	143.0	68.2	74.8	5590.4	123981.5	73.9
21	2010	77.1	68.2	8.9	78.7	124060.2	73.9
22	2011	75.0	68.2	6.8	45.8	124106.0	73.9
23	2012	48.7	68.2	-19.5	381.5	124487.5	73.9
24	2013	102.6	68.2	34.4	1181.2	125668.7	73.9
Return Periods (Years)					25	50	100
Frequency Factor (K) for Gumbel Distribution					2.043	2.591	3.135
Design Rainfall-Different Return Periods (P24					219	260	300

Table-4a: Hydrological Parameters of Watersheds for Bridges and Sizing of Bridge Structures

Curve No, CN = 49

Potential Maximum Retention, S = (1000/CN) - 10

Direct Runoff or Excess Precipitation, Pe = (P-0.2*S)^2/(P+0.8*S)

Station (Km)	Area (Km^2)	Length of Channel (Km)	High Point (m)	Low Point (m)	Drop in Channel Bed Levels, (m)	Time of Concentration ,Tc (Hr)	Time to Peak, Tp (0.67 *Tc)	P (100 year, 24 hour Rainfall), mm	P (100 year, 24 hour Rainfall), in	Curve Number, CN	Potential Maximum Retention, S	Direct Runoff, Pe (in)	Peak Discharge (cumec)
9+672	(K4 Route)												
12+940	43.5	13.3	167	114	53	4.08	2.74	300	11.81	49	10.41	4.70	394.83
14+225	20.4	9.5	245	104	141	1.90	1.27	300	11.81	49	10.41	4.70	398.04
14+985 15+550	18	9	245	102	143	1.78	1.19	300	11.81	49	10.41	4.70	375.88
18+040	15.17	8.5	264	120	144	1.66	1.11	300	11.81	49	10.41	4.70	339.31
19+150	2.43	2.1	143	108	35	0.57	0.38	300	11.81	49	10.41	4.70	158.50
20+050	As per Site -At Malir Naddi												
Interchange on M9													

Table-4b: Hydrological Parameters of Watersheds for Bridges and Sizing of Bridge Structures

Station (Km)	Peak Discharge (cumec)	Manning 'n' Value	Width of Hydraulic Structure Required, m	Width of Hydraulic Structure Provided, m	Depth of Flow (m)	Area of Flow (m^2)	Wetted Perimeter (m)	Hydraulic Radius	R^(2/3)	Slope	SL^0.5	Velocity (m/sec)	Discharge from Manning Eq. (m^3/sec)
9+672	(K4 Route)												
12+940	394.83	0.035	93	100	1.29	122	97.03	1.25	1.16	0.010	0.10	3.24	394.83
14+225	398.04	0.035	94	90	1.27	121	97.36	1.24	1.15	0.010	0.10	3.30	398.04
14+985 15+550	375.88	0.035	91	90	0.99	91	93.92	0.97	0.98	0.022	0.15	4.13	375.88
18+040	339.31	0.035	87	90	1.05	92	89.56	1.03	1.02	0.016	0.13	3.67	339.30
19+150	158.50	0.035	59	60	0.86	52	61.60	0.84	0.89	0.015	0.12	3.08	158.50
20+050	As per Site -At Malir Naddi												
Interchange on M9													

Table-5a: Discharge Calculations for Box Culverts
Rainfall Intensity = 85 mm/hr

Sr. No.	Station (Km)	Rainfall Intensity, I (mm/hr)	Runoff Coefficient, C (m)	Drainage Area (Sq. m)	Drainage Area (hector)	Discharge (cumec)	10% increased Discharge (cumec)
1	3+160	Existing bridge to be widened (KWSB conduit)					
2	4+782	Existing Culvert to be widened					
3	5+168	Existing Culvert to be widened					
4	5+258	Existing Culvert to be widened					
5	5+422	Existing Culvert to be widened					
6	6+329	Existing Culvert to be widened					
7	6+612	Existing Culvert to be widened					
8	8+224	Proposed Culvert as per site					
9	9+300	Proposed Culvert as per site (Existing Nullah)					
10	10+525	85.00	0.25	100000	10	0.60	0.65
11	10+700	85.00	0.25	380000	38	2.26	2.49
12	10+830	85.00	0.25	1000000	100	5.95	6.55
13	11+145	85.00	0.25	880000	88	5.24	5.76
14	11+425	85.00	0.25	300000	30	1.79	1.96
15	11+800	Proposed Culvert as per Site (Existing Nullah)					
16	12+202	Proposed Culvert as per Site (Existing Nullah)					
17	13+995	Proposed Culvert as per Site (Existing Nullah)					
18	16+000	Proposed Culvert as per Site (Existing Nullah)					
19	16+255	Proposed Culvert as per Site (Existing Nullah)					
20	17+691	Proposed Culvert as per Site (Existing Nullah)					
21	17+770	Proposed Culvert as per Site (Existing Nullah)					
22	17+802	Proposed Culvert as per Site (Existing Nullah)					
23	17+824	Proposed Culvert as per Site (Existing Nullah)					
24	17+868	Proposed Culvert as per Site (PARCO Oil Lines)					
25	18+860	85.00	0.25	120000	12	0.71	0.79
26	18+800	Proposed Culvert as per Site					
27	19+500	Proposed Culvert as per Site					
28	20+200	85.00	0.25	560000	56	3.33	3.67
29	20+900	Proposed Culvert as per Site					

Table-5b: Size Calculations for Box Culverts

Sr. No	Station (Km)	Culvert Slope (m/m)	Width of Culvert m	Depth of Flow m	Area of Flow (m^2)	Wetted Perimeter, P (m)	Hydraulic Radius, R (m)	$R^{2/3}$ (m)	Velocity of Flow, m/sec (m^3/sec)	Culvert Capacity Q (m^3/sec)
1	3+160	Existing bridge to be widened (KWSB conduit)								
2	4+782	Existing Culvert to be widened								
3	5+168	Existing Culvert to be widened								
4	5+258	Existing Culvert to be widened								
5	5+422	Existing Culvert to be widened								
6	6+329	Existing Culvert to be widened								
7	6+612	Existing Culvert to be widened								
8	8+224	Proposed Culvert as per site								
9	9+300	Proposed Culvert as per site (Existing Nullah)								
10	10+525	0.01	1.00	0.29	0.29	1.59	0.18	0.32	2.70	0.79
11	10+700	0.01	1.50	0.52	0.78	2.55	0.31	0.46	3.80	2.98
12	10+830	0.01	3.00	0.57	1.70	4.13	0.41	0.55	4.61	7.85
13	11+145	0.01	3.00	0.52	1.56	4.04	0.39	0.53	4.42	6.91
14	11+425	0.01	1.50	0.44	0.66	2.39	0.28	0.43	3.55	2.36
15	11+800	Proposed Culvert as per Site (Existing Nullah)								
16	12+202	Proposed Culvert as per Site (Existing Nullah)								
17	13+995	Proposed Culvert as per Site (Existing Nullah)								
18	16+000	Proposed Culvert as per Site (Existing Nullah)								
19	16+255	Proposed Culvert as per Site (Existing Nullah)								
20	17+691	Proposed Culvert as per Site (Existing Nullah)								
21	17+770	Proposed Culvert as per Site (Existing Nullah)								
22	17+802	Proposed Culvert as per Site (Existing Nullah)								
23	17+824	Proposed Culvert as per Site (Existing Nullah)								
24	17+868	Proposed Culvert as per Site (PARCO Oil Lines)								
25	18+860	0.01	1.00	0.33	0.33	1.66	0.20	0.34	2.84	0.94
26	18+800	Proposed Culvert as per Site								
27	19+500	Proposed Culvert as per Site								
28	20+200	0.01	2.00	0.53	1.07	3.07	0.35	0.49	4.12	4.40
29	20+900	Proposed Culvert as per Site								

Table-6: Protection Work along the Embankment

S. No.	Chainages	Remarks
1	4+300 to 4+590	One Side
2	5+300 to 6+120	One Side
3	10+460 to 11+500	Both Sides
4	11+680 to 11+860	Both Sides
5	12+640 to 12+780	One Side
6	15+980 to 16+360	Both Sides
7	17+680 to 17+840	Both Sides
8	18+900 to 19+750	Both Sides

Annexure – A

Average Runoff Coefficients for Rational Formula

Topography and Vegetation	Soil Texture		
	Open sandy loam	Clay and silty loam	Tight clay
Woodland			
Flat	0.10	0.30	0.40
Rolling	0.25	0.35	0.50
Hilly	0.30	0.50	0.60
Pasture			
Flat	0.10	0.30	0.40
Rolling	0.16	0.36	0.55
Hilly	0.22	0.42	0.60
Cultivated land			
Flat	0.30	0.50	0.60
Rolling	0.40	0.60	0.70
Hilly	0.52	0.72	0.81

Ref: Design of Bridge Structures by T.R.Jagadesh, M.A. Jayaram, Page 11.

Annexure - B

TABLE 3-18 Runoff Curve Numbers (average watershed condition, $I_a = 0.2S$)

Land Use Description	Average % impervious[b]	Curve Numbers for Hydrologic Soil Group A	B	C	D
Fully developed urban areas[a] (vegetation established)					
Lawns, open spaces, parks, golf courses, cemeteries, etc.					
Good condition; grass cover on 75% or more of the area		39	61	74	80
Fair condition; grass cover on 50% to 75% of the area		49	69	79	84
Poor condition; grass cover on 50% or less of the area		68	79	86	89
Paved parking lots, roofs, driveways, etc.		98	98	98	98
Streets and roads					
Paved with curbs and storm sewers		98	98	98	98
Gravel		76	85	89	91
Dirt		72	82	87	89
Paved with open ditches		83	89	92	93
Commercial and business areas	85	89	92	94	95
Industrial districts	72	81	88	91	93
Row houses, town houses, and residential with lots sizes 1/8 acre or less	65	77	85	90	92
Residential: average lot size					
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acre	12	46	65	77	82
Developing urban areas[c] (no vegetation established)					
Newly graded area		77	86	91	94
Western desert urban areas					
Natural desert landscaping (pervious area only)[f]		63	77	85	88
Artificial desert landscaping		96	96	96	96

Land Use Description	Treatment or Practice[d]	Hydrologic Condition	Curve Numbers for Hydrologic Soil Group A	B	C	D
Cultivated agricultural land						
Fallow	Straight row or bare soil		77	86	91	94
	Conservation tillage	Poor	76	85	90	93
	Conservation tillage	Good	74	83	88	90
Row crops	Straight row	Poor	72	81	88	91
	Straight row	Good	67	78	85	89
	Conservation tillage	Poor	71	80	87	90
	Conservation tillage	Good	64	75	82	85
	Contoured	Poor	70	79	84	88
	Contoured	Good	65	75	82	86
	Contoured and	Poor	69	78	83	87
	conservation tillage	Good	64	74	81	85

(continued)

TABLE 3-18 Runoff Curve Numbers (average watershed condition, $I_a = 0.2S$) (*Continued*)

Land Use Description	Treatment or Practice[a]	Hydrologic Condition	Curve Numbers for Hydrologic Soil Group			
			A	B	C	D
	Contoured and terraces	Poor	66	74	80	82
	Contoured and terraces	Good	62	71	78	81
	Contoured and terraces	Poor	65	73	79	81
	and conservation tillage	Good	61	70	77	80
Small grain	Straight row	Poor	65	76	84	88
	Straight row	Good	63	75	83	87
	Conservation tillage	Poor	64	75	83	86
	Conservation tillage	Good	60	72	80	84
	Contoured	Poor	63	74	82	85
	Contoured	Good	61	73	81	84
	Contoured and	Poor	62	73	81	84
	conservation tillage	Good	60	72	80	83
	Contoured and terraces	Poor	61	72	79	82
	Contoured and terraces	Good	59	70	78	81
	Contoured and terraces	Poor	60	71	78	81
	and conservation tillage	Good	58	69	77	80
Close-seeded	Straight row	Poor	66	77	85	89
legumes	Straight row	Good	58	72	81	85
rotations	Contoured	Poor	64	75	83	85
meadows[c]	Contoured	Good	55	69	78	83
	Contoured and terraces	Poor	63	73	80	83
	Contoured and terraces	Good	51	67	76	80
Noncultivated agricultural land						
Pasture or range	No mechanical treatment	Poor	68	79	86	89
	No mechanical treatment	Fair	49	69	79	84
	No mechanical treatment	Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	Contoured	Fair	25	59	75	83
	Contoured	Good	6	35	70	79
Meadow		—	30	58	71	78
Forestland—grass or		Poor	55	73	82	86
orchards—evergreen		Fair	44	65	76	82
deciduous		Good	32	58	72	79
Brush		Poor	48	67	77	83
		Fair	35	56	70	77
		Good	30	48	65	73
Woods		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads		—	59	74	82	86
Forest-range						
Herbaceous		Poor	*	80	87	93
		Fair		71	81	89
		Good		62	74	85
Oak-aspen		Poor		66	74	79
		Fair		48	57	63
		Good		30	41	48

TABLE 3–18 Runoff Curve Numbers (average watershed condition, $I_a = 0.2S$) (*Continued*)

Land Use Description	Treatment or Practice[a]	Hydrologic Condition	Curve Numbers for Hydrologic Soil Group A	B	C	D
Juniper		Poor	[g]	75	85	89
		Fair		58	73	80
		Good		41	61	71
Sage-grass		Poor		67	80	85
		Fair		51	63	70
		Good		35	47	55

[a]For land uses with impervious areas, curve numbers are computed assuming that 100% of runoff from impervious areas is directly connected to the drainage system. Pervious areas (lawn) are considered to be equivalent to lawns in good condition. The impervious areas have a *CN* of 98.

[b]Includes paved streets.

[c]Use for the design of temporary measures during grading and construction. Impervious area percent for urban areas under development vary considerably. The user will determine the percent impervious. Then using the newly graded area *CN*, the composite *CN* can be computed for any degree of development.

[d]For conservation tillage poor hydrologic condition, 5 to 20% of the surface is covered with residue (less than 750-lb/acre row crops or 300-lb/acre small grain). For conservation tillage good hydrologic condition, more than 20% of the surface is covered with residue (greater than 750-lb/acre row crops or 300-lb/acre small grain).

[e]Close-drilled or broadcast.

For noncultivated agricultural land:
Poor hydrologic condition has less than 25% ground cover density.
Fair hydrologic condition has between 25 and 50% ground cover density.
Good hydrologic condition has more than 50% ground cover density.

For forest-range:
Poor hydrologic condition has less than 30% ground cover density.
Fair hydrologic condition has between 30 and 70% ground cover density.
Good hydrologic condition has more than 70% ground cover density.

[f]Composite *CN*'s for natural desert landscaping should be computed using Figure 3-21 based on the impervious area percentage (*CN* = 98) and the pervious area *CN*. The pervious area *CN*'s are assumed equivalent to desert shrub in poor hydrologic condition.

[g]Curve numbers for group A have been developed only for desert shrub.

3.7.6 Antecedent Soil Moisture Condition

Antecedent soil moisture is known to have a significant effect on both the volume and rate of runoff. Recognizing that it is a significant factor, SCS developed three antecedent soil moisture conditions, which were labeled I, II, and III. The soil condition for each is as follows:

Condition I:	Soils are dry but not to wilting point; satisfactory cultivation has taken place
Condition II:	Average conditions
Condition III:	Heavy rainfall, or light rainfall and low temperatures have occurred within the last five days; saturated soil

Annexure - C
Manning coefficient of roughness

Type of lining	condition	n
Glazed coating of enamel	In perfect order	0.010
Timber	(a) Plane boards carefully laid	0.014
	(b) Plane Boards inferior workmanship or aged,	0.016
	(c) None-plane boards carefully laid	0.016
	(d) Non-plane boards inferior workmanship or aged	0.018
Masonry	(a) Neat cement plaster	0.013
	(b) Sand and cement plaster	0.015
	(c) Concrete, Steel troweled	0.014
	(d) Concrete, Wood troweled	0.015
	(e) Brick in good condition	0.015
	(f) Brick in rough condition	0.017
	(g) Masonry in bad condition	0.020
Stone work	(a) Smooth, dressed ashlar	0.015
	(b) Rubble set in cement	0.017
	(c) Fine, well packed gravel	0.020
Earth	(a) Regular surface in good condition	0.020
	(b) In ordinary condition	0.025
	(c) With Stones and weeds	0.030
	(d) In poor condition	0.035
	(e) Partially obstructed with debris or weeds	0.050
Steel	(a) Welded	0.013
	(b) Riveted	0.017
	(c) Slightly tuberculated	0.020
	(d) Cement Mortar lined	0.011
Cast Iron & Ductile Iron	(a) Unlined	0.013
	(b) cement mortar lined	0.011
Asbestos Cement		0.012
Plastic (Smooth)		0.011