5 TEST FOR EVALUATING LOCAL SCOURING

5.1 Objectives

The test aims to evaluate the extent of the local scouring around the distributor for determining the penetration of the foundation and the range of the protection works against scouring.

In the test, time variation of maximum scour depth and the range of scouring upstream and downstream of the cross structure and development of scouring with bed lowering downstream of the cross structure were observed.

5.2 Test Conditions

5.2.1 Model

A straight channel with 15 m long, 1 m wide and 0.45 m deep is used. Undistorted model with the scale of 1/75 is used. Bed slope upstream of the cross structure is 1/570 and that of downstream is 1/215. Sand for the movable bed has 0.16 mm in average diameter.

5.2.2 Law of Similarity

Froude's law of similarity is applied and the reduced ratio of each factor is shown in Table-5.1

Table-5.1 Reduced scales of Basic Quantities by Froude's Law of Similarity

	Model Dimensions and Flow Items	Dimensions	Reduced Ratio Ratio	Scale
Geometrical Items	Horizontal (X)	L	Xr	1 : 75
	Vertical (h) (Water Depth, Elevation)	L	hr	1 : 75
	Gradient (h / X)	-	$hr \cdot Xr^{-1}$	1 : 1
	Area (A)	L^2	hr•Xr	1 : 5,625
	Volume (Vm)	L^3	$hr \cdot Xr^2$	1 : 421,875
Flow Items	Froude's Number (Fr)	-	1	1 : 1
	Velocity (V)	L•T-1	$hr^{1/2}$	1 : 8.66
	Discharge (Q)	L3•T-1	$Xr \cdot hr^{3/2}$	1 : 48,713
	Time (T)	T	$Xr \cdot hr^{-1/2}$	1 : 8.66
	Pressure (P)	$F \cdot L^{-2}$	hr	1 : 75
	Roughness Coefficient (n)	$L^{-1/3} \cdot T$	$hr^{2/3} \cdot Xr^{-1/2}$	1 : 2.05
	Discharge Coefficient (C)	$L^{1/2} \cdot T^{-1}$	$Xr^{-1/2} \cdot hr^{1/2}$	1 : 1
	Tractive Force (z)	$F \cdot L^{-2}$	hr	1 : 75
	Energy (E)	F•L	hr^4	1 : 31,640,625
	Momentum (mv)	F•T	$hr^{7/2}$	1 : 3,653,544

5.2.3 Discharge and Quantity of Supplied Sand

Quantity of sand supplied in the test is determined by the sediment transportation equation obtained by the preparatory test. Discharge of 1,750 cumecs is applied for the series of the test, which is 70% of the peak design flood.

	Prototype	Distorted Model	Extra Model
Discharge	1,750 m3/sec	35.9 l/sec	14.7 l/sec
Width of the channel	183 mm	2,44 m	1.00 m

5.2.4 Period of the test

Period of the test is determined based on the time for scouring depth and length being stable and stabilized bed configuration. It is 30 to 60 minutes.

5.2.5 Test Items

The test items are shown in Table-5.2.

Table-5.2 Purpose and Condition of the Tests

Purpose Test No.		Bed gradient D/S of the Cross Structure	Bed lowering D/S of the Cross Structure (m)	(feet, inches)	Discharge (m3/s)	(cusec)	Sediment Concentration (%)
Preparatory test							
1		1/215	0 m		400	14,098	0
					1,500	52,868	0
					2,500	88,113	0
Evaluating local scouring around the structure							
2		1/215	0 m		1,750	61,679	0.783
3	prototype	1/215	3.75 m	12.3'	1,750	61,679	0.783
	model		5 cm	2"	14.7 lit/s		
4	prototype	1/215	7.5 m	25'	1,750	61,679	0.783
			10 cm	4"	14.7 lit/s		
Evaluating protection works							
5	prototype	1/215	0 m		1,750	61,679	0.783
					14.7 lit/s		
Examining section of cross structure							
6	prototype	1/215	0 m		1,750	61,679	0.783
					14.7 lit/s		
Evaluating local scouring around the structure							
7		1/215	0 m		1,750	61,679	0
8	prototype	1/215	3.75 m	12.30'	14.7 lit/s		0
			5 cm	1.97"			

5.3 The Extra Model Test

5.3.1 Objectives

To confirm the extent of the scouring quantitatively for determining the penetration depth of the foundation and are of gabions. The applied model is non-distorted with its scale of 1/75.

5.3.2 Result

The flow condition are shown in Photo-11 through -14.

The result of the test is shown in Fig.-5.1 to 5.4.

Fig.-5.1 Result of Extra Model Test for Diversion Weir

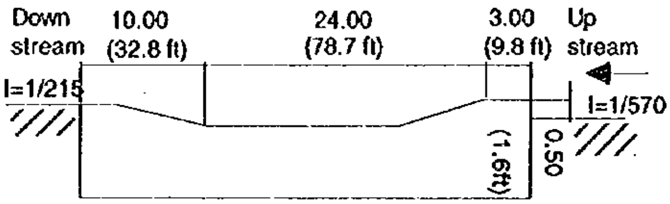
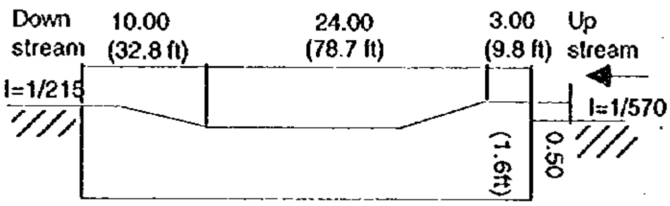
Test No.	Purpose	Typical Cross Section	Result
1	Preparatory Test		No serious scouring upstream and downstream of the weir occurred at the discharge of 400 m^3/sec even without sand supply. At the discharge of 1,500 m3/sec, scouring developed upstream and downstream of the weir up to 1.5 - 2.25 m deep. At the peak flood discharge (2,500 m^3/sec), scouring developed about 6.25 m deep and about 15 m long upstream of the weir and about 2.25 m deep and about 30 m long downstream. Extent of scouring decreased by the bed aggradation when sand supplied. Based on the result, discharge in the model test was determined to be 1.750 m^3/sec, 70 % of the design peak flood. Duration for the test was determined until the scoured depth being constant with sand supply.
2	Test for Confirmation of Scouring around the Cross Structure		1.5 m deep scouring was observed down stream of the weir just after starting the test. The scouring up stream of the weir reached about 2.25 m at the maximum and about 2.25 m long. It reached about 2.25 m deep and 13 m long down stream of the weir 10 minutes after starting the test, which is equivalent to 1.44 hours at the site. After that, extent of scouring decrease in accordance with the river bed aggradation up stream of the weir. Sediment deposited in the dissipater of the weir 20 minutes after starting the test, equivalent to 2.88 hours at the site.

Fig.-5.2 Result of Extra Model Test for Diversion Weir

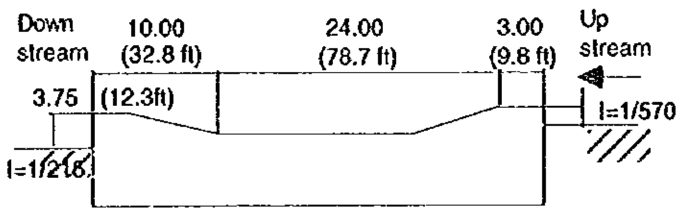
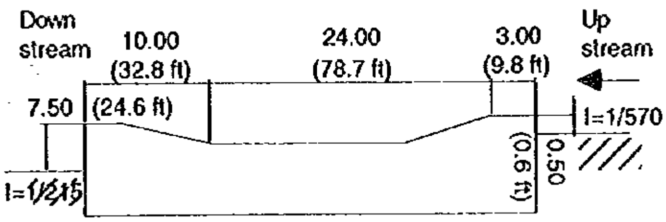
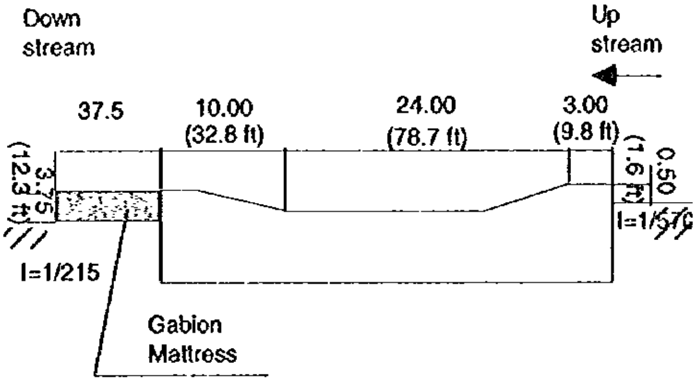
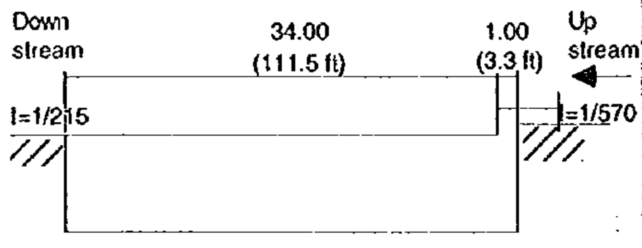
3	Test for Confirmation of Scouring around the Cross Structure		Serious scouring had developed down stream of the weir from just after starting the test. Scouring depth reached to 11.25 m from the initial bed level after 5 minutes equivalent to 17 - 26 minutes at the site. Then, the depth of scouring increased and it reached 16.5 m deep after 25 minutes and 41 m long equivalent to 43 minutes at the site. Scoured depth decreased gradually with a little extent of fluctuation, then it because steady after 60 minutes, equivalent to 8.66 hours at the site. Finally, the depth of scouring was 9.75 m and 37.5 m long.
4	Test for Confirmation of Scouring around the Cross Structure		Serious scouring was developed down stream of the weir just after starting the test. About 10 - 15 m deep scouring from the initial channel bed developed down stream of the weir after 2 - 3 minutes, equivalent to 17 - 26 minutes at the site. After that, the scouring reached down to the bottom of the channel within 5 minutes from the start, equivalent to 43 minutes at the inset resulting to be impossible to measuring the depth of scouring. Then, the length of scouring down stream of the weir developed about 45 m at the maximum after 20 minutes, equivalent to 2.88 hours at the site. At last, the scouring length decreased and became steady at about 37.5 m long after 10 minutes, equivalent to 10.1 hours at the site.

Fig.-5.3 Result of Extra Model Test for Diversion Weir

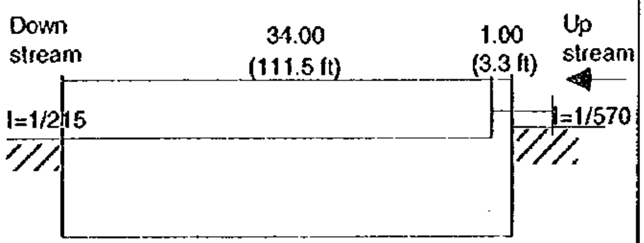
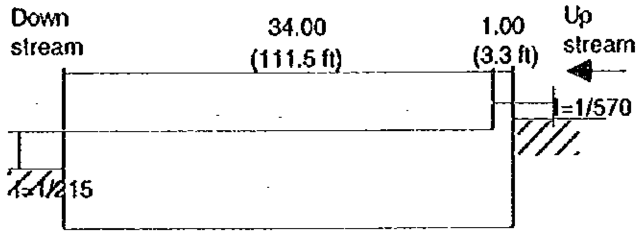
<table>
<tr>
<td>5</td>
<td>Test for Protection against Scouring</td>
<td>
</td>
<td>Serious scouring was developed down stream end of gabions placed in down stream of the weir just after the start of the test. About 3.75 m deep of the scouring from the initial bed level developed after 2 - 3 minutes equivalent to 13 - 26 minutes at the site and scouring also developed beneath the gabions at the same depth.

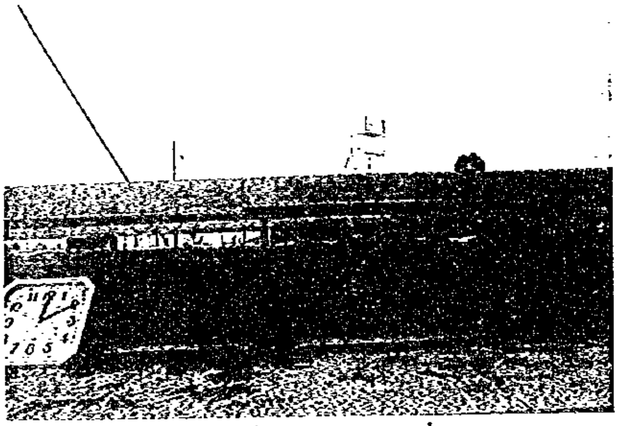
Settlement of the gabions started from downstream-most, and extended toward upstream one by one. Sand under the gabions was scoured with the settlement of the gabions. The scouring, however, was not increased and it was confirmed gaabions were effective as the countermeasure against scouring.</td>
</tr>
<tr>
<td>6</td>
<td>Test for Different Type of the Cross Structure</td>
<td>
</td>
<td>As it was judged that diversion of cross structure would be less effective when heavy sedimentation accumulated in the dissipater of the weir, reduction of sediment accumulation in the dissipater was examined by changing the cross-section of the weir.

It was also observed that the channel bed down stream of the weir was raised in accordance with the channel bed aggradation up steam of the weir and sediment was accumulated in the dissipater.

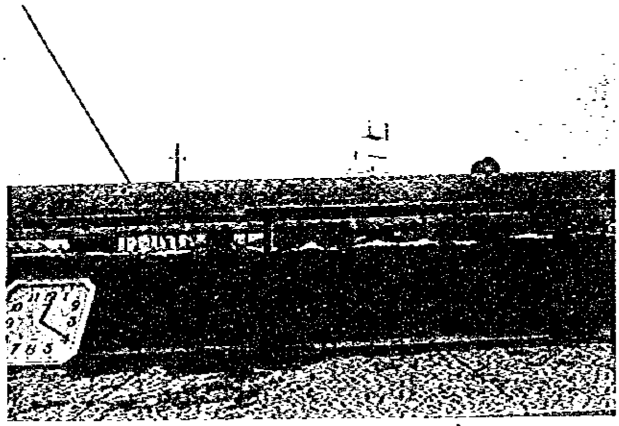
It was concluded that accumulation of sediment in the dissipater tends to increase with the bed aggradation down stream of the weir. In such case, it is difficult to remove the sedimentation by changing the cross section of the weir.</td>
</tr>
</table>

Fig.-5.4 Result of Extra Model Test for Diversion Weir

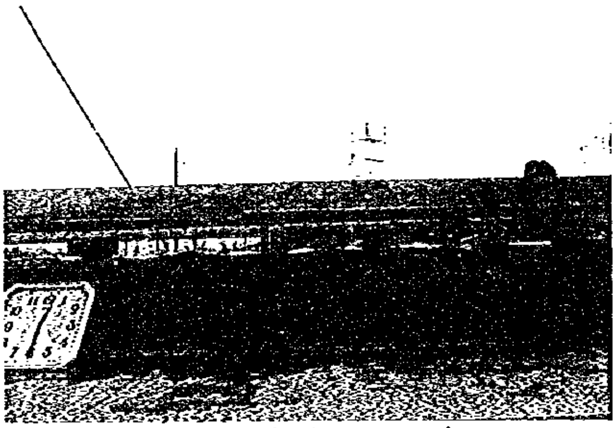
7	Test for Confirmation of Scouring around the Cross Structure		The purpose of the test without sand supply, is to confirm the sedimentation in the dissipater when bed down stream of the weir is lowering. Scouring was observed up stream and down stream of the weir instead of the accumulation of sediment in the dissipater because of decreased sediment from up stream. Maximum scoured depth was about 3.75 m up stream of the weir and about 1.8 m down stream of the weir. Therefore, protection to the scouring is necessary since the scouring dovelops the weir when the sediment accumulation is a little in the dissipater.
8	Test for Confirmation of Scouring around the Cross Structure		This test without sand supply was performed to examine the scouring when the bed lowered down stream of the weir. The bed lowered 3.75 m from the initial bed level same to the model test No.3. Scoured down stream was about 13.5 m and its length was about 53 m at the end of the test. It is assumed that the extent of scouring down stream of the weir might be considerally large with lowered bed down stream and less supply of sand.



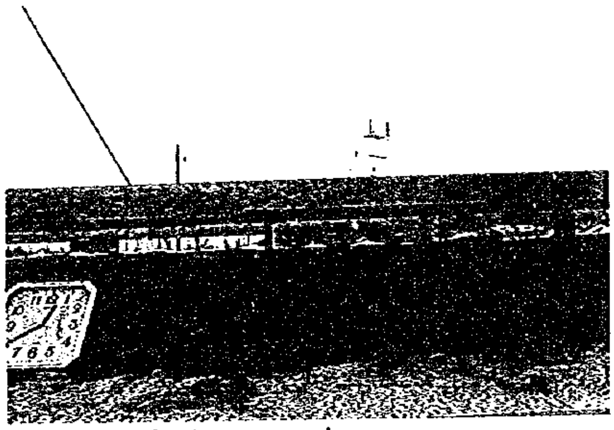
1) 10 minutes passed.



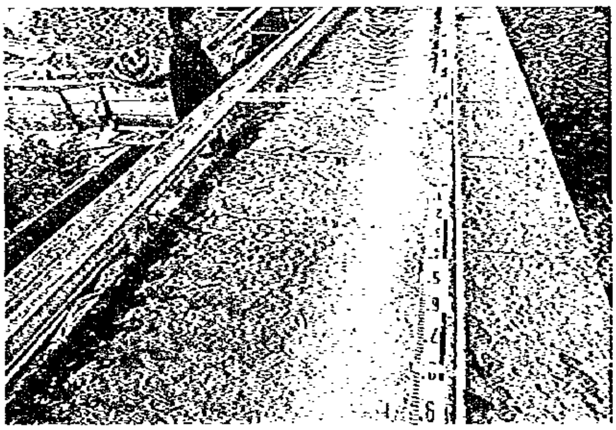
2) 20 minutes passed.



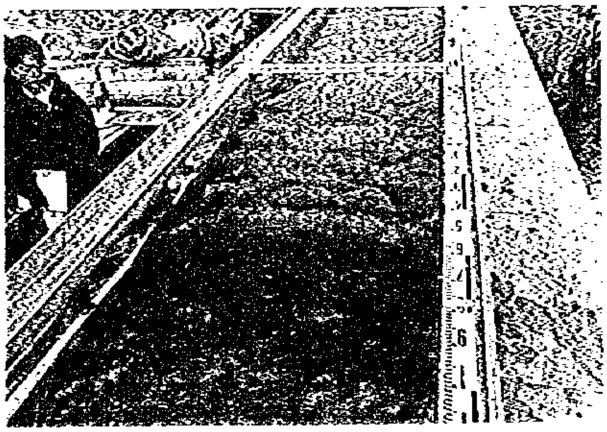
3) 30 minutes passed.



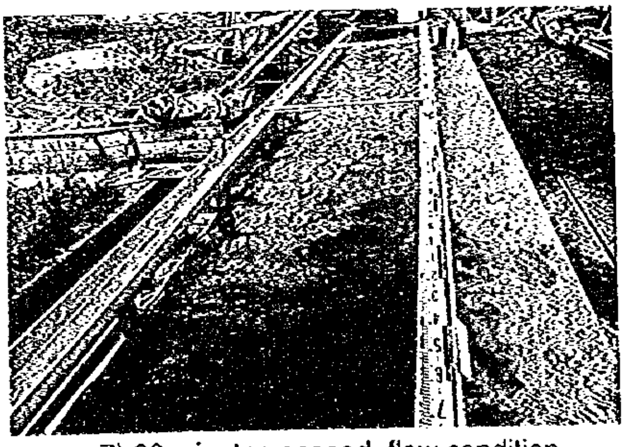
4) 40 minutes passed,
the dissipator is filled up with sediment.



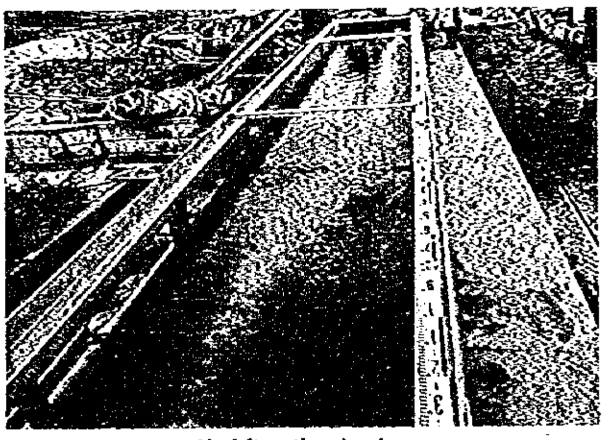
5) 10 minutes passed, flow condition.



6) 20 minutes passed, flow condition.

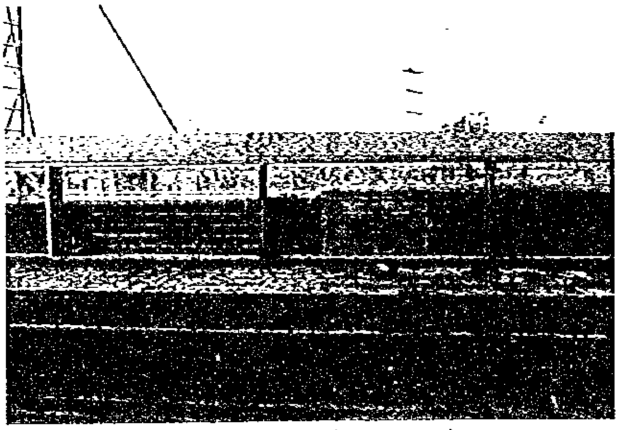


7) 30 minutes passed, flow condition.

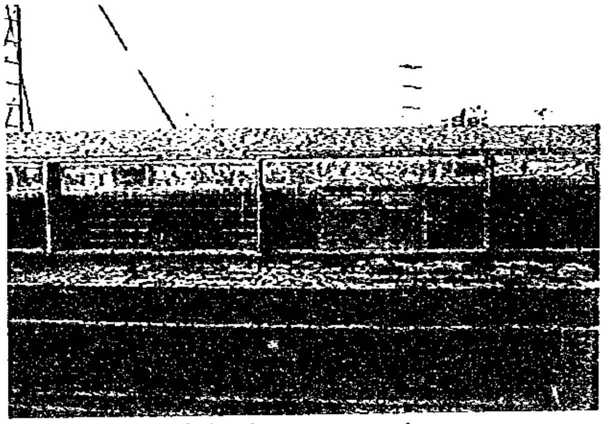


8) After the test.

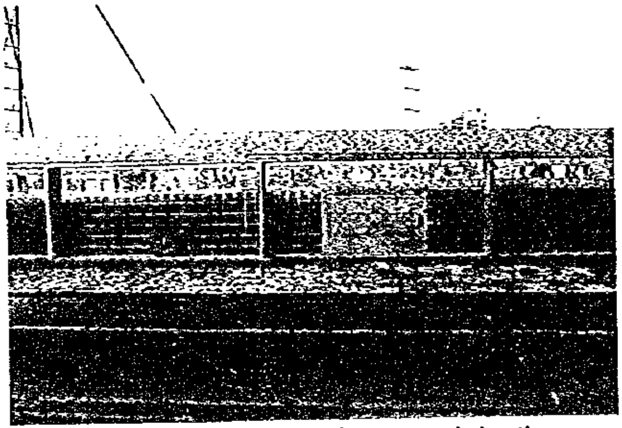
Photo-11 Flow in the Extra Model Test without bed degradation in the downstream channel. (Case.2)



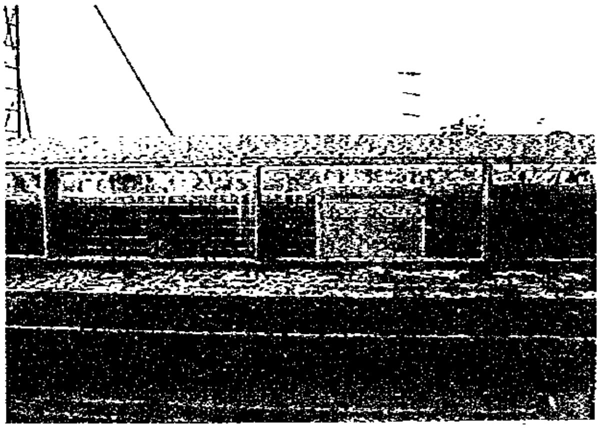
1) 30 seconds passed.



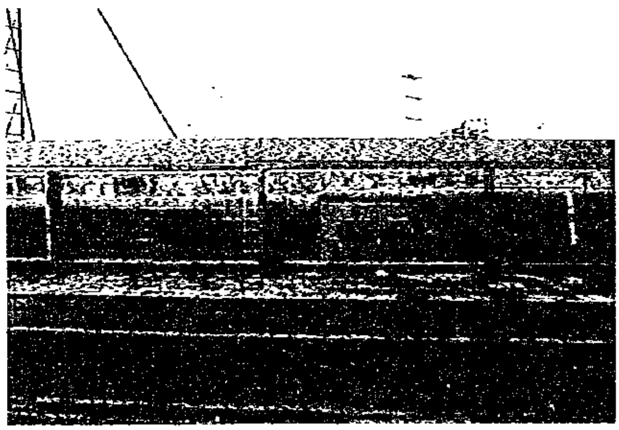
2) 1 minute passed.



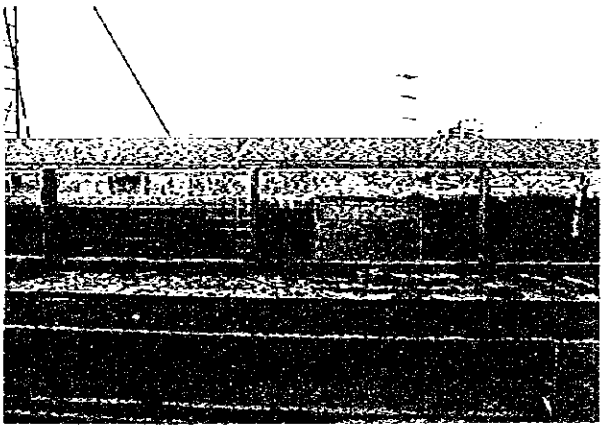
3) 2 minutes passed, scoured depth 7.5m (24.6 feet)



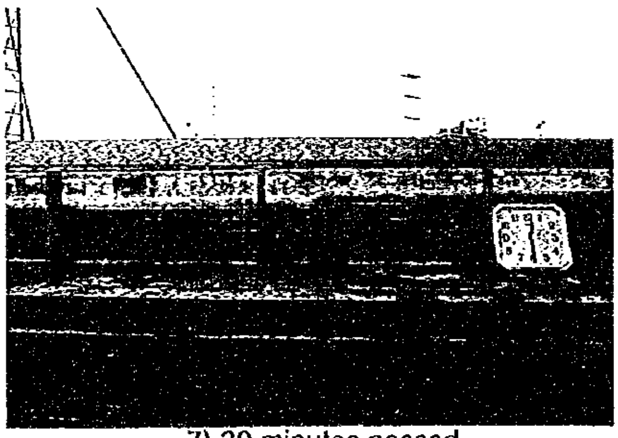
4) 5 minutes passed.



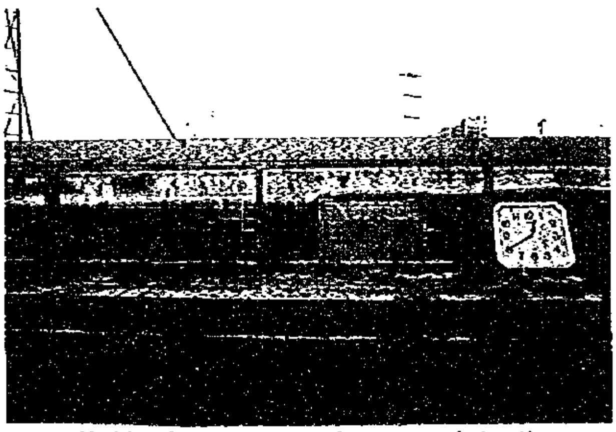
5) 10 minutes passed, scoured depth 11m (36.1 feet)



6) 20 minutes passed.

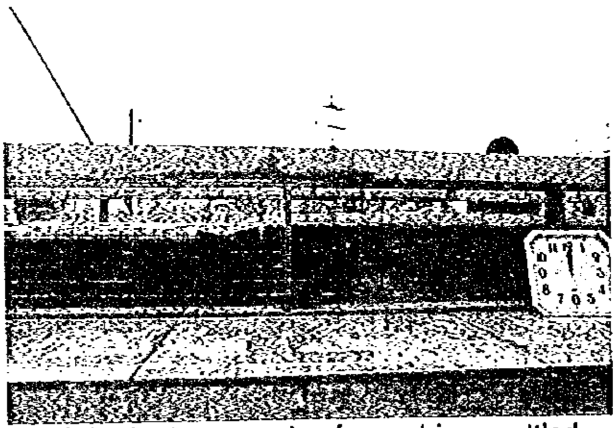


7) 30 minutes passed.

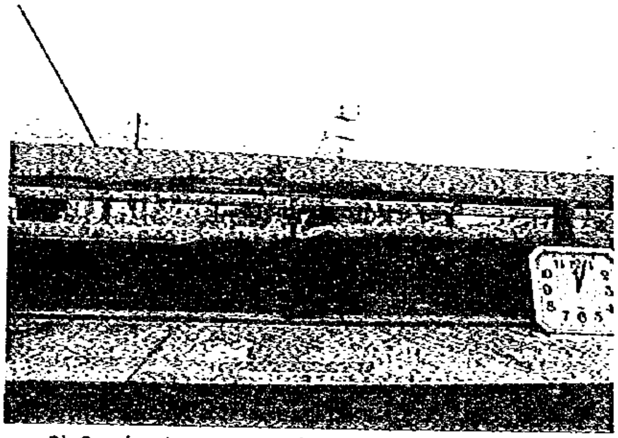


8) 40 minutes passed, scoured depth 11m (36.1 feet)

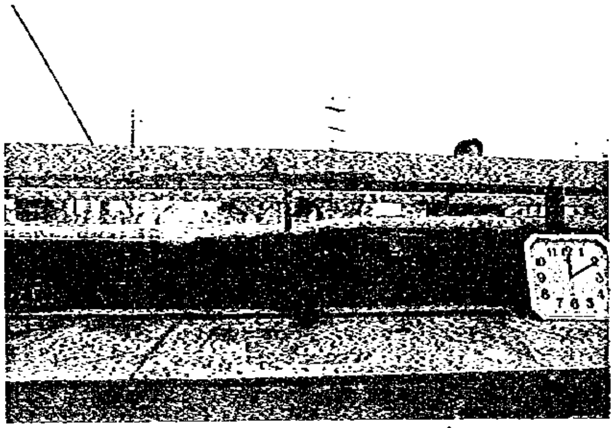
Photo-12 Flow in the Extra Model Test with bed degradation of 3.75 m (12.3 feet). (Case. 3)



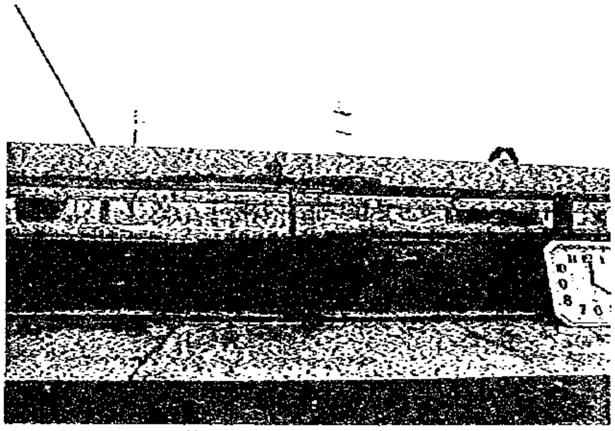
1) 1 minute passed, a few gabions settled down 4m (13 feet)



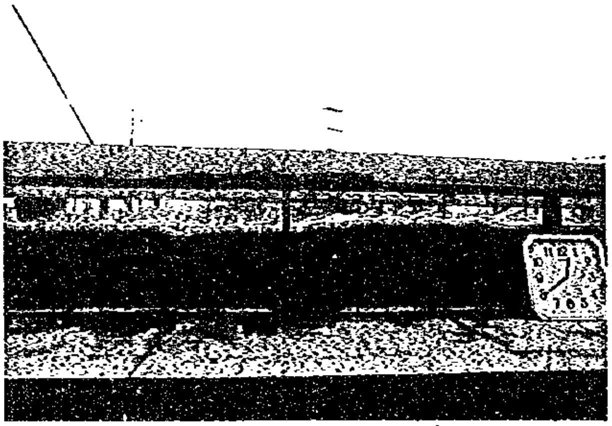
2) 3 minutes passed, most gabions settled down 4m (13 feet)



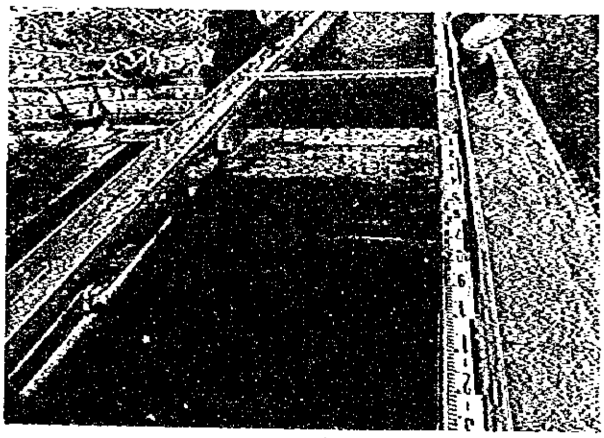
3) 10 minutes passed.



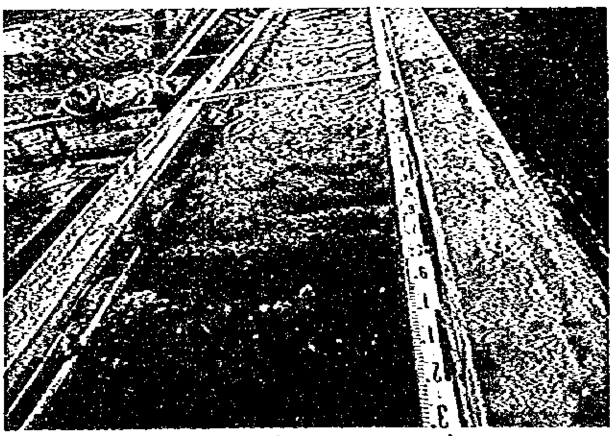
4) 20 minutes passed.



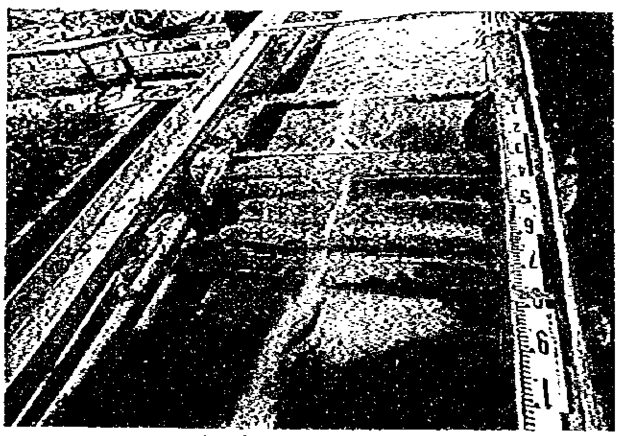
5) 40 minutes passed.



6) Before the test.

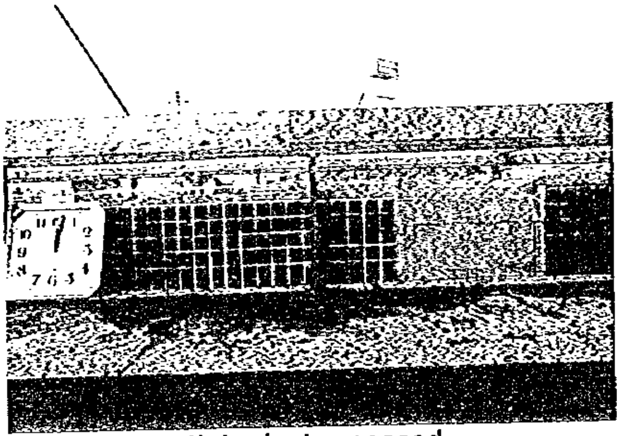


7) 15 minutes passed.

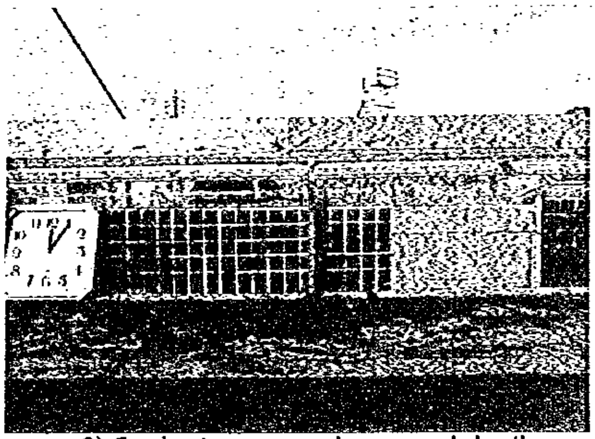


8) After the test.

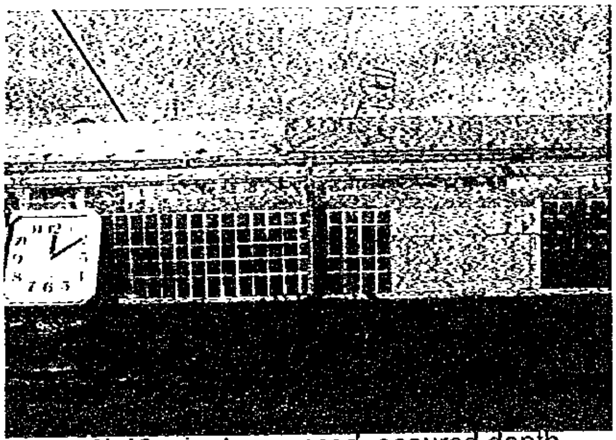
Photo-13 Flow in the Extra Model Test with gabion protection on the degraded bed.



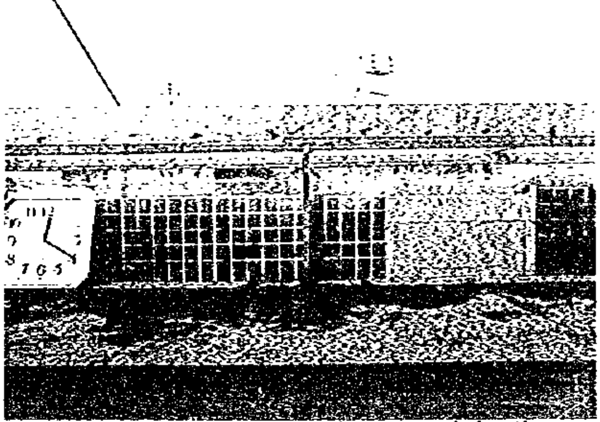
1) 1 minutes passed,



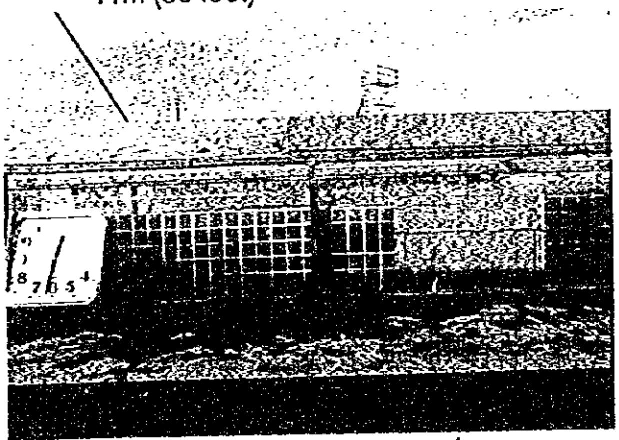
2) 5 minutes passed, scoured depth 7.5m (24.6 feet)



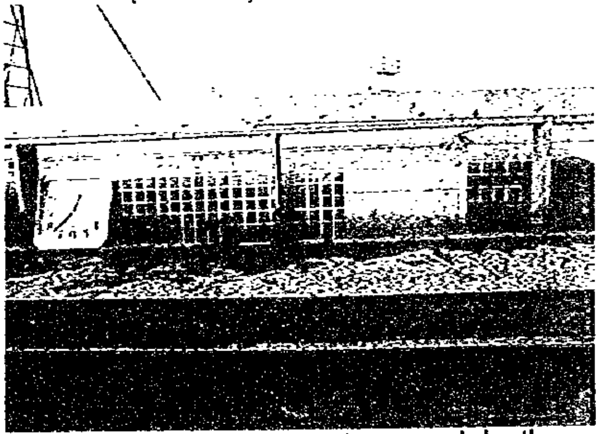
3) 10 minutes passed, scoured depth 11m (36 feet)



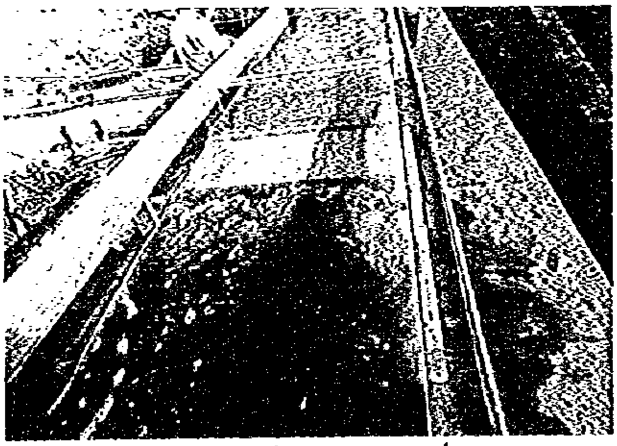
4) 20 minutes passed, scoured depth 15m (49.2 feet)



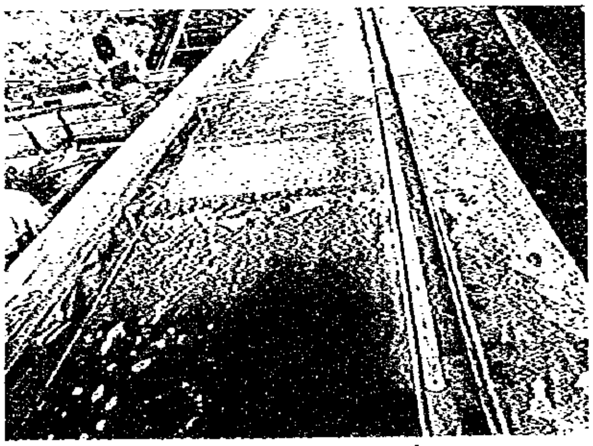
5) 32 minutes passed.



6) 38 minutes passed, scoured depth 22m (72 feet)



7) 10 minutes passed.



8) 38 minutes passed.

Photo-14 Flow in the Extra Model Test with bed degradation of 3.75m (12.3 feet), with sand supply.

6 CONCLUSION

6.1 Sediment transportation equation

It was confirmed that the sediment transportation equation to maintain the river bed in the condition of dynamic equilibrium on the distorted model can be obtained by the following formula.

$$\frac{q_s}{u_* \cdot d} = 8.37\tau_*^{1.78}$$

where,

q_s : Volume of sediment in the unit width, (m^3/sec/m)

u_* : Function velocity (m/sec)

d: Mean particle size of bed material (m)

τ_* : Dimension less tractive force

S : unit weight of bed material in water (g/cm^3)

The concentrate of the sediment is 1.1 % to maintain the riverbed in equilibrium in the up stream section (I=1/143) of the distorted three dimensioned model with the discharge of 1,000 m^3/sec.

6.2 The Distributor

6.2.1 The Function of the Distributor

Flow capacity of each and its diagram are shown in Table-6.1 and Fig.-6.1 respectively. The test results are tabulated in Fig.-6.2 to 6.5.

The shares of flood distribution was shown cyclic changes in accordance with riverbed alteration by the hydraulic model test.

The recommended type of the distributor is a like the Case 3 of the model test, which has the cross structure to fix the channel bed elevation and the guide walls to draw the diverted flow to each channel. This type of the distributor shows the longer cycle of the bed alteration because rapid variation of the bed is reduced at the apex by the distributor.

In addition to this, it is easy to know the change of flow direction in the next flood. In other words, the function of sharing flood flows could be maintained of the maintenance works for flattering the river bed up stream of the cross structure.

Table-6.1 Flow Capacities of Main Wahs

Main Branch /sec)	Name of Discharge Wah {cusec}	Width of wah (m) {feet}	Depth (m) {feet}	River bed Gradient {sec/ft^3}	Manning's Roughness Coefficient (sec/m$^{1/3}$)	Velocity (m / sec) {ft / sec}	(m^3
North	Talha	15	1.5	1 / 300	0.025	2.68	60
		{49.2}	{4.92}	{0.037}	{8.79}	(2,115)	
	Moldi	40	1.5	1 / 300	0.025	2.88	173
		{131.1}	(4.92}	{0.037}	{9.44}	{6,097)	
	Behu	25	1.5	1 / 300	0.025	1.81	105
		{82.0}	{4.92}	{0.037}	{5.93}	3,700	
	Sharti	100	0.8	1 / 300	0.025	1.97	158
		{327,9}	{2.6}	{0.037}	{6.46}	{5,569}	
South	Darel	30	1.0	1 / 300	0.025	2.21	66
		{98.4}	{3.28}	{0.037}	{7.25}	{2,326}	
	Sirag	300	0.8	1 / 300	0.025	1.98	476
		{983.6}	{2.62}	(0.037}	{3.28}	{16,777}	
Escape	Bhakker	150	0.8	1 / 300	0.025	1.98	237
		{491.8}	{2.62}	(0.037}	{3.28}	{8,353}	
Total	1,513						
	{53,326}						

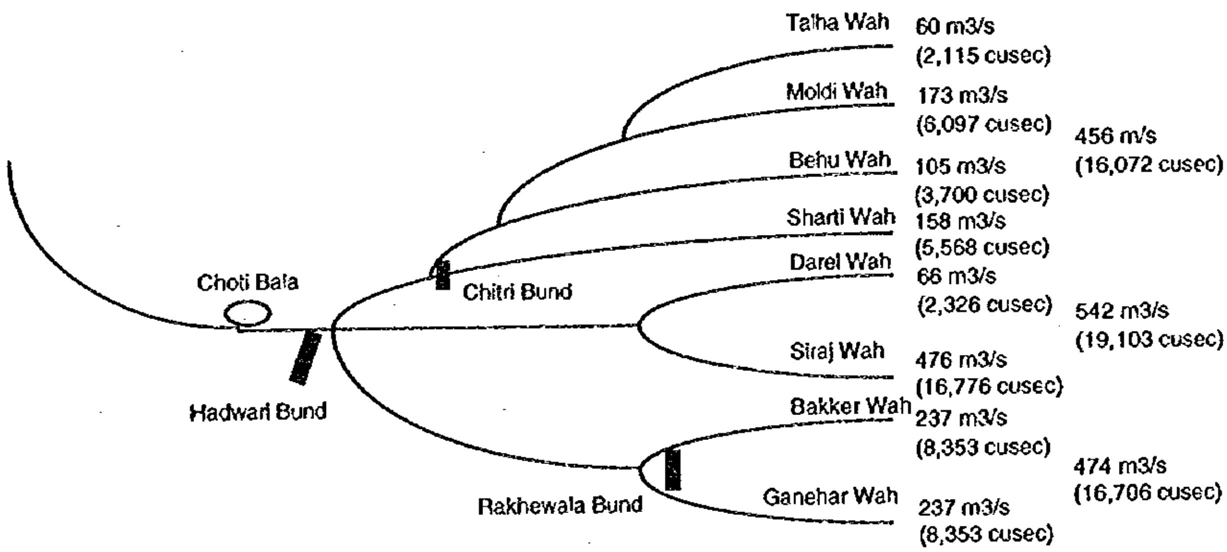
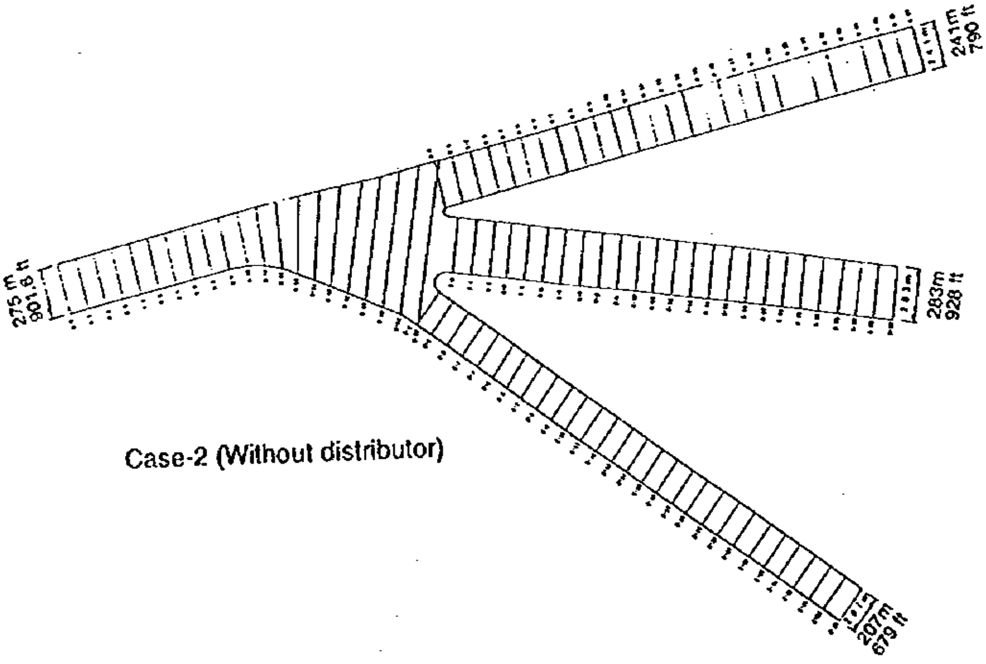
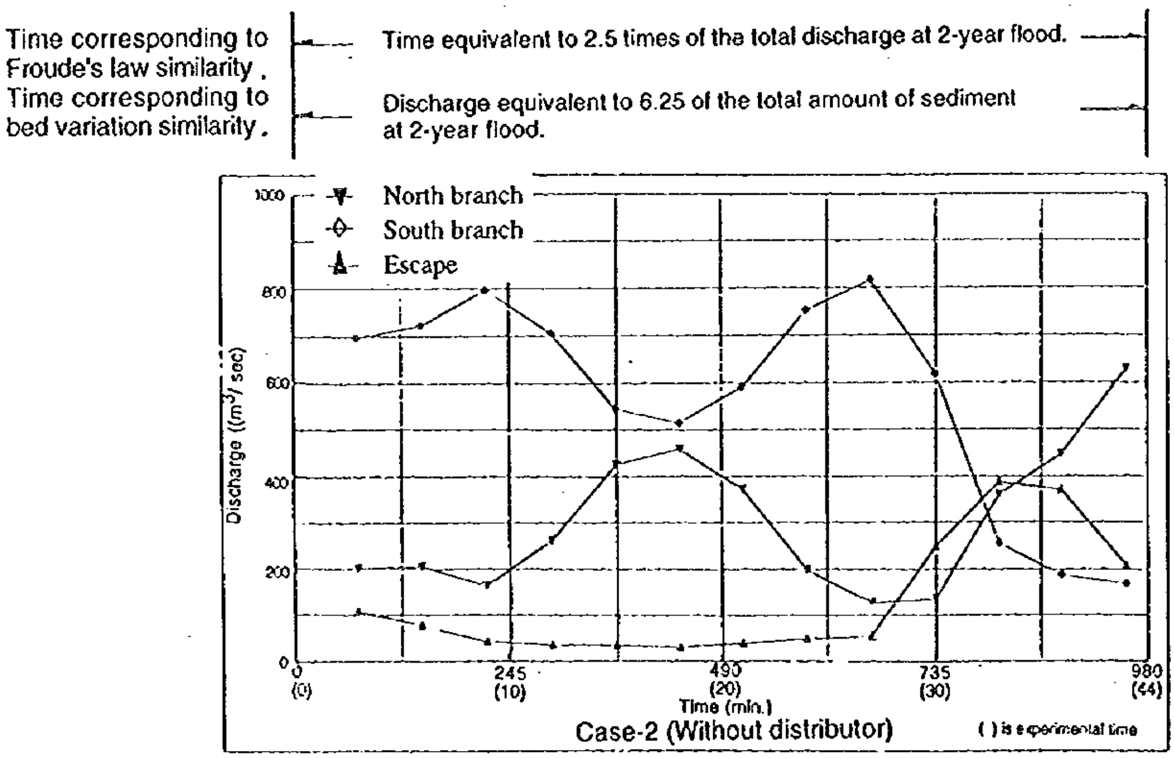


Fig.-6.1 Diagram of Discharge Capacity in Main Branches on Mithawan Pachad

Fig.-6.2 The Test Results



Case-2 (Without distributor)

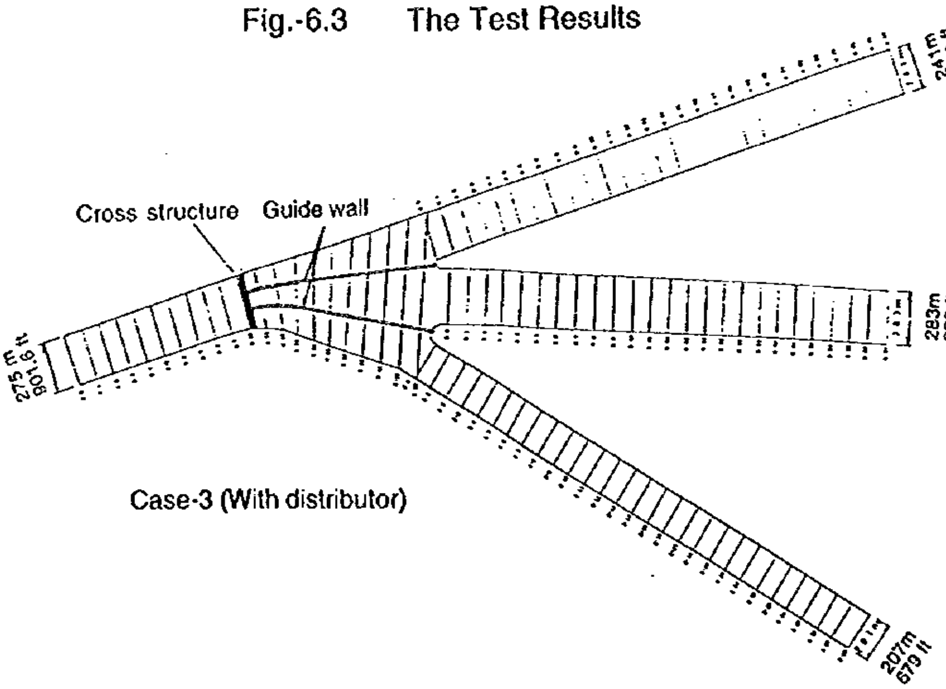


Case-2 (Without distributor)

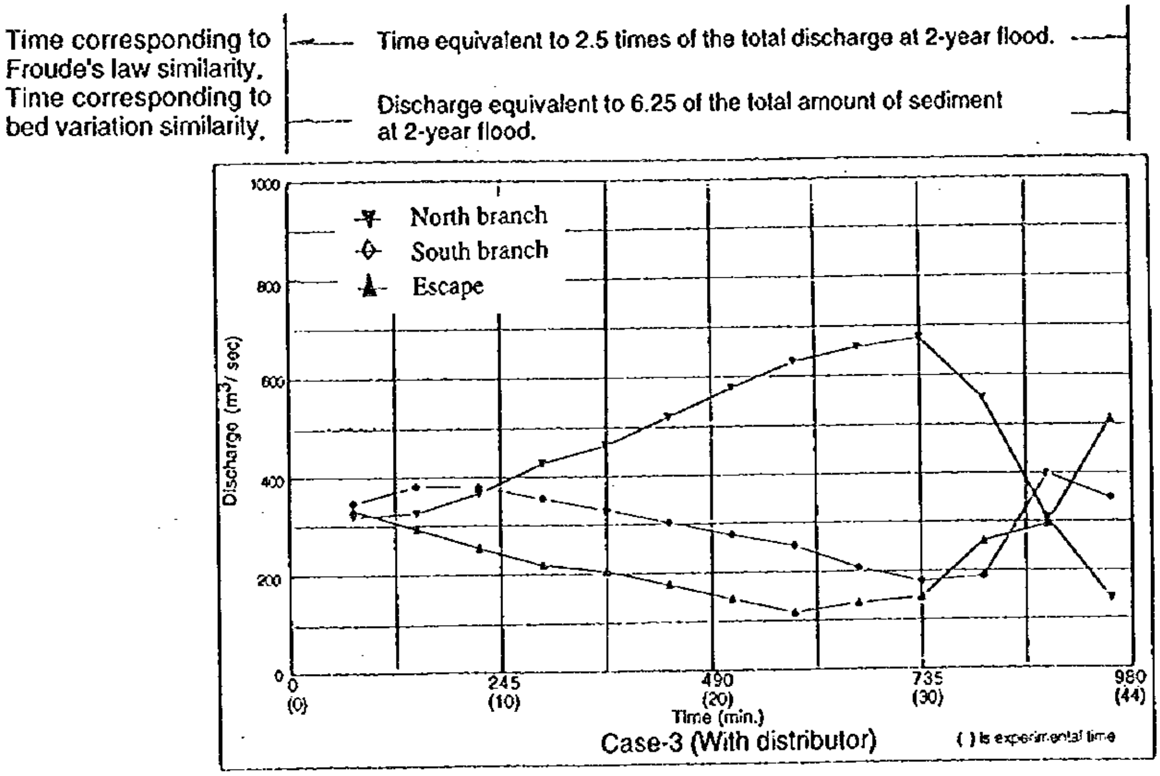
Case 2 Function for the diversion of flow
Without the distributor, it is difficult to control the shares of diversion because the flow direction varies with the river bed alteration up stream.
It is supposed that the flood discharge begger than 2 year return period must spill out from one of the 3 channels.

Case 2 Evaluation
It is difficult to hold stable cultivation without structure since the farms can not be escaped.
It is necessary to make the appropriate countermeasure against flood.

Fig.-6.3 The Test Results



Case-3 (With distributor)



Case-3 (With distributor)

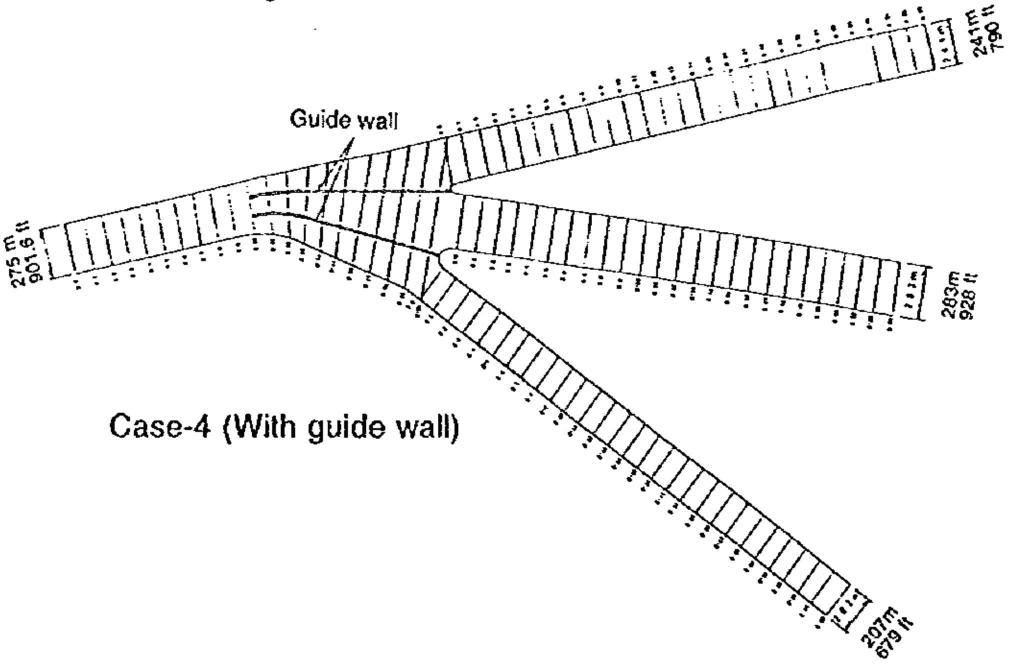
Case 3 Function for the diversion of flow

With the cross structure and guide walls, period of variation of the shares of discharge or period of bed alteration become long. Applying the duration by the similarity of river bed variation, it is posiible to divert the flow 2 times at the planned shares of distribution after the completion of structure. It is easy to forecast to which channel the flow concentrates since the cycle of river bed variation is long. Further more, as the weir is placed in the narrow part of river width, it is possible to keep stable shares of distribution provided the river bed kept flat.

Case 3 Evaluation

To maintain the function of the distributor, operation and maintenance works are necessary such as river bed flattening upstream of the weir. The function for flow diversion is the best of all the type.

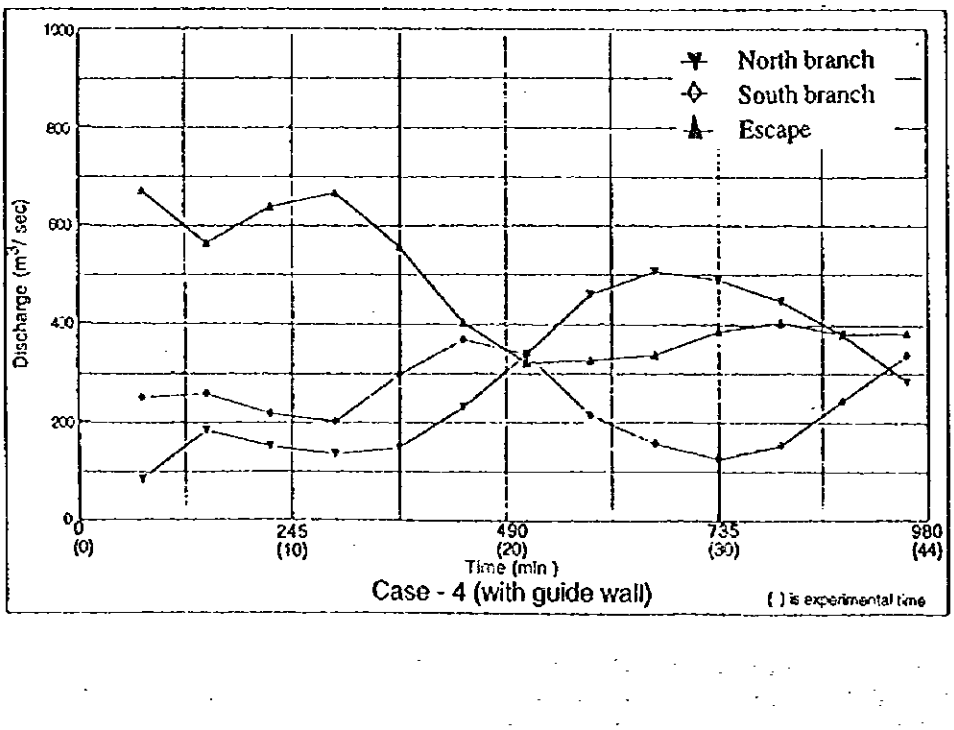
Fig.-6.4 The Test Results



Case-4 (With guide wall)

Time corresponding to Froude's law similarity, — Time equivalent to 2.5 times of the total discharge at 2-year flood.

Time corresponding to bed variation similarity, — Discharge equivalent to 6.25 of the total amount of sediment at 2-year flood.



Case - 4 (with guide wall)

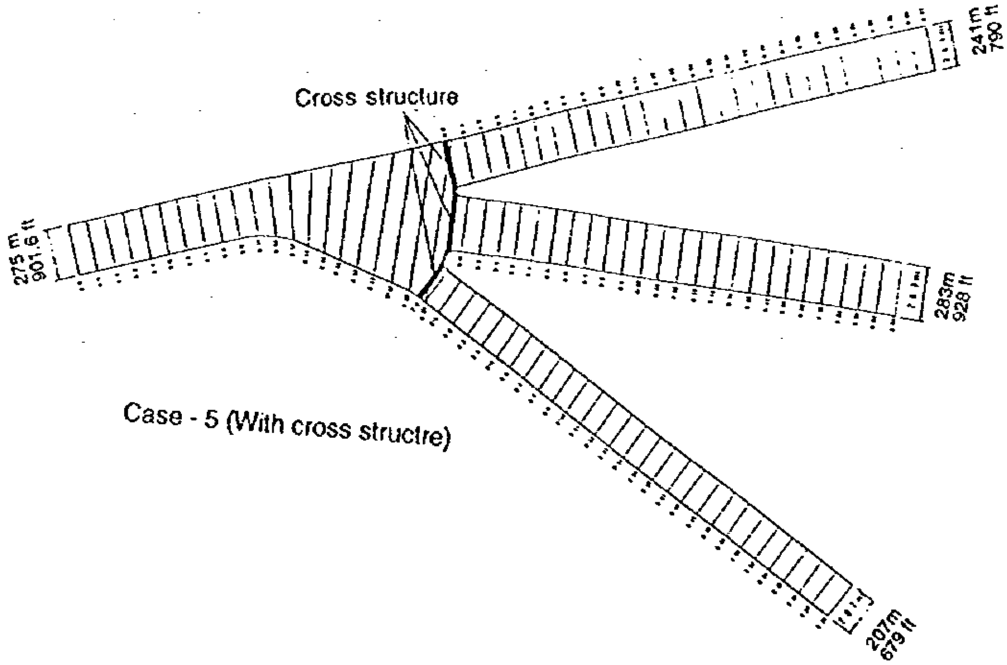
Case 4 Function for the diversion of flow

The period of the change of shares of distribution i.e.. the cycle of river bed alteration is longer than the Case 2. But as there is no structure to fix the river bed elevation, it is difficult to forecast to which channel the flow concentrates after the completion of the structure. The maximum inflow is smaller than the case without structure, but it is forecase that the flood flow will sipillout from the channel one of three channels.

Case 4 Evaluation

The Share of distribution is improved a little compared to the case without structure, but the reliability is not so high.

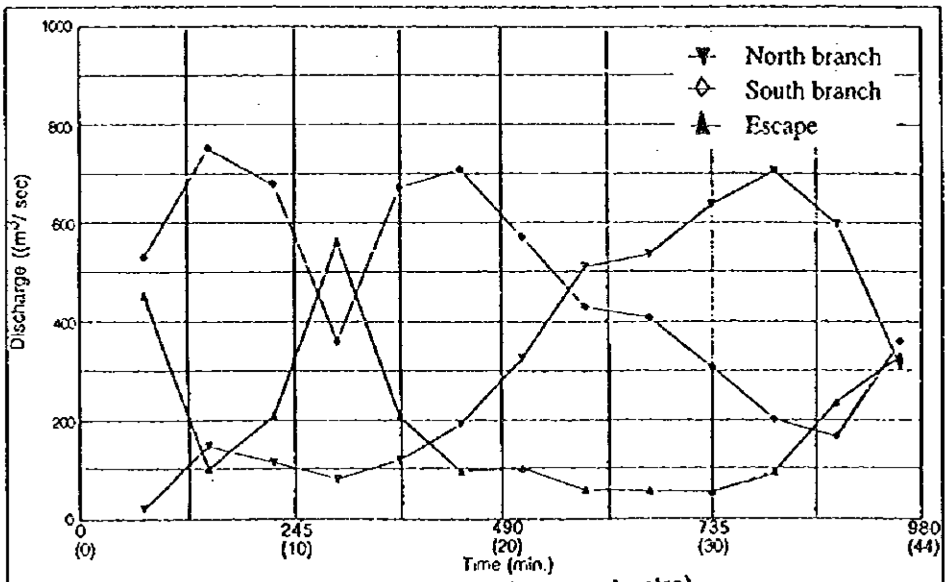
Fig.-6.5 The Test Results



Case - 5 (With cross structre)

Time corresponding to Froude's law similarity, — Time equivalent to 2.5 times of the total discharge at 2-year flood.

Time corresponding to bed variation similarity, — Discharge equivalent to 6.25 of the total amount of sediment at 2-year flood.



Case - 5 (With cross structre)

Case 5 Function for the diversion of flow

The change of the shares of distribution is similar to the case of without structure. The reason is that the flow direction is determined by the river bed alteration at the aplex. Then, it can not be expected the function for flood diversion only by placing the weir at this place. The maximum inflow is also close to that of without structure.

Case 5 Evaluation

The function for flow diversion is low.

6.2.2 Location of the distributor

Compared the test of Case-3 (with the cross structure and the guide walls at the flow diverted point) and the Case-5 (with the cross structure at the month of each channel), the former is more suitable location for the distributor than the latter by its stable distribution.

The altering point of flow direction, however, moves upstream because of the sediment deposition in the upper reaches of the cross structure. Therefore, it is impossible to keep the shares of flood distribution stable even when the cross structure placed at the point (M 2+100).

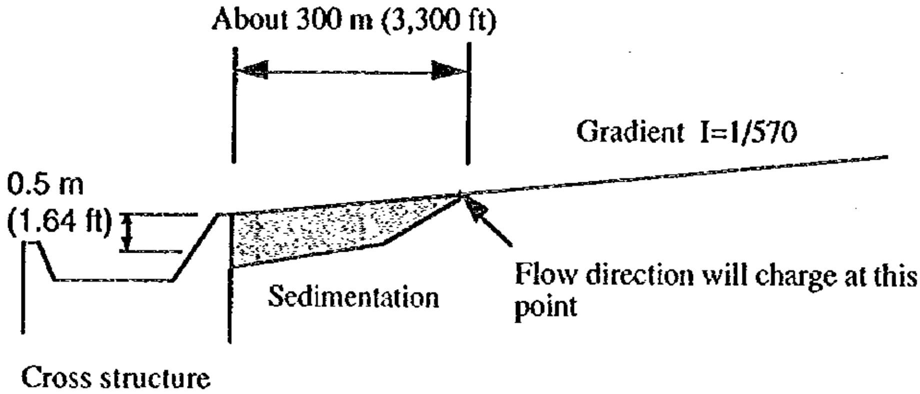


Fig.-6.6 Sedimentation upstream of the cross structure

6.2.3 Shares of Flood Distribution

As the shares of flood distribution changes with the river bed alteration, it is difficult to forecast to which channel flows will concentrate. Table-6.1 shows variation of shares with time. The share in Case 3 is closest to the designed shares.

Table-6.1 Fluctuation of shares of flood distribution

Case	By Froude's law similarity				By riverbed alteration similarity			
No	Nos. of flood	North branch	South branch	Escape	Nos. of flood	North branch	South branch	Escape
2	1 time	25%	69%	6%	1 time	20%	71%	9%
					2 times	21%	74%	5%
					3 times	38%	59%	3%
	2 times	27%	59%	14%	4 times	34%	62%	4%
					5 times	15%	74%	11%
					6 times	31%	35%	34%
3	1 time	38%	36%	26%	1 time	32%	36%	32%
					2 times	37%	37%	26%
					3 times	47%	33%	20%
	2 times	60%	24%	16%	4 times	57%	28%	16%
					5 times	65%	21%	14%
					6 times	51%	25%	24%
4	1 time	14%	24%	62%	1 time	13%	25%	62%
					2 times	15%	22%	63%
					3 times	17%	29%	54%
	2 times	41%	23%	36%	4 times	34%	31%	35%
					5 times	48%	17%	35%
					6 times	44%	17%	39%
5	1 time	10%	60%	30%	1 time	8%	64%	28%
					2 times	11%	60%	29%
					3 times	13%	58%	29%
	2 times	27%	59%	14%	4 times	34%	57%	9%
					5 times	56%	38%	6%
					6 times	65%	23%	12%

6.3 Scouring around the Distributor

6.3.1 Local scouring immediate upstream of diversion weir

Local scouring develops immediate upstream of the cross structure by the spiral flow. Determination of the location and the extent of local scouring, however, is impossible as it occurs depending on the local hydraulic condition upstream of the structure.

6.3.2 Local Scouring immediate down stream of the cross structure

Fig.-6.7 shows the variation of maximum scouring depth with the passage of time depth and Fig.-6.8 shows the maximum length of scouring with time downstream of the cross structure.

Depth and length of scouring become bigger in accordance with extent of river bed degradation downstream of the cross structure. Maximum depth of scour is about 2.5 m and the maximum length is about 15m when the riverbed degradation does not occur. If the river bed degradation reached to 3.5 m deep, depth of scour will be 18 m and length will be 45 m. When gabions are placed at the apron, the extent of scouring is reduced to less than 1/2 in the depth, and less than 1/6 in the length of that of without gabions.

6.3.3 Protection against Local Scouring

The extra model test showed the extent of the scouring around the distributor.

Up stream of the cross structure, scouring is 1.5 to 3.8 m (5 to 13 feet) deep and 4 to 8 m (13 to 27 feet) long. Therefore, the length of the protection against scouring must be 10 m from the cross structure.

Down stream of the cross structure, length of protection is necessary to count the depth of the bed degradation and the local scouring depth. Maximum estimate of bed degradation is 3.8 m (19 feet) in the Escape. Total length of the protection is shown in Fig.-6.9.

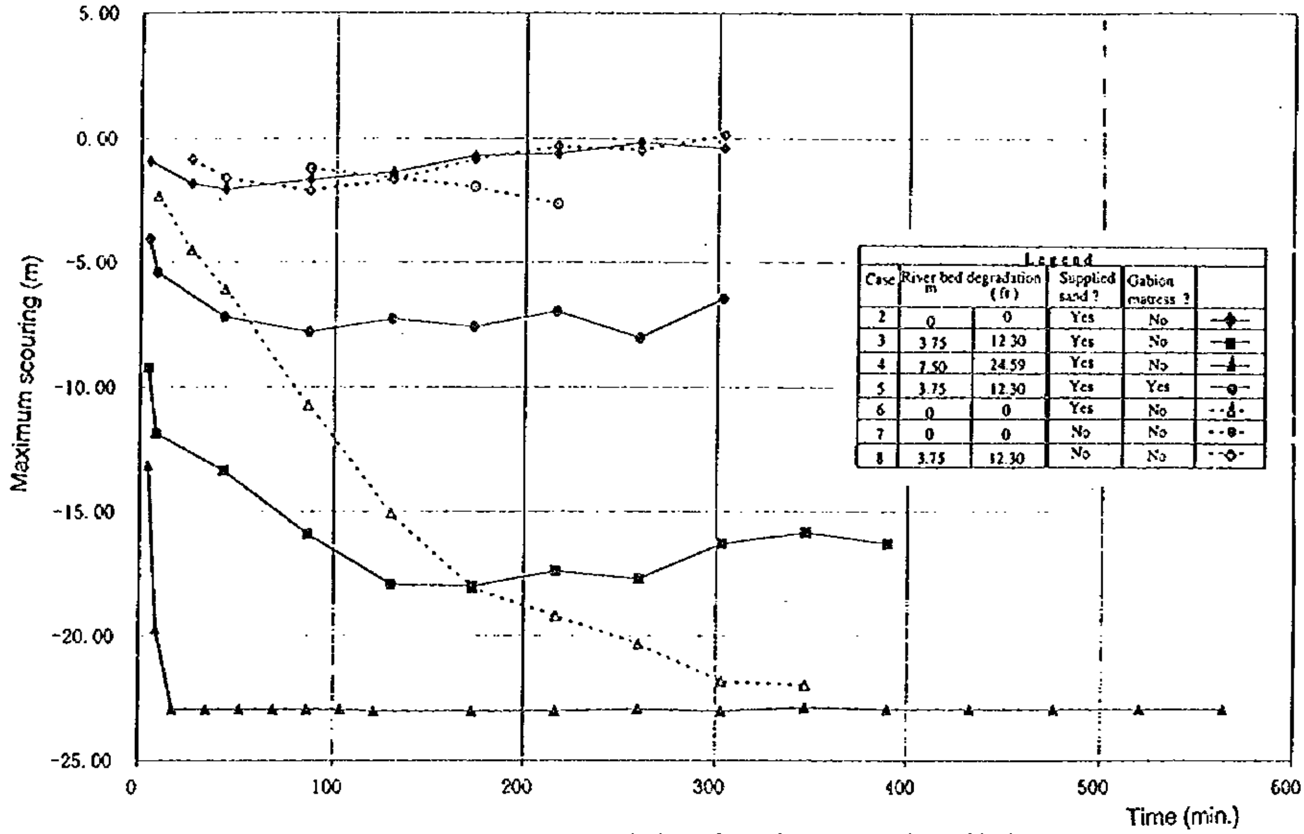


Fig.-6.7 The variation of maximum scouring with time

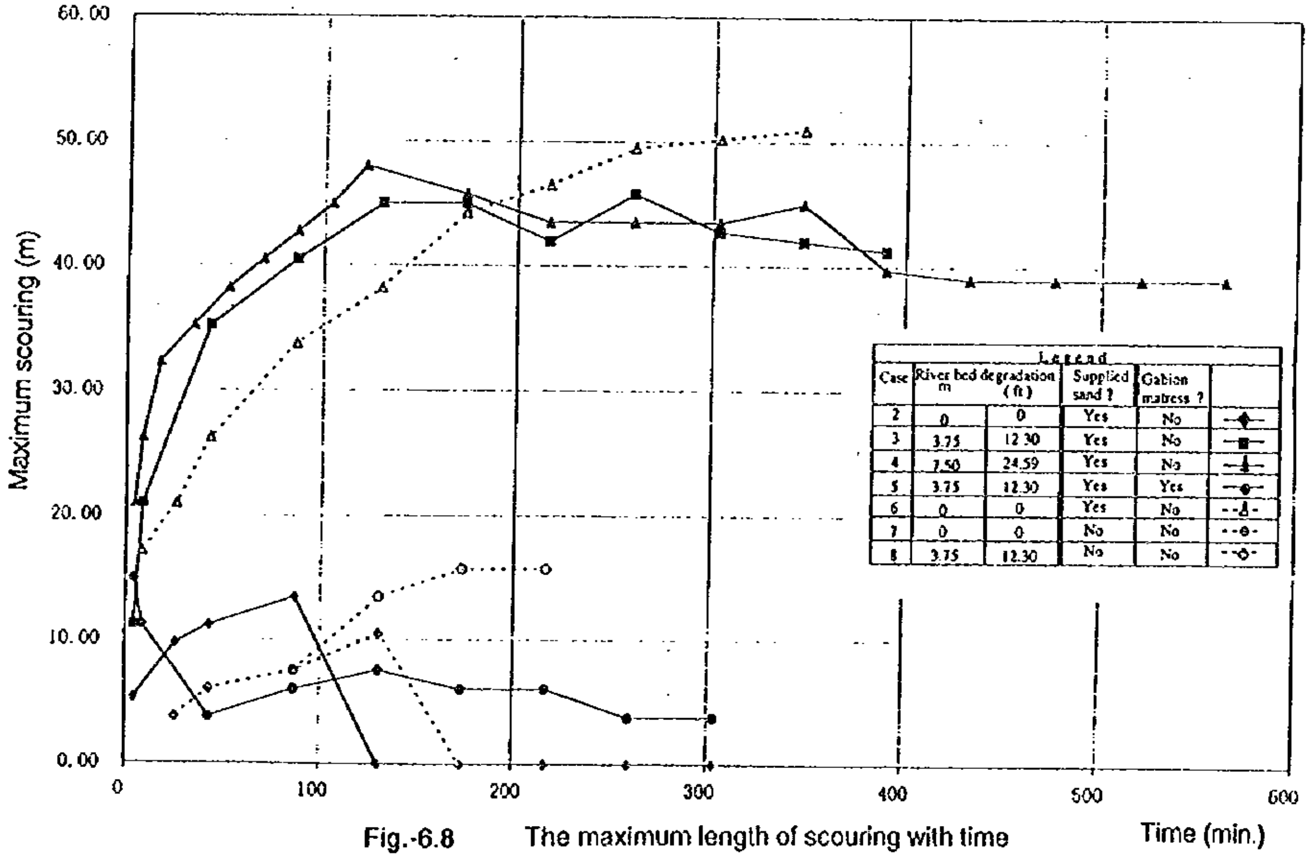


Fig.-6.8 The maximum length of scouring with time

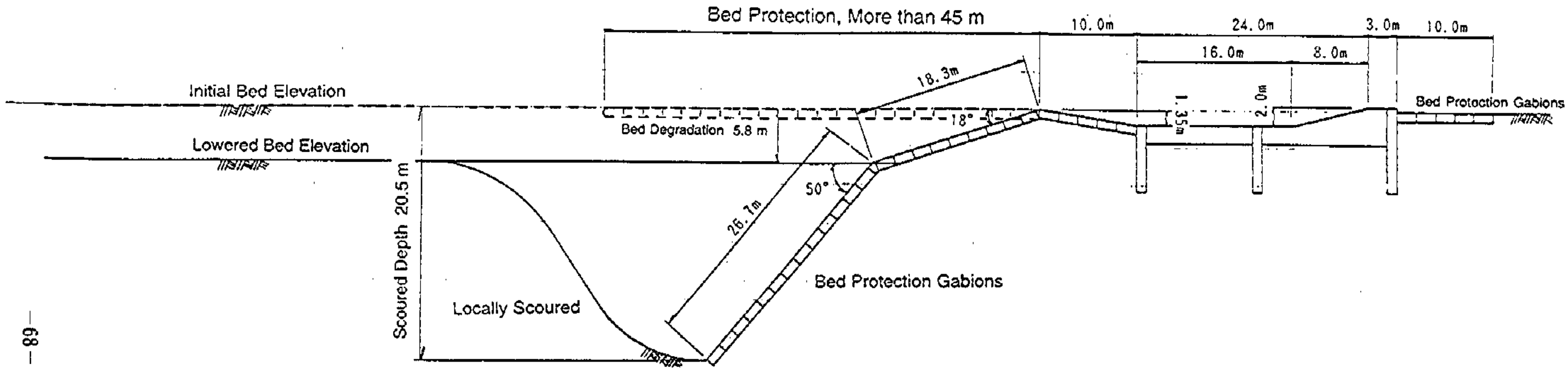


Fig.-6.9 Area Protection Gagion Required around the Cross Structure

Characteristics of the Channels on Mithawan Alluvial Fan

Characteristics of the Channels on Mithawan Alluvial Fan

(1) Variation of the Channels on Mithawan Alluvial Fan

1) Chronological shift of Sharti wah

Horizontal shift of Sharti wah was studied using old topo-maps (Fig.-2.3 and 2.4) in 1950s and '70s issued from Survey of Pakistan, topo-map of Mithawan feasibility study by IPD (Fig.-2.5) in the beginning of '80s and satellite image (Fig.-2.6) in May of 1992.

In 1950's Sharti wah was still minor channel. In 1970's upper reaches at the wah widened as same as at present, but it flowed toward north and joined with Behu and Moldi wahs. In 1980's it flowed toward west and lengthened to near D. G. Khan canal. The change of the water course after 1979 has been caused by slope sliding and/or farmer's restoration works raising bed by filling flood water into the channel since Chitri bund was built to stop flood concentration into Sharti wah in 1979.

Aerial photo taken in 1950's shows that sand deposition had already covered farm land in the middle reaches of Sharti wah. It means that flood flows were concentrating on Sharti wah at the time. It is said that the degradation of the channel bed of Sharti wah developed down to 4 to 5 m by the 1976's flood.

2) Vertical change of channel bed

Bed lowering at the fan-head near Hadwari bund was so severe in the first phase hydraulic model tests that it could not be understood by existing engineering knowledge about the bed variation. The second phase hydraulic model test was executed to solve bed variation experimentally.

Discharge forming equilibrium of river-bed slope:

Prior to the hydraulic model test, discharge resulting stabilized or equilibrium of bed slope was studied. Flood discharge of 2 to 3-year return period tends to bring stabilized bed slope in the rivers with perennial flow. In Mithawan, discharge of 1,000 cumecs (35,300 cusecs) of 2 to 3-year return period was applied as the discharge considering experience in the rivers having perennial flow.

Stabilized bed slope in hydraulic model test:

Content of sediment load controls bed variation, but conventional equations could not be applied for estimating sediment load in Mithawan hill torrent, because its bed material was only very fine sand which was regarded usually as a suspended load in normal flow condition. Therefore, coefficients of Brown's equation to match Mithawan hill torrent was determined experimentally. Following equation was applied for deciding necessary quantity of sand to be supplied during mobile bed model tests.

$q_s / (u^* \times d) = 8.37 \times Tau^{1.78}$

where, 'd' is mean diameter of bed material in meter, 'u*' is shear velocity in meters/sec, 'qs' is sediment transportation in unit width in cum/sec/m, 'Tau' is non-dimensional tractive force.

Followings are results of the hydraulic model test.

(a) Channel bed slope were same before and after flowing water in North branch and Escape. In South branch, bed slope after flood was gentler than initial slope because of lowering of bed in the upper reaches of the channel.

(b) Bed slope and bed configuration of the model would agree with those of the site if above equation is applied for determining quantity of sand supplied for the test. This means that stabilized bed slope would be reproduced by the model test.

Then vertical bed alteration in North branch, South branch and Escape of the model were computed using the equation. Calculated change of height in each bed was agreed with the actual change in the model test. It suggested that bed alteration at the site would be estimated using the equation.

Under the conditions in Table-1, changes of bed in the major channels were computed as shown in Table-2. Degradation of the channel bed reached 3.5 m in North and South branches and 5.8 m in Escape.

In the model test, the water course was oscillating from North branch to Escape and shares of flood distribution varied with the passage of time, because sand bars developed and moved in upstream of the structure during flood.

Table-1 Item on Estimated Basis

Branch		Discharge	Width of Channel	Length of Channel	River Bed Slope
North Branch	Model Prototype	50.8 lit/sec (1,750 m^3/sec)	1.60 m (240m)	18.0 m (2.7km)	1/63 (1/250)
South Branch	Model Prototype	50.8 lit/sec (1,750 m3/sec)	1.88m (=6.16 feet) (282 m)	16.0m (=52.46 feet) (2.4 km)	1/55 (1/220)
Escape	Model Prototype	50.8 lit/sec (1,750 m^3/sec)	1.38m (=4.52 feet) (207m)	18.67m (=61.21 feet) (2.8km)	1/55 (1/215)

Table-2 Degradation of River Bed

Branch	Supply of sand	Outflow of sand	Rate of Degradation	Degradation of Bed
North Branch		3.03 lit/sec	-0.0067 cm/sec	9.4 cm in Model (3.5m=11.5 feet)
South Branch	0.66 lit/sec in Prototype	3.03 lit/sec	-0.0067 cm/sec	9.4 cm in Model (3.5m=11.5 feet) in Prototype
Escape		3.50 lit/sec	-0.0110 cm/sec	15.4 cm in Model (5.8m=19.0 feet) in Prototype

3) Development of sand bars

Upstream of the distributor at the site, channel width 'B' is 275 m, discharge 'Q' 400 cumecs, mean diameter of bed material 'dm' 0.03 cm and bed slope 'i' 1/570. Computed variables for Yamamoto's monogram shown in Fig.-1 are non-dimensional tractive force Tau* 3.75, relative depth 'h/d' 3,416 and ratio of channel width to depth 'B/H' 268. Indicated by these variables in Fig.-1, Mithawan hill torrent falls in the region of flat bed formation.

Alternate sand bars developed in the hydraulic model test, though the variables of the model fall out of the region of sand bars development.

It means that development of sand bars are hardly judged in Yamamoto's monogram because the bed material is so fine. It is expected that sand bars occur in the site since they developed in the model test. It is supposed that dimension of sand bars at the site is smaller than the one estimated from the model test since dimension of sand bars extended with water depth, which is much enlarged in distorted model test than actual depth.

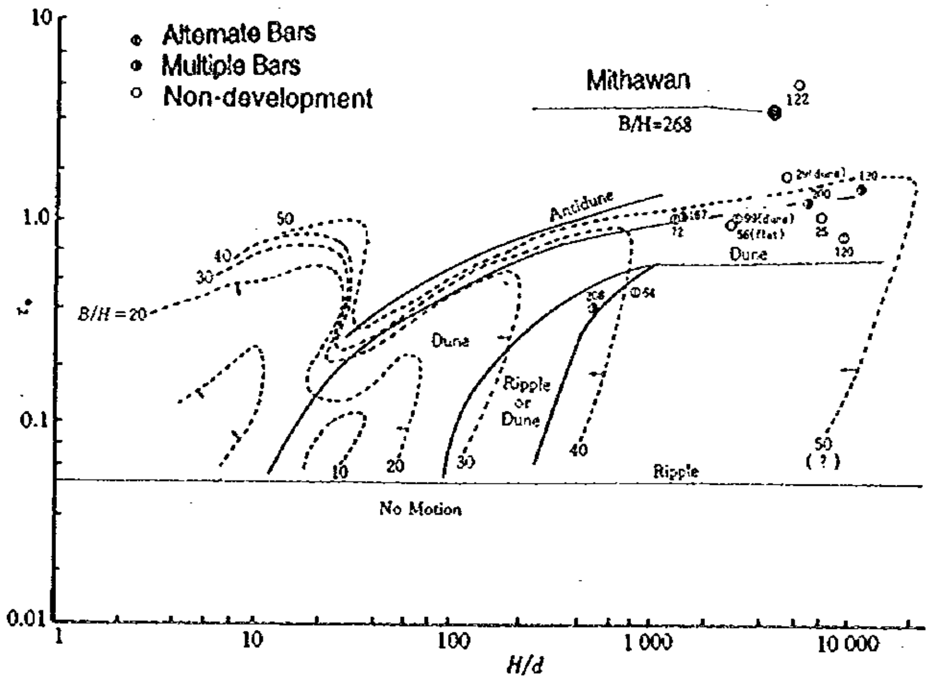


Fig. 1 Criteria for Development of Meso-Scale Bed Configration (dm> 0.02cm)

4) Scouring of wah

Typical dimensions of the channels in Pachad are 10 m wide, 1.5 to 2 m deep from farm land with maximum flow capacity of 40 to 60 cumecs.

Vertical change of channel bed is calculated here. Relation between the channel width and change of bed at a constant sediment concentration is shown in Fig.-2. Narrower the width, larger the vertical change of bed. Figs.-3 through Fig.-6 show relations between inflow of sediment load and bed alteration at a constant bed width. Bed alteration by the variation of discharge and sediment concentration reduces if width of bed become wider. High concentration of sediment load results aggradation of channel bed and low concentration results degradation. It is difficult to say with accuracy about the computed values of bed variation because it is affected greatly with the density of flood water, width and depth of channels and bed slopes.

It, however, indicates qualitative trends that prevalent channels of about 10 m wide in Pachad are sensitive to the change of flood discharge.

(2) Change of Bed and Cross-bed Embankment "Wakra"

1) Wah and Wakra

In pachad surface of farm land is higher than channel bed and bed crossing embankments, so called wakra/ganda, are placed in the channels to raise water surface for the purpose of drawing water into the bund (farmland). Intervals of each wakras are 150 m in average ranging 70 to 250 m depending the area of the bunds.

Wahs are 1.5 to 2.5 m deep and their average width is 10 m with wide range of 5 to 70 m. Flow velocity is estimated 2 to 4 m/s by Manning's formula. Inlets of the bunds are 3 to 6 m wide with 0.5 to 1m high and estimated capacity is 5 to 10 cumecs.

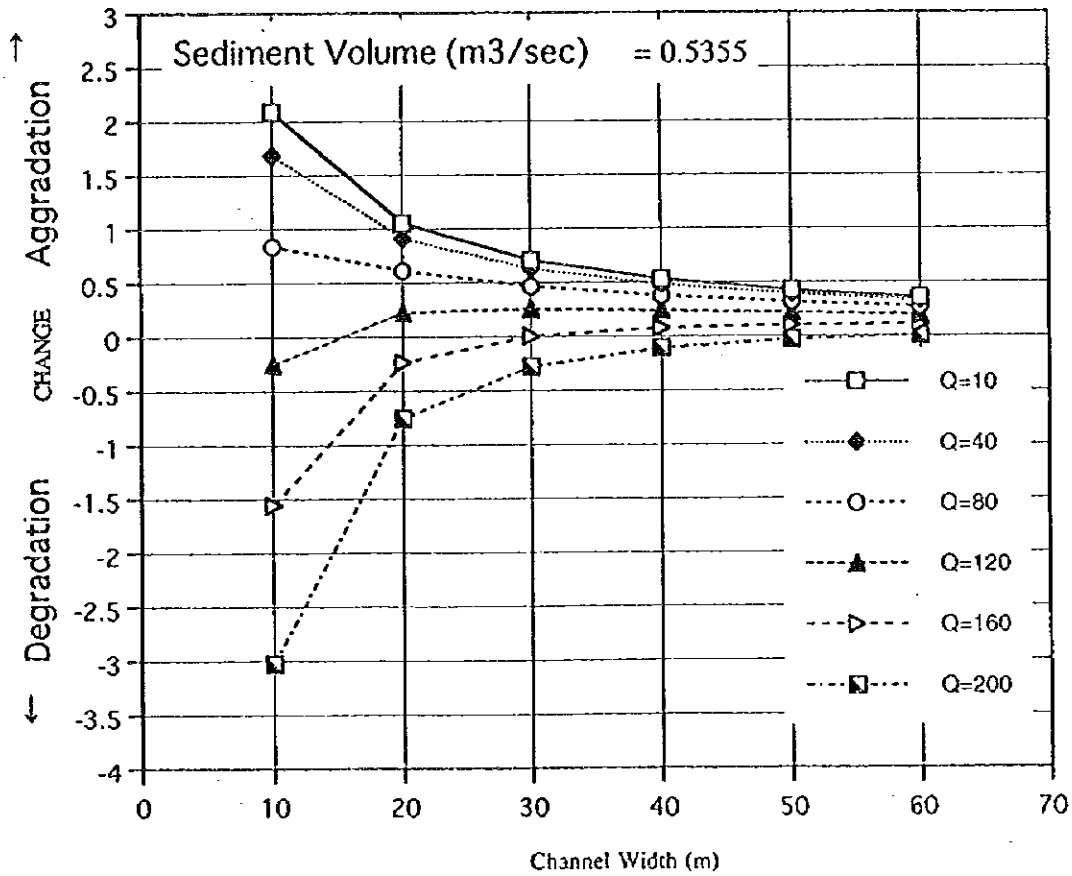


Fig. 2 Relations between Bed Alteration and Channel width (Sediment Concentration)

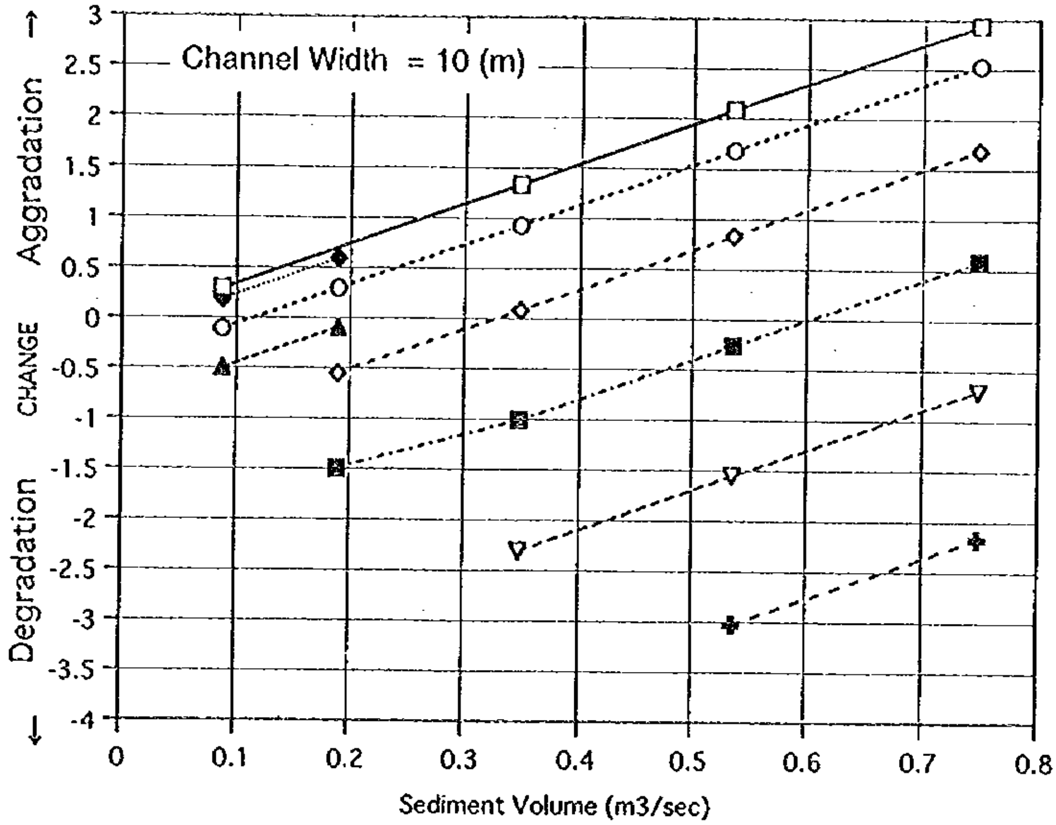


Fig. 3 Relations between Bed Alteration and Channel width (Channel width 10m)

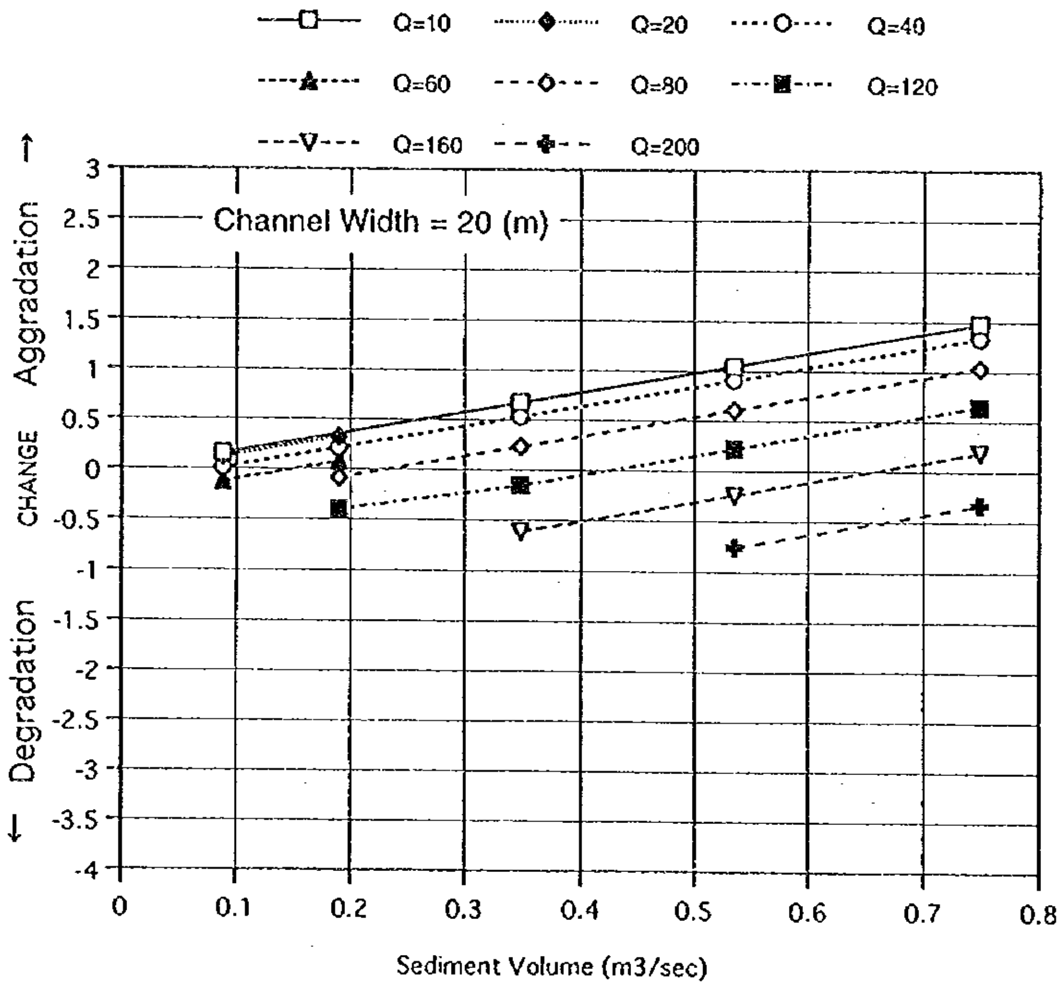


Fig. 4 Relations between Bed Alteration and Sediment Concentration (Channel width 20m)

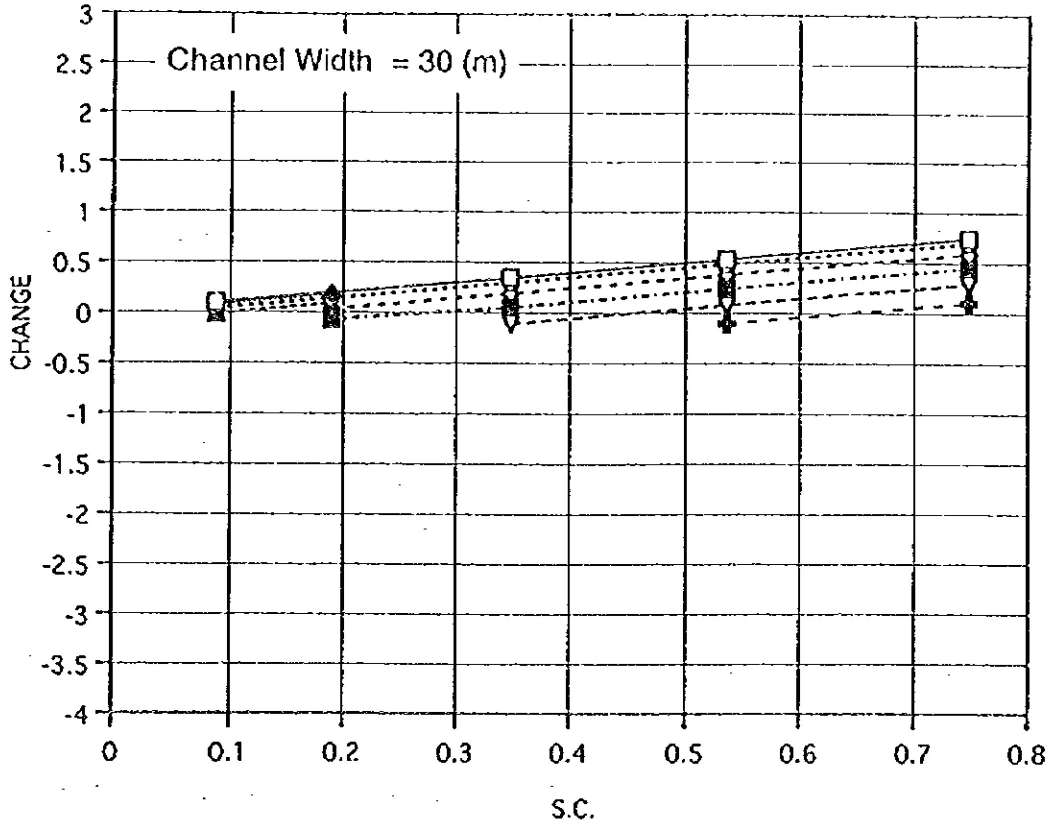


Fig. 5 Relations between Bed Alteration and Sediment Concentration (Channel width 30m)

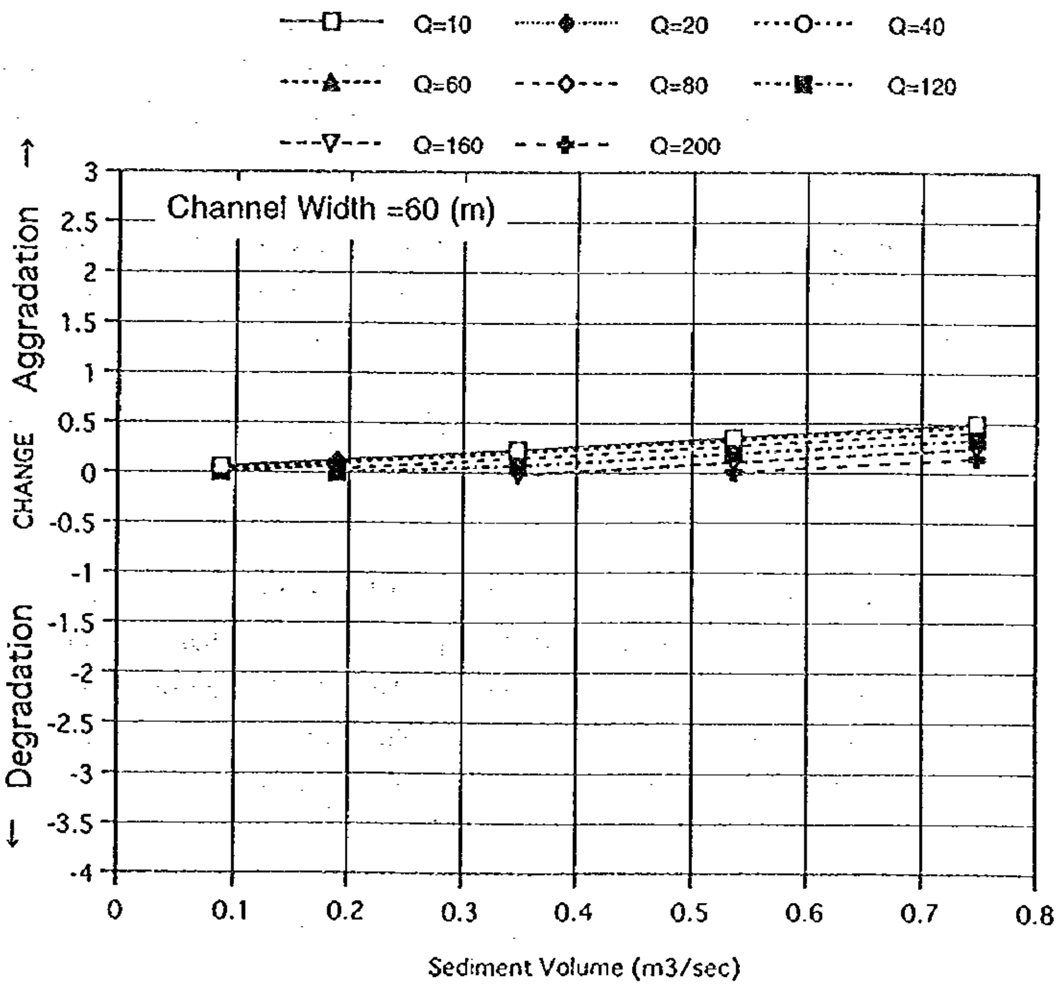


Fig. 6 Relations between Bed Alteration and Sediment Concentration (Channel width 60m)

2) Flow condition

Here we study how the wakras affect to flow condition and sediment transportation.

During drawing water:

Flow velocity is estimated 0.25 to 0.5 m/s in 10 m wide channel when discharge is 5 to 10 cumecs. Then, tractive force 'Tau_0' is 0.04 to 0.15 kg/sq.m, friction velocity 'u*' is 1.9 to 3.8 cm/s.

Diameter of sand on the channel bed is somewhat larger than that of in fan-head. Suppose 'd_{60}' ranges 0.5 to 1 mm, critical friction velocity is computed 1.7 to 5.5 cm/s by Iwagaki's equation.

It means that coarser particles remain in the channel and silt and clay flow into the bund as a suspended load when water is raised by 'Wakra'.

When releasing water by demolishing wakra:

Fig.-7 shows the change of flow condition after demolition of 'wakra' when intake is finished in a particular bund. Let the average height of wakra 2 m and the average bed slope of a channel 1/250, then length of pond reaches 500 m upstream. When wakra is demolished, water moves 150 m downstream to next wakra.

When wakra-1 is demolished, water moves very fast to wakra-2. Velocity at point-A downstream of demolished wakra is very high in a few seconds until point-A submerged in the pond of wakra-2. Let this period stage-1.

Scores of seconds after the point-A being submerged until the water surface of the pond of wakra-2 becoming steady, water moves at considerable velocity. Let this period stage-2.

After this stage, about 15 to 40 minutes of intake period to bund-2, velocity will be steady at 0.25 to 0.5 m/s, which depends on the discharge of intake to a particular bund. Let this period stage-3. Until demolition of wakra-4, flow velocity at point-A varies affected by demolition of wakra. After that, velocity will be constant depending on the discharge Q_i in the wah.

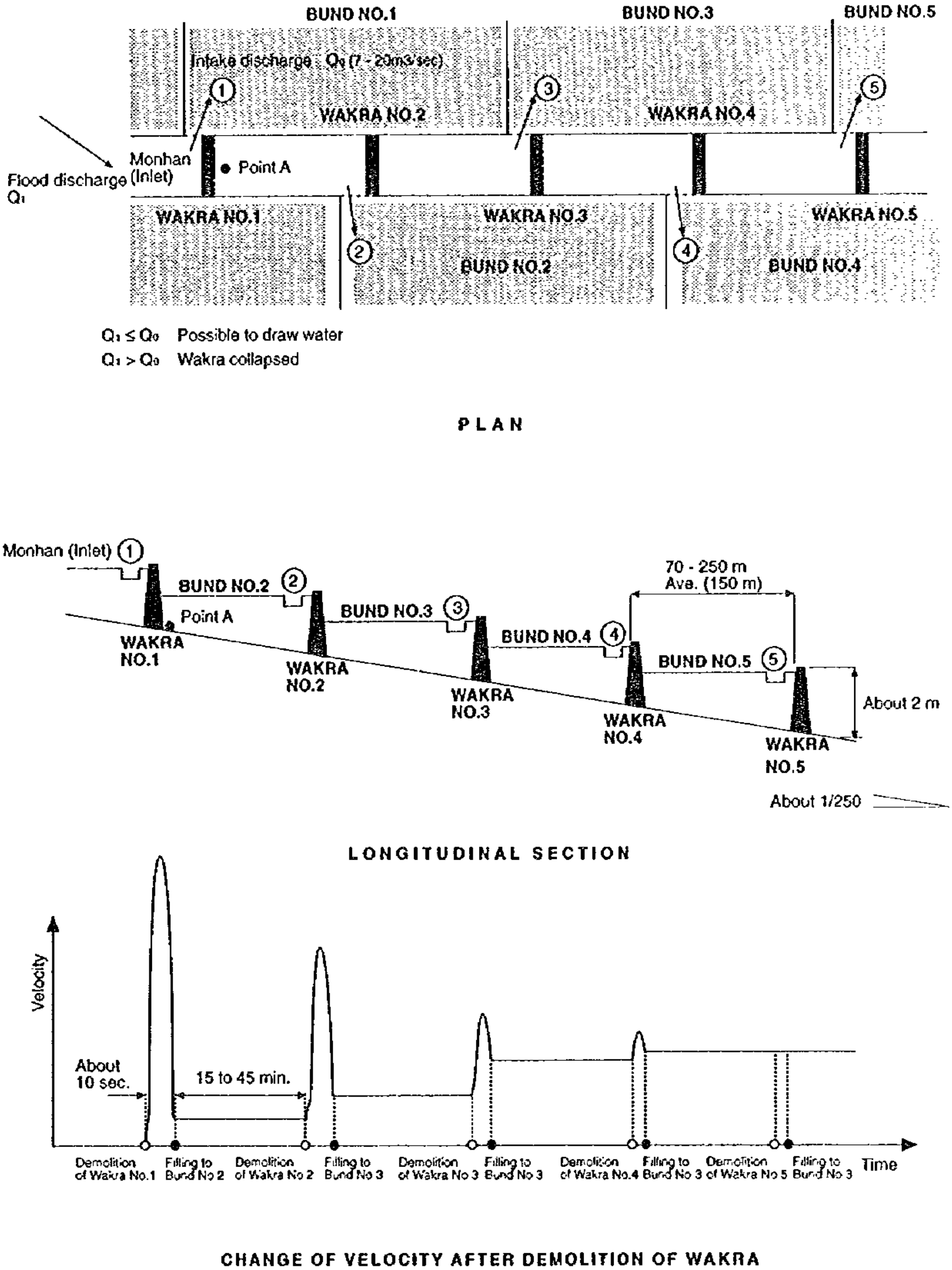


Fig. 7 Schematic Intake System in Flood Irrigation

For stage-1, flow velocity at point-A after demolition of wakra-1 is calculated by the equation below with assumption of head of water in the pond of wakra-1 transformed fully to velocity head.

$$V = a\,(2\,g\,h)^{1/2}$$

where, 'V' is velocity in m/s, 'h' is head of water in the pond of wakra-1 and 'a' is coefficient.

Velocity in stage-1 is computed about 6 m/s as average height of wakra is 2 m. Shear velocity 'u*' reaches 25 to 45 cm/s under this condition and channel bed is supposed to be scoured considerably.

In stage-2 and stage-3, mean velocity in the pond depends on a water depth. Sediment transportation also varies with a water depth in the pond. Table-3 shows the relation between the water depth and the factors related to sediment transportation at a constant discharge of 10 cumecs (353 cusec).

Table-3 Velocity, Shear Velocity and Tractive Force by Depth

Water Depth (m)	Velocity (m/s)	Shear Velocity (cm/sec)	Tractive Force (kg/m2)
0.4	2.5	19	3.5
1.0	1.0	8.6	0.6
2.0	0.5	4.0	0.15

When water depth is 0.4m, sand particle less than 2.5 mm diameter can be transported. And water depth at 1 and 2m, then sand less than 1.4 and 0.7 mm diameter could move respectively.

<u>When wakra collapsed or without wakras:</u>

When flood discharge is larger than the capacity of inlet of the bund, water surface rises in the wah. In such case, wakras must be collapsed by over-topping or seepage, then flood rushes without any obstruction.

In the case of the flood flows with 1.5 m deep in 10 m wide wah, discharge reaches about 40 cumecs with velocity of 2.8 m/s. Then scouring on the bed develops, as the shear velocity 'u*' reaches 24.2 cm/s that is much higher than critical shear velocity of channel bed material.

3) Change on width of channels

As mentioned above, typical wahs in Pachad are 10 m wide and 2 m deep and maximum flow capacity is 40 to 60 cumecs. Since maximum capacity of the inlet of each bund ranges 5 to 10 cumecs, wakras must be collapsed by raised water surface in the wah when flood discharge is beyond the capacity of inlet.

Wakras reduce sediment transportation when they function well. However, even during low flood, small wahs might be scoured when wakras are collapsed. Degradation of a wah by scouring results increase of flow capacity of the wah, then more flood flowing into the wah accelerates degradation of the wah. When bank of the wah reaches high enough to fall down, the wah becomes wider because of banks collapse resulting retarding degradation. Capacity of channel enlarges and repeated same process widens the channels more.

(3) Formation of Secondary Fan

1) Sediment Transportation

During low floods when wakras function well, most part of wash load and suspended load flow into the fields and bed load remains on the channel bed. Therefore, no secondary fan is developed and all the eroded material in the upper reaches remain on the fan.

During high floods, sediment from the upper reaches and eroded material in the wah deposits intersection point downstream and forms secondary fan. Bed load remains on the secondary fan and suspended load and wash load flow downstream.

2) Secondary Fan Formation

Immense degradation occurred in 1976 in Sharti wah and floods attacked the wah succeeding two years. Whole the flood had flowed into the wah in these three years. About 25 years before the catastrophic degradation in Sharti wah (there had been a sign of lowering of channel bed), in the aerial photo taken in

1950's indicated development of minor secondary fan along the wah in the mid-fan. It suggests that formation of a large secondary fan takes tens of years.

Recent degradation of Talha wah is supposed to have started about 15 years ago because existence of Hadwari bund and Chitori bund have regulated direction of flood flows to Talha wah since the beginning of 1980's.

3) Damage to Farm Land

Fig.-8 shows secondary fans in Mithawan alluvial fan distinguished from the satellite image. A considerable large secondary fan has formed in the lower reaches of Sharti wah near D. G. Khan canal. Its area is about 14 sq.km, with 7 km long from the apex to the edge and 3 km wide at the edge. The fan has rather steep slope at the end with gradient of 1/40 to 1/140 and relative height of 3 to 5 m. Slope on the top flat area is 1/250 to 1/300. Average thickness of the fan is estimated at about 1.2 m.

The satellite image shows that the areas covered with secondary fan are not cultivated at present because wahs have shifted and intake from the wah has been inoperative addition to deposition of sand on the farm land. Because of that, considerable wide area has been used only for grazing.

Degradation of wahs and formation of secondary fans develop tens of years in natural condition. It results shift of wahs causing flood irrigation being impossible and reduction of flood irrigation area.

Monitoring for the channels and taking appropriate measures to stop an unfavorable change of the channel are very important. Such measures could regulate the formation of secondary fans and large scale degradation.

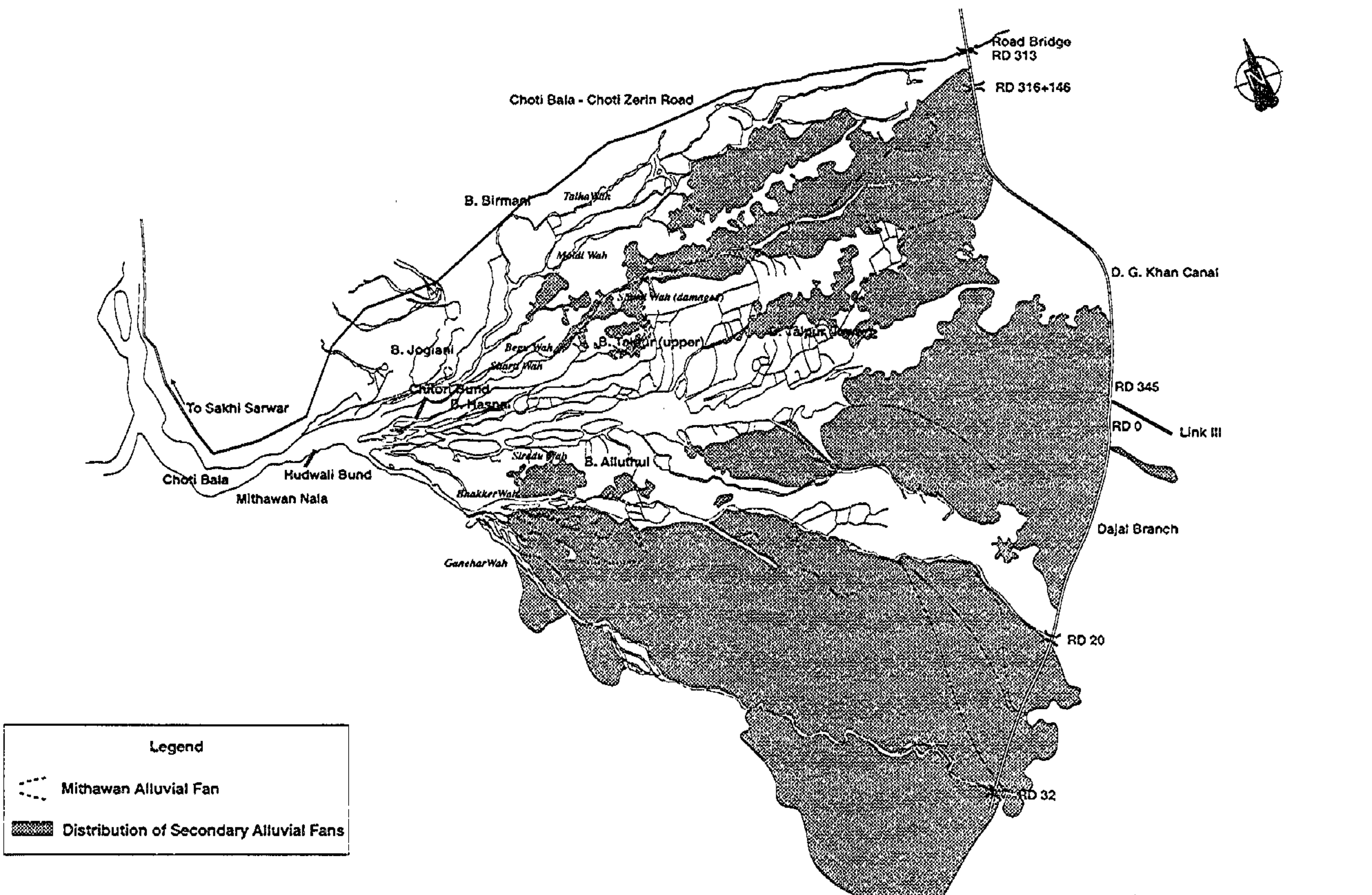


Fig. 8 Distribution of Secondary fans by the Satellite Image

Project Area

1 GENERAL CONDITIONS

D. G. Khan hill torrent belt where the Project area of Mithawan hill torrent is located lies between the Indus River and the Sulaiman Range in the south-west of Punjab Province and is bordered by the Province of Sind in the south, Balochistan in the west, and the N.W.F.P. in the north. Mithawan hill torrent area is located in the center of D. G. Khan hill torrent districts, and is bordered by Vidore hill torrent area in the north, Kaha hill torrent in the south and west. The D. G. Khan irrigation canal lies at the east of it. Mithawan hill torrent area lies within the Punjab and approximately between north latitudes of 29°47' to 30°25' and east longitudes of 69°58' to 70°17'.

Original Mithawan hill torrent basin measures around 900 square km. It is divided into the area of the upper reaches of the darrah (outlet of the valley) at Choti Bala, so called watershed, and the area of the lower reaches of the darrah down to the D.G.Khan canal (alluvial fan), so called pachad. The area of watershed is 628 square km and that of the pachad is 264 square km.

The major village in the Project area is Choti Bala at about 46 km east-south-east of D. G. Khan City. There are two routes to Choti Bala, in which one is from Choti Zerin located in the east connected by 24 km asphalt paved road and the other one is from Sakhi Sarwar located in the north connected by 20 km poorly maintained feeder road. The national road connecting the Provinces of Punjab and Balochistan divides the Project area in two.

2 PHYSICAL CONDITIONS

2.1 Rainfall

Rainfall record is available only one observation station in Mithawan hill torrent area, i.e., Fort Munro. Nearby the Mithawan watershed there are a few observation stations in Kaha and Vidore watershed. Those data are shown in Table-1. Annual rainfall ranges from 180 to 390 mm in D.G.Khan hill torrent belt, in which northern area and higher elevation have more rainfall. More than 60 % of annual rainfall concentrates in three monsoon months of July to September.

Table-1 Average Monthly Rainfall in the Area (mm)

Station	Barkhan	Mar Bun	Ziarat Sheru	Fort Munro
Jan.	17.3	7.0	6.5	7.5
Feb.	12.1	5.1	5.8	14.6
Mar.	22.6	24.7	12.1	19.6
Apr.	31.4	24.0	31.8	19.8
May	22.3	19.4	29.7	11.9
Jun.	47.8	18.1	39.4	20.7
Jul.	104.0	80.8	70.2	69.4
Aug.	75.7	73.9	45.0	60.9
Sep.	34.5	42.6	24.2	32.7
Oct.	7.7	2.2	0.6	4.0
Nov.	7.9	0.5	0.4	3.2
Dec.	6.3	3.8	0.8	3.6
Annual	389.5	302.1	266.7	267.9
S.D. (1)	170	95	196	n.a.
C.V. (2)	0.5	0.3	0.7	n.a.
Years (3)	21	16	11	n.a.

(1) Standard deviation of annual rainfall
(2) Coefficient of variance of annual rainfall
(3) Years of observation

Large value of C.V. in the Table-1 means annual rainfall fluctuates much.

In the area it rains usually from afternoon to night. The rainfalls in monsoon months have high intensity and short duration. On the other hand, they have low intensity and long duration from February to April. Probable rainfall is shown in Table 2.2 in Chap. 2 (p.p.2-7).

2.2 Hydrology

Hill torrent floods occur several times a year from July to September of monsoon months and from February to April of spring. Monsoon floods occasionally damage in the canal irrigated area. Hill torrent flood is characterized short flood duration with high peak flood discharge. In Mithawan hill torrent water runs 10 times approximately a year and their flooding duration are 1 day at most.

There are run-off data of Mithawan hill torrent from 1958 to 1964, from 1975 to 1987 and in 1989 observed at Choti Bala by staff gauges, which are shown in Table-2. The 1994-flood was estimated 2,070 cumec by the flood marks.

Table-2 Run-off Data in Mithawan Nallah

Year	Peak Discharge (cumecs)	Year	Peak Discharge (cumecs)
1958	2,193	1979	729
1959	502	1980	2,251
1960	1,631	1981	110
1961	1,270	1982	518
1962	1,674	1983	299
1963	968	1984	232
1964	611	1985	730
1975	1,695	1986	1,446
1976	1,637	1987	65
1977	518	1989	1,392
1978	2,264		

2.3 Geology

Mithawan watershed lies on Sulaiman fold belt trending its axis north and south. Geological distortion of this area is formed mainly in the period of Plio- Pleistocene age which Himalayan tectonic movement still continued from Cretaceous and even it may go on so far. Fort Munro Anticline runs in the center of Sulaiman Range and Baghal Chur Syncline on the boundary area of northern Mithawan watershed and Sakhi Sarwar watershed. The watershed is mainly composed of sedimentary rocks of Cretaceous to Tertiary age and deposits of Quaternary age.

The main compositions of respective ages are:

the Cretaceous — hard lime stone, sandstone and shale forming Sulaiman Range,

the Paleocene	hard sandstone and limestone lying east- and westward of the Cretaceous,
the Eocene	relatively hard shale and limestone (Gajiz formation) or limestone and soft hale (Kirthar formation),
the Miocene and Pliocene	limestone, sandstone, shale and hard claystone lying between Sulaiman Range and antecedent river darrah, and
the Plio-Pleistocene	claystone, shale, sandstone and conglomerates form the cliff of antecedent river darrah and decreasing its altitude of land surface to eastward.

Geology in the Mithawan watershed is shown in Fig.-2.1 and stratigraphy is shown in Table-3.

Ground surface in the area is characterized by the wide spread gravel deposit. The gravel layers are classified into 4 groups by their origin, that are old gravel layers, terrace gravel deposit 1, terrace gravel deposit 2 and recent river deposits.

Old gravel layers seem to have originated from Molasses in early diluvial epoch composed mainly of coarse grains associated with Himalayan orogeny. The thickness is 5 to 20 m and various sizes of particles compose it ranging from boulder to silt and clay. The fines are washed out from surface layer. Boulders outcropped to surface are weathered and faded to chocolate color. These sediments cover Chaudhwan formation of Pliocene age and are distributed in Mithawan darrah extending 20 km north and south. Furthermore they are found on the high land rising to 360 m above sea level at the darrahs of Choti nallah, Nangar nallah, Rakhi nallah, Siri nallah and main Mithawan nallah. Gradient of the surface is less than 4 degrees. These sediments seem to have overlaid Rakhi Gaj formation, but to be eroded and almost washed out accompanied by gradual up heaving of the area.

Terrace gravel deposit 1 forms mainly the out-washes of Rakhi nallah and Nangar nallah, spreading from the apex of the fan of antecedent rivers at around 900 m ASL down to 360 m. The other small scale terraces with their elevation at around 900 m are also composed of these deposits. Their surface inclinations are less than 3 degrees. The highest point of this deposits is higher than that of terrace deposit 2 described below. The types and size of the gravel are almost same as the older gravel deposits.

Terrace gravel deposit 2 is extending widely around the southward area forming the mountain foot of Sulaiman ranges and in lowland of downstream side of antecedent river darrah. These deposits originated eroded terrace deposit 1 and are eroded by recent river flows. The slope of the extending area is less than 2.5 degrees. The types and size of the gravel are almost same as old gravel layers.

Recent river deposits are formed with the eroded material from terrace deposits 2, and dissecting downward. Boulders compose this deposits from the apex to mid-fan of the alluvial fans.

Table-3 Stratigraphy of the Mithawan Watershed

Geological Age		Strata
Quaternary	Holocene	Cultivable layer (Qcs)
		Alluvial deposit (Qal)
		Dune deposit (Qd)
		Piedmont gravel deposit (Qp)
		Terrace gravel deposit (Qtg)
		Flood plain deposit (Qs)
		---------Un-conformity----------
	Pleistocene	Dada gravel layer (Qdc)
Tertiary	Pliocene	Chaudhwan formation (Nscd)
		Siwalik group
		Litra formation (Nsl)
		Vihowa formation (Nsv)
		----------Dis-conformity-----------
	Miocene to Oligocene	Chitarwata formation (Nc)
		----------Dis-conformity------------
	Eocene	Kirthar formation (Pk)
		Gajiz formation (Pg)
	Paleocene	Dungan formation (PD)
		Khadro formation (PK)
		----------Un-conformity------------
Upper Cretaceous		Moro formation (KM)
		Pab Sandstone (Kpb)
		Fort Munro formation (KFm)

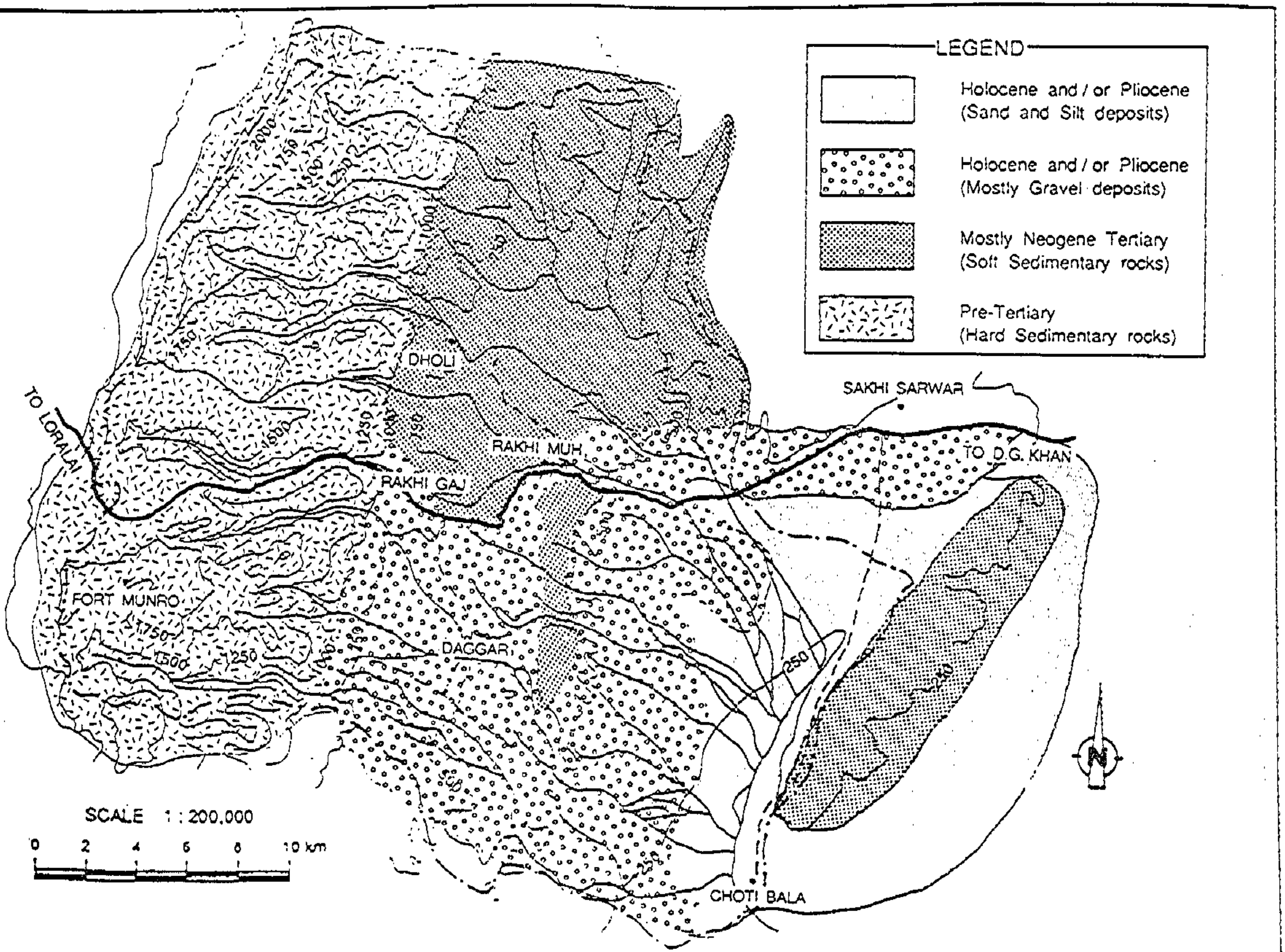


Fig. 2.1 Geological Map of Mithawan Watershed

2.4 Topography

Mithawan hill torrent basin is divided into two regions, watershed upstream of the darrah (outlet of the valley) and pachad downstream of the darrah (alluvial fan).

Area of watershed is 627 square km and that of pachad is 264 square km.

2.4.1 Watershed

The watershed is characterized by north and south extending steep ridges and valleys formed by folding, and is categorized 4 zones as shown in Fig.-2.2:

Zone I:	Sulaiman Ranges,
Zone II:	Northern half of the area between the Sulaiman Ranges and the darrahs of antecedent rivers,
Zone III:	Southern half of the area between the Sulaiman Ranges and the darrahs of antecedent rivers,
Zone IV:	Area between the darrahs of antecedent rivers and present Mithawan darrah.

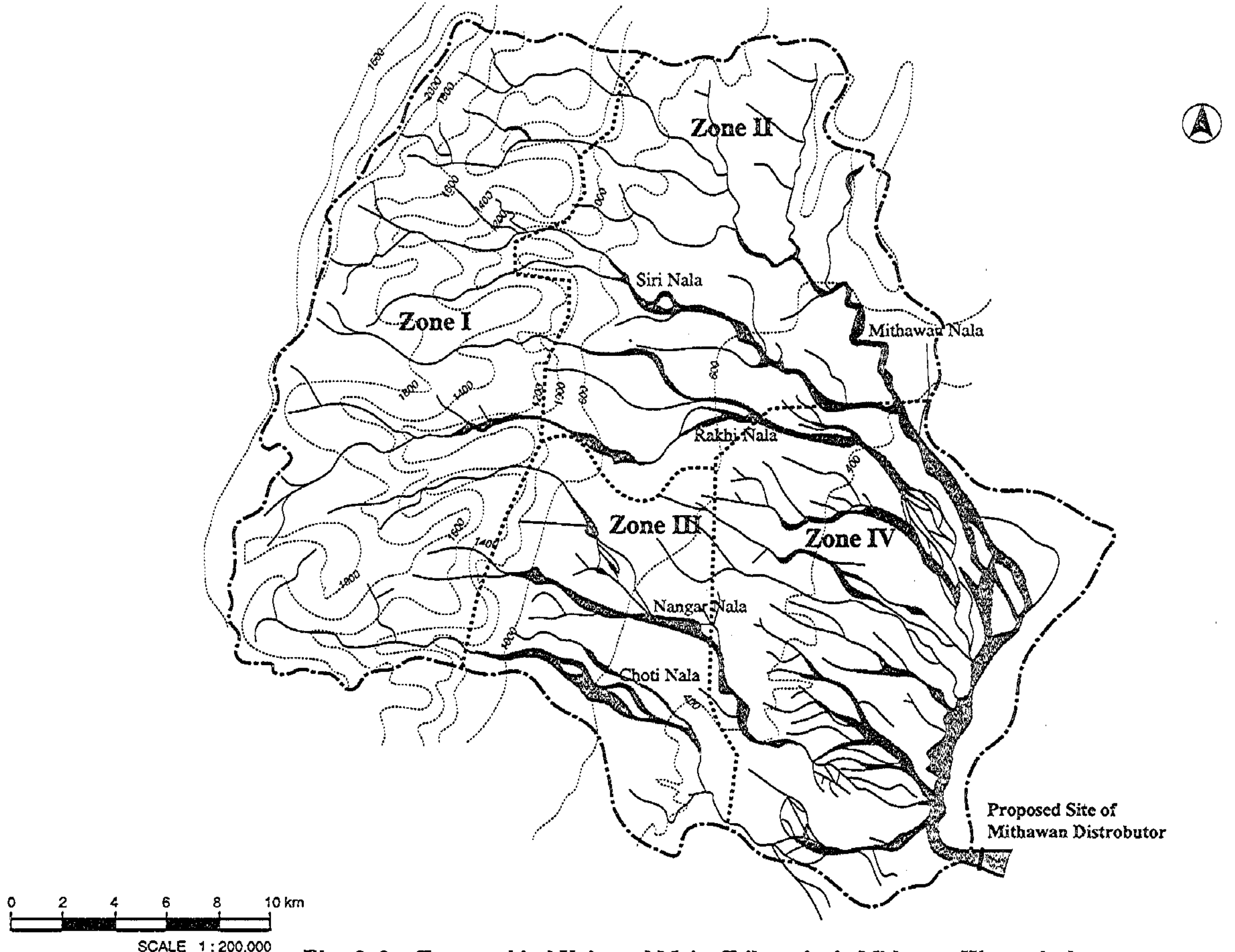


Fig. 2.2 Topographical Units and Major Tributories in Mithawan Watearshed

Salient features of the areas are described below.

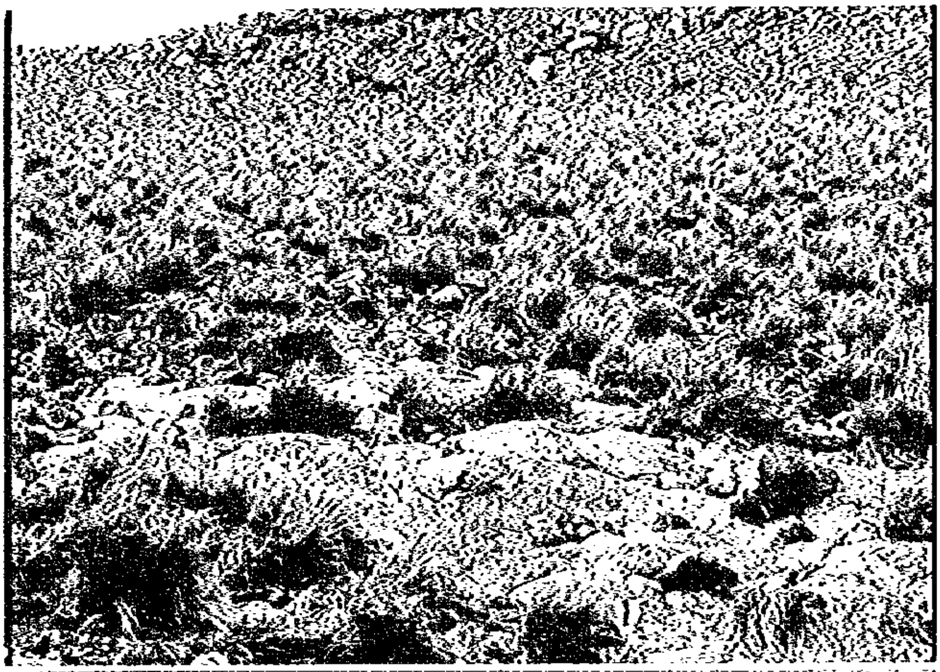
The area I (Sulaiman Range) extending north and south rises up to 2,000 m above sea level with usual altitude more than 1,000 m above sea level. It consists of hard sedimentary rocks of Pre-Tertiary age with central anticline axis called Fort Munro Anticline. The Ranges are asymmetric feature having relatively gentle western slope and eastern steep slopes comprising single layer plane inclined 30 to 40 degrees. Antecedent river flowing eastward dissected deeply the Ranges. The slope of the river bed is over 1/20. Grasses cover the ground surface with 1 m deep root systems which hold the top soil layer, for there are no grazing during cold season. The area seems to be hardly eroded (refer photo-1 & 2).

The area II consists of actively weathered and eroded soft sedimentary rocks of Tertiary to Pleistocene age with altitude ranging from 500 to 1,000 m above sea level. Partly very deep gully with depth 50 to 100 m dissected the land and some gravel layers remains on the top of non-eroded flat land. Scarps of 100 to 300 m high bound the area to its eastern and southern end. River beds of this area have gradient of from 1/40 to 1/70 and flow into three nallahs (Mithawan, Siri, Rakhi) at the eastern end of the darrah. Most of the area without gravel coverage is eroded easily. Especially the bases of the bank of the valley tend to be eroded and it results to follow the slope slip supplying great volume of sediment downstream (refer photo-3).

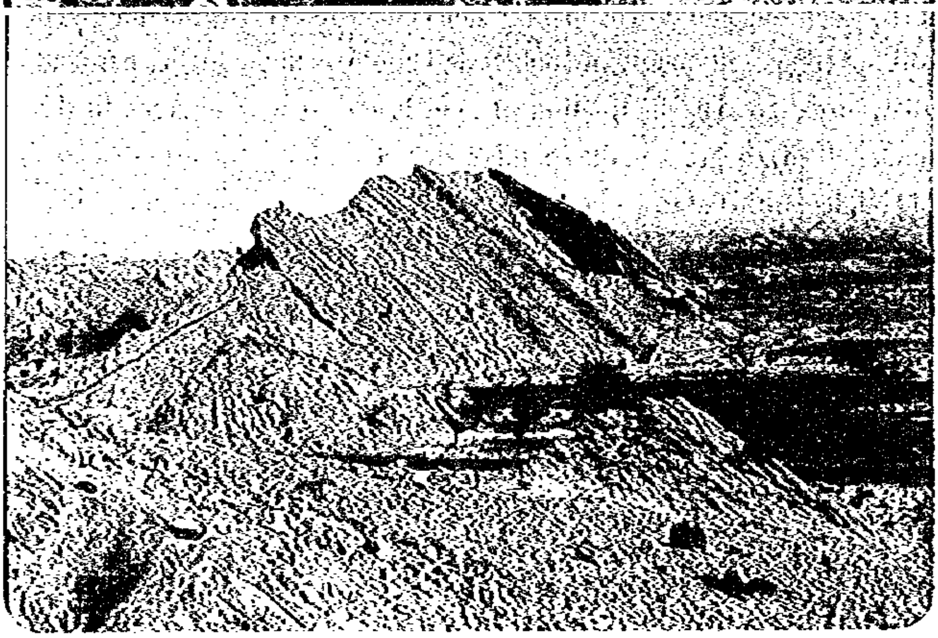
The area III with altitudes between 340 and 1,000 m above sea level is more eroded than area II so that the basement rocks of Tertiary to Pliocene age are covered with diluvial and alluvial gravel deposits that form flat basin. Erosion might be hardly occurs in this area (refer photo-4).

The area IV with altitude between 220 and 700 m above sea level is overlaid by sub-recent to recent river deposits and downstream of antecedent rivers is formed alluvial fans. The deposits are composed mainly of cobbles and boulders in the higher part and of sand in Mithawan nallah. The inclination of land is less than 2 degrees in the northern area and less than 4 degrees in the southern area. The alluvial fans in this area are composed of boulders from 0.3 to 1 m in diameter at the apex. There are small areas of cultivated land down stream of the fans and easy erosive Tertiary sediment rocks are exposed in some part of the area (refer photo-5).

Zone I is composed mainly of pre Tertiary and Mesozoic hard sedimentary rocks, which resist to erosion.



Zone I, ground surface higher than 1,500 m AL is covered with grasses, because of no grazing during winter.



Zone II is composed soft sedimentary rocks of Neogene Tertiary, which are easily eroded.

Zone III is Composed of Neogene Tertiary rocks but covered with gravel layer. It resists to erosion except along the channels.

Zone IV is consisted of alluvial fans and slopes covered with gravel layer.

Drainage system in the watershed is mentioned below. Many gullies originated from the highest part of the area combined together and forms 9 major channels in the Area-I. They flow out to the Area-II or Area-III through the darrah (outlet of the valleys) at the elevation of 500 to 800 m above sea level (ASL). These 9 valleys form minor alluvial fans at the outlets and merge on the plains at the elevation of 300 to 600 m ASL. They forms 5 major tributaries, namely from the north Mithawan, Siri, Rakhi, Nangar and Choti nallahs (Choti nallah has already separated from the Mithawan hill torrent drainage system by the tran-basin works).

The five major tributaries flow out to the Area-IV through the darrah at the elevation of 250 to 300 m ASL. All tributaries are actively forming alluvial fan. The elevation of the apex of the fans is 230 to 300 m ASL and those of the edge are 220 to 250 m ASL. Radius of the fans ranges 1 to 7 km and slope is about 1/100. The upper parts of the fans are covered with cobbles and boulders with 10 to 40 cm in diameter. It means that the materials supplied from the upper reaches of the fan are sieved and almost large materials remain on the fan. Then flood with fine sediment flow down to the Mithawan hill torrent.

The major tributaries join to the Mithawan nallah which finally flow out to the Mithawan pachad through the Mithawan darrah locating at downstream of Choti Bala village. The riverbed is composed almost finer than sand from about 4 to 5 km upstream of Choti Bala with its bed slope of 1/200 to 1/250.

Schematic drainage system of the Mithawan hill torrent is shown in Fig.-2.3 and physical features of the channels in the watershed are shown in Table-4 .

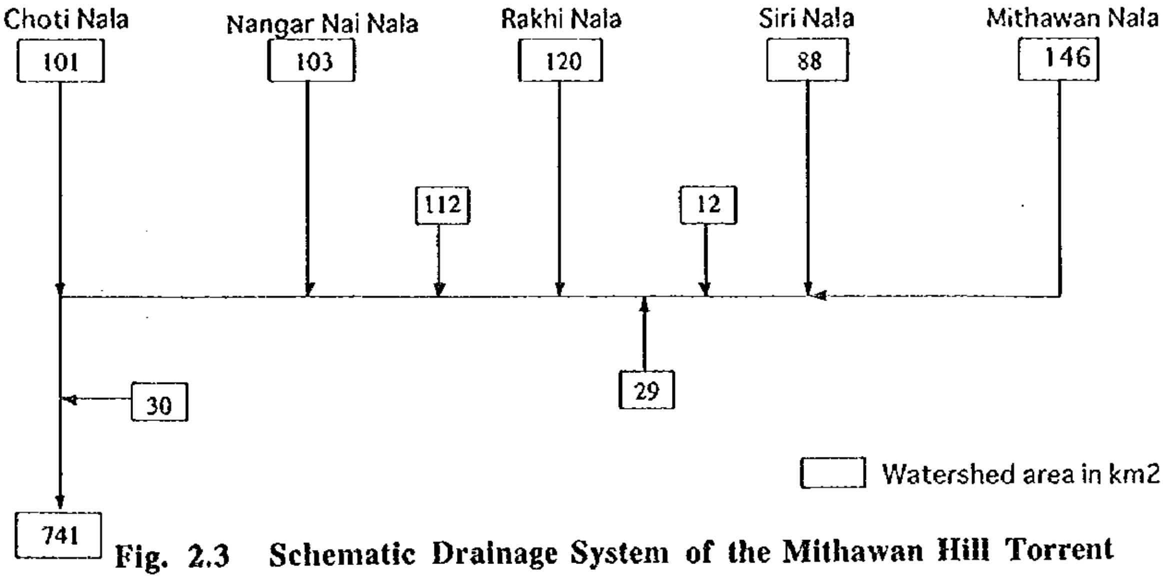


Fig. 2.3 Schematic Drainage System of the Mithawan Hill Torrent

Table-4 Features of Major Tributaries of Mithawan Nallah

Name of Tributaries	Drainage Area (sq.km)	Division	Elevation ASL (m)	Distance (km)	Bed Slope
Mithawan	145	u/s	600 to 2100	14.7	1/6 to 1/18
		m/s	360 to 600	15.3	1/59 to 1/70
		d/s	254 to 360	9.7	1/92
Siri	88	u/s	700 to 1900	13.8	1/8 to 1/16
		m/s	360 to 700	14.1	1/41
		d/s	joined with Mithawan at El. 360 m		
Rakhi	120	u/s	640 to 1830	17.0	1/14
		m/s	390 to 640	11.1	1/45
		d/s	234 to 390	10.0	1/67
Nangar	103	u/s	800 to 1940	12.7	1/10 to 1/15
		m/s	310 to 800	16.6	1/24 to 1/75
		d/s	214 to 310	5.5	1/61
Choti	101	u/s	800 to 1940	12.8	1/10 to 1/16
		m/s	280 to 800	15.2	1/16 to 1/83
		d/s	220 to 280	7.0	1/117
Mithawan Main	41	Siri to Rakhi	254 to 234	3.6	1/180
	112	Rakhi to Nangar	234 to 214	5.4	1/275
	30	Nangar to Darrah	214 to 200	4.5	1/321

2.4.2 Alluvial Fan

Considerable morphological variation is observed on the Mithawan alluvial fan, pachad, since it is still on the process of fan formation. The fan has 264 square km of area with about 20 km of radius and length of 22 km on the end (edge), on which D.G.Khan canal is located. The angle of spreading of the fan is 60 to 70 degrees at the apex. The surface gradient is 1/250 at the apex and 1/ 200 to 1/300 at the mid-fan and edge. Elevation is 200 m ASL at the apex and 120 m ASL on the edge. The alluvial fan is composed of sands, silts and clays derived from high land of the watershed. The composing grain size decreases gradually with the increase of distance from the apex.

Most of the part of the fan has been used for crop cultivation or grazing. Flood irrigation has been applied for the cropping land being located down to 15 km from the apex in the northern part and down to 10 km in the southern part of the fan. The cropping lands are surrounded with bunds/ridges which are embanked well for effective storage of run-off water. Secondary fan has covered wide crop land from the mid-fan toward the edge. There are many channels for flood irrigation on the fan as shown in

Fig.-2.4. Elevation of the riverbed is lower than that of the fans down to the mid-fan in the North branch and the Escape but it is kept at the same level in the South branch.

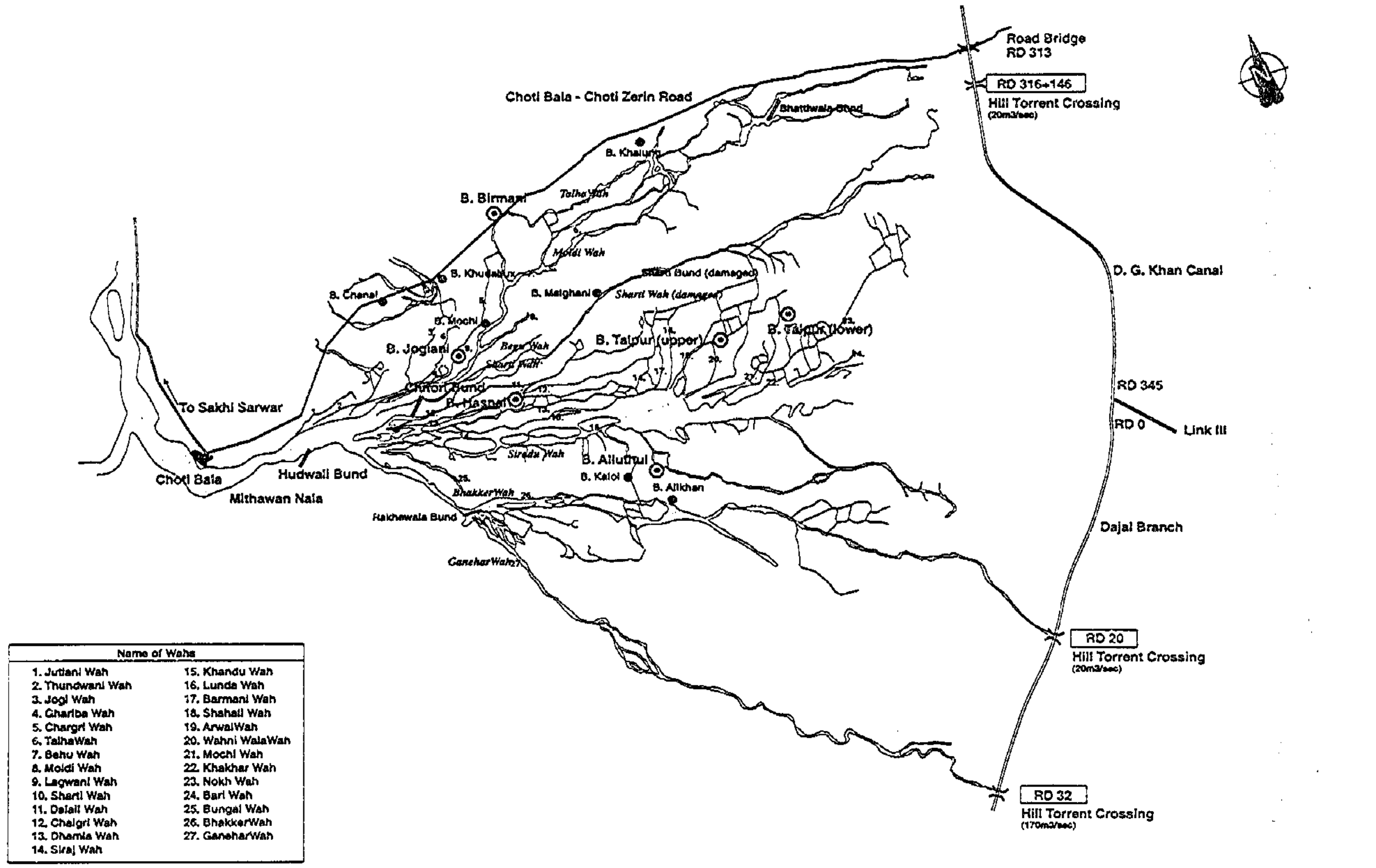


Fig. 2.4 Channels for Flood Irrigation on the Fan

2.4.3 River Morphology on the Mithawan Fan

Bed gradient immediate downstream of the apex of the Mithawan fan is shown in Fig.-2.5. The figure shows that the bed slope upstream of Sta. M2+100 is 1/570 and it is 1/250 downstream of the Sta. M2+100. Bed elevation in the Escape is the lowest of the three main channels downstream of the distributaries. Bed of Talha wah in the North branch is on the process of degradation at present.

The width of the channel upstream of the Sta.M2+100 is wider than that of each branch downstream of the Sta.M2+100 in main Mithawan, but the total of each width of the three branches downstream of the Sta. is wider than that of the upper reaches. Accordingly, it can be said that the total channel width or capacity of the channel downstream of the Sta. M2+100 is wider than that in the upper reaches of the Sta.

The riverbeds of the channels on the fan are mostly flat in the cross sections. The height of river banks, however, varies depending on the extent of flood concentration. The height of the river banks is about 60 cm down to 2 to 3 km downstream from the apex except the channel degraded by the concentrated flood flows in which the river bank reaches to 3 to 4 m high.

The Mithawan hill torrent has sandy riverbed from about 5 km upstream of the apex. The bed materials are medium to fine sand with little variation longitudinally down to the mid-fan. Thickness of the sand layer estimated about 35 m at the apex judging from the geological features and the drilling log of the deep tube well at Basti Jogiani.

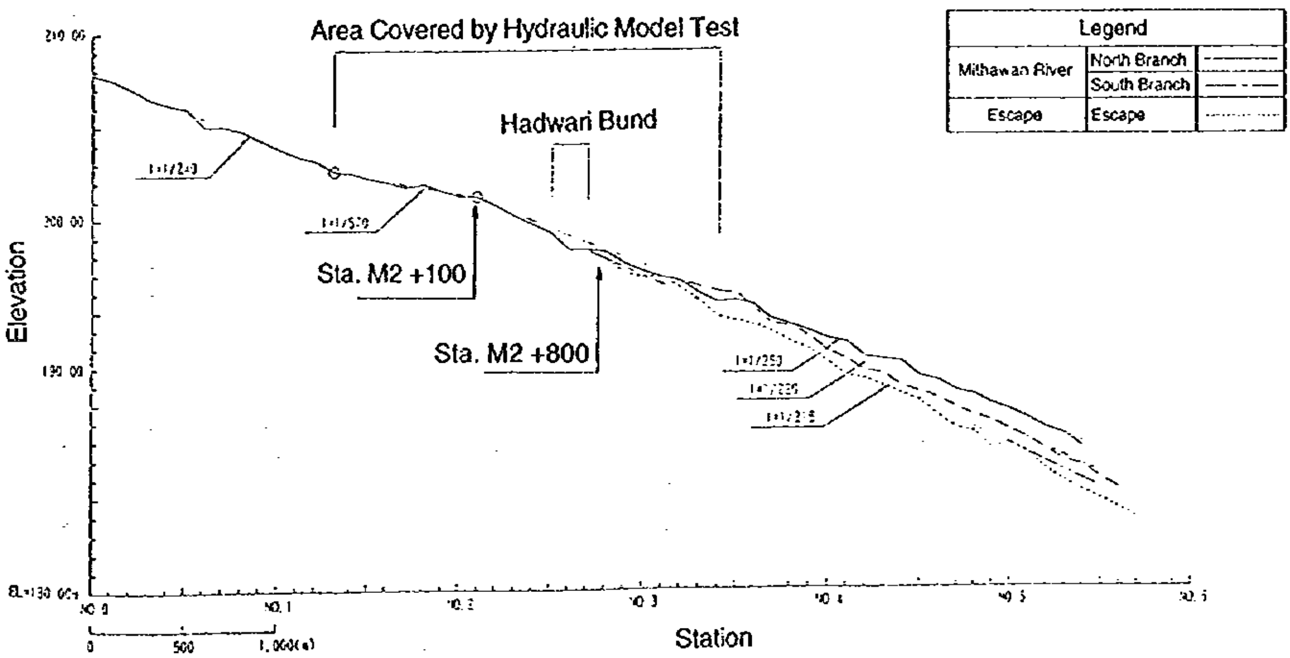


Fig. 2.5 Bed Gradient Immediate downstream of the Apex of the Mithawan Fan

2.4.4 Secondary Fans Distribution on the Fan

There are slightly higher undulate secondary fans composed of sand from the mid-fan toward the edge of the fan. Secondary fans have developed downstream of the intersection point where flood flow overflows from the channel during flood. When flood flow concentrates hardly enough to manage, it would form the secondary fan in wider channel sections and/or downstream of intersection point depositing the materials eroded from the riverbed and the sediment carried from the upper reaches. Table-5 shows area of the secondary fans by distance from the apex. Secondary fans are distributed mainly in the area from the mid-fan to the edge and total area covered with secondary fan on the Mithawan fan reaches 54 % of the fan area. Distribution of the secondary fans is different in the haqooq and in the non-haqooq area. The reason is that the haqooq area with water right is looked after the cultivators for their cropping, but non-haqooq area is used for grazing leaving as it being.

Fig.-2.6 shows the distribution of secondary fans by the satellite image. Large secondary fan with the area of 46.5 sq. km is located between Genehar wah and Bakker wah in the non-haqooq area, where a part is used for cropping land and mostly used for grazing area. Genehar wah bed lowered about 5 m from the fan surface, but the inlet of the wah has been reduced to stop bed lowering downstream.

Table-5 Distribution of Secondary Fans by Distance from Apex

Region	Area	Distance from the Apex (km)				Total
		0 to 5	5 to 10	10 to 15	15 to end	
Haqooq	Total	4	25	44	64	137
	Cultivable (A)	1	19	40	63	123
	Secondary fan (Af)	0	1	12	31	44
	Af/A (%)	0	5	30	49	36
Non-Haqooq	Total	5	20	32	53	110
	Cultivable (A)	3	19	31	52	105
	Secondary fan (Af)	0	8	22	49	79
	Af/A (%)	0	40	71	94	75
Whole	Total	9	45	76	117	247
	Cultivable (A)	4	38	71	115	228
	Secondary fan (Af)	0	9	34	80	123
	Af/A (%)	0	24	48	70	54

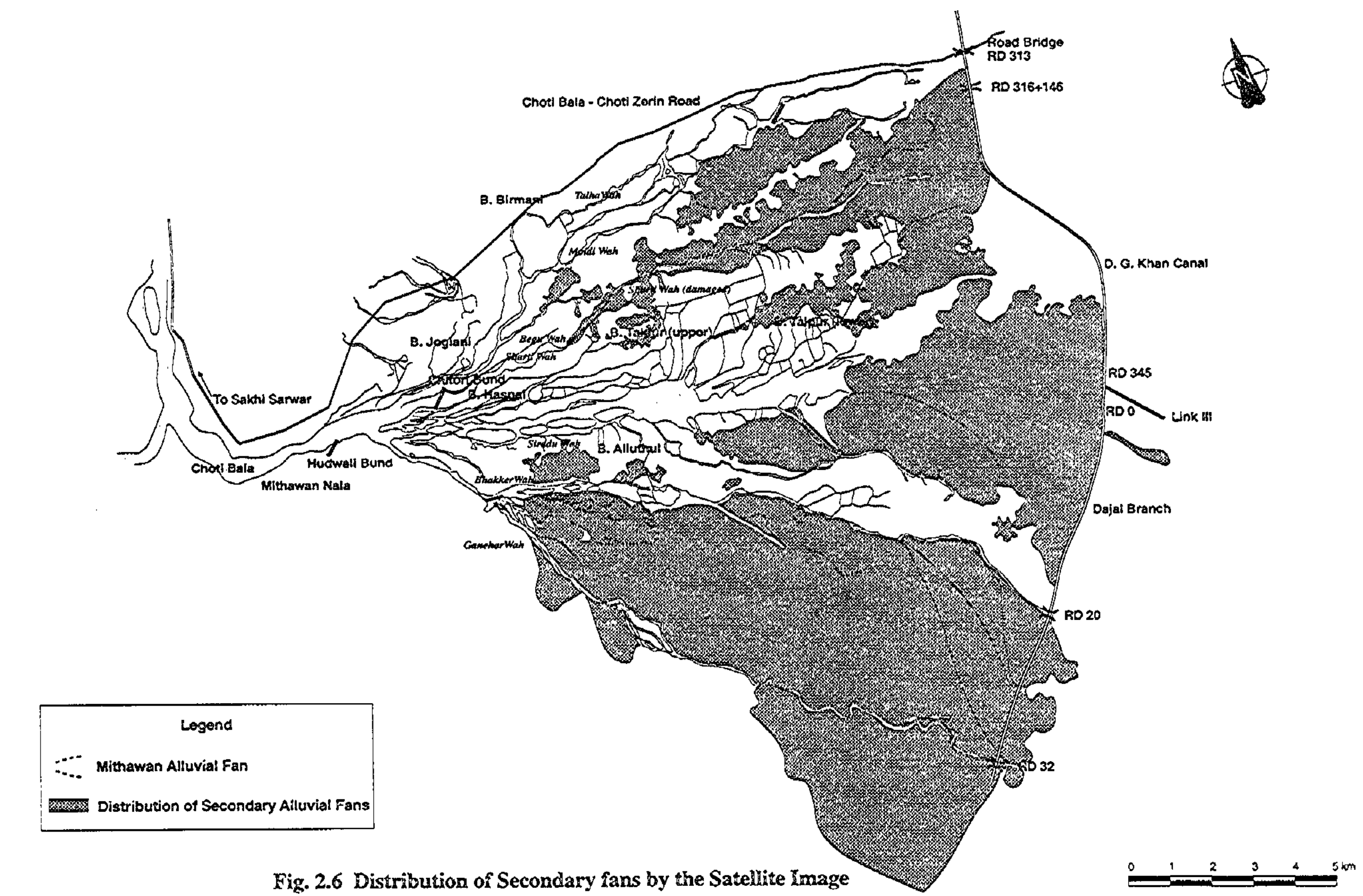


Fig. 2.6 Distribution of Secondary fans by the Satellite Image

There is large secondary fan downstream of the South branch/Siraj wah of its area being 30 sq. km. In this secondary fan, cropped lands are found being left without cultivation. There is another large secondary fan downstream of Sharti wah of the area of 14 sq. km. In the mid-fan along Talha, Behu and Moldi wahs in the North branch, there are several small secondary fans.

2.5 Erosion in the Watershed

2.5.1 Weathering and erosion in the watershed

Weathering or erosion is affected by the climate in the region. Annual erosion has observed in the lower hills in the eastern part of Himalayan ranges in Nepal which has similar geological formation. Annual volume of erosion in the area is estimated 6,000 to 57,000 cum/sq. km in denuded grazing slopes and 800 to 920 cum/sq. km from the area covered with vegetation. The rivers are transporting sediment annually about 1,000 to 8,000 cum/sq. km.

Weathering effect reaches about 1 to 2 millimeters deep a year vertically from the surface in Japan that belongs to the temperate zones with annual rainfall of 1,800 mm.

Langbein and Schumm (1958) concluded that annual rainfall of 10 to 14 inches is the optimum condition for the fan formation. Under this condition, the vegetation coverage is minimum and sufficient volume of water is supplied for sediment transportation.

2.5.2 Sediment transportation

Mithawan hill torrent watershed has its area of 627 sq. km and elevation of the highest peak is 2,107 m ASL and that of the lowest is 200 m at the outlet of the valley. Length of the main Mithawan channel is 53 km and its average riverbed slope is 1/28. Gravel layers cover 40 % and Pre-Tertiary rocks cover 38 % of total area which are eroded slightly, but remained 22 % of the area are exposing erosive rocks.

At the Kaha darrah (outlet of the valley), sediment concentration was measured during 1994 monsoon season. On the basis of the measurement, volume of annual sediment transportation is estimated at 1.1 mil. cum assuming 10 % bed load of measured concentration. Watershed area of the Kaha hill torrent is about 9 times of that of Mithawan and it is composed of pre-Tertiary mostly with gentle surface slope.

Moreover, the channels are segregated by many gorges cutting the ranges, which accelerates deposition of the sediment in its upstream.

At the Choti nallah sand-pocket, volume of transported sediment is estimated. In 1995, there was 2 times of minor floods and one high flood. The minor flood carried sediment about 185 cum/sq. km by one flood, it was the total sediment load, in which clay and silt as wash load was 60 % and sand as suspended load was 40 %. Estimated volume of transported sediment excluding wash load was 3,550 cum/sq. km by one flood from the observation of deposit consisted of only sand in sand-pocket and in the improved channel.

Observed sediment volume in the reservoir shows 2,100 cum/sq. km by four-year observation and 1,700 cum/sq. km by 8-year observation in another dam. Assuming 80 % on the deposition rate, volume of sediment transportation is estimated 2,000 to 2,500 cum/sq. km a year.

Above discussions conclude estimated volume of sediment transportation is 2,000 to 2,500 cum/sq. km a year in the Mithawan hill torrent watershed at present.

2.6 Soil and Vegetation

There are dotted small crop lands along the channels in the Area-I, II and III classified above. In this area, the soils in the crop land are gravely soils.

In the Area-IV and V, the soil of the piedmont plains derived mainly from sedimentary rocks of the Sulaiman Range, ranges in texture from gravely soil to clay.

The soils in crop land in the areas range in texture from gravely soil to clay, but in the Area-IV, gravely and sandy soils are dominant, on the other hand clay and loam are the dominant soil textures in the Area-V (pachad). The soils of alluvial fan are generally non-saline and non-alkaline. The soils of the alluvial fan are always in dry condition.

Trees and shrubs are growing in water courses on the slopes in a hilly area, but their density is very low. The hill slopes are covered with grasses with deep root systems in the high altitude. Shrubs and grasses are growing but low density on the piedmont slopes. The areas along the channels grow various kinds of shrubs and grasses owing to the rather high soil moisture. In the pachad, natural vegetation remains little by crop cultivation, over-grazing, cutting, etc.